THE DEVELOPMENT OF A COMPREHENSIVE MANUAL FOR RIVER REHABILITATION IN SOUTH AFRICA

Liz Day, Mark Rountree, Hans King

WATER RESEARCH COMMISSION

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The Development of a Comprehensive Manual for River Rehabilitation in South Africa

Report to the
WATER RESEARCH COMMISSION

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WRC Report TT 646/15
The Development of a Comprehensive Manual for River Rehabilitation in South Africa

Part 1: Summary Document

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1 INTRODUCTION

South Africa's rivers tend to be in a poorer condition than terrestrial ecosystems, with more than 80% of rivers in the country considered to be threatened (Driver et al., 2004). This is not only a result of what happens on river banks, but also the result of how land and water is used and managed throughout the river's catchment. Such effects stem in part from the fact that South Africa is a water-scarce country with multiple demands on limited water resources from urban settlements, agriculture and industry. In addition to affecting the plants and animals that rely on rivers for their habitats and sustenance, unsustainable approaches to water resource management threaten access by human communities to a range of ecosystem services provided by rivers, and upon which our society is dependent, such as:

- flood attenuation;
- water quality improvement;
- baseflow provision;
- biodiversity support; and
- recreational use.

In order to retain such services and the ecosystems that provide them, a balance must be struck between the demands of human development, and the ecological requirements of naturally functioning rivers.

The **River Rehabilitation Manual** is a three-part series that aims to empower landusers, communities and environmental protection practitioners in the practicable rehabilitation of rivers in South Africa. Even if readers are not planning rehabilitation works, this document aims to create an awareness of processes driving river degradation and solutions, so that small interventions can be identified timeously and can be implemented before the problem escalates and requires much larger interventions.

> The present summary document is intended only to provide a broad overview of the philosophy and main outputs of the River Rehabilitation Manual. The full documentation should be referred to when planning or undertaking any actual river rehabilitation projects.

2 BACKGROUND

The Water Research Commission of South Africa (WRC) funded a project to develop national guidelines for river rehabilitation that would provide locally appropriate river rehabilitation objectives and structures to enable more effective protection and management of watercourses. The project outcomes are intended to be used to guide implementers in the selection of appropriate rehabilitation solutions to a suite of problems and are presented in three volumes, namely:

1. the **Guidelines for River Rehabilitation;**
2. a **Technical Manual for River Rehabilitation** and
3. **Case Studies of River Rehabilitation interventions in South African Rivers**.

Together, these volumes constitute the overall **South African River Rehabilitation Manual**. Figure 1 illustrates how they link together, with information in the **Guidelines** directing the reader to identify and contextualise a problem in river condition, and then identify and evaluate a range of potential options for addressing the problem. These are illustrated to various degrees in the **Case Studies**. While the Guidelines provide a contextual basis for interpreting the source and implications of an identified problem, the **Technical Manual** is an advisory document that outlines how to implement a range of options, including caveats as to circumstances in which they should or should not be considered, and, importantly, when they require expert input in their design or implementation.

This file binding comprises Volumes 1 and 2 – Volume 3 has been presented in CD format only, and is available at the back of this file.

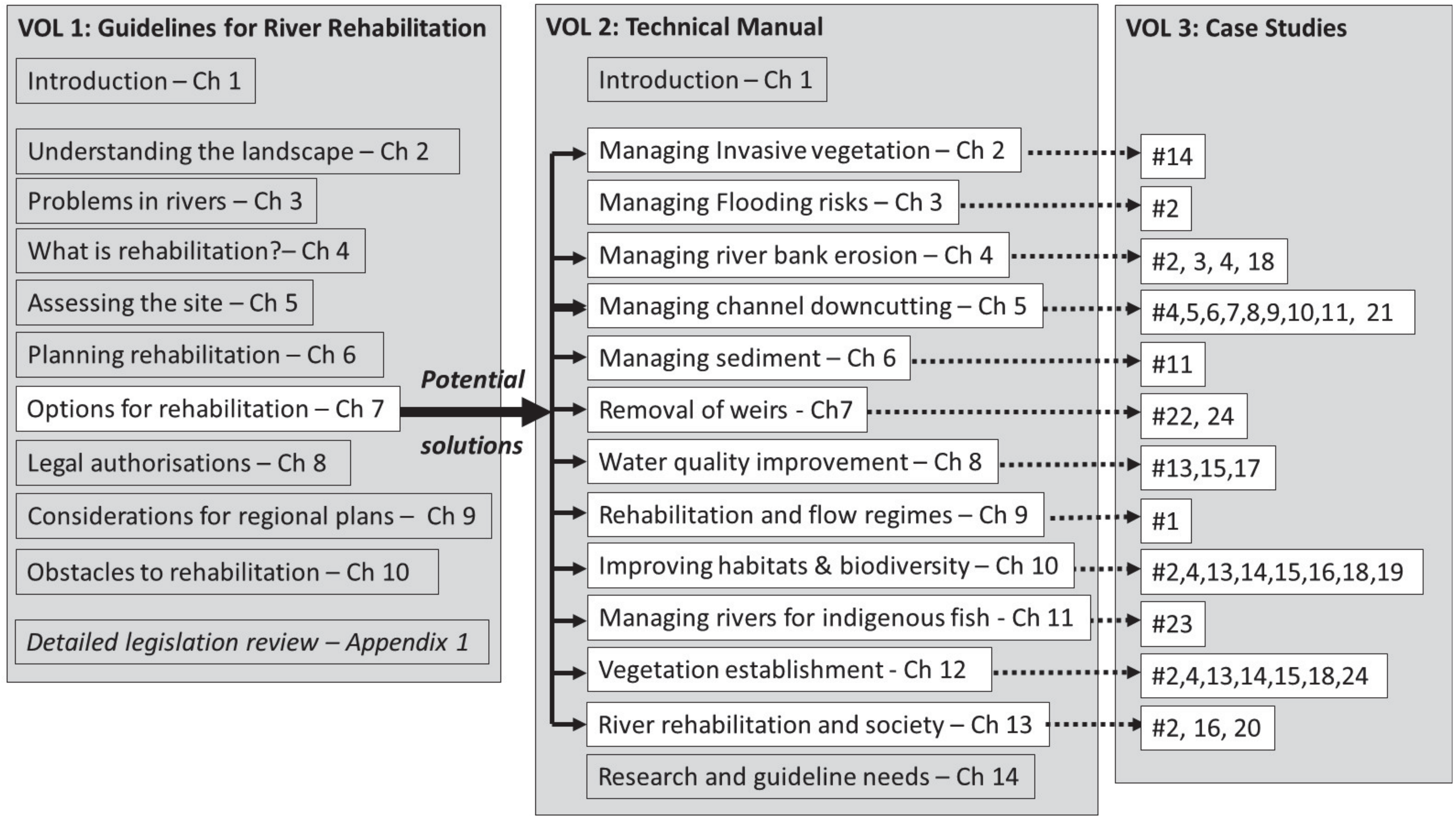

Figure 1: Integration of the three outputs of the River Rehabilitation Manual in guiding rehabilitation decisions and interventions

3 OPTIONS FOR REHABILITATION ADDRESSED IN THE MANUAL

The following issues are dealt with in the Technical Manual for Rehabilitation

3.1. Costs of not rehabilitating

Although most of the Technical Manual focuses on the ecological, biodiversity and financial costs of rehabilitation, in many cases, failure to implement appropriate rehabilitation activities timeously can also have tremendous costs, often orders of magnitude greater than the costs of early intervention, and resulting at best in stabilizing the degradation process, with no chance of returning the system to its original condition. Remember that "*it is easy, fast and cheap to damage natural streams, but difficult, slow and expensive to return them to their natural conditions*" (Rutherford et al., 2001). Some of the implications of not rehabilitating are documented in the Case Study Assessments (Volume 3).

3.2. Options to manage invasive vegetation

3.2.1. Identifying situations where alien plants are drivers of river degradation

A number of factors may indicate that invasion by alien plants is a contributing or primary cause of river degradation, noting that they do not need to occur on the site or even in the affected reach to result in problems, but may be upstream, upslope of or on the opposite bank of the affected area. Look for signs of the following:

- Increased sediment in the river channel or an accelerated tendency for the channel to meander;
- Lining of the river bank by alien trees, that might confine flows in flood conditions;
- Extensive alien invasion at a catchment or sub-catchment level – use tools such as GOOGLE historical imagery to note changes in extent over time;
- Obstruction of the river bed with felled trees / large branches;
- The presence of large logs / branches along the river bank, deflecting stream flows onto the opposite bank or increasing stream velocities;
- Decreases in dry season stream flows over time, and possible encroachment of terrestrial plant species into flood channels and the river margins;
- Debris dams against bridges or culverts, characterized by large sediment loads and/or woody debris comprising alien trunks and branches;
- Smothering of riverine vegetation by alien plants, including weedy creepers;
- Establishment of young trees on islands and sand bars, previously non-existent or existing only as temporary features that washed away in floods.

3.2.2. Establishing a structured approach to alien plant control

Once alien plants have been identified as problematic, the following steps need to be considered:

Step 1: Planning alien control, including considerations around:

- Setting objectives

- Deciding on focus areas
- Planning and preparation
- Addressing alien clearing impacts

Step 2: Deciding on Alien clearing and control methods, including:

- Physical (or mechanical) control
- Chemical control
- Biocontrol
- A combination of approaches.

Details as to the most appropriate method in different circumstances are included in the Technical Manual (Volume 2: Section 2.1).

Step 3: Methods for the disposal of alien plant material
Step 4: Maintenance / How to follow-up on alien clearing
Step 5: Alien clearing monitoring
Step 5: The need for trained implementers – who should do this work?
Step 6: Considering legal issues and permitting
Step 7: Guidelines for the removal of specific alien plant species.

3.2.3. Control of other plant species

Since alien vegetation is not the only type of vegetation that can be invasive and affect perceived or real river function, the Technical Manual also includes specifications around the removal of some common problematic indigenous or cosmopolitan species.

3.3. Options to reduce flooding risks by improving flood conveyance or flood attenuation

Floods damage agricultural infrastructure along the river, and occasionally overtop the river channel, cause bank erosion and may inundate large areas of productive agricultural land. This puts agricultural production and job security in the valley periodically at risk. Maintaining productive agricultural areas is thus essential for the economy of the country, to secure employment and food security, but similarly maintaining and where possible improving the ecological condition of the river can ensure sustained provision of ecosystem services.

Main principles for managing flooding risks at the site

The guiding principles to managing flooding risks along a river should be:

1. to allow the river as much lateral space as possible to allow floodwater to spread and thereby reduce velocities and minimize erosion and safety hazard,
2. to restrict floodplain activities to those compatible with occasional flooding (such as for pastures or recreation), and
3. to keep rivers and riparian zones clear of invasive vegetation in order to preserve their conveyance function and reduce flood heights.

There are a variety of rehabilitation options that can be employed to address overbank flooding risks through improved flood conveyance and increased flood attenuation where appropriate. The options included in the Technical Manual are summarized in Figure 2 with intervention options along the x-axis graded by those requiring increasing areas of lateral space, and costs for implementation, and along the y axis by, from bottom to top, options which generally represent the rehabilitation towards increasingly natural conditions of the river reaches.

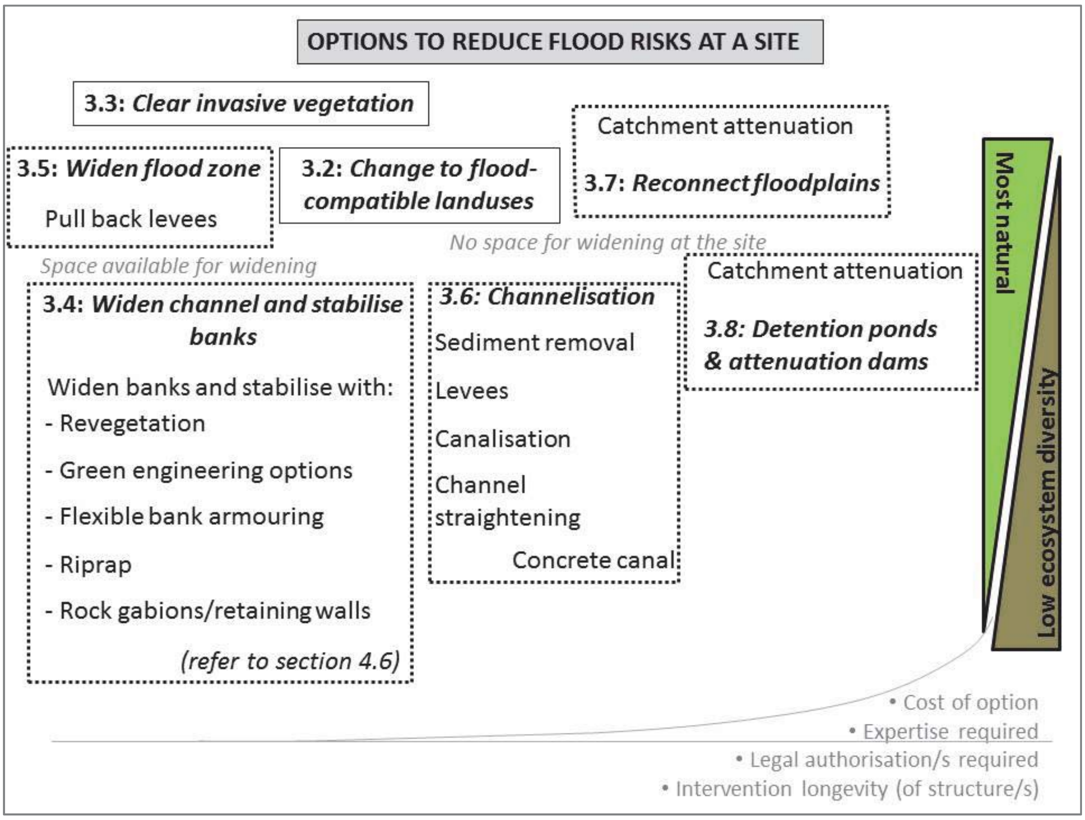

Figure 2: A summary of the rehabilitation options available for reducing flooding risks at the site scale. Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed

3.4. Erosion: Managing eroding banks (lateral erosion)

Options for the management of river erosion at a site level fall into two broad categories. The first category is **managing eroding banks**, which is where usually only one bank, or a short section of both river banks, are eroding. The second category of erosion involves managing sites and reaches which are **downcutting or incising**, which is when the river bed is eroding down into itself and resulting in donga or gulley formations and steep, vertical banks for extensive lengths along both banks of the river. This erosion type is also sometimes called headcut erosion and is dealt with in Section 3.5.

A range of options for bank stabilization in cases of lateral erosion are presented in this section, from hard engineered solutions through to small-scale "soft" or so-called green options (green options including bank landscaping and re-vegetation, informal erosion control structures, the armoring of banks with erosion mats and re-vegetation, and the use of groynes with re-vegetation in the space between the groynes). A general rule is that informal structures can be used to address small areas of low risk in lower energy rivers, but with increasing risk, flood volumes and flow velocities, increasingly harder options would need to be considered.

Wherever possible, a realistic assessment of expected discharges in the river, flow heights and velocities, the erosion resistance of the various parts of the river, and the consequence of the failure of the structure as well as its maintenance requirements should be taken into account when comparing and selecting rehabilitation options.

Rehabilitation options for addressing bank erosion are summarised in **Figure 3**, with the y axis, from top to bottom, showing options that generally represent rehabilitation towards increasingly natural conditions of the river reaches, at the top.

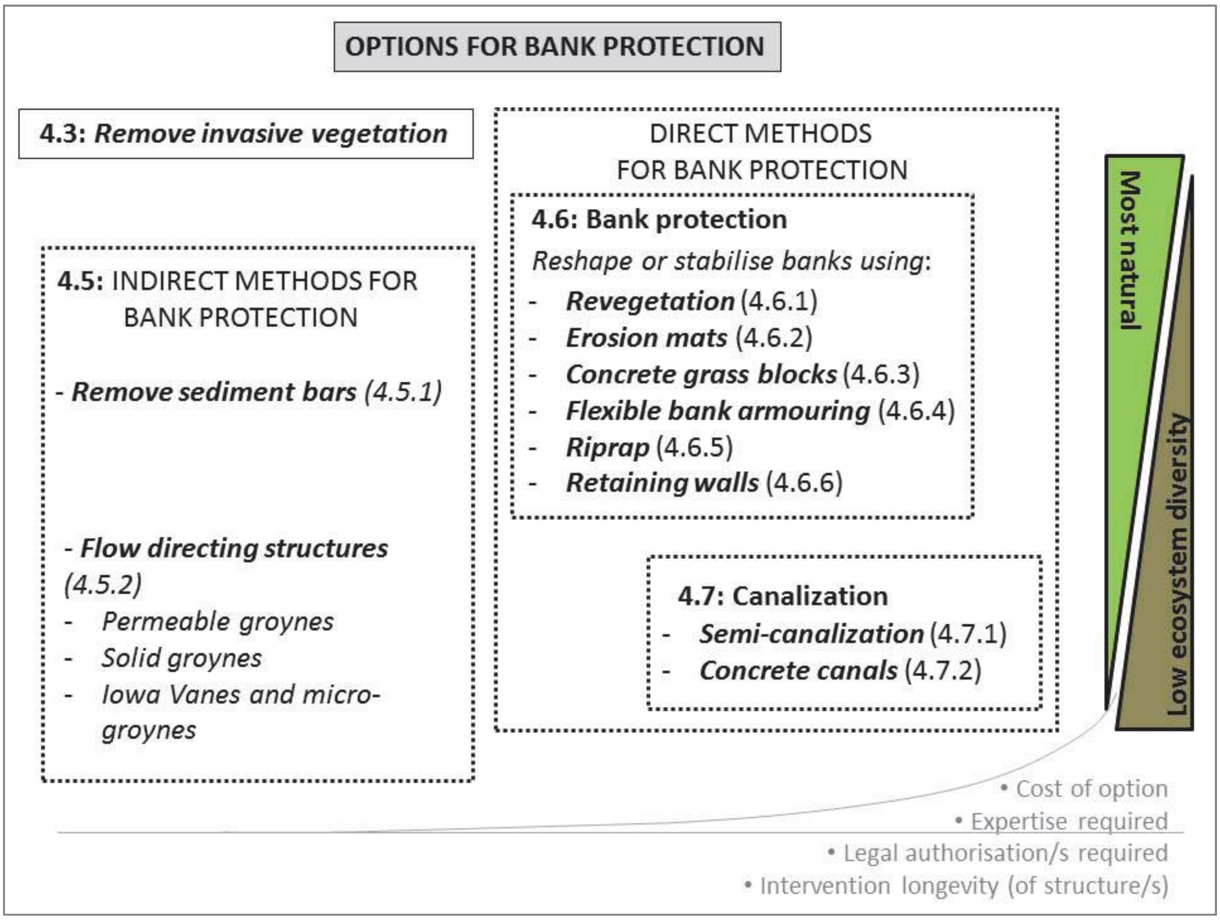

Figure 3: Options for addressing lateral or bank erosion in rivers.
Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed

3.5. Erosion: Managing river downcutting (incision)

When addressing bed erosion protection, as with bank erosion protection, the cause of erosion must be understood before effective remedial measures can be planned. Often bed erosion takes place when a river is constricted and subjected to abnormally high flood levels and flow velocities during floods, but this must be verified, or an alternative explanation sought.

The types of intervention that address river bed incision directly vary in decreasing environment friendliness, from re-vegetation of the river bed, to grade control structures such as block ramps or vertical drop weirs, and finally to full canalization of the river. Additional options include the concept of off-channel stormwater detention ponds, to reduce the size of flood peaks passing down the river.

Rehabilitation options for addressing river bed incision are summarised in **Figure 4**.

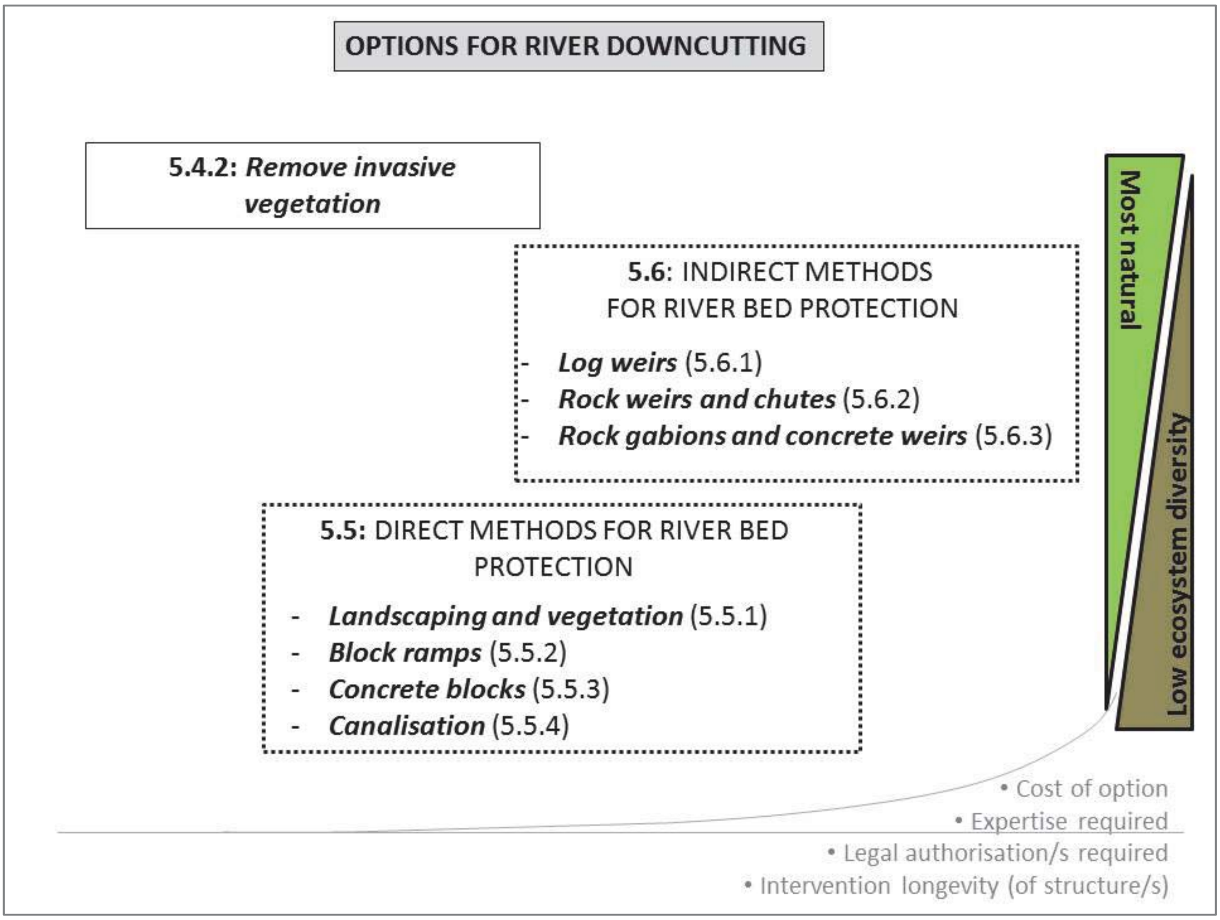

Figure 4: Options for addressing channel incision / downcutting in rivers.
Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed

3.6. Managing sediment

Sediment erosion, transport and deposition are important processes that create habitat diversity in rivers. However, where sediment deposition rates are very high, the increased sediment stored in the river reach increases the chance of flooding through increased channel roughness and reduced channel depth. Excessive sediment deposition is thus sometimes perceived as a problem in some river reaches.

Assessing whether sediment removal is appropriate

In general, removal of sediment from a watercourse is not a good idea due to risks of initiating instability (incision and bank erosion) and the loss or degradation of habitat diversity associated with widespread sediment removal. However, in some cases, effective management of the watercourse and mitigation of risk for adjacent landuses is not possible without some sediment management actions. Each case must therefore be considered based on the reach-specific evidence and understanding of sediment processes for that site or reach. For cases where the removal of sediment is found to be justified, best practice must be used to carry out the necessary work to minimise adverse effects on the environment.

Options for addressing the management of sediment in rivers are presented visually in Figure 5.

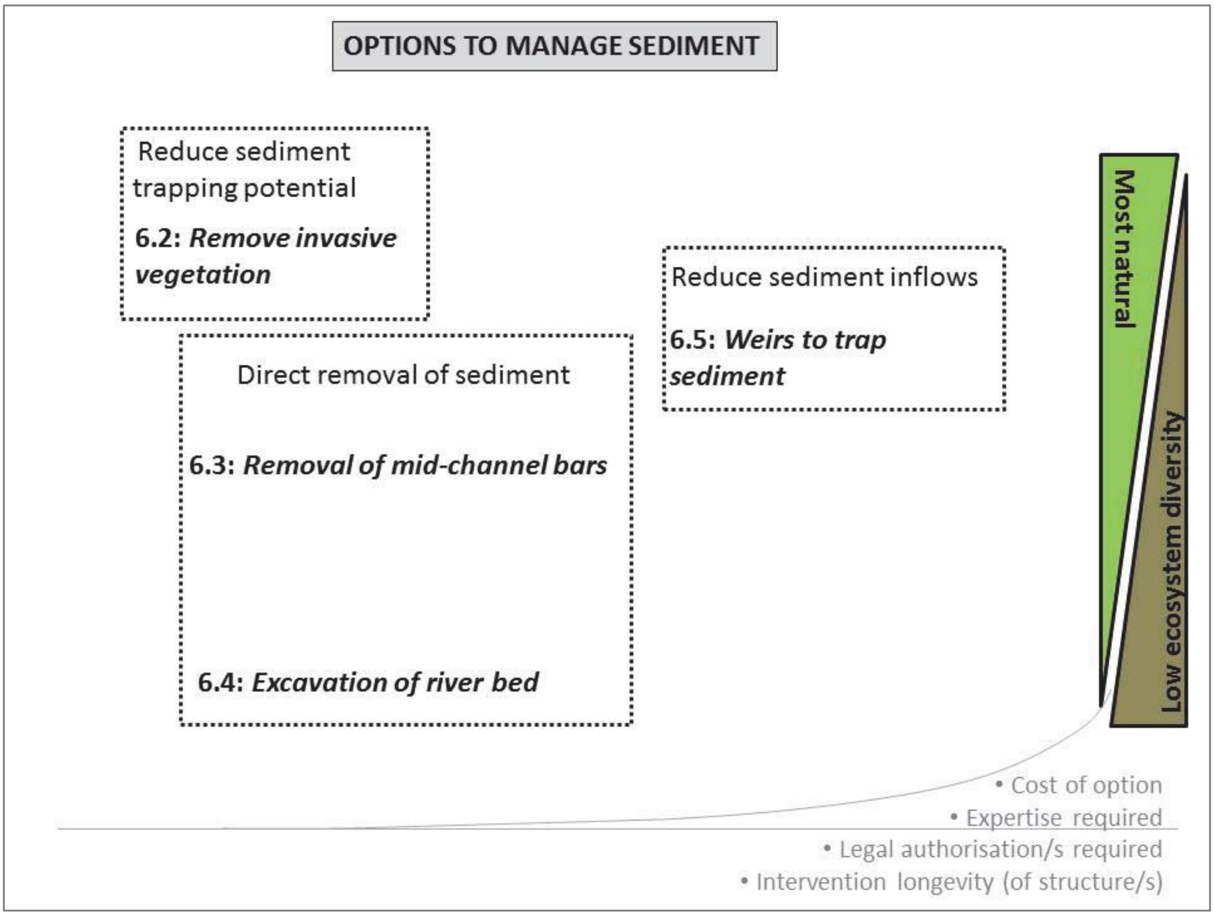

Figure 5: Options for managing sediment.
Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed

3.7. Removal of weirs

Dams and weirs often have negative impacts on the environment and their removal is sometimes a rehabilitation option for a river, to restore free-flowing river conditions, reinstate migration routes for instream biota, and restore more natural flows and sediment delivery to downstream reaches. Despite the potential benefits to be obtained through the removal of weirs, their removal or decommissioning is often a major exercise and should not be undertaken lightly. Due to the high risks and specialist insight required, ***qualified environmental practitioners and engineers should be consulted prior to considering the potential for the removal of dams.***

3.8. Water Quality Improvement

Water quality, particularly in urban areas, can be a major limitation to effective rehabilitation, especially downstream of Waste Water Treatment Works where nutrient levels are usually dramatically increased. Acid mine drainage, industrial effluent, general runoff from urban and industrial areas, agricultural return flows as well as the more diffuse runoff from agricultural areas, are also sources of water quality problems. ***Efforts to improve water quality in rivers and wetlands should focus as far as possible on preventing grossly elevated nutrient levels from reaching watercourses***. Although rivers and wetlands have some assimilative capacity to absorb and process nutrients, often the enormous volumes introduced in concentrated form at point sources (such as waste water discharge points) overwhelms the dilution capacity of the baseflow of the receiving stream and the assimilative capacity of the river ecosystem. Focused efforts at significant sources of pollution (such as waste water treatment works), effective catchment management measures, the use of vegetated swales and implementation of buffers and sediment and litter traps in the contributing tributaries can aid in reducing nutrient loads in rivers and wetlands.

Techniques to improve water quality that are addressed in the Technical Manual include:

- Measures to address specific variables of concern;
- Managing diffuse runoff;
- Managing point source pollution;
- Instream measures to improve water quality.

3.9. Rehabilitation and flow regime

A crucial component of river condition is the extent to which its natural flow regime is maintained. Although the setting of adequate flow regimes for rehabilitated rivers is beyond the scope of the Rehabilitation Manual, it is essential that all rehabilitation projects are undertaken with a full understanding of the extent to which the natural flow regime has been altered in any river undergoing rehabilitation, and the implications of such changes for river function and habitat and resource quality.

Options for addressing flow regime changes are not addressed in the Rehabilitation Manual, other than indirectly in terms of the removal of alien plants and the removal of dams where appropriate. Flow regime changes require the reallocation of scare water resources and are therefore difficult, and often economically unfeasible, particularly for single land owners, to implement.

3.10. **Improving riverine habitat quality and biodiversity**

Chapter 10 of the Technical Manual provides a number of options that have the primary objective of increasing instream and/or riparian and floodplain habitat diversity. They should be read in the context of the more general information around assessing river condition and rehabilitation opportunities and constraints on the site / river reach that you are working on, bearing in mind that in most cases, rehabilitation towards a more natural condition should be the preferred option. In some cases, however, the extent of permanent, often catchment-level changes to river functioning and condition mean that such an approach may not be feasible, and interventions around improving river condition would be best considered as remedial activities, which largely ignore natural condition.

It should be remembered, moreover, that efforts to improve biodiversity by addressing physical habitat types at the level of a site or reach will not succeed if the river is affected by over-arching problems of water quality, water quantity and flow regime, erosion or sedimentation.

Taking cognisance of these factors, the interventions and approaches for general aquatic habitat improvement that are included in this chapter have been summarised in Figure 6.

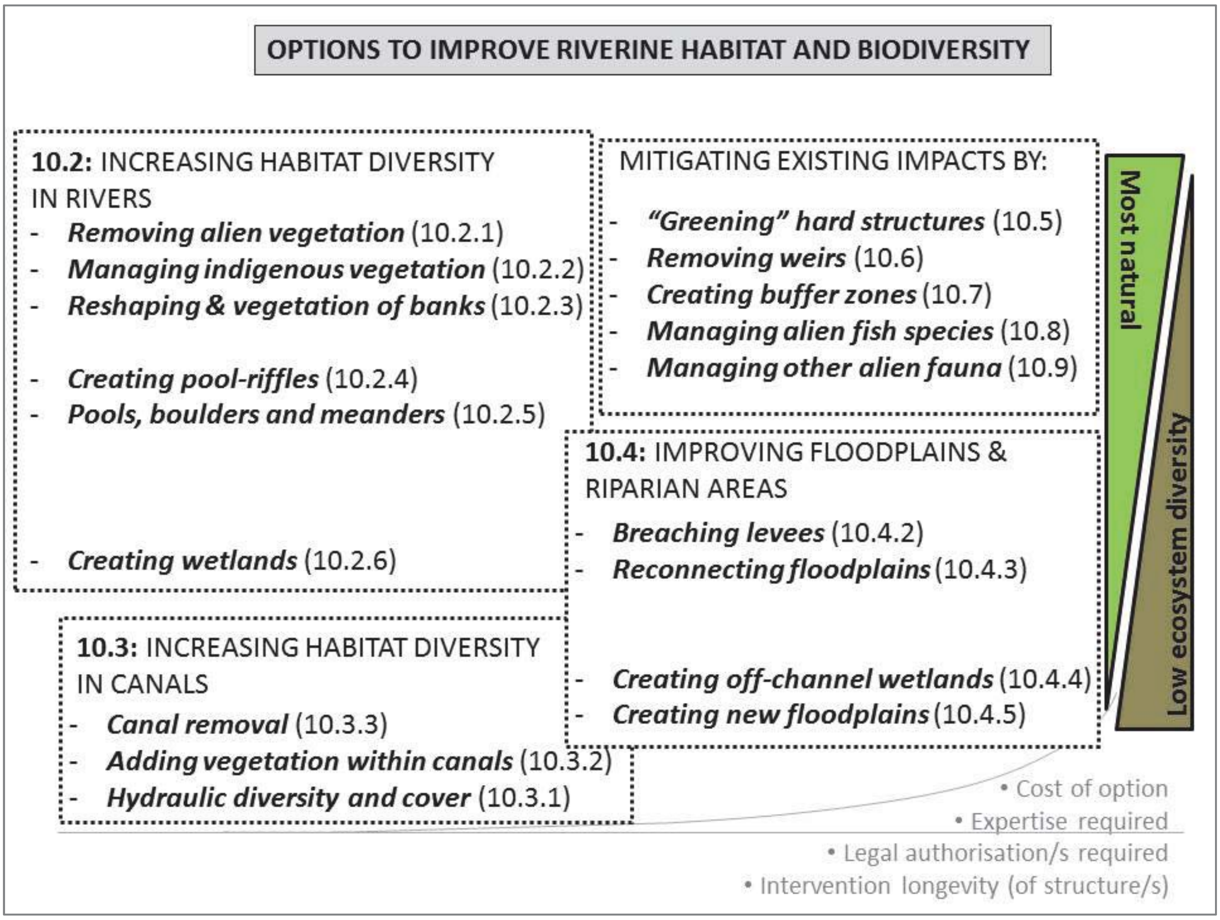

Figure 6: Options for improving habitat quality and diversity
Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed

3.11. Managing rivers for indigenous fish

Indigenous fish require ecologically healthy rivers to thrive – that is, rivers that are in a good to excellent River Health status. The smaller endemic Cape species of fish require ecologically healthy rivers from which alien fish are absent. All river rehabilitation actions that are soundly planned and implemented should be of benefit to fish. However, technical approaches for rehabilitating rivers for fish are dealt with in the fish section of the Technical Manual.

3.12. Vegetation establishment for river rehabilitation

The appropriate establishment of plants as a means of improving habitat diversity, providing specific habitat types for species of concern, managing issues such as water temperature and shading and, in particular, addressing issues of bank and bed erosion is a critical part of most river rehabilitation projects. Chapter 12 of the Rehabilitation Manual has been structured to guide readers through planning the planting process, implementation and maintenance activities, and includes guidelines as to plant selection, placement, maintenance and paths and lighting. The chapter also provides listings of typical indigenous plants associated with rivers in different provinces of South Africa, and broad guidelines around plant traits that should be considered in determining their suitability for bank stabilization.

3.13. River rehabilitation and society

Brief recommendations around the following important issues are also included in the Technical Manual (Chapter 12):

- Social and security considerations in river rehabilitation projects;
- Effects of river rehabilitation on human health;
- The need for effective resource prioritisation.

4 LEGAL AUTHORISATIONS NECESSARY FOR RIVER REHABILITATION

There is a plethora of legislation and authorisations which are potentially applicable to individuals or organisations wishing to undertake river rehabilitation initiatives (see Appendix 1). The two most important and overarching pieces of legislation are the National Environmental Management Act (NEMA) and the National Water Act (NWA).

At all times, it is recommended that

1) ***the Relevant provincial Department of Environmental Affairs, and***
2) ***Regional Department of Water and Sanitation or relevant Catchment Management Agency***

be contacted prior to undertaking any rehabilitation activities in order to confirm that the most up to date NEMA and NWA requirements and authorisation processes are adhered to.

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VOLUME 1:
GUIDELINES FOR RIVER REHABILITATION

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- Mr B Madikizela (Water Research Commission) – Chair of Reference Group
- Mr N van Wyk (Department of Water and Sanitation)
- Mr P Ackerman (Department of Water and Sanitation)
- Ms N Muthraparsad (Department of Water and Sanitation)
- Mr U Bahadur (Department of Environmental Affairs)
- Mr A Wohlitz (City of Tshwane)
- Mr ND Impson (Cape Nature)
- Dr MU Uys (Laughing Waters)
- Mr Chris Brooker (Chris Brooker and Associates)
- Mr IP Bredin (INR)

Lastly, the authors would also like to thank the WRC for this opportunity to develop what they hope will be a valuable resource to enable more widespread rehabilitation and protection of South Africa's watercourses, and to their families for bearing the many long hours committed to this project.

Table of Contents

List of acronyms and abbreviations

CMA	Catchment Management Agency
DEA	Department of Environmental Affairs
DEADP	Western Cape Dept. of Environmental Affairs and Development Planning
DWA	Department Water Affairs (name change from DWAF applicable after April 2009)
DWAF	Department Water Affairs and Forestry (until 2009)
DWS	Department of Water and Sanitation (Name change from DWA applicable after May 2014)
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
GA	General Authorisation (in terms of the NWA)
IAP	Invasive Alien Plants
MAR	Mean Annual Runoff
NFEPA	National Freshwater Ecosystem Priority Area
NWA	National Water Act
PES	Present Ecological State
SANBI	South African National Biodiversity Institute
SASS	South African Scoring System (an instream invertebrate biomonitoring tool)
WfWetlands	Working for Wetlands
WMA	Water Management Area
WULA	Water Use Licence Application – relating to Section 21 Water Uses in the National Water Act

Glossary of terms

Active channel bank The bank of the channel(s) that has been inundated at sufficiently regular intervals to maintain channel form and to keep the channel free of established terrestrial vegetation.

Alluvial soil A deposit of sand, mud, etc. formed by flowing water, or the sedimentary matter deposited thus within recent times, especially in the valleys of large rivers.

Anastomosing A river reach pattern or type where multiple channels flow along faults or weaknesses of underlying bedrock. These steep channels are separated by large, stable, vegetated islands which are very seldom inundated.

Bar Accumulations of sediment associated with the channel margins or bars forming in meandering rivers where erosion is occurring on the opposite bank to the bar.

Base flow The long-term flow in a river that continues after storm flow has passed.

Buffer A strip of land surrounding a wetland or riparian area in which activities are controlled or restricted, in order to reduce the impact of adjacent land uses on the wetland or riparian area.

Catchment The area contributing to runoff at a particular point in a river system.

EcoRegions Denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources, and are designed to serve as a spatial framework for the research, assessment, management and monitoring of ecosystems and ecosystem components. Several levels or scales of Ecoregions can be delineated (e.g. Level I low resolution/detail; Level III high resolution and detail). In South Africa, Ecoregions form the basis of the River Health monitoring assessments with Level II delineations available for use.

Ephemeral stream A stream that has transitory or short-lived flow.

Floodplain A relatively level alluvial (sand or gravel) area lying adjacent to the river channel, which has been constructed through deposition of alluvial (water-transported) sediments by the watercourse. Typical floodplains generally have a meandering river channel which overtops its banks during flood events resulting in the floodplain being saturated for extended periods of time. Meandering usually develops upstream of a local (e.g. resistant dyke) base level, or close to the mouth of the river (upstream of the ultimate base level, the sea). Ox-bows or cut-off meanders – evidence of meandering – are often present on the floodplain

Floodplain	A valley bottom wetland which is inundated when a river overtops its banks during flood events resulting in the wetland soils being saturated for extended periods of time.
Groundwater	Subsurface water in the zone in which permeable rocks, and often the overlying soil, are saturated under pressure equal to or greater than atmospheric pressure.
Habitat	The natural home of species of plants or animals.
Hydrology	The study of the occurrence, distribution and movement of water over, on and under the land surface.
Infilling	Dumping of soil or solid waste onto the wetland surface. To fill in a wetland (or riparian area) in order to raise the ground level above the flooding or saturated zone; usually for the purposes of construction. Infilling generally has a very high and permanent impact on wetland functioning and is similar to drainage in that the upper soil layers are rendered less wet, usually so much so that the area no longer functions as a wetland.
Levee	Levees or berms are raised areas of sediment along the upper banks of rivers. These are naturally occurring features within depositional floodplain rivers, but are typically small and difficult to discern in the field. In agricultural environmental, large levees are often constructed along the active channel margins, or along the banks, to prevent floods from spilling out of the channel on to the floodplains or upper riparian areas. This allows for the protection of infrastructure and landuse activities within the floodplains, but reduces flood attenuation and ecological condition of the river reach.
Macro channel	Over much of southern Africa, uplift in the recent geological past and subsequent incision has caused many rivers to flow within an incised 'floodplain', outside of which flood flows have no recorded influence. This incised feature (essentially a "restricted floodplain") has been termed the macro-channel.
Mid-channel bar	Single bar(s) formed within the middle of the channel; flow on both sides.
Peat	Peat is a brownish-black organic soil that is formed in acidic, anaerobic wetland conditions. It is composed mainly of partially-decomposed, loosely compacted organic matter with more than 50% carbon. The 50% carbon content is mostly applicable for the sphagnum peat moss peat deposits in the Northern Hemisphere. The South African soil classification uses a > 10% carbon content as a guideline. Inorganic soil particles are blown or washed into peatlands and also form part of the peat.

Perched water table	The upper limit of a zone of saturation in soil, separated by a relatively impermeable unsaturated zone from the main body of groundwater.
Present Ecological State	Present Ecological State is a term for the current ecological condition of the resource. This is assessed relative to the deviation from the Reference State.
Reference Condition	Reference State/Condition is the natural or pre-impacted condition of the system. The reference state is not a static condition, but refers to the natural dynamics (range and rates of change or flux) prior to development.
Rehabilitation	An intervention that promotes the recovery of ecosystem functions and values in a degraded system in order to regain some of the value the system previously had to society (Dunster and Dunster 1996)
Remediation	Improving the current state of an ecosystem without reference to its initial state (Petts et al. 2000)
Restoration	Manipulation of a site in order to revert the watercourse back to its full range of natural (historic) processes and functions (National Ocean Service and National Marine Fisheries Service 2002; US EPA 2003)
Riparian	Riparian includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent, and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent areas.
Runoff	Surface runoff from rainfall which can then enter in to the stream channel network.
Sedges	Grass-like plants belonging to the family Cyperaceae, sometimes referred to as nutgrasses. Papyrus is a member of this family.
Terrace	Area raised above the level regularly inundated by flooding (infrequently inundated).
Watercourse	As defined by the National Water Act, means a) a river or spring; b) a natural channel in which water flows regularly or intermittently; c) a wetland, lake or dam into which, or from which, water flows; and d) any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes where relevant, its bed and banks.

Wetland	Refers to land that is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which under normal circumstances supports or would support vegetation typically adapted to life in saturated soil (National Water Act 36 of 1998).

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1 INTRODUCTION

Philosophy and aims of the River Rehabilitation Manual

South Africa's rivers tend to be in a poorer condition than terrestrial ecosystems, with more than 80% of rivers in the country considered to be threatened (Driver et al. 2004). This poor condition of our rivers is not only a result of what happens on river banks, but also the result of how land and water is used and managed throughout the river's catchment. Such effects stem in part from the fact that South Africa is a water-scarce country with multiple demands on limited water resources from urban settlements, agriculture and industry. In addition to affecting the plants and animals that rely on rivers for their habitats and sustenance, unsustainable approaches to water resource management threaten access by human communities to a range of ecosystem services provided by rivers, and upon which our society is dependent, such as:

- flood attenuation;
- water quality improvement;
- baseflow provision;
- biodiversity support; and
- recreational use.

In order to retain such services and the ecosystems that provide them, a balance must be struck between the demands of human development, and the ecological requirements of naturally functioning rivers.

> *It is easy, quick and cheap to damage natural streams, but hard, slow and expensive to return them to towards natural state, and often it is not possible to reinstate the complex functioning of the natural state back to a degraded river reach. Therefore the highest priority for river management is to avoid damage in the first place, especially to rivers that remain in good condition (Rutherfurd* et al*. 1999.)*

This document (Volume 1) and the associated Technical Manual for river rehabilitation (Volume 2) aims to empower landusers, communities and environmental protection practitioners in the practicable rehabilitation of rivers in South Africa. Even if readers are not planning rehabilitation works, this document aims to create an awareness of processes driving river degradation and solutions, so that small interventions can be identified timeously and can be implemented before the problem escalates and requires much larger interventions. The support of local landowners and communities in the rehabilitation of degraded rivers would allow the condition of water resources to be stabilised or improved, enabling more sustainable provision of ecosystem goods and services derived from these sources, and thereby giving effect to the Department of Water and Sanitation's slogan relating to water resources, that aims to ensure:

Some, for all, forever, together.

1.1. Background

The Water Research Commission of South Africa (WRC) funded a project to develop national guidelines for river rehabilitation that would provide locally appropriate river rehabilitation objectives and structures to enable more effective protection and management of watercourses. In addition to an initial Review document, that looked at river rehabilitation practices and approaches to the development of rehabilitation manuals globally (Day et al. 2013), the project produced three main reports, namely (1) the **Guidelines for River Rehabilitation** (this document), (2) a **Technical Manual for River Rehabilitation** and (3) **Case Studies of River Rehabilitation interventions in South African Rivers**. These documents can be used to guide implementers in the selection of appropriate rehabilitation solutions to a suite of problems. Together, these volumes constitute the overall **South African River Rehabilitation Manual**.

1.2. Purpose of this document

This document comprises the Guidelines for River Rehabilitation. It is intended to provide clear, practical guidelines to the implementation of a wide range of rehabilitation and remediation activities that are of relevance in South Africa, and which take cognisance of legal, social, economic and ecological issues and aspects that affect river management options and opportunities. The Rehabilitation Guidelines document is intended to be used in conjunction with the Technical Manual for River Rehabilitation. The latter document provides more detail on the technical methods for undertaking rehabilitation activities, whereas the guideline provides an overarching framework in which to consider, initiate and monitor rehabilitation activities.

The Rehabilitation Guidelines are intended for use by readers who have an interest in river rehabilitation activities. The document can be used to elucidate problems and help to identify and evaluate a range of potential solutions to these problems, in order to achieve a stabilised or improved river condition. The associated Technical Manual for River Rehabilitation provides details of the different options that could be implemented.

1.3. What the Guidelines are not

The Rehabilitation Guidelines are not intended to make specialists of its readers, and, in both this document and the Technical Manual, users are urged to consult engineering, hydrological, geomorphological, ecological or other specialists, particularly where the consequences of failure of a rehabilitation approach or failure to implement timeous or adequate rehabilitation measures are serious, in terms of human life, damage to property or infrastructure, or degradation to important ecosystems or endangered species.

1.4. Provisos and limitations

This manual presents approaches and options for the rehabilitation or management of rivers and riparian zones. These guidelines and approaches for river management specify where technical expertise and legal authorisations are required prior to proceeding with any interventions. The methods presented cannot account for site-specific issues which may arise, and thus for many of the moderate to high risk options, additional expert input is recommended. With regards to legislative issues, Appendix 1 provides a detailed overview of the aspects of existing legislation which are applicable in terms of river and wetland rehabilitation activities. However, at all times, it is recommended that the

1) Relevant provincial Department of Environmental Affairs, and

2) Regional Department of Water and Sanitation or relevant Catchment Management Agency

be contacted prior to undertaking any rehabilitation activities in order to confirm that the most up to date NEMA and NWA requirements and authorisation processes are adhered to.

1.5. Aquatic Ecosystems addressed in the River Rehabilitation Manual

The River Rehabilitation Manual focusses on river rather than wetland rehabilitation. The National Water Act (Act 98 of 1998) does not however define rivers, other than to include them in the general definition of a watercourse, cited as meaning:

- *(a)* a river or spring;
- *(b)* a natural channel in which water flows regularly or intermittently;
- *(c)* a wetland, lake or dam into which, or from which, water flows; and
- *(d)* any collection of water which the Minister may, by notice in the *Gazette,* declare to be a watercourse.

The scope of systems covered in the project has been assumed to extend to all channeled and channelised inland aquatic ecosystems, including channeled valley bottom and floodplain wetlands, as defined by the National Wetlands Classification System (SANBI 2013) as well as artificial stormwater drains and canals.

1.6. Structure of the Guidelines for Rehabilitation

The Guidelines for Rehabilitation (this document) have been structured so as to provide the user with a clear understanding of natural river systems and the manner in which various natural and artificial drivers affect river function and condition. Developing this understanding is important, as it should form the basis on which decisions around the need for and type of rehabilitation interventions that are required.

The document has been structured to provide first (**Section 2**) an overview of largescale processes that determine river type and function in the landscape – this is useful in allowing a user to contextualise a particular river in terms of its climate, catchment and landscape, and the natural river ecosystems and habitat types that one might expect in (simplified) models of river systems. **Section 3** provides an overview of the main problems affecting rivers in South Africa – this section is intended to guide users in identifying what problems might be afflicting the particular river or river reach they are considering, and more importantly, what would need to be addressed to bring about effective rehabilitation.

Section 4 unpacks what is actually meant by rehabilitation, and the different degrees of interventions that can be envisaged, from cosmetic approaches, to large-scale efforts to restore or alter rivers, to achieve more natural and/ or at least improved levels of ecological or other function.

This leads to **Section 5**, which homes in on the level of a rehabilitation site or reach, and guides the user through an assessment of the site, an identification of drivers and symptoms of degradation, an assessment of the actual need and/or urgency (if any) of intervention and a consideration of the costs (ecological and other) of not doing anything. Relevant Case Studies (Volume 3) are referred to throughout.

Armed with an understanding of the impacts affecting the site in question, the reader is led, through **Section 6**, through a structured approach to rehabilitation planning, including numerous checks on feasibility and meeting selected objectives. **Section 7** follows with a brief overview of different options for rehabilitation, looking at the key problems already identified in Section 3, and providing the reader with broad guidelines as to how to approach the selection of the most appropriate rehabilitation approaches to addressing particular problems and a summary of the options available to address each objective addressed. The section is not however prescriptive and at all times aims to allow the reader to make an informed decision, drawing on the information already gained in previous sections of the Guidelines.

Summary information around legal considerations and required authorisations for different kinds of rehabilitation interventions are outlined in **Section 8**, drawing on current legislation, while **Section 9** outlines considerations such as the identification of priority rehabilitation sites, in a regional or national context, which while not considered in this manual, are likely to be important issues in project planning and funding for many rehabilitation projects. Finally, **Section 10** briefly unpacks some of the key obstacles to river rehabilitation in South Africa, and how these issues should be addressed through legislation change or other approaches.

While the document has tried to focus on practical rehabilitation implementation, ensuring legal compliance in rehabilitation activities is also important, and in addition to the brief comments on legislation triggers outlined in Volume 2 and Section 8 of the present volume, **Appendix 1** in this volume provides a detailed review of current legislation, as of August 2015.

1.7. Overall structure of the River Rehabilitation Manual

Three documents comprise the overall River Rehabilitation Manual, viz:

1) the **Guidelines for River Rehabilitation** (this document),
2) **The Technical Manual for River Rehabilitation** and
3) **The Case Studies of River Rehabilitation Interventions.**

These three documents are intended to work together in assisting in the selection of appropriate rehabilitation solutions to a suite of problems. **Figure 1.1** illustrates how they link together, with information in the Guidelines (this volume) directing the reader to identify and contextualise a problem in river condition, and then identify and evaluate a range of potential options for addressing the problem. These are illustrated to various degrees in the Case Studies (Volume 3). While the Guidelines provides a contextual basis for interpreting the source and implications of an identified problem, the Technical Manual is an advisory document that outlines how to implement a range of options, including caveats as to circumstances in which they should or should not be considered, and, importantly, when they require expert input in their design or implementation.

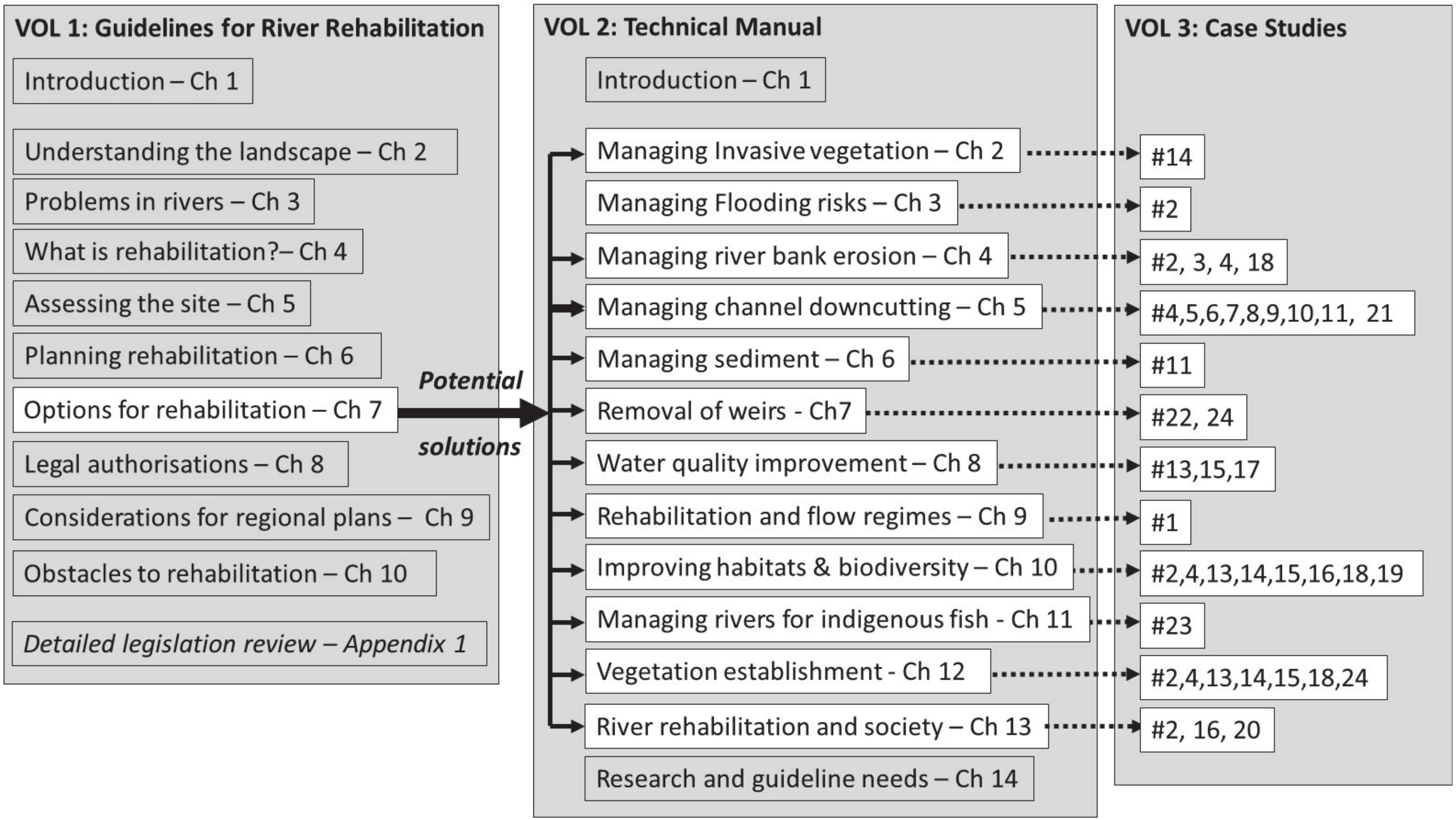


Figure 1.1: Integration of the three outputs of the River Rehabilitation Manual in guiding rehabilitation decisions and interventions

2 UNDERSTANDING THE LANDSCAPE

2.1. The need for an interdisciplinary approach

Rivers are complex systems, and if river rehabilitation efforts are to achieve any measure of success, they need to be based on an understanding of the main drivers and responses at different scales of river function. Rivers moreover are set apart from many other ecosystem types by the degree to which they integrate with and are influenced by the surrounding landscape, or catchment. In fact, the physical, chemical and biological characteristics of any river are determined almost entirely by the nature of its catchment and the activities, human and natural, that take place in it (Davies and Day 1998).

When embarking on a river rehabilitation project, it is thus critically important to understand the river in terms of the landscape processes and landuse context of the system, as well as of the perceived problem being evaluated. For this reason, Dollar et al. (2007) emphasise the need for river rehabilitation activities to be truly interdisciplinary in nature, highlighting the need for practitioners in different fields to achieve a common understanding of the cause of the problem they are evaluating, and the processes by which it should be addressed. These authors outline a framework for achieving such an interdisciplinary understanding of rivers, which is based on an understanding of parallel hierarchies of river geomorphological, hydrological and ecological organisational structures and elements, and how these interact with each other, at different spatial and temporal scales, to produce changes in ecosystem state (see **Figure 2.1**).

Scale related both to the spatial scale – the location and size of the symptom, underlying cause and potential solutions – as well as the temporal (time) scale over which problems and solutions develop and can be implemented. Many observers take decisions based on the assumption that the current state of the river has existed for a long time, and his can lead to poor selection of rehabilitation options and a limited understanding of the river processes. For instance, it is not often understood that alien vegetation has only been present for the last 30 to 50 years. Dense stands of alien vegetation in and alongside rivers can have a de-stabilising effect, and it is only when historical aerial photography is studied that a longer term perspective on river condition, and the relatively recent impacts of invasive vegetation, are revealed. Similarly, the extent and nature of very recent agricultural and urban development along rivers is often not recognised. It can take river systems years to many decades to adjust to the changes in hydrology and bank form that are caused by urban development and encroachment in to the riparian zone, so some river bank erosion may simply be the response of the river to the relatively recent, in geomorphological time scales, constriction of the river channel associated with agricultural or urban encroachment.

The links between spatial scales is important, as is an understanding of the time scales over which the processes operating at different scales occur. Generally, the larger the spatial scale, the longer the time period that should be considered when trying to understand the symptoms (such as an eroded bank) and underlying causes.

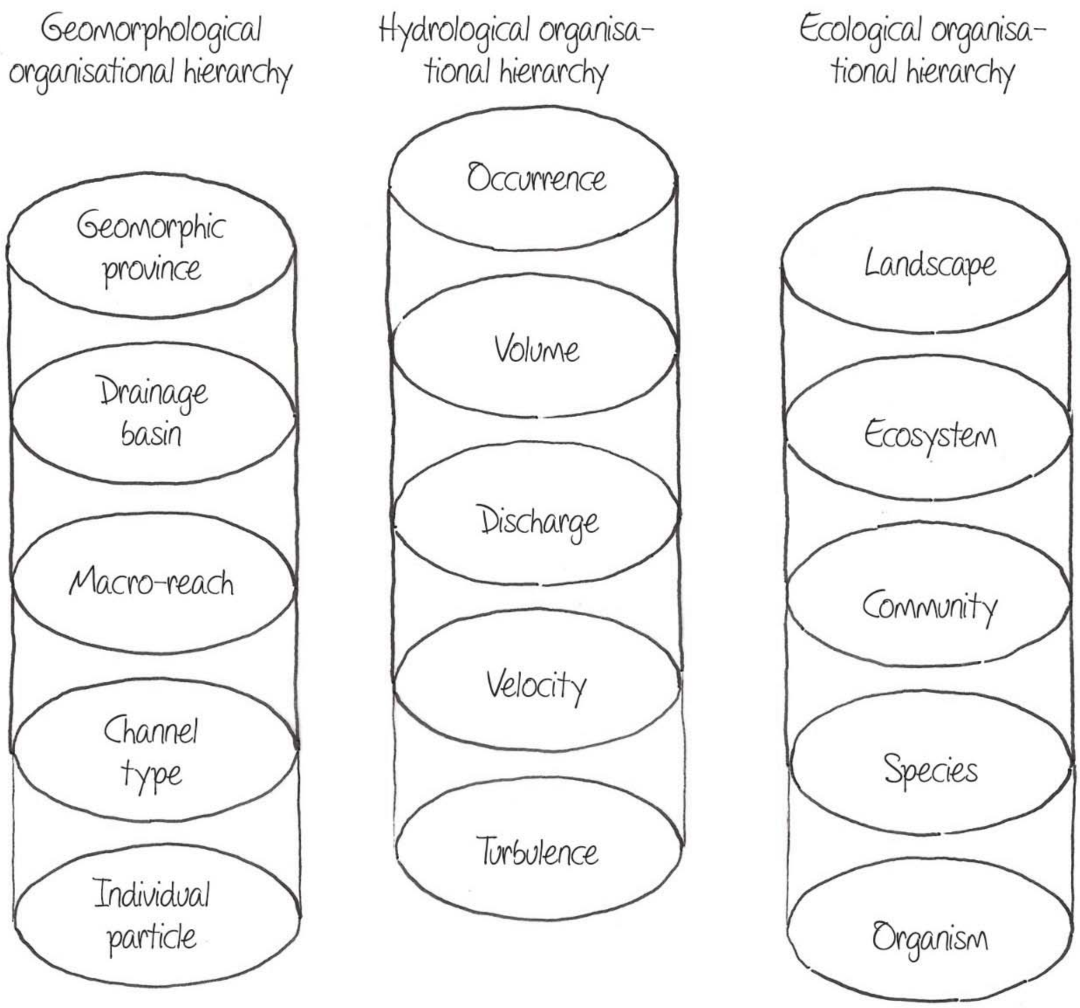


Figure 2.1: Hierarchical descriptions of the levels of organisation that characterise the geomorphological, hydrological and ecological subsystems of a river. Figure after Dollar et al. (2007).

There are three key disciplines to understanding river processes. Central to the riverine processes is the pattern of flows, which is the hydrology (and, at the site scale, the hydraulics) of the river. The flowing water interacts with the sediment transported from the catchment to create the geomorphological or physical structure of the river channel bed, banks and floodplains. The last discipline is represented by ecology – plants and animals establish on the geomorphological template (created by the flows and sediment) and respond to the flow patterns of the river, which is determined by the hydrology of the catchment.

The following sections of this chapter outline some of the key hydrological, geomorphological and ecological factors and hierarchies in the context of which perceived river degradation and rehabilitation activities must be interpreted.

2.2. Rainfall and floods

The average rainfall in South Africa is less than 500 mm per annum – well below the world average of 860 mm. The eastern and southern coasts are moderately well-watered, while the interior and western regions range from arid to semi-arid. The south-western Cape receives winter rainfall, but this quickly changes to a summer-dominated rainfall pattern across the majority of the country. The timing and pattern of rainfall in a particular area have important implications for the approaches and timing of rehabilitation activities. For example, the planting of riparian vegetation needs to coincide with the rainfall period, although ideally attempt to miss the worst flood peaks, in order to maximise the chance of successful establishment of new plants. In many areas, irrigation may be required to accelerate vegetation establishment due to the aridity of the region.

Sixty-five percent of the country receives less than 500 mm of rain annually, but even in the areas that receive more rain, rainfall is highly variable. This variability in rainfall, typical of arid and semi-arid areas, results in a much higher variation in discharge between rare floods and more frequent floods (such as those up to the 1:2-year event) than that which occurs in temperate European and North American climates (Baker 1977; McMahon et al. 1992). The periodic occurrence of extreme large floods has important implications for how South African rivers function, and this has consequences for the types of rehabilitation activities which can be implemented given the occasional extreme large floods which the river, and rehabilitation structures, must be able to cope with. This means that some rehabilitation approaches that are feasible in temperate areas and cited as success stories in European and North American literature, are often not appropriate for the extreme variation in flow regime experienced in many of our South African rivers.

A major difference between South African rivers and European rivers is that in South Africa the difference between "normal" flow rates and "flood" flows is a factor of 20 to 500 times. In Europe this is very much less, so river stabilisation techniques that are appropriate for European conditions many not necessarily be appropriate in South Africa. River stabilisation techniques such as the use of root wads on banks, and tree trunks for the construction of weirs will very seldom be appropriate in South Africa due the far higher flow variability.

2.3. Ecoregions

South Africa is a geologically, geomorphologically, climatically and ecologically complex country, and this results in a diverse range of ecosystems, including rivers. An important part of contextualising a river or river reach is therefore to be able to identify its particular characteristics, in terms of all of the above. In South Africa, rivers have been grouped into river **ecoregions** or types.

Ecoregions are areas of similar ecological characteristics, grouped together. Rivers in the same ecoregion are ecologically more similar to one another than rivers in a different ecoregion, and share similar physiography, climate, geology, soils and potential natural vegetation.

The South African ecoregional classification (Kleynhans et al. 2005) divides the country's rivers into 31 distinct ecoregions, or groups of rivers which share similar physiography, climate, geology, soils and potential natural vegetation. Consideration of the ecoregion in which a particular river or river reach falls is an important informant of both the identification of causes of river degradation, and the most appropriate manner of addressing such issues in a rehabilitation context.

Figure 2.2 illustrates the extent of the different river ecoregions in South Africa. The characteristics of each ecoregion can be accessed in DWAF (2005).

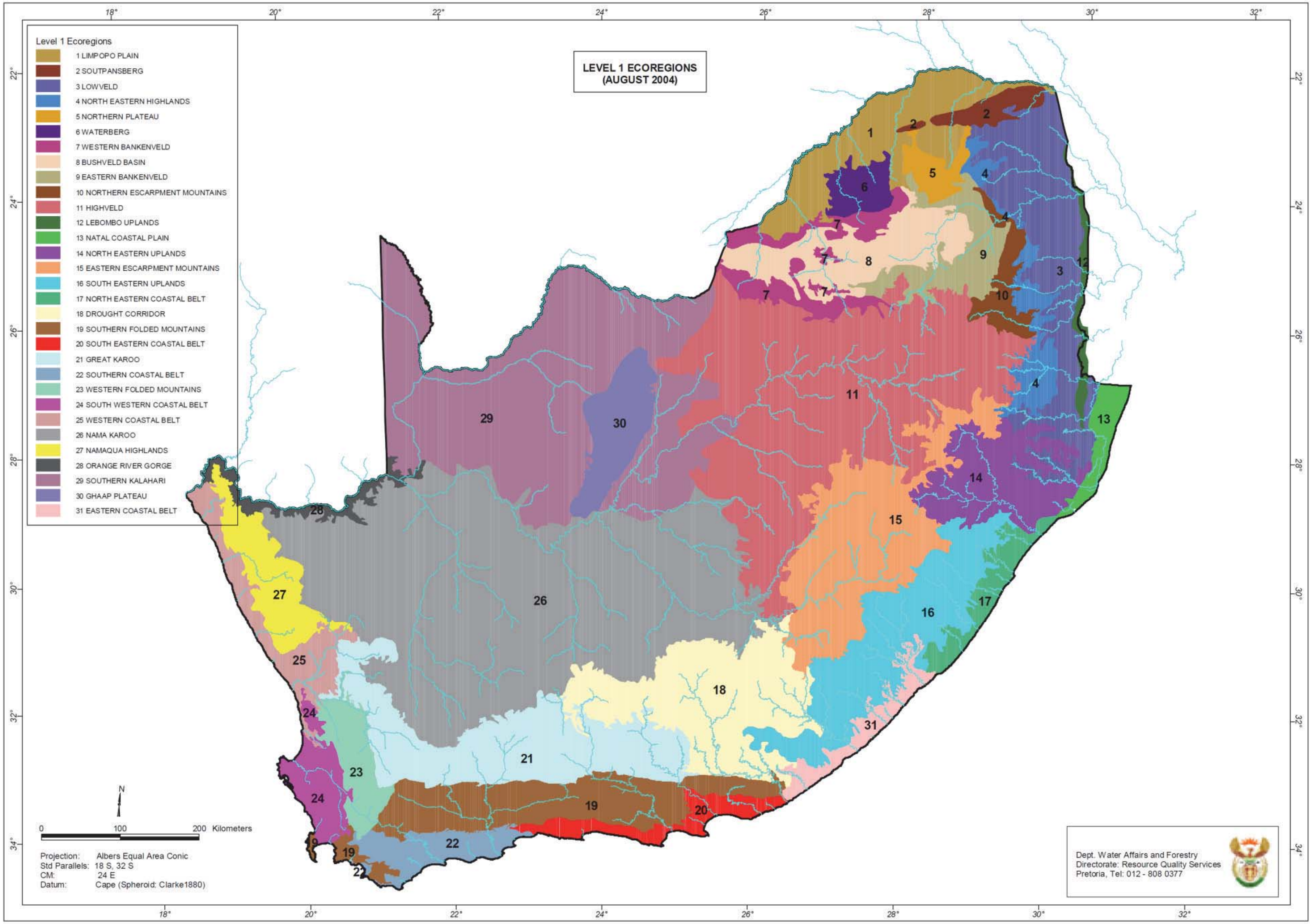


Figure 2.2: Level I River Ecoregions for South Africa, Lesotho and Swaziland. Figure after DWAF (2005)

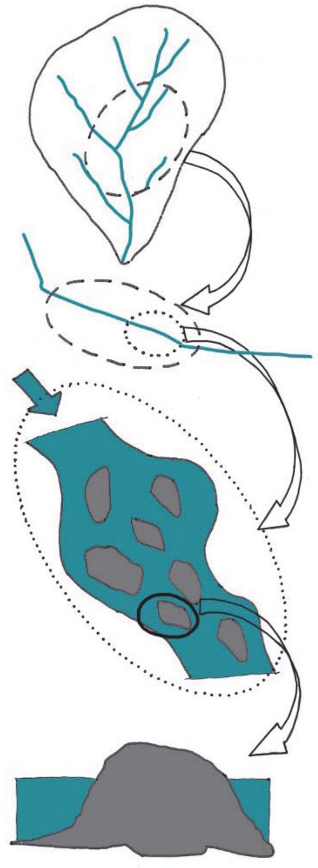
2.4. River dynamics

Rivers are complex systems. Their form (morphology) and behaviour (erosion, deposition and flooding patterns) at any given point along their length are the result of the interaction between the characteristics of the catchment which it drains and the local site conditions which creates the template upon which habitat and living organisms (especially vegetation) occur.

A river system is best understood using a hierarchical patch dynamics approach (Table 2.1), as this enables the observer to link a particular reach with both smaller and larger scale aspects of the river system which may be influencing the processes and characteristics (or perceived problems) at a site. Very long term (geological) time scales of the geomorphological development of the subcontinent (Partridge et al. 2010) provides some context of the evolution of river and valley forms across the country (Figure 2.3), but these time and spatial scales are not relevant for most river rehabilitation projects. River rehabilitation tends to be focussed at the reach or even geomorphological unit scale, where more contemporary processes are at play.

For example, at the level of the geomorphic unit (see Table 2.1), an island or mid-channel sandbank which becomes covered with invasive alien vegetation may cause changes in flooding patterns and other impacts. At a small scale, this may cause erosion if floods (that could once flow over the island that is now infested with alien trees) are diverted towards an opposite bank. The increased speed and height of the floods could erode a previously stable bank. If many banks and islands become infested in one section of the river, then the flooding characteristics of the entire reach may change. The increased flow resistance from vegetation could result in a general reduction in flood velocities and an increase in flood heights. The reduced velocities could cause increased sediment deposition, and the raising of the bars and river bed height (due to sediment deposition) could further increase flood heights. Thus changes at a small spatial scale (the island) can have impacts at that (the bank), and at larger (the reach), spatial scales.

Table 2.1: A spatially nested hierarchical approach to understanding river systems (after Frissell et al. 1986, and Dollar et al. 2007).

Spatial Scale		Description	Temporal Scale	Hydrological Descriptors	Sediment Descriptors	Processes
	**Geomorphic province** (10-1 000 000 km^2)	Large areas of the country with similar geological history and characteristics.	$>10^6$ years	Rainfall patterns	Long term production, storage	Tectonic (long term geological timescales)
	Basin (10s to 100 000 km^2)	The defined catchment area of a river or stream	10^4-10^6 years	Rainfall patterns, MAR	Long term production, storage	Tectonic, (geological timescales), climate change
	Zone (10s to 100s of kms of river length)	A long length of a river with similar slope, sediment, flow and valley width characteristics (for example, a foothills zone).	10^2-10^4 years	MAR, flood peaks, baseflows	Production, transport, storage	Landuse changes, climate variability, erosion
	Reach (1-10s of kms of river length)	A short length of a river with similar slope, channel planform (pattern), sediment storage and habitat characteristics (for example, a braided reach).	10^1-10^3 years	MAR, peaks, daily discharges, frequencies	Transported and stored volumes, calibre	Sediment transport, vegetation stabilisation
	Geomorphic unit (10s to 1000s of m^2)	Bars, banks, islands, pools and riffles are examples of geomorphic units – small areas within a reach which have particular sediment and flow characteristics.	10^{-1}-10^1 years	Discharge, velocity, flow depth, shear stress	Calibre, stored volume, critical shear stress	Vegetation stabilisation, flow-sediment-vegetation interactions

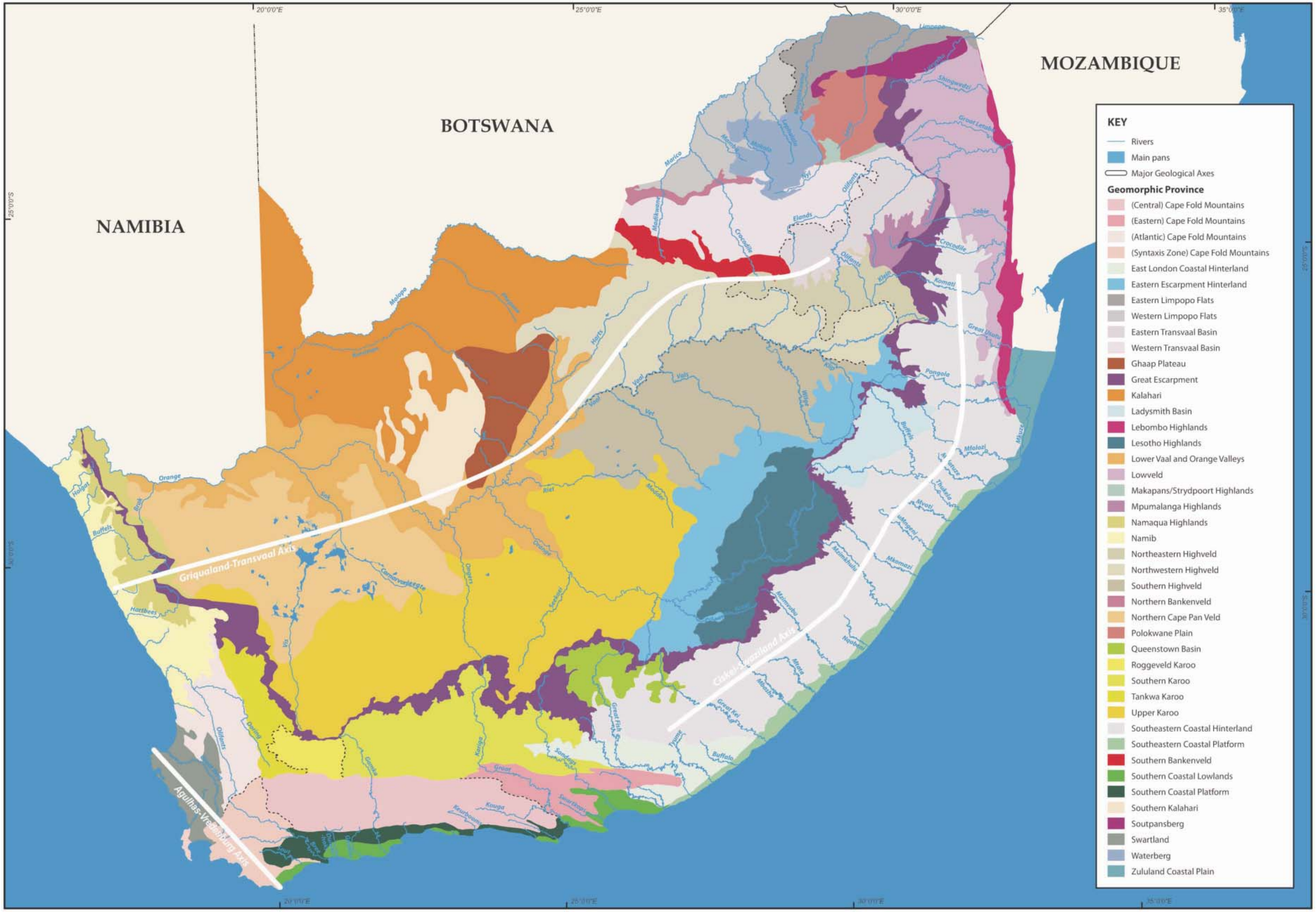


Figure 2.3: The geomorphic provinces of South Africa (Partridge et al. 2010).

Erosion and deposition are natural processes within river systems. In the very long term (hundreds of years or more) the relative balance of sediment inputs to sediment outputs, or, more simply, the amount of sediment stored within a river zone or reach, determines if the zone or reach is either net erosional, depositional or stable (in that sediment inflows are equal to outflows).

Depositional rivers tend to be the most difficult to manage – they are associated with wide valley floors and often large areas of the valley/floodplain are inundated during flooding. Due to the mobility of the channel position imparted by sediment deposition, these rivers have the capacity for large adjustments in the size (width) and position of the channel. This and the need to maintain large flooding areas can be problematic for adjacent landuse and infrastructure.

At shorter timescales, which are of relevance to river management (years to decades), there are natural periods or cycles of deposition, stability and erosion in all river systems. These cycles are associated with climate variations, changes in sediment loads from the catchment, and can be induced by changes at the site or reach scale (such as a river reach becoming well vegetated, slowing flood velocities and thus trapping more sediment).

In the context of rehabilitation, ***it is critically important to understand that the "natural condition" of a site or reach is in fact represented by a range of conditions*** which, for rivers, is usually a function of the recovery time from the last major flood and sediment events at that site. Vegetation succession also plays an important role in the changing biophysical condition of the reach.

The idea of what constitutes the "natural" (sometimes also referred to as Reference) condition of a watercourse provokes passionate arguments among researchers but forms the backbone of rehabilitation practice for managers and stakeholders (Fryirs and Brierley 2009). Naturalness should be considered as a functional condition whereby the river is able to adjust its character and behaviour in response to flow, sediment, and vegetation fluxes (Brierley and Fryirs 2005, Hughes et al*.* 2005). Historical records, such as anecdotal evidence, old maps or aerial photographs, or even historical Google Earth imagery, can be used to generate some understanding of the original historical condition and dynamics of the river reach under investigation. The historic morphology (channel patterns) of the reach can inform to a large degree the underlying natural dynamics of a river system. For example, braided rivers typically indicate a high sediment load and dynamic channel planform. When attempts are made to confine and stabilise these reaches (cf. **Figure 2.4**), the excess sediment which was formerly transported through, and stored within these reaches needs to be more actively managed.

South Africa does not have a river classification system that can account for process and the diversity of river reach types across the country, much less the typical habitat types one can expect within different reaches. A hierarchical classification system to the level of zones was developed (Rowntree and Wadeson 1999), and some development on the classification (van Niekerk et al. 1995) and behaviour (Rountree et al. 2001; Rountree and Rogers 2004; Tooth and McCarthy 2004) of select reach types has been undertaken, but no national classification system has yet been developed. By way of example, refer to Rosgen's (1994) description of a variety of different river reach types and their characteristics. He described rivers by the number of low flow channels, degree of channel incision, sinuosity, width to depth ratios, slope and the dominant sediment type. Such a system could be used to characterise the expected reference condition of rivers and thus provide a framework within which rehabilitation efforts could be couched. It is important to note however that it may not always be possible to restore a river back to its natural condition. When channels become even moderately degraded, thresholds (such as the degree of incision) may in some cases be exceeded which cannot be rehabilitated, and a new meta-stable state of the river arises. These concepts have formed the basis of a widely lauded approach to river management (Brierley and Fryirs 2005).

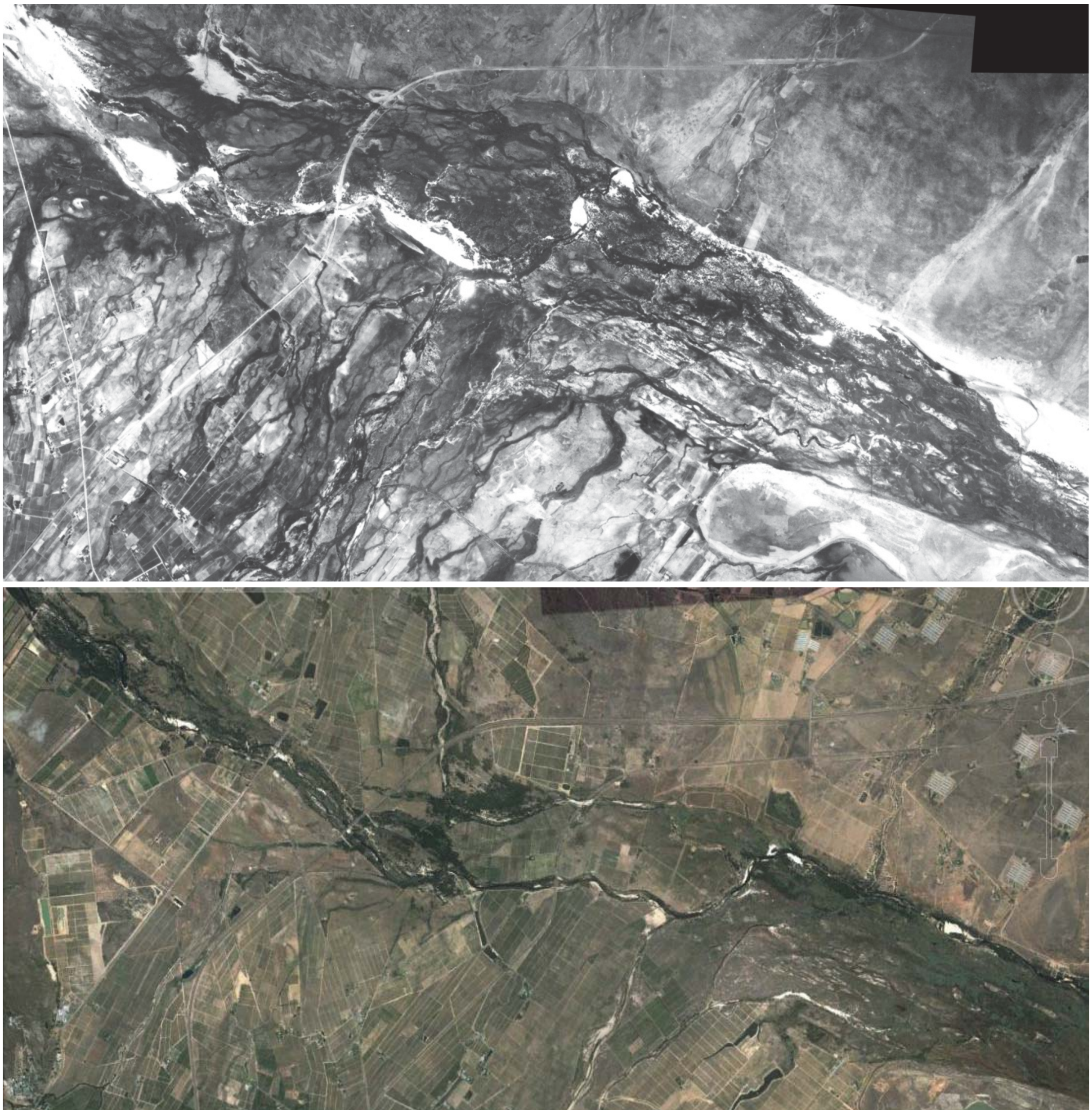


Figure 2.4: A formerly braided reach of the upper Breede River near Robertson in the Western Cape in 1949, above, and 2010, below (Rountree 2012).

In southern Africa, the expected changes and dynamics of some river reaches may be more extreme due to the atypically large floods which characterise the arid and semi-arid regions of the region (see Section 2.2). Episodic stripping of sediments associated with infrequent, extremely large magnitude floods has been used to explain fluvial changes in several semi-arid rivers of Australia, India, North America and southern Africa (Womack & Schumm 1977; Baker 1977; Nanson 1986, Kochel 1988; Gupta et al. 1999; Bourke & Pickup 1999; Tooth 2000; Dollar 2002; Rountree et al. 2001; Parsons et al. 2006). Episodic stripping occurs when gradual aggradation (i.e. raising of the river bed by sediment deposition) is set back by extreme flooding events (Nanson 1986) and evidence of such river dynamics have been observed in the eastern seaboard rivers (Rountree et al. 2001). Vegetation establishment and encroachment within and alongside the river channel follows a similar pattern (Carter and Rogers 1995), mirroring and probably enhancing the sediment storage patterns (**Figures 2.5 and 2.6**).

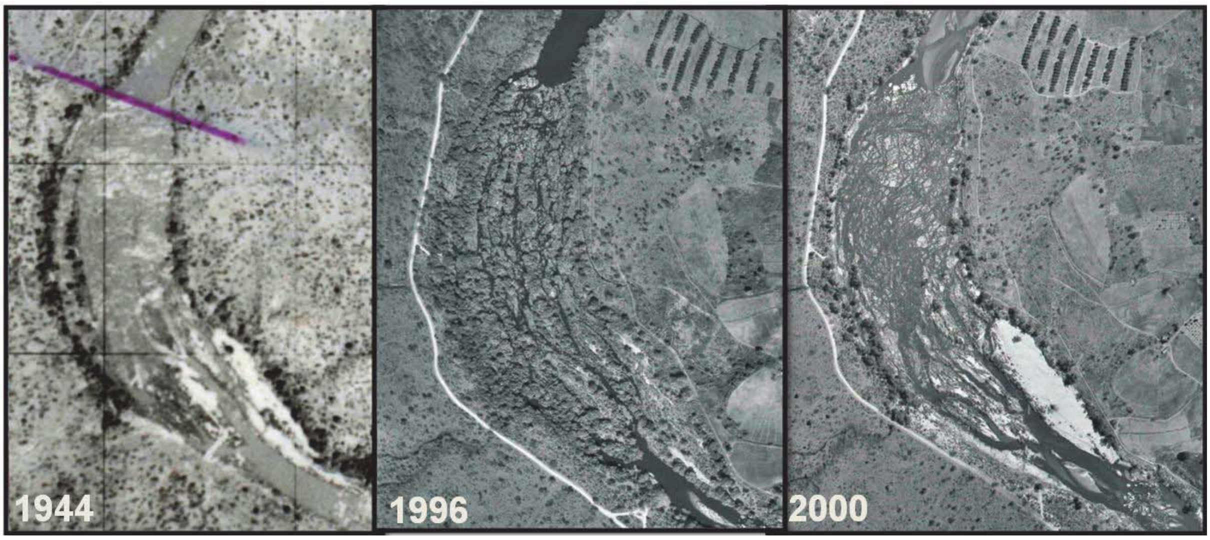


Figure 2.5: Vegetation encroachment in rivers can be a natural process, as indicated in these historical images of the Sabie River in the Kruger National Park. Progressive vegetation growth occurs in periods between large flood events, resulting in the densely vegetated riparian forest condition seen in 1996. However, this growth is reset periodically by very large floods – as in 1921, prior to the 1944 aerial photo, and in early 2000, prior to the 2000 aerial photograph (source: Rountree and Rogers 2004).

The above is intended to demonstrate the complexity of the underlying natural processes of sediment transport and storage within river systems, and the associated changes in vegetation which can result. A good understanding of the underlying natural morphology and dynamics (rates and ranges of natural change) is invaluable to be able to assess the current condition of the river reach and how far, if at all, it has changed from the range of natural states which might be expected. An understanding of the underlying processes is also important to be able to identify and, through rehabilitation efforts work towards, a desired condition of the river.

Rehabilitation efforts addressing the erosion or deposition of sediment should always be required to provide sufficient motivation for the proposed rehabilitation interventions. It would be important to know if the resultant condition of the watercourse would, relative to the current degraded condition, be closer or further from the expected natural condition, and historical data sources can be used to determine this.

It is therefore highly recommended that any river rehabilitation project begin with a thorough analysis of historical aerial photographs or other similar historical sources to describe and understand the natural condition and dynamics of the river or reach, in order to motivate for a suitable condition, in sympathy with the natural processes, to be achieved through rehabilitation efforts.

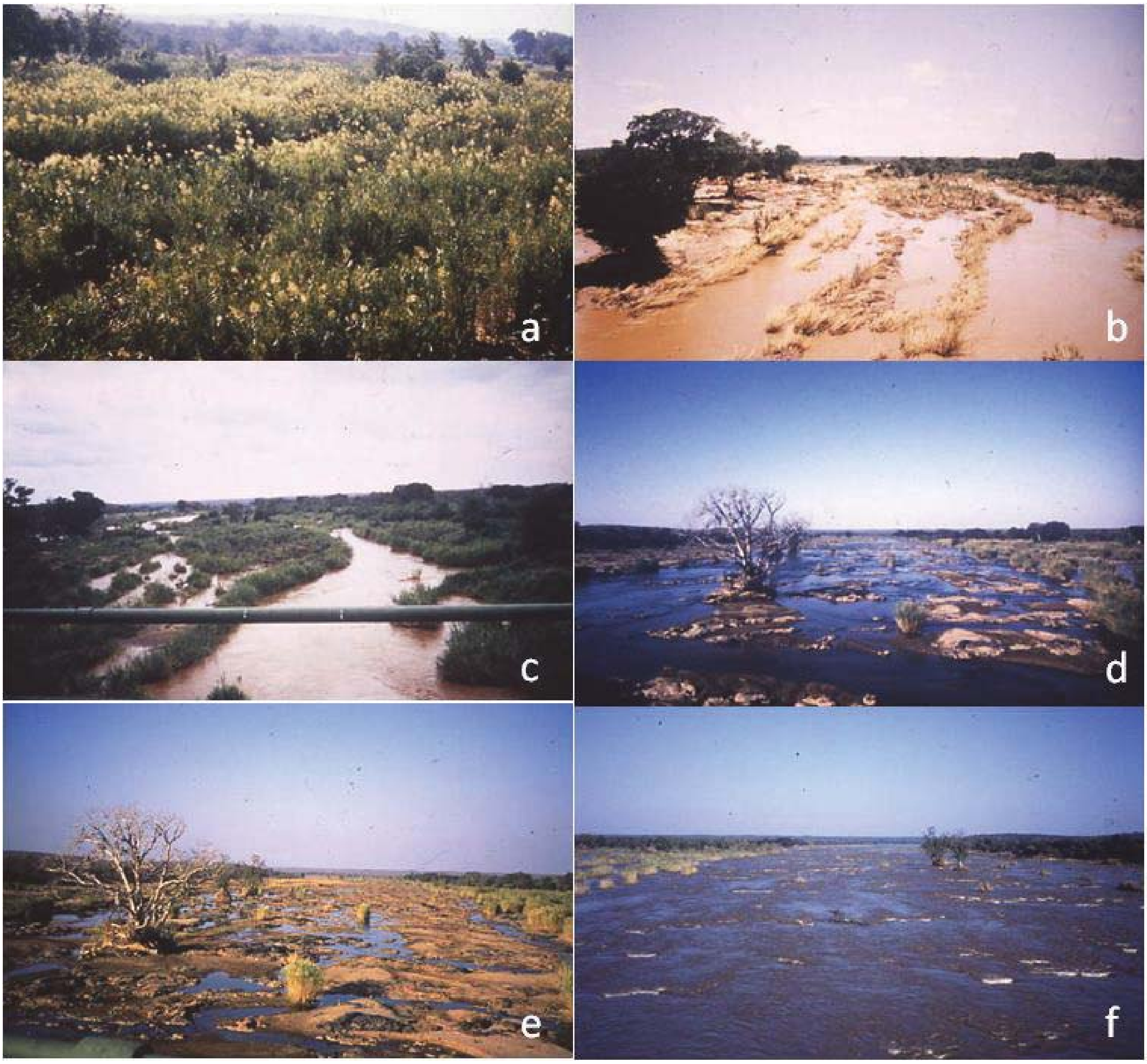
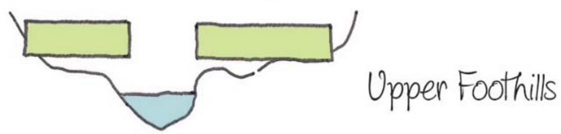
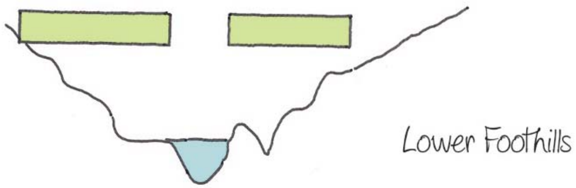
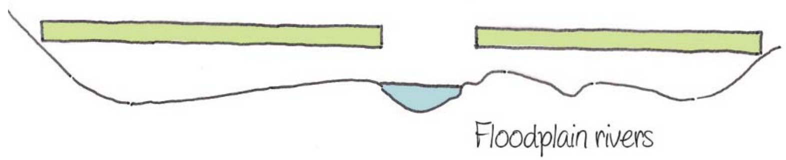


Figure 2.6: The Olifants River in Mpumalanga circa 1989 (a), 1991 (b), 1992 (c), 1996 after a large flood event (d), 1999 (e) and in 2000 after a further large flood (f). Stripping of vegetation and sediment after the large floods in 1996 and 2000 is characteristic of some river reac types in this region. All these diverse conditions represent a relatively natural condition of this river reach which is located within the Kruger National Park (photos: K.H. Rogers and M. W. Rountree).

Table 2.2: Characteristics of typical river zones

Typical river zone cross section with the extent of associated riparian zone (zone in which flooding occurs) indicated in green	*Riparian area*	*Sediment characteristics*	*Typical river reach types*
	Limited to narrow margins along the active channel	Large bed elements with little suspended material	Single channel bedrock-dominated reaches (cascades, pool rapids)
	Can have terraces which are areas important for sediment storage, flood attenuation and riparian biota	Predominantly cobble, with some gravel and sand. Varying suspended loads	Single channel mixed bedrock and alluvial reaches, pool rapid and pool riffle sequences
	Often have incised macro-channels which act as restrictive floodplains	Increasingly mixed (gravel/sand) with varying suspended loads	Single to multiple channel mixed bedrock and alluvial reaches, pool riffle sequences, braided reaches,
	Very wide with high habitat diversity (lakes, oxbows, floodplain wetlands)	Sandy to very fine	Single to multiple channel alluvial reaches, single thread, meandering floodplains, and braided reaches; may be large floodplain lakes and wetlands (e.g. northern KZN).

2.5. Rivers as longitudinal ecosystems

The different reaches of a river are typically characterised by particular chemical, physical and biological conditions, which interact in a continuum along the length of the river. This notion of a continuum is a fundamentally important concept in understanding river function. Although rivers clearly change their characteristics with distance downstream, becoming deeper, wider, often more slowly flowing, less oxygenated and warmer, each river operates as a coherent whole, with the processes and features of the upper reaches successively influencing the lower reaches and their processes and features, from the source of the river to the sea (Davies and Day 1998). This concept of the river as a continuous longitudinal ecosystem is the basis of the River Continuum Concept (RCC) of Vannote et al. (1980), which has largely shaped our current understanding of river function. The River Continuum Concept presents rivers as generally having continuous gradients of physical and chemical conditions, from their sources to the sea, although there are some exceptions to this (e.g. rejuvenated rivers that pass over waterfalls or rapids in their lower reaches). These gradients are formed largely as a result of changes in gradient and substratum, which results in the progressive modification of other variables with distance down the river. As a general rule, rivers tend to increase in temperature, discharge, turbidity and the concentrations of dissolved salts and nutrients with distance downstream, and to decrease in flow rate and dissolved oxygen concentrations with distance downstream. The RCC further outlines the role of driving variables (e.g. nutrient inputs, flow regime and temperature) in eliciting responses from biota, which usually take the form of progressive changes in patterns of community structure with distance downstream. These occur because different species or groups of species are confined to those reaches in which physical and chemical conditions are suitable for their particular requirements. Taxa with similar requirements form species assemblages, typical of a particular river reach. These organisms themselves play a role in affecting the characteristics of the river further downstream – e.g. if organisms in the upper reaches of a river feed on large pieces of plant material (e.g. leaves) fallen into the river, small particles of these leaves will be wasted, and will pass downstream, where they will supply other aquatic communities.

The processes and features of upstream reaches thus influence those in reaches further downstream, and impacts in one reach can have effects that extend all the way downstream. By the same token, however, the fact that rivers function as continua also means that rivers can recover from impacts. Organisms that are lost from one section of a river may re-colonise that section, from upstream, unimpacted areas.

Importantly, the RCC also addresses sources of food and energy pathways in rivers – another important consideration in rehabilitation planning. Sources of food can be either externally sourced (e.g. as leaf litter) or be produced in the river, through photosynthesis. The RCC uses the ratio of food that is produced to that that is consumed (measured as the ratio of the amount of oxygen generated by photosynthesis (P) to the volume consumed in respiration (R)) to describe food and energy pathways in a river. The theory postulates that the P:R ratio will be <1 in canopied headwater streams that usually rely heavily on external inputs of leaves; >1 in foothill river reaches where light availability encourages algal growth and <1 in lowland river reaches, where the river receives nutrient inputs from upstream, and turbidity often discourages photosynthesis other than in rooted marginal vegetation. Such concepts allow an understanding of how some impacts such as the invasion of naturally low-growing riparian fringes with canopies of tall alien trees, or the replacement of indigenous trees with European trees, subject to unnatural (autumnal) leaf falls, may bring about fundamental changes in ecosystem function, with knock-on effects on downstream river reaches as well.

It must be stressed that the above concepts cannot be applied universally to South African rivers. Many mountain headwater systems lack canopies and have high P:R ratios; many rivers classified as foothill or lowland rivers flow within deep beds of sand, or are highly seasonal, flowing only sporadically and supporting very different aquatic ecosystems to those encompassed by the RCC. Nevertheless, the concept does at least promote consideration of a river as an interconnected single system and considers important biological processes as well as geomorphological, physico-chemical and hydrological processes.

2.6. Aquatic habitat types in rivers

While holding onto the important concept of a river as a continuous longitudinal ecosystem, and taking cognisance of the comments made in Section 2.4. with regard to the lack of a clear geomorphological classification for South African rivers that takes account of process, it is nevertheless useful to look at different reaches or zones within the river, that tend to display similar characteristics at the scale of habitat for fish and aquatic invertebrate communities, at least within the same ecoregion (See Section 2.3). On this basis, many aquatic ecologists consider a river in terms of the following main zones, which represent a simplified array to the hierarchical reaches described by Rowntree and Wadeson (1999) on the basis of gradient. Broadly, the zones comprise:

- the headwaters, or upper, source area of a river
- the mountain stream reach
- the foothill reaches
- the lower (or lowland river) reaches
- the estuary

Note however that not all rivers have all of the zones listed, and there are many variations between different kinds of rivers (e.g. in the fynbos, the headwaters of many streams are not covered over by a canopy of trees). Nevertheless, the above zone types, illustrated schematically in **Figure 2.7** and described in terms of typical riparian habitat, sediment and reach types in Table 2.2) do provide an imperfect framework for describing the hydrological, physico-chemical and biological features in a particular zone, notwithstanding the fact that there is enormous variation between ecoregions as to the characteristics of particular zones.

The above river zones also form the basis for the setting of so-called biological "bands" for macroinvertebrates, as developed by Dallas (2007). These biological bands are applied to SASS5 – the South African Scoring System (version 5) which uses aquatic macroinvertebrates in a river as a gauge of water and habitat quality. Aquatic macroinvertebrates have been rated, at the level of Family, in terms of their tolerance to poor water quality, with the highest scores being allocated to the most pollution sensitive taxa, and the lowest scores allocated to pollution tolerant taxa. When the aquatic macroinvertebrate community in a particular river reach is sampled, different scores can be obtained for the reach, including taxonomic diversity, a Total Score and an Average Score per Taxon, which indicates the prevalence or not of pollution-sensitive taxa. Biological Bands were developed for each ecoregion, as a tool for interpreting SASS5 scores in different river zones. Particular suites of macroinvertebrates typically occur in particular river zones, and those assessed at a particular site can thus be compared to a theoretical or actual reference condition, for the same ecoregion, and the present state of the river with regard to its macroinvertebrate community structure and water quality can thus be gauged. This is a useful informant of river rehabilitation planning, and highlights again the importance of developing an early understanding of river reference condition, prior to embarking on river rehabilitation projects, particularly where these may include attempts to increase instream biodiversity by adding habitat types.

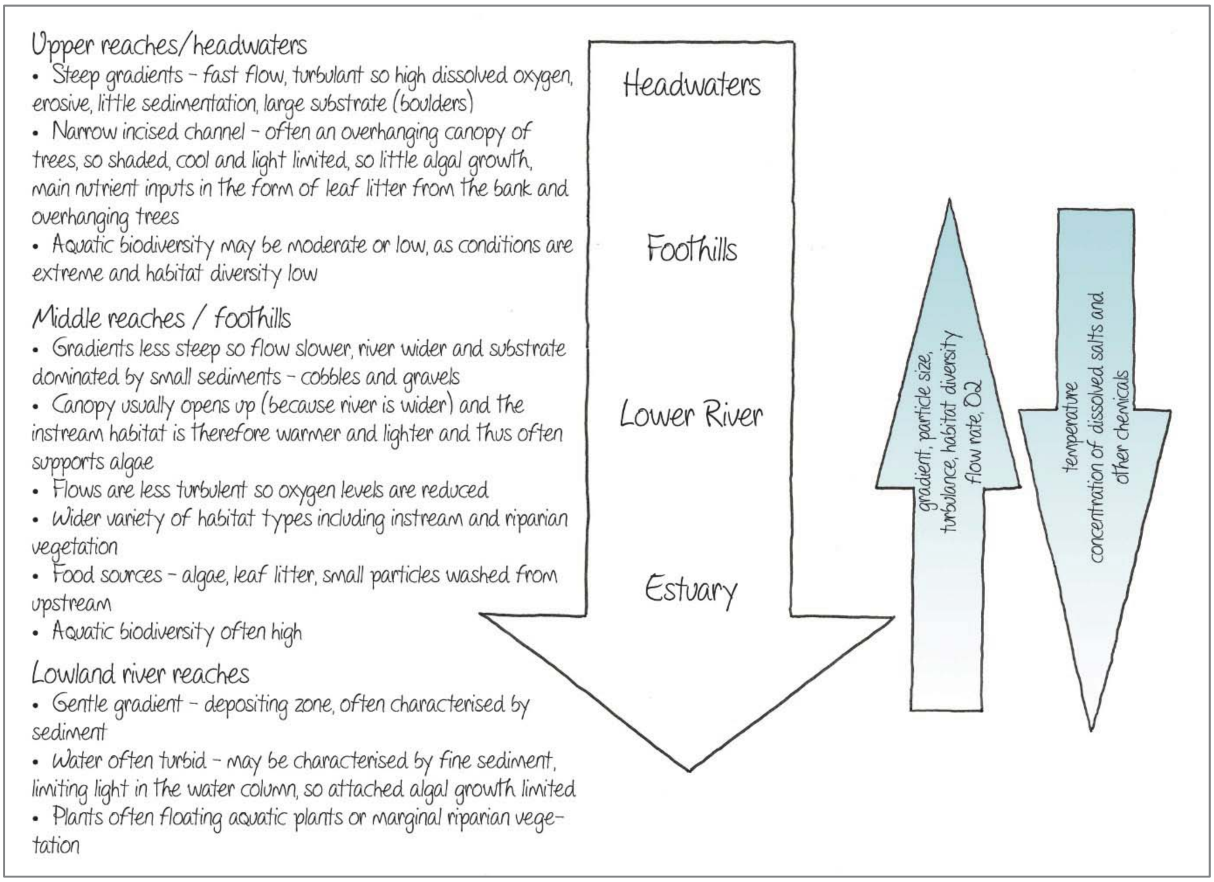


Figure 2.7: Schematic of a "typical" river, illustrating gradients in hydrology, geomorphology and biology with distance through the system. Nopte that in practice many South African rivers do not conform exactly to these zones, or display the stated characteristics uniformly.

In addition to changing along their lengths, rivers also change across their widths, with depth and over time (see **Figure 2.8**). Recognition of such connectivity and how it affects river function is very important in interpreting the condition of a river, its trajectory of change and the consequences of intervening in any aspects of the river corridor.

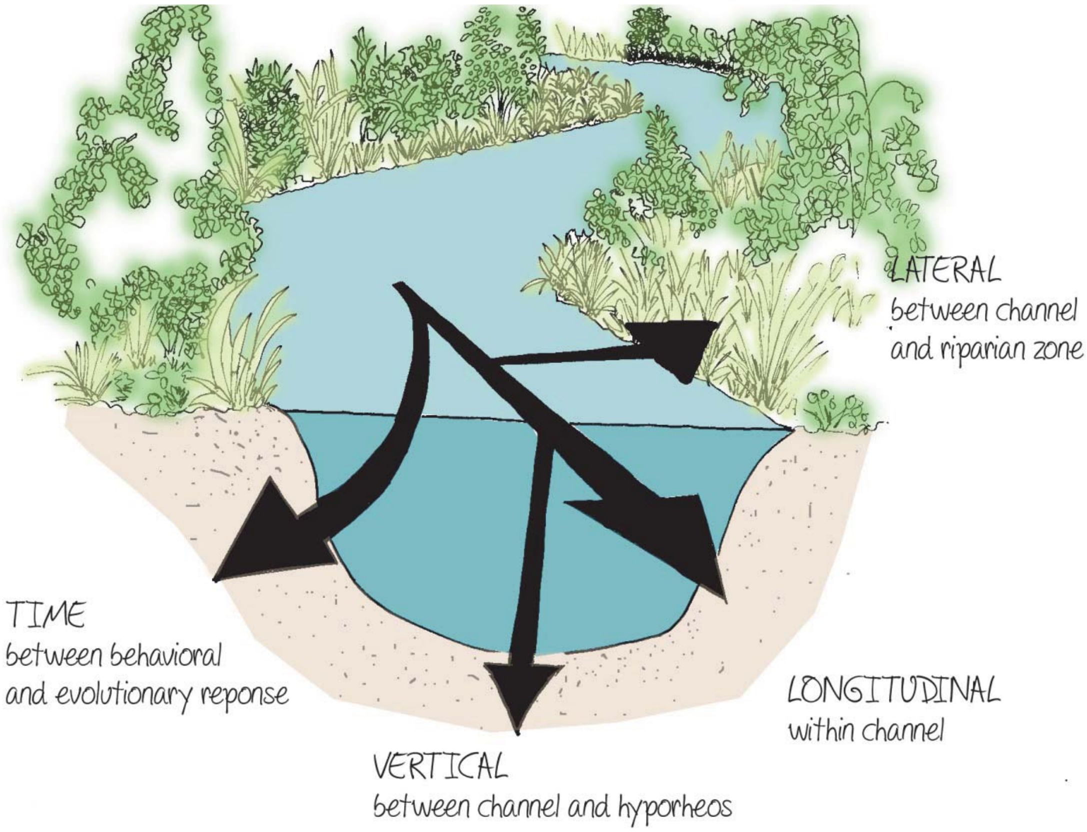


Figure 2.8: Temporal, vertical, lateral and longitudinal connectivity along a river (adapted from Davies and Day 1998)

2.7. River flow characteristics

The occurrence and behaviour of water in a river drive the processes underlying its dynamics, as described in Section 2.4, and determine to a large degree the nature of aquatic habitats (Section 2.7). Of particular importance in the context of river rehabilitation are the characteristics of the discharge (i.e. the volumetric flow rate) and velocity levels in the hydrological hierarchy of **Figure 2.1**. Although it is the discharge that is used to characterise the severity of floods and to specify environmental flows, it is only through the consequent hydraulic characteristics that its effects can be understood and described: fish habitats are broadly characterized in terms of flow velocity and the associated depth, and the erosion and deposition of sediment are responses to flow velocity and depth through the shear stresses they impose on the river bed and banks. The assessment of flood impacts, channel stabilization methods and habitat enhancement measures therefore require being able to predict the relationship between discharge on the one hand and the consequent flow velocity and depth on the other.

How fast and deep water flows in a river depends firstly on the **channel geometry**, i.e. the size and shape of its cross-section, its gradient, and the presence of any disrupting features such as rock outcrops or weirs. All of these features may be modified for rehabilitation purposes, e.g. widening a channel will generally reduce both flow depth and velocity, while flattening its gradient will increase the flow depth and reduce the velocity.

Within a given channel geometry, the **flow depth** and **velocity** are governed by its **resistance** to flow – the greater the resistance, the deeper and slower the flow. Flow resistance is determined by physical characteristics of the river, and arises from features that cause loss of hydraulic energy or impose forces against the flow.

The most important sources of resistance are the **surface resistance** or “friction” between the flow and the river bed and banks, and “**form resistance**” resulting from flow separation (or wake formation) around objects or boundary irregularities. In natural rivers, surface resistance results primarily from the bed roughness and form resistance from vegetation and large rocks, such as in riffles. An increase in discharge will result in increases in both flow depth and velocity where surface resistance dominates, but a proportionally larger increase in flow depth with less effect on velocity where form resistance dominates. For example, in a concrete-lined channel, where resistance is purely of the surface type, an increase in discharge will result in faster flows whereas in a wetland the velocity would stay much the same and the increase in discharge would be accommodated by a significant increase in flow depth. Flood levels are therefore increased considerably by vegetation in rivers (see **Box 2.1**). The effects on flow resistance of some naturally occurring and artificially introduced river features are discussed below.

River substrate

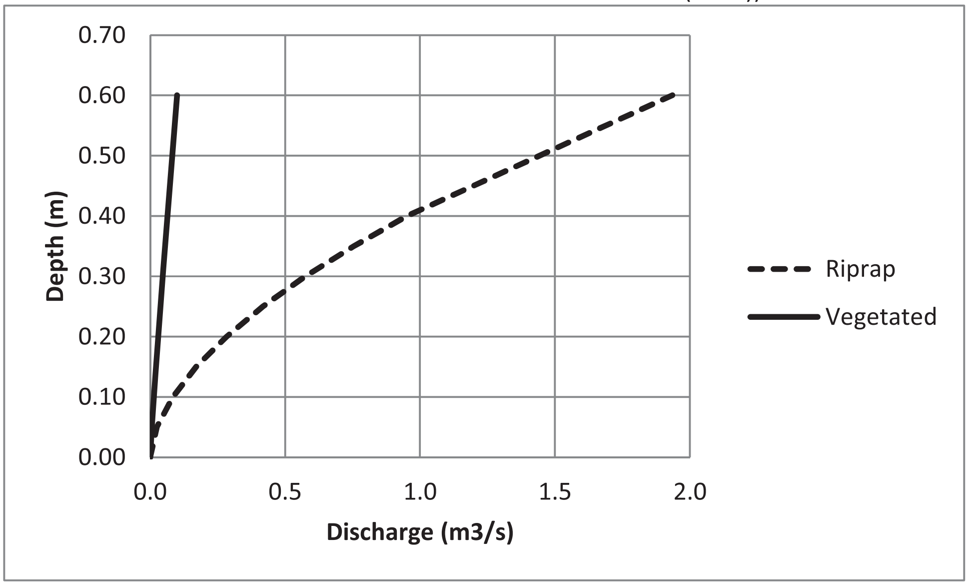
The material forming the river bed and banks (e.g. sand, gravel, riprap, submerged vegetation) is a major contributor to flow resistance. For bed material coarser than sand and relatively deep flows (i.e. the water level well above the top of the substrate material), the resistance is predominantly of the surface type, and increases with the size of the substrate material. With reducing relative depth the influence of the form roughness of the individual bed particles increases the overall resistance considerably, and becomes dominant if large rocks protrude through the water surface. Sand beds behave differently and are deformed by the river flow into a variety of “bed forms”, with geometries that change in a complex way with flow intensity and produce different degrees of form resistance at different discharges.

Vegetation

Vegetation occurs naturally in rivers and is also often introduced as a rehabilitation measure. It invariably increases flow resistance. Its effect depends on its growth type (submerged, emergent, free-floating or floating-leaved) and its distribution (extensive, in patches or along the banks) as well as the particular species morphology. Deeply submerged vegetation contributes mainly to surface-type resistance, while emergent vegetation adds form resistance within stands and additional surface resistance at the stand-clear channel interfaces. The resistance-affecting characteristics can change with season and flow condition – some plants bend and flatten under fast flows, resulting in lower resistance at high discharges, for example (see **Box 2.1**).

Box 2.1: Effect of vegetation on discharge and depth

The diagrams above show two 5.0 m wide channels with gradients of 0.0010. The bed of one is lined with 0.10 m diameter riprap, the other is covered with emergent vegetation stems with diameters of 5.0 mm and spacings of 5 cm. The relationship between flow depth and discharge for each is shown below. (Calculations for the riprap channel were done using the Darcy-Weisbach equation with the friction factor as recommended by Bray and Davar (1987). Calculations for the vegetated channel were according to the method of Jordanova et al. (2006)).



Water levels are shown in the top diagrams for discharges of 0.10 m^3/s (dashed line) and 0.30 m^3/s (solid line). These show that flow depth is greatly increased by vegetation (0.60 m compared with 0.11 m for the lower discharge and 1.63 m compared with 0.21 m for the higher discharge), and that flow depth increases much more rapidly with discharge when form resistance dominates over surface resistance. The flow velocity has changed from 0.18 m/s to 0.29 m/s for the riprap channel and has stayed constant at 0.033 m/s in the vegetated channel.

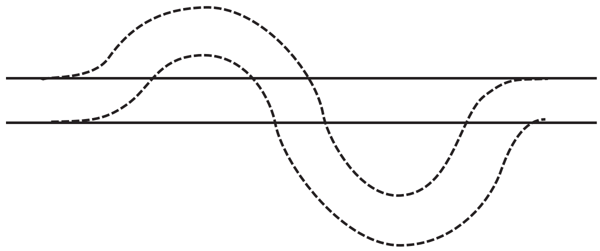
Channel irregularity and obstructions

Abrupt changes in cross-sectional shape and size along a channel (such as natural rock outcrops or artificial habitat-enhancing features) can increase the form resistance considerably if they induce flow separation or local flow acceleration. While increasing hydraulic diversity in instream habitats, especially at low flows, such features would raise water levels under flood conditions.

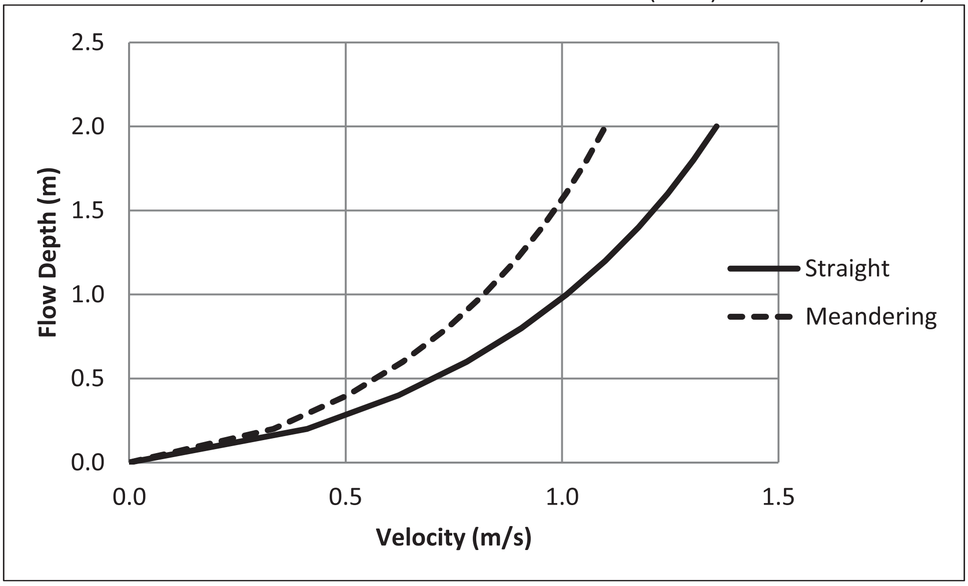
Channel alignment

Channel curvature induces secondary circulation which extracts energy from the primary flow, and dissipates this as the secondary circulation decays after the bend. This effectively increases the channel resistance. Meandering (successive, alternating bends) can increase the effective resistance by as much as 30%. Realigning a channel to reduce its slope by introducing curvature would therefore result in deeper and slower flows by virtue of both the reduced slope and increased sinuosity (see **Box 2.2**).

Box 2.2: The Effect of Channel Alignment on Flow Resistance



A straight, 5 m wide channel on a gradient of 0.0010 is realigned to create the meandering form shown. The effect on the relationship between flow depth and velocity is shown below. (Calculations were done using the Manning equation, with the effect of meandering accounted for using James's (1994) linearization of the United States Soil Conservation Service (1963) recommendation.)



Cross section size and shape

Resistance generally decreases with increasing discharge as the ratio of cross-sectional area to the resisting boundary length increases and the roughness size relative to the flow depth decreases. Compound (or two-stage) channels (used for increasing flood capacity while preserving natural in-channel habitats) present a special case where the resistance is increased by the interaction between main channel and floodplain flows when the water level rises above the bank level. This effect is enhanced by floodplain roughness (especially due to vegetation).

Natural and rehabilitated channels usually include many resistance-inducing features and their combined effects become very complex. Where resistance may play a role in the design of rehabilitation approaches that could potentially affect or would need to protect infrastructure or important property or ecosystems, final estimations of resistance should be left to experienced professionals, and supported by field data wherever possible.

3 PROBLEMS IN RIVERS

This section describes the main types of problems commonly encountered in rivers. The sections described below link directly with the Technical Manual for River Rehabilitation document in that potential solutions for each problem type are summarised here and evaluated and described in detail in the Technical Manual.

3.1. The effects of inappropriate structures and disturbances

The most common form of human-induced disturbance of sediment processes is the construction of features that alter the hydraulics and geomorphic characteristics of the river channel and flood plain (e.g. structures which alter the channel width, depth, slope, roughness and alignment characteristics). Such features may cut off floodplain area, alter channel planform, reduce incoming sediment, induce channel and bank erosion or change the capacity to transport and store sediment (USDIBR 2006), negatively impacting upon the lateral and longitudinal connectivity (**Figure 2.7**) of watercourses and altering flow velocities which cause changes in the physical habitats upon which biota depend. Such site specific landuse activities can thus play a major role in the degradation of watercourses, and include:

- dams;
- river diversions;
- the condensing of multi-channel braided systems into single channel rivers
- canalisation;
- construction of levees;
- roads, drifts and bridges;
- bank protection structures;
- the removal of sediment and debris from within the watercourse;
- grazing;
- sand and gravel mining;
- recreation; and
- encroachment from urbanisation, agriculture and industrial areas.

The impacts associated with these activities are described in the subsections below, but note that these impacts also fall within the suite of main impact types following in this chapter.

3.1.1. Dams and weirs

In-channel dams inundate the basins upstream of them, creating lake-like conditions in formerly wetland or riverine habitats. Migration routes for instream biota are usually severed, and downstream the releases from the dam create an altered water quality, temperature and flow regime. In the case of medium and large dams, almost all sediments downstream of the dam may be trapped in the dam, starving downstream reaches of sediment and causing erosion and incision of the bed. Flow alterations below dams also play a critical, but sometimes less obvious, role in degrading the downstream river reaches.

In the southern African environment, numerous weirs have been constructed in rivers and wetlands to arrest erosion head cuts, limit the incision of the river bed, or as water extraction facilities for municipalities and farmers. Where such structures are incorrectly designed or placed, the structures may not only fail, but can also contribute to the instability of the river. Leopold (1997) criticizes the widespread use of drop structures (weirs) to control erosion and sediment issues as unsustainable, and likely to result in structural failure in the long term, suggesting that a preferred approach would be to attempt to mimic natural river geomorphological processes. While Leopold's point of view must be taken note of, the practicality and sustainability of alternative methods to drop structures for stabilizing river incision must be taken into account, as there are few other viable methods for gully stabilisation. Should drop structures be the chosen alternative, due professional care must be exercised to ensure not only the stability of the structures, but the minimizing of negative impacts on the geomorphological processes in the river.

Spillway design can also have profound implications for river condition. Poorly designed spillways have two major problems:

- Should the spillway discharge capacity be exceeded during large floods, the water ponding upstream of the weir would spread out into the floodplain and outflank the weir. When this water returns to the watercourse it could very likely create a gulley around the end of the weir, leading to its foundation being undermined and the collapse of the weir.; his can be exacerbated by inadequately designed stilling basins downstream of weirs, as these can release excessively turbulent water into the natural channel causing bank and bed erosion.
- The increase in standing water and sediment upstream of the weir often leads to a proliferation of in-channel vegetation in this area. Such vegetation can be enough to divert the bulk of a flood flow around the structure (instead of flowing over it), and again lead to structural failure by outflanking.

In addition to issues of spillway height, incorrect spillway orientation can also trigger riverine impacts, by directing the flow of water into the river bank downstream, where it causes erosion. For this reason the orientation of spillways must be determined by an understanding of the flow of water during floods.

3.1.2. River diversions

In mining areas of southern Africa, small watercourses are often diverted away from the mining site in order to open up valley bottom areas for open cast mineral extraction. These river diversions usually are engineered channels with very limited habitat diversity. In other areas, rivers are diverted to maximize areas for agricultural land or other developments. Apart from issues such as disconnection from natural floodplains, loss of biodiversity and loss of natural habitat diversity, such systems often also give rise to serious flooding of adjacent areas in peak flood events, as they do not run through the lowest points of the landscape, but are perched, and when they overtop their banks, water floods into low-lying areas.

3.1.3. Flood protection using levees and channel straightening

Levees are artificial earth banks, constructed to contain floods in the river channel, usually in order that the adjacent floodplain may be developed. Levees are used to prevent floodwater entering lands (in the floodplain or riparian zone) which are under cultivation and/or developed.

Straightening of river channels and the creation or artificial raising of earth berms/levees along the top of the banks serves to increase the flood conveyance of river channels. However, the associated concentration of braided rivers into single channels, excavation of river beds and disturbance to the banks all contribute to situations where many rivers flow in artificially deep and narrow channels, with an associated unnatural increase in flow velocity and sediment transport capacity. The increase in sediment transport in some reaches leads to an increase in sediment deposition and resultant meandering of the river channel in downstream reaches beyond the end of the levees.

River bends and obstructions in rivers have also historically often been removed to increase flood conveyance – that is, to speed up the rate of transfer of floodwaters along the river channel, thus reducing overtopping of the river in these reaches, but increasing the flow rate of floodwaters in downstream reaches. The resulting decrease in surface roughness and increase in riverbed slope in river reaches affected by channel straightening tends to increase both river flow velocity and erosive power (USACE Wes Streambank Investigation and Stabilisation Handbook).

The consequences of straightened channels and levees (that is, reduced overbank flooding) include:

- Deeper flows and faster flow velocities in the reach with levees;
- Reduced flood attenuation of the reach with levees;
- Reduced deposition and increased sediment transportation in the leveed reach;
- Consequently increased flood peak discharge rates and velocities in the downstream reaches, as well as increased risks of bank erosion in the straightened/leveed reach.

The reduction in flooding frequency on floodplains where berms are installed can also promote encroachment of human settlements in these flood prone areas. However when large floods which breach these levees occur, such as those which occurred in New Orleans in the USA in 2005 during the floods associated with Hurricane Katrina, widespread devastation can result.

3.1.4. Roads, drifts and bridges

Roads, drifts and bridges, like dams and weirs, can, create migration barriers to biota, resulting in reach to zone scale instream biological impacts. This effect apart, the main impacts of bridges and weirs usually tend to be localised, affecting the immediate up and downstream beds and banks of the river. Localised scour (small scale erosion) around structures or flow impediments (**Figure 3.1**) tends to be associated with bridges, and involves the removal of material near or around structures or channel obstructions (Simons and Sentürk 1992), usually as a result of turbulence caused by the shape of the obstruction. Other impacts are often the combined effect of narrow bridge culverts or raised pavements, in rivers with high levels of invasion by woody alien trees, which wash downstream in floods and cause debris dams against bridges and other elevated structures.

Figure 3.1 Local scour around bridge pier (source: internet)

Figure 3.2 Debris dam against bridge piers (woody vegetation flotsam blocking bridge) (photo: H. King)

Low level drift crossings tend to be more benign than bridges in terms of bed and bank scour, and are less likely to clog with woody debris during floods (see **Figure 3.2**). They may however present more significant instream biological flow barriers, at least at low flows.

Even apparently benign features such as roads can alter the natural bank or topography and impact upon the river channel, channel bank stability and floodplain processes. Road crossings that concentrate diffuse, wide floodplain flows into a few small channels or culverts can also inadvertently trigger gully and donga formation where these are situated in alluvial sediments. Seldom are options for relocating and setting back roads from watercourses considered, since it is often only the flood-prone areas along watercourses which remain open for further road construction.

Possibly one of the greatest negative impacts of bridges on rivers is that they create an expectation that the river will remain in a fixed position and not meander – in a steep sided valley this is not a problem, but on flat lowland rivers it definitely is.

3.1.5. Bank protection structures

Eroding, undercutting banks and/or migrating active channels are often engineered and stabilised. These stabilised banks can prevent the natural migration of the active channel, and thereby reduce physical habitat diversity and dynamics, as well as altering the sediment trapping functions of rivers and their floodplains. Steep (near vertical) engineered banks may also limit lateral connectivity, preventing some riverine fauna from moving up the bank and onto the floodplain. If the structures or engineered banks prevent or limit the establishment of natural vegetation that provides protective cover, shading and habitat, then the quality of longitudinal ecological corridors along the bank and riparian zone will be reduced. In particular, for the reasons given, vertical river training walls are seen as the most undesirable options for bank stabilisation.

3.1.6. The removal of sediment, vegetation and debris from within the watercourse

Removal of sediment (small sedimentary bars, deposits and bed and bank material), vegetation and (natural woody) debris can similarly reduce in-channel and riparian habitat diversity. Removal of in-channel features is often undertaken to reduce flooding risks and prevent secondary (deflected) currents from causing erosion of the banks of the river, but the promotion of a straight, single channel river reduces habitat diversity. Usually the removal of sedimentary bars is temporary unless the cause for the formation of the bar is successfully addressed first, otherwise the bar will form again. Often the backwaters and secondary channels provide important habitats for instream biota that would not be able to withstand the stronger currents of the main channel, whilst the small bars and lower riparian vegetation also slow down flood velocities and serve to reduce flow speeds and increase flood attenuation and sediment deposition. These physical environments and their associated ecosystem services are reduced or lost during channel straightening and vegetation/bar/debris removal.

Removal of natural woody debris from river channels can also remove an important food source from the river – many aquatic invertebrates feed on decaying leaves and other debris, and instream biodiversity can thus be significantly affected by the systematic removal of this kind of material that provides an important instream microhabitat.

3.1.7. Grazing and vegetation alteration

Grazing in riparian areas and wetlands is a natural phenomenon, but excessive grazing, or conversion from natural vegetation cover to planted pastures, reduces vegetation and habitat complexity, and also is usually associated with a reduction in vegetation robustness (reduced stature and resistance offered to floods). These changes reduce the flood attenuation and sediment trapping efficiencies. Other indirect effects of grazing include trampling of river beds, and the creation of localised erosion gullies in river banks, while severely trampled riparian areas may be more vulnerable to erosion. In West Australia, rehabilitation programmes that have focused on the protection of small channels from grazing livestock have improved water quality and bank stability.

3.1.8. Sand and gravel mining

The removal of sediment from the channel is usually undertaken to reduce the risk of overbank flooding, particularly in rapidly aggrading reaches. It can also be removed in mining operations.

Sediment removal disturbs the river bed and banks, degrading habitat condition, especially where the sediment is being removed from the active channel and marginal zone. If the frequency of removal exceeds recovery rate, the zone of removal will remain a disturbed, degraded area that often supports only disturbance tolerant weedy species, with low levels of faunal diversity.

In addition to the onsite impacts, downstream and upstream impacts can result from poorly managed sediment mining areas:

- Where sediment is being removed at a greater rate than sediment is flowing into the reach, the downstream reaches can become starved of sediment, triggering increased erosion (similar to the impacts below a dam);

- Where the removal of sediment creates a deeper, narrower channel with a bed and/or banks of erodible sediments, the reach can be destabilised through lateral and vertical erosion, resulting in upstream headcut migration and downstream sediment deposition; and
- Elevated fine sediment loads can degrade the quality of instream habitats downstream.

In special cases, contaminated bed sediments may be a critical management issue. In some Gauteng and Northwest catchments where gold mining has occurred, heavy metal and even radioactive elements are present in the sediments of rivers and wetlands. The disturbance of such sediments can mobilise these pollutants and present risks for both the site and downstream environments and biota.

3.1.9. Encroachment from urbanisation, agriculture and industrial areas

The encroachment of landuses onto floodplains and into the riparian area of rivers is associated with a combination of impacts. In addition to the site specific impacts described above, widespread landuse conversion at a catchment scale can dramatically alter the flow rates, water quality and sediment regimes of watercourses.

3.1.10. Mechanical disturbance of the river bed and banks

The bulldozing of riverbeds and banks is sometimes necessary to protect infrastructure and developments close to rivers, and is promoted by some landusers as a means of reducing bank overtopping. This practise is however generally very harmful to river stability and should be avoided as much as possible. The most negative effects of the bulldozing of rivers are the stripping of indigenous vegetation and the promotion of un-natural and unstable river geometries. For example, bulldozing disturbs the composition of the river bed locally, increasing the risk of erosion. The segregation of river sediment into windrows of fine and coarse material facilitates the erosion of both (the most stable river bed material is a mixture of fine and coarse particles).

- In parts of the Western Cape, Eastern Cape and Kwa-Zulu Natal, mechanically disturbed riverbeds are an ideal place for fast growing alien vegetation such as Oleander, Black Wattle and Silver Wattle to get established;
- In the Western Cape as well as the Eastern Cape, the alteration of rivers by channel excavation and the construction of levees was historically common, largely to prevent flooding of adjacent floodplains and allow agriculture and other landuses in these areas;

3.2. Invasive plants

Invasion of rivers and riparian areas by plants, and the various responses by landowners to such invasion, has contributed significantly to the deterioration in condition seen in many of South Africa's river. Problems such as erosion and sedimentation that affect the management and potential use of rivers are also often associated with alien invasion, with many cases of extreme riverine degradation being traced back to often seemingly-insignificant invasion of the riparian or riverine area by alien or other invasive plants (see Volume 3, Case Study #14).

3.2.1. Which are the key invasive alien plant species affecting South African rivers?

Of the 117 major invasive alien plant species recognized in South Africa (Cadman et al*.* 2010), 27 are considered aggressive transformers of riparian zones. That is, they alter the structure and function of natural riparian (that is, river bank) areas. Seven aquatic species are further recognised as significant invaders of aquatic ecosystems including rivers (e.g. Bromilow 2001, Ractliffe et al*.* 2003a), and comprise five floating species (*Pistia stratiotes* (water lettuce), *Azolla filiculoides* (Water fern), [1]*Lemna gibba* (Duck weed), *Salvinia molesta* (Kariba weed) and *Eicchornia crassipes* (Water hyacinth), and the rooted *Rorippa nasturtium-aquaticum* (Watercress) and *Myriophyllum aquaticum* (Parrot's Feather). Six other species have been listed (e.g. FCG and Wetland Solutions 2011a and b) as occurring in both aquatic areas and along river banks and margins. These include common garden escapees such as *Commelina bengalensis* (Wandering Jew), *Pennisetum clandestinum* (Kikuyu grass) and *Tropaeolum* spp. (Nasturtium), which have all become particularly problematic in invading urban riverine areas, smothering indigenous vegetation and significantly impacting plant species and structural habitat diversity along riparian zones (see **Figure 3.3**).

Information about the biology, habitat and control of the key invasive alien species specifically affecting rivers is provided in Appendix 2-A of Volume 2 (The Technical Manual) of this document.

Figure 3.3: An urban reedbed smothered by *Commelina benghalensis* (Wandering Jew) (Photo: Liz Day).

[1] Note that *Lemna gibba* is recorded as indigenous in South Africa, although listed as invasive and a problem in many of our watercourses (Bromilow 2001)

3.2.2. How do invasive plants spread?

Riparian invaders tend to disperse mainly downstream, especially during floods (Versfeld 1998), although many are also dispersed upstream at least at times by other mechanisms such as wind or birds. Riparian zones are particularly vulnerable to invasion, being usually physically dynamic areas, with changes in flows, especially floods, altering river banks and beds and exposing bare soil for colonisation by weeds. Downstream dispersal of aliens from established nodes is usually rapid and effective, resulting in the rapid expansion of nodes of aliens, often characterised by the "sudden" appearance of thickets of alien vegetation in previously undisturbed areas (**Figure 3.4**).

Alien and invasive plants defined

An **alien species** is defined in the Biodiversity Act as:

a. a species that is not an indigenous species; or
b. an indigenous species translocated or intended to be translocated to a place outside its natural distribution range in nature, but not an indigenous species that has extended its natural distribution range by natural means of migration or dispersal without human intervention".

An **invasive species** is one whose establishment and spread outside of its natural distribution range:

a. threatens (or has clear potential to do so) ecosystems, habitats or other species and
b. may result in economic or environmental harm or harm to human health.

Figure 3.4: *Prosopis* species typically invade flat alluvial floodplains rather than river banks, and rapidly form impenetrable thickets in moist conditions. Olifants River, Western Cape (Photo: Kate Snaddon).

3.2.3. Characteristics of invasive alien species

Typical invasive species often share common characteristics that allow them to establish successfully and often rapidly into new habitats, including (Picker and Griffiths 2011): their usually wide tolerances for different conditions and life-history traits that commonly include their ability to reproduce in large numbers, their fast growth rates and their tolerance for (anthropogenically) disturbed habitats.

3.2.4. Effects of invasive alien plants

Depending on the species, its growth form (e.g. tree, seedling or creeper), its density and the zone into which invasion occurs, invasive alien plants can have profound impacts on river function, and are often attributed as the main underlying factors triggering river degradation.

> DID YOU KNOW?
>
> **Effects of aliens on runoff**
>
> Runoff from catchments infested with *Acacia mearnsii* (black wattle) and *Acacia cyclops* is estimated to be 30-70% lower than comparable uninvaded indigenous catchments in the fynbos (Richardson et al. 1997). Note however that e effect of aliens on streamflow varies between geographic areas, and between different plant species.

- In **aquatic habitats**, alien plant invasion (usually comprising floating rather than rooted plants) can result in smothering of rooted indigenous marginal vegetation, thus increasing the risks of erosion, as well as blocking flows, covering and shading of open water habitat. At the same time, many invasive alien aquatic plants are effective in nutrient and heavy metal uptake.
- In **lower and upper riparian habitats**, direct impacts resulting from invasion include:
    - shading, which inhibits understorey vegetation – this can affect both biodiversity and the role of such vegetation in preventing bank erosion;
    - In dense stands, or even where alien vegetation grows in single rows along river banks, confinement of floods can occur, with alien trees preventing bank overtopping in floods, and promoting downcutting and bank and channel erosion (see **Figure 3.5**). Note that the effects of this may be reflected on river banks that are in fact not invaded by aliens, where the full force of water blocked by stands of aliens on one bank, is deflected to the opposite bank. Where erosion of valley bottom wetlands occurs as a result, this can also trigger headcut erosion, by increasing the gradient between downcut streams and their inflowing, vegetated tributaries (see Volume 3, Case Study #16).
    - Alien trees can also block river channels, particularly secondary flood channels where rapid dry season invasion may be more feasible, and in some circumstances promote upstream sedimentation, by raising the river bed.

Figure 3.5: Constriction by rigid stands of invasive (alien) Black Wattle (*Acacia mearnsii*) trees along the river bank may promote flooding and erosion of the opposite bank. (Photo: Hans King)

One of the most profound impacts associated with many invasive alien plants is their effect in reducing stream flows. This effect is likely to be most pronounced during the dry season, and can result in changing a river from a perennial to a seasonal system, with profound implications for its flora and fauna (e.g. fish and invertebrates).

Indirect effects associated with invasive alien plants along river channels and in the riparian areas include a high propensity for severe flood damage, affecting both river bank stability and infrastructure such as roads and bridges. This results from the unnaturally high volumes of large woody debris in such catchments, often mobilized by erosion of inherently unstable, alien invaded river banks during large flood events. Where these accumulate against bridges and other structures, they result in debris dams, upstream, sedimentation and often severe bank scour (see Volume 3: Berg River bridge case study).

3.2.5. Invasive non-alien plants

It is not just alien species that can be invasive. Opportunistic, often cosmopolitan plant species such as *Typha capensis* and *Phragmites australis* are known to invade rivers where perennial, often nutrient enriched baseflows (often as a result of irrigation return flows or sewage effluent (Day and Snaddon 2000) and increased sediment loads create conditions suitable for the establishment of reeds in river channels, leading to increased sediment trapping and raising of river bed levels (Rountree 2012). Along the middle reaches of the Breede River, in the Western Cape, extensive invasion of the river by *Salix mucronata* and *Morella serrata* (Kotze 2012a and b and RHP 2011) has taken place (**Figure 3.6**). These locally indigenous species have responded to changes in flow regime (irrigation releases maintain constant low flows in the river in summer) by expanding into the sandy lowflow river margins, where they form dense stands that contribute to concentration of flows and flood erosion during high flows, as a result of constriction of the floodplain (Kotze 2012a, 2012b, 2012d and Day 2013c).

Figure 3.6: Irrigation releases have allowed indigenous *Salix mucronata* to establish along the naturally sandy, dynamic banks of the central Breede River (Western Cape) where they constrict flood flows and contribute to erosion during floods (Photo: Liz Day).

3.2.6. *Biodiversity considerations in alien clearing*

While removal of alien vegetation is often one of the most important components of river rehabilitation, broader biodiversity considerations at times may also come into play, when the knock-on effects of alien clearing are considered in certain circumstances, resulting in a need for careful planning of alien clearing activities. Key concerns include:

- Circumstances where the physical habitat provided by alien plants is important for indigenous species, which will be negatively affected in the event of its removal: Examples of this, already outlined in Section 2.4.1, include the use of alien thickets along urban rivers by the endemic Knysna Warbler (*Bradypterus sylvaticus*), where removal of riparian understorey alien plants in a planned river rehabilitation project in a suburb of Cape Town would destroy a key element of the warblers' habitat, viz breeding and feeding sites (Hockey 2008), and furthermore that removal of large alien trees from the riparian corridor would change the nature of the understorey. Key mitigation measures recommended included the need for alien clearing to be phased, and such that minimum areas of suitable alien or indigenous habitat were at all times available along the riparian corridor in the area being rehabilitated.
- Situations in which although alien plants occur, rehabilitation of the system to a natural state is not feasible, sustainable removal of aliens is unlikely, and reduced habitat availability and quality would result from the removal of the vegetation: Examples are provided in Day and Snaddon (2000), in their assessment of the Keysers River, Cape Town, finding that the establishment of rooted alien aquatic plants such as *Myriophyllum aquaticum* in the channelised stream provided habitat for indigenous wetland-associated invertebrates and fish, including the Western Cape endemic *Galaxius zebratus*.
- Situations in which alien clearing will result in the creation of large areas of unvegetated land on sloping ground, vulnerable to erosion into adjacent rivers and wetlands. Active intervention in terms of replanting of disturbed areas with appropriate indigenous vegetation is recommended in such circumstances (Holmes et al*.* 2008).

3.2.7. *Effects of removal of alien vegetation*

While invasion of riverine habitats by alien plants has severely compromised many aspects of riverine hydrology, geomorphology, water quality and habitat quality, removal of alien vegetation, particularly woody invasive vegetation, has also contributed in places to large-scale riverine degradation. The main factors contributing to this effect include the large-scale increase in the availability of large woody debris in areas that have been cleared of woody aliens, but from which woody debris has not been removed. During floods, such debris may enter the river, causing debris dams and precipitating bank erosion and scour. Where debris blocks culverts and bridges, loss of infrastructure and significant damage up and downstream may occur, with erosion on the Keysers River, the Berg River, the Breede River and the Langtou River all linked at least in part to the passage of felled alien trees into the channel during flooding (Day et al*.* 2011, Ractliffe 2009, Brown and Fowler 2000, Day 2012 and see also Holmes et al*.* 2008). Mobilisation of sediment has also occurred as a result of clearance of alien vegetation, without revegetation in steeply sloped valleys prone to erosion (Day 2012 and Holmes et al*.* 2008). At least during the early phases following clearing, such areas may contribute large sediment loads into adjacent rivers, and in places become themselves significantly eroded and associated with donga formation and other erosion effects.

In situations in fynbos vegetation where dense to closed alien stands have existed for some time, thresholds may already have been passed whereby ecosystems no longer have the capacity to recover unaided after removal of aliens, but require either vegetation manipulation, modification of the physical environment, or both (Holmes et al. 2008). By contrast, in assessments carried out in the Kruger Park, although Mpumalanga sites were able to recover vegetation structure, richness and diversity in the few years following a major flood event, irrespective of earlier invasion intensity. This applied to both high altitude Grassland Biome and low altitude Savanna Biome sites, leading to the conclusion that savanna riparian ecosystems are resilient to disturbance by aliens and good natural restoration potential follows alien clearance (Holmes et al. 2008) – although this may not strictly apply in sites subject to closed-stand alien invasion. Such sites may need some active restoration intervention to re-instate riparian woodland structure and composition, especially in transformed catchment areas.

3.3. Flooding

Floods are naturally occurring events and a range of floods is important for river ecosystems. Large floods are responsible for channel formation and smaller floods control and maintain instream and riparian habitats and biota. In southern Africa, the very large or extreme (1:50 to 1:100 year return interval) floods are responsible for scouring sediment and vegetation from the channels and redistributing that sediment across the reach. Infrequent moderate and large floods can be expected to overtop the river channel, but when regular small floods begin regularly to overtop the channel, this can be caused by

- increased vegetation (often invasive alien vegetation, especially woody trees) growing on the channel bed or banks. The increased vegetation slows down the flow velocities and caused higher flood levels;
- sedimentation of the river channel, possibly due to upstream catchment erosion, but also often in response to the slower flow velocities caused by vegetation growth in the channel;
- encroachment in to the channel, with the result that the smaller, narrower channel is too small to convey large floods; and
- cutting off of the secondary channels and floodplain, which causes larger volumes of water to be confined to less flow area, and resulting in higher water levels during floods.

3.4. Erosion

3.4.1. General

The most frequently perceived problems identified in river rehabilitation studies tend to be the visible impacts of erosion and deposition processes associated with floods. Erosion and deposition are natural processes within watercourses, but the extent, severity and frequency of these impacts can increase in response to site-specific as well as catchment-wide landuse activities.

In the southern African context, additional considerations are the infrequent, extreme rainfall and flood events, which can cause catastrophic changes to the ecology and morphology of rivers. In arid and semi-arid areas such as exist across much of southern Africa, the variation in discharge between rare floods and more frequent floods (such as the 2-year event) is much higher than in temperate climates (Baker 1977; McMahon et al. 1992). Episodic stripping is the term used to describe the process of widespread catastrophic erosion of sediments and vegetation from rivers during these extreme flooding events (Nanson 1986), and this concept has been used to explain fluvial changes in several semi-arid rivers of Australia, India, South Africa and North America (Womack and Schumm 1977; Baker 1977; Nanson 1986, Kochel 1988; Gupta et al. 1999; Bourke and Pickup 1999; Tooth

2000; Rountree et al. 2001; Dollar 2002). Such over-riding flood impacts strongly determine the succession rates and patterns of instream and riparian vegetation (Carter and Rogers 1995; Rountree et al. 2000; Parsons et al. 2006).

Both extreme large and more frequent small flood events can cause erosion of river beds and banks, removal of riparian vegetation, and flooding of and widespread damage to urban and agricultural infrastructure. However rivers and wetlands are adapted to a wide variety of flood flows, and often the major impacts perceived to be caused by floods may in fact be more directly linked to other impacts such as developments in the catchment or landuse activities the site in question.

In this document and the associated technical manual we have distinguished between:

- ***Bank erosion***: lateral (sideways) erosion of river banks associated with isolated sites or meandering bends of rivers; and
- ***Channel downcutting*** or river bed erosion: vertical erosion/incision associated with gully formation and downcutting of the river channel.

3.4.2. Bank erosion processes

The instability of river banks usually results from a combination of different processes, depending on the channel form and the bank soil characteristics (Abernethy and Rutherfurd 1998, 1999; Thorne 1990; Thorne et al. 1996). The destabilizing processes may be classified as **erosion**, **mass failure** and **weakening processes** (Thorne et al. 1996).

Erosion refers to the detachment and removal from the soil surface of individual particles (in non-cohesive soils) or clumps of particles (in cohesive soils) by the flowing water. Erosion may occur over extended distances through general channel adjustments or at isolated locations, and may be caused by water flowing parallel to the banks, water impinging at an angle against the banks after being deflected by bends or obstructions, or by boatwash or wind waves. Erosion occurs when the erosivity of the flow exceeds the erosion resistance of the soil. For straight, regular channels, the erosivity of the flow depends primarily on the channel gradient and the flow depth (Lane 1955), represented approximately by the flow velocity. (In natural channels the relationship is complicated considerably by the local channel geometry and is difficult to estimate reliably.) The resistance of the bank to erosion depends mainly on the grain size of the bank material and the slope of the bank. For sands and larger grain sizes the resistance can be estimated using the Shields criterion (Graf 1971) with allowance for bank slope (Lane 1955). Clay content increases the resistance to erosion by introducing cohesion between particles.

Mass failures occur by collapse or sliding of the bank. Noncohesive banks fail by downslope movement of individual particles or by sliding along shallow slip surfaces. Three types of rotational slipping can occur for cohesive banks at angles less than about 60^{o} (ASCE Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment 1998): slope failure, toe failure and base failure; for steeper slopes failure may be by planar slipping or slab failure by toppling or cantilever failure (**Figure 3.7**). The type that occurs depends on the geometry of the bank section, the soil type and the moisture content of the bank material, as well as the type and density of bank vegetation (Abernethy and Rutherfurd 2000).

The dependence of bank stability on the height and slope of the bank is shown very approximately in **Figure 3.8**. Bank stability analyses should be carried out by a qualified geotechnical engineer if banks higher than about 3 m are to be allowed in a design (Federal Interagency Stream Restoration Working Group 2001). Various approaches are available for modelling bank failure mechanisms and analysing bank stability (Rinaldi and Darby 2008).

The resistance of the bank to mass failure depends on the cohesion of the soil and its internal friction resistance. The cohesion is increased by clay content while the internal friction resistance depends on soil density, particle size gradation and particle shape.

The moisture content of the bank increases the likelihood of mass failure by increasing the weight of the soil mass and decreasing the soil strength (Pollen 2007; Rinaldi and Darby 2008). The flow of water from the bank back into the river at the end of a flood event also creates destabilizing forces.

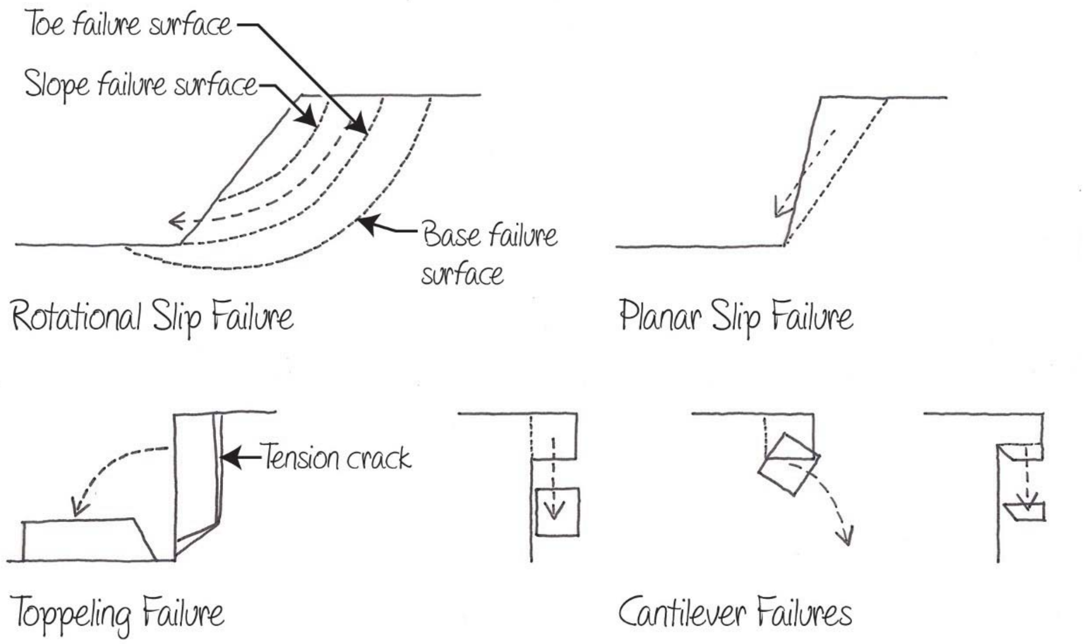


Figure 3.7: Bank failure mechanisms (after ASCE Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment 1998)

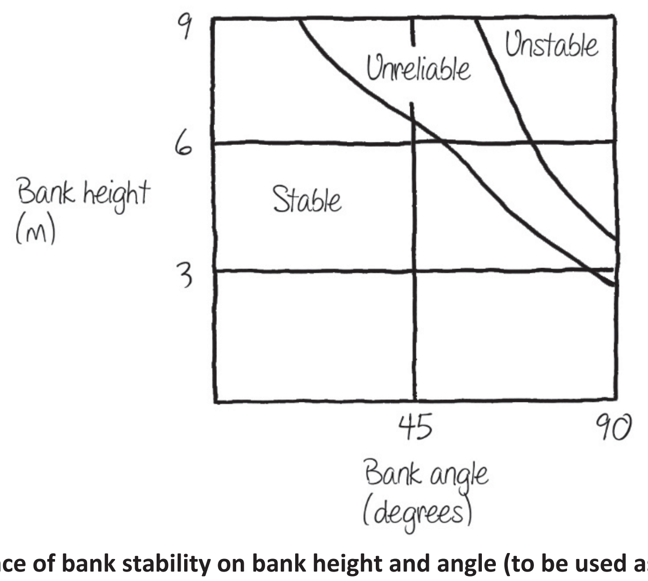


Figure 3.8: Dependence of bank stability on bank height and angle (to be used as a rough guide only; after Federal Interagency Stream Restoration Working Group 2001)

Mass failures are commonly triggered by erosion at the toe of the bank (Thorne et al. 1996). This effectively increases the slope and height of the bank, making it more vulnerable to slip failure. Progressive undercutting of the toe may also lead to cantilever failures.

Weakening processes (or "subaerial preparation") increase soil erodibility and reduce the stability of the banks (Abernethy and Rutherfurd 1999). Erodibility can be increased by desiccation, rainsplash and rill formation, trampling by people or animals, destruction of riparian vegetation, and by windthrown trees whose detached rootballs can deflect flow against the bank. Hydrologically, the stability of a bank against mass failure can be decreased by leaching of cohesive minerals and by a raised moisture content.

3.4.3 Channel incision processes

The erosion of river beds and creation of gullies and incised river channels can be caused by a one or a combination of various processes. These include:

- Processes which increase flow depth and velocities, and thus increase the potential for erosion, such as
    - the reduction in channel width through invasive alien vegetation encroachment on the banks (which serve to concentrate flood flows within the active channel, thus increasing flood depths overall, and velocities within the remaining open sections of the channel);
    - levee (or berm) construction, which constrain the extent of flooding and increase the depth and velocity of floods within the levees;
    - river straightening and canalization, which, through straightened and/or deepened river channels, increases the velocity of the water as well as disturbs the river bed;
- The reduction or removal of riparian vegetation cover, such as the removal of reed or Palmiet beds within rivers which reduced the resistance to flow and thus increases flow velocities, but more importantly, directly reduces the protection of the river bed and banks which was afforded through the vegetation cover;
- Increased flows from interbasin transfers, or increased flood peaks such as in catchments with urban areas where runoff is very high. The elevated flows and/or increased flood peaks increases the potential for erosion of the river reach.
- Reduced sediment supply, such as below dams and weirs, can cause the river bed to incise as the reach downstream is starved of sediment.

Thus when

1) flows or floods increase,
2) sediment supply is decreased or
3) the resistance of the channel (a factor of riparian vegetation cover, inchannel vegetation, bars and islands, the depth and width characteristics and the meandering pattern of the river channel) is reduced,

then the balance between the erosive potential of the river flow regime and the amount of sediment supplied to the reach is altered to cause a relative increase in erosive energy relative to the available sediment. This causes the river channel to adjust and erode as it seeks to accommodate these changes.

3.5. Problems with sediment

The physical form of a watercourse is the result of the interaction between flow, sediment and vegetation. The three are intricately linked: artificial manipulations of the river's bed, banks and floodplain will affect flow and sediment movement through the system. Similarly changes in the volume and distribution of water and supply of sediment will result in adjustments in river form, and result in changes in vegetation species presence and abundance.

Although we tend to focus on water in rivers, the catchments from which rivers arise yield both water and sediment. The resultant watercourses (rivers and/or wetlands) are the manifestations of the interaction between water and sediment. The river flows dictate the watercourse size (larger floods tending to create larger channels), whilst the sediment that is moving down the system is the actual physical template or habitat upon which biota live or grow.

The processes of sediment movement, patterns of sediment deposition and duration of sediment storage create the physical conditions for the watercourse. Watercourses that predominantly transport sediment tend to have deep, steep river channels. Watercourses where deposition and storage of sediments becomes increasingly important tend to be flatter, wider and may even change to floodplain or wetland systems. Although there is a tendency to treat wetlands and river/riparian systems as distinctive entities, in reality there is a continuum between wetlands and river systems (**Figure 3.9**). This continuum can be used to predict/inform changes as a result of altered hydrology in the catchment. In general terms, watercourses which allow for shallow, diffuse low velocity flow conditions allow for wetlands to be formed, whilst those watercourses where flows are confined and of high velocity tend to become erosive and create conditions for the formation of river systems to develop. Changing the hydrology alone, such as in urban areas where runoff peaks are increased, can change the watercourse morphology and convert a watercourse from a wetland to a river.

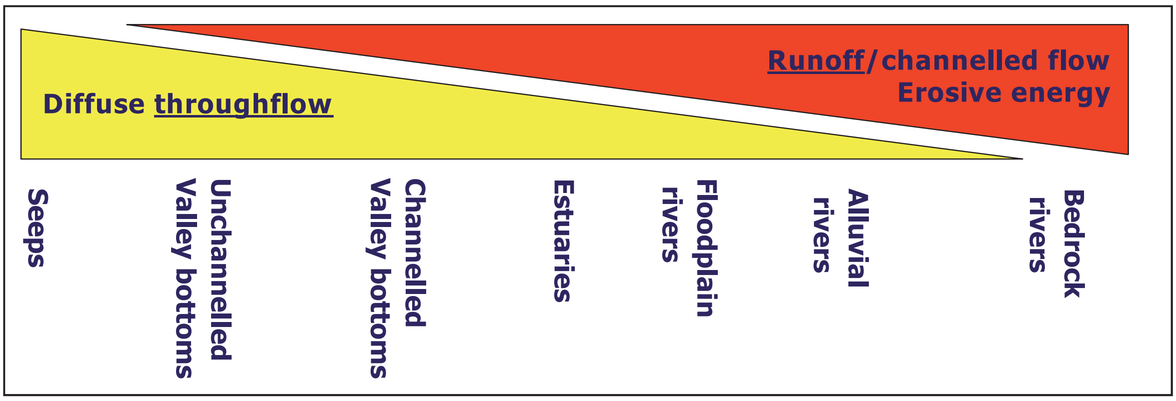


Figure 3.9: The continuum of rivers and wetlands is related to the pattern of hydrology and energy of flows (influencing the frequency of erosion and duration of sediment storage) flowing through the watercourse (Rountree and Batchelor, unpublished).

Landuse changes within the catchment can however cause changes in hydrology (for example, increased stormwater runoff in urban areas) as well as sediment yields (such as increased sediment runoff/erosion associated with ploughed fields). Sediment supply relative to runoff is an important determinant of the watercourse morphology. Where sediment supply is abundant relative to flow capacity, wetlands or alluvial rivers form. Where sediment supply is more limiting, erosive rivers with little or no sediment (e.g. incised rivers) form. Sediment supply can be increased by activities in the catchment that expose the soil surface, such as vegetation clearing or reduced vegetation cover. Alternatively, sediment supply can be reduced by construction of weirs or dams in streams or by reduced exposure of the soil surface to rain splash or depth of surface runoff, such as by hardening of surfaces or increased vegetation cover. Thus adjustments to river flow and/or sediment supply result in morphological adjustments to the morphology (beds and banks) of the watercourse.

Bed elevation change (aggradation or degradation of the bed) is a common response to catchment flow and sediment changes. These changes can be triggered by anthropogenic activities or can occur naturally. Aggradation and degradation are long-term processes that take place over long reaches (Simons and Sentürk 1992). However, rapid bed degradation (channel incision) can occur when sediment yields are critically reduced (as below dams and, at a smaller scale, weirs) or when flows are increased from the catchment (as with urbanising catchments or increased flows from interbasin transfers). Deeply incised (eroded) reaches of river can result within years to a few decades.

3.6. Water quality

Water quality is an integral part of river habitat quality (DWAF 2008a), and can act as a primary habitat bottleneck (Wolters 2013). ***In fact, rehabilitation measures may fail unless rehabilitation options consider water quality along with water quantity and the physical attributes of the channel*** (King et al. 2003).

Water quality is a relative term

Remember that water quality is perceived as “good” or “bad” only in terms of the requirements of a particular user. For example, unimpacted water from a saline lake would be perceived as of “poor” quality from the perspective of a human requiring drinking or irrigation water. However, it would probably be of “good” quality to a brine shrimp that survives only in saline waters.

Changing landuse activities in the catchment can cause changes in water quality. Urbanization of the catchments and its associated stormwater runoff is increasingly recognised as a threat to freshwater biodiversity (Grimm et al. 2000; Groffman et al. 2003; Walsh 2004) not only because of the increased hydrological disturbance and habitat loss, but also because of an increased delivery of pollutants to streams (**Figure 3.10**). In areas where urbanisation includes large areas of poorly serviced or unserviced human settlements, stormwater runoff from urban surfaces may include high loads of raw sewage and other domestic waste, which are passed into the river system.

Figure 3.10: Polluted runoff from poorly serviced urban and peri-urban areas passes directly into river systems (Photo: Liz Day)

The effects of urbanization are not just a 'big city' problem, but are also associated with extensive peri-urban and increasingly dense informal settlement areas. Streams in urban areas typically are less able to process nutrients, and have greater in-stream plant growth and fewer animal species than streams with undeveloped catchments (Walsh et al*.* 2005b).

3.6.1. Natural water quality

Natural river water quality is a factor of:

- Climate: temperature influences the rate of evaporation; precipitation affects the amount of water falling to the ground; both these factors influence the concentrations of different components in surface water
- Geomorphology: the "structure or shape of a river bed, for example, influences the velocity of runoff and the amount or perturbation of the water. These factors in turn can influence water oxygenation; temperature; erosion power and concentrations of suspended solids in the water column
- Geology: the underlying rock formations influence water quality. For example, waters passing through areas dominated by sedimentary rocks of former seabeds (such as the Malmesbury shales) tend to have higher concentrations of dissolved salts, leached from the ancient marine sediments that comprise the shales, than do waters flowing through sedimentary rocks formed in freshwater or terrestrial environments (such as the very old, weathered Table Mountain sandstones which yield high quality freshwater).
- Biota: different communities of plants and animals can also affect water quality – e.g. plants high in humic acids in the fynbos biome result in runoff from these areas that tends to be highly acidic.

3.6.2. What causes changes in water quality?

- ***Changes in water <u>quantity</u>*** (including changes in the magnitude, duration and/or frequency of flows) can affect processes such as flushing of sediment and algal material (this would have implications for concentrations of suspended solids, as well as rates of nutrient uptake, oxygenation (as a result of photosynthesis) and general concentrations of dissolved material (e.g. pollutants entering a river will be more concentrated (and thus potentially more damaging) where flows have decreased.
- ***Changes in river morphology***: The most common impacts include canalisation and channelisation which affect the degree to which rivers can process pollutants naturally.
- ***Pollution***: The main forms of pollution that are likely to affect aquatic ecosystems have been grouped in terms of inorganic and organic pollution types, as follows:
  - **Inorganic Pollution**

    Inorganic pollutants include salts, metals and minerals. They alter water chemistry and may interact with other chemical constituents in the water, to affect water quality. Some heavy metals for example may be highly toxic under certain conditions, but not others. Aluminium for example is a naturally abundant element that is relatively insoluble in the neutral pH range (pH 6-8). Under acidic conditions, aluminium is present in a soluble, toxic form, that is available to living organisms. Under alkaline conditions, it is present as soluble, but biologically unavailable complexes (DWAF 1996). At low pH, however, aluminium may also form complexes with ions and a number of different organic materials, including the humic substances commonly found in blackwater fynbos systems. Some heavy metals can be highly toxic to aquatic organisms even at very low concentrations. Dissolved copper is one such example. The effect of elevated copper concentrations on aquatic organisms is related to factors such as the duration of exposure, and the life stage of the organism, with early life stages (e.g. eggs and larvae) being apparently more sensitive than adults. Copper toxicity varies with water hardness, with similar concentrations of dissolved copper being more toxic in soft water than in hard water.

    Pollutant types
    There are two broad categories of pollutants affecting rivers – pollutants that enter streams from point sources (e.g. effluent pipelines) and those that enter from non-point or diffuse sources, leaking into the system from a diffuse area. Of the two categories, point source pollutants are usually much easier to control and identify.

    Other heavy metals (e.g. mercury and lead) can accumulate in the living tissue of plants, invertebrates, fish and bacteria – a process called "bioaccumulation". Thus even if it is present in water at low concentrations, over time it may accumulate in the food chain to potentially lethal levels. Factors such as water hardness (measured in terms of concentrations of calcium) can be important in determining the toxic effects of lead in aquatic environments, with lead being potentially more toxic in soft than in hard waters.

    When is poor water quality harmful?
    Note that water quality impacts on riverine animals and plants and their habitat quality depend on both the duration and intensity at which they are exposed to particular water quality constituents – sustained low level pollution by particular contaminants, for example, may have just as significant an impact as short pulses of much higher concentrations.

    Other forms of inorganic pollution include salts, which while not necessarily directly toxic, alter water chemistry – the body chemistry of aquatic organisms adapted to life in fresh (non-saline) waters, for example, will usually be unable to function in highly saline conditions, which affect processes such as osmoregulation and general water and salt balance.

- **Organic Pollution:**
- *Phosphorus*: In natural freshwater conditions, phosphorus concentrations are often growth-limiting, and the most significant ecological effect of elevated phosphorus concentrations is its stimulation of aquatic plant growth. However, not all forms of phosphorus are available for uptake by plants, and factors such as light, temperature and the availability of other nutrients also play important roles in determining plant growth. The following terms from DWAF (1996) are used to define and describe the effects of broad ranges of phosphorus concentrations in aquatic ecosystems:
    - < 0.005 mg P/l:: oligotrophic conditions; that is, low levels of species diversity; low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants, no presence of problem algae;
    - 0.005-0.025 mg P/l: mesotrophic conditions – that is, high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic;
    - 0.025-0.250 mg P/l: eutrophic conditions – that is, usually low levels of species diversity; usually highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species that are toxic to humans, livestock and wildlife;
    - >0.250 mg P/l: hypertrophic conditions – that is, usually low levels of species diversity, highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species that are toxic to humans, livestock and wildlife.
- *Nitrates:* Nitrates are the end products of aerobic stabilisation of organic nitrogen.
- *Nitrites:* Nitrites are an intermediate stage in the conversion of ammonia to nitrate, and occur naturally in fresh and saline water.
- *Ammonia:* Ammonia is a common pollutant in sewage and industrial effluents; it exists in a free, un-ionised form (NH_3), which is toxic, and an ionised form (NH_4^+), which is not toxic. The concentration of the toxic form varies with pH and temperature – at low to medium pH, NH_4^+ dominates; as pH increases, toxic NH_3 increases. Ammonia affects the respiratory systems of many animals.
- The overall effects of nitrogen on aquatic ecosystems can be summarised as follows, based on average summer inorganic nitrogen concentrations:
    - <0.5 mg N /l: oligotrophic conditions – that is, low levels of species diversity; low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants, no presence of problem algae;
    - 0.5-2.5 mg N/l: mesotrophic conditions – that is, high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic;
    - 2.5-10 mg N/l: eutrophic conditions – that is, usually low levels of species diversity; usually highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species that are toxic to humans, livestock and wildlife;

    - >10 mg N/l: hypertrophic conditions – that is, usually low levels of species diversity, highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species that are toxic to humans, livestock and wildlife.
  - While organic pollution is not in itself necessarily harmful to aquatic ecosystems, in high concentrations, it encourages the growth of algae (including nuisance and toxic algae, as well as habitat-altering filamentous algae), and hence increases in decomposer microbes. Rapid decomposition of organic material may lead to anaerobic (very low oxygen) conditions.

- ***Other Pollutants***
  - *Suspended Solids:* Unnaturally high concentrations of sediment suspended in a water body may be associated with the following impacts: reduction in light penetration through the water, leading to a decrease in photosynthesis (particularly important in the case of deep waters, possibly less important in the case of shallow systems). Changes in photosynthetic rate may affect food availability for aquatic organisms higher up the food chain. Suspended solids may also interfere with the feeding and breathing mechanisms of certain aquatic organisms, including fish, tadpoles and many invertebrate species. Settling out of suspended material may result in smothering of plants and bottom-dwelling animals.
  - *pH:* pH is a measure of the activity of hydrogen ions in a water sample. Surface waters exhibit a range in pH between 4 and 11. In the fynbos bioregion, pH may drop to as low as 3.9, owing to the influence of organic acids, such as humic and fulvic acids. Diurnal and seasonal variations in pH are also common, due to differences in photosynthetic and respiration rates, which affect the concentrations of CO_2 in the water. Changes in pH can affect the ionic and osmotic balance of aquatic organisms, the availability and toxicity of certain trace metals, non-metallic ions such as ammonium and certain other elements. Metals that are particularly affected by changes in pH are silver, aluminium, cadmium, cobalt, copper, mercury, manganese, nickel, lead and zinc. All of these become increasingly biological available or soluble at lowered pH. Changes in pH also affect the rate at which large organic molecules are able to adsorb trace metals and other materials.
  - *Bacterial contamination and other pathogens – effluent inflows, particularly those associated with human or livestock sewage effluent but including domestic waste can be associated with high levels of bacteria and other pathogens (nematode eggs and worms, parasitic flukes) which affect human and/or aquatic ecosystem health or use.* High levels of faecal bacteria in water, for example, can cause diseases in humans in contact with such water. Counts of *Escherichia coli* bacteria are often used as a measure of these and other pathogens that may be present in such polluted water, and indicate recent exposure to faeces derived from warm-blooded animals (e.g. humans, other mammals (e.g. dogs, livestock, baboons) or birds.

- ***Acid Mine Drainage***
  - In South Africa, mining activities can be associated with environmental contamination such as acid mine drainage (AMD). AMD is highly acidic water, usually containing high concentrations of metals, sulphides, and salts as a consequence of mining activity. The major sources of AMD include drainage from underground mine shafts, runoff and discharge from open pits and mine waste dumps, tailings and ore stockpiles, which make up nearly 88% of all waste produced in South Africa (Manders et al. 2009). When underground mine shafts are abandoned and fill with water, such waste may discharge

into surface water systems, with potentially highly significant effects on downstream users including aquatic ecosystems. The final product of AMD is a function of the geology of the mining region, presence of micro-organisms, temperature and also of the availability of water and oxygen, which means that the quality of AMD may be highly variable from one region to another, requiring different approaches in its prevention, containment and treatment (Manders et al. 2009).

3.6.3. Effects of changing water quality

Changes in water quality may result in:

- Shifts in the physical position of a community of riverine organisms (e.g. if the upper reaches of a river become turbid and nutrient-enriched, one might find that riverine communities resembled those occurring in the lower (turbid and nutrient-enriched) reaches of the river more closely than those naturally associated with the upper reaches)
- the loss of key species or the introduction of (sometimes nuisance) species (snails, blackflies, excessive plant growth);
- Reduction in diversity as a result of increased concentrations of toxins, etc.;
- Reduced ecosystem functioning.

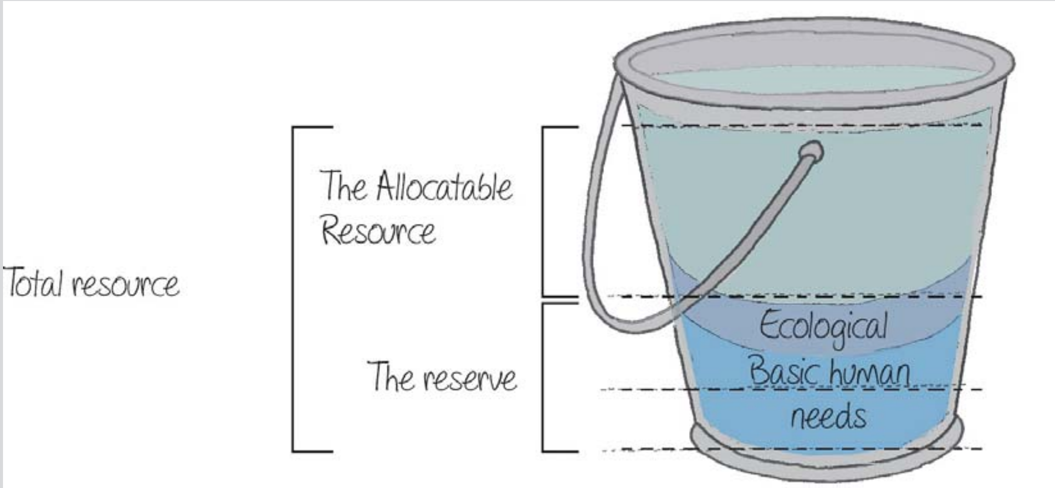
3.7. Flow related issues

River flow is the defining element of river habitats. Flow creates the patterns and processes commonly associated with fluvial environments and so strongly determines the physical (geomorphological), chemical and biological processes in rivers that it is considered the 'master variable' in river studies (Power et al. 1995, Resh et al. 1988, Poff et al. 1997). Not surprisingly, therefore, ***a crucial component of river condition is the extent to which its natural flow regime is maintained***. The USDIBR (2006) noted the importance of instituting natural flows and sediment processes to enable real river rehabilitation, while Tourbier et al. (2004) stress that rehabilitation objectives must take into account what is realistically achievable within the context of altered flow regimes in the system.

Although the setting of adequate flow regimes for rehabilitated rivers is beyond the scope of this Manual, it is essential that all rehabilitation projects are undertaken with a full understanding of the extent to which the natural flow regime has been altered in any river undergoing rehabilitation, and the implications of such changes for the river environment.

Within South Africa, flows for the environment are guaranteed through the National Water Act. A portion of all available water in a catchment is "reserved" to (1) sustain an accepted degree of ecological functioning (The Ecological Reserve) and (2) provide for the basin human needs for those people directly dependent on the river for water supply (see **Box 3.1**, below).

Box 3.1: Environmental flows and the Ecological Reserve



The Total Water Resource, comprised of the Reserve and Allocatable Resource.

Under the South African National Water Act, all water resources are considered to be an indivisible natural asset under the custodianship of national government. Thus there is no riparian ownership of water any more. The only right to priority of use is that of the 'Reserve', consisting of a 'Basic Human Needs Reserve' and an 'Ecological Reserve'. The Basic Human Needs Reserve ensures the water that is required by domestic users for drinking, food preparation and personal hygiene. The Ecological Reserve refers to "*the quantity and quality of water required … to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource*" (NWA, Ch 1, para. 1.(xviii)).

3.8. Effects of losing habitat diversity

One of the outcomes of many of the impacts already discussed in this section is that of habitat simplification, or loss of diversity. Such losses may relate to losing structural complexity – for example, in a channelised system, there may be a loss of boulders, cobbles and vegetated bars or banks that create a multi-dimensional environment, with many different flow types, places of refuge and different feeding niches, that can support a wide array of different plant and (particularly) animal taxa. Where only a few habitat types exist, only a few species will typically be able to occur in that reach, leading (in many cases) to dominance by the most competitive. These are often pest or nuisance species, such as the larval stages of midges. The lack of more diverse habitat types that might support competitors or predators (e.g. dragonfly nymphs) means that these animals can occur in large numbers, and dominate the ecosystem.

Poor water quality can have a similar effect on habitat diversity, in that if it is above certain critical thresholds for key variables (e.g. low concentrations of dissolved oxygen, high concentrations of ammonia, or an abundance of orthophosphate) the quality of water may override the advantages of even diverse physical habitat, with only a few taxa being able to survive or thrive under such conditions. Again, the absence of predators and a more complex food web in the system will favour dominance by the hardiest, pollution tolerant species, again at often nuisance proportions.

Dominance by floating aquatic plant species or algae in nutrient enriched waters, as well as by several dipteran species (e.g. Chironomid midge larvae), are examples of such conditions.

3.9. Losing species of concern

When key habitats are lost (such as due to disturbance, reduced flows or damming and the subsequent drowning of habitats) or become unavailable for use through poor water quality or weirs and dams which prevent up and downstream migration, then riverine species in the system may be at risk of local extinction. Maintenance of key species depends on ensuring that suitable flow patterns, water quality, connectivity and natural vegetation are provided. It is important to ensure that all aspects required for the species life cycle are in place. However, even when suitable flows and habitat are maintained, indigenous species can also be placed at risk through the impacts of alien fauna.

3.10. Types and effects of alien fauna

Invasion of rivers and associated dams and lakes by alien fauna has had profound impacts on riverine species diversity and, in some cases, habitat quality.

Most of the alien invasive fauna that have invaded freshwater habitats are fish, with 17 taxa now established in South African waters. *Cyprinus carpio* (Common carp), *Onchorhynchus mykiss* and *Salmo trutta* (Rainbow and Brown trout) and *Micropterus salmoides, Micropterus dolomieu* and *Micropterus punctulatus* (Largemouth, Smallmouth and Spotted bass) were all actively introduced into rivers to enhance freshwater fisheries, while some aquarium fish were introduced accidentally through the aquarium trade. Others escaped from fish farms (e.g. *Hypophthalmichthys molitrix* (Silver Carp), *Ctenopharyngodon idella* (Grass Carp) and *Pterygoplichthys disjunctivus* (Vermiculated Sailfin) (Picker and Griffiths 2011)), and are now well-established in many natural watercourses.

Inter-basin transfers (that is, the transfer of water from one catchment to another, often by means of pipes or tunnels from dams) has also resulted in the invasion of many systems by non-indigenous fish taxa (*Clarias gariepinus* (African sharp-toothed catfish) for example was accidentally translocated from the Orange-Vaal system into the Great Fish River system via the Orange-Fish River tunnel in 1975 (Cambray and Jubb 1977), and thus reached the Sundays River, the Kei system (de Moor and Bruton 1988) and, eventually, and in part the result of deliberate introductions, most of the main rivers in the Eastern Cape (Cambray 2003, Weyl and Booth 2008, Booth et al*.* 2010).

In the rivers of the Cape Floristic Region (CFR) of the Western Cape, alien fish species have eliminated native fish stocks from as much as 80% of river habitat (estimates exceed 90% in some catchments) through predation and competition (Paxton et al*.* 2002, Marr 2011, Woodford et al*.* 2005, Impson et al*.* 2000, Wolhuter and Impson 2007, Jordaan et al*.* 2012). Indigenous fish populations in these catchments now persist only in those reaches which are, as yet, un-invaded, i.e. those areas upstream of natural or artificial barriers such as waterfalls or even weirs and dam walls (see Volume 3, Case Study 23).

Invasive alien fish have had profound environmental impacts on natural river systems in South Africa, with negative impacts including:

- the transfer of parasites (Picker and Griffiths 2011);
- impacts on aquatic invertebrate communities and knock-on food chain effects (e.g. Impson (2012) found that invasion of Western Cape streams by small mouthed bass resulted in increased algal cover on rocks and loss of rocky substrate, as a result of increased fish predation on grazing invertebrates)
- Impacts to indigenous fish (in some cases leading to localised extinctions) through predation, competition for food and breeding habitat, and in some cases hybridisation with alien fish species
- Changes in habitat quality – Carp for example are bottom-feeders and known to stir up sediments, leading to increased turbidity that has been linked to long-term changes in aquatic habitat type and quality

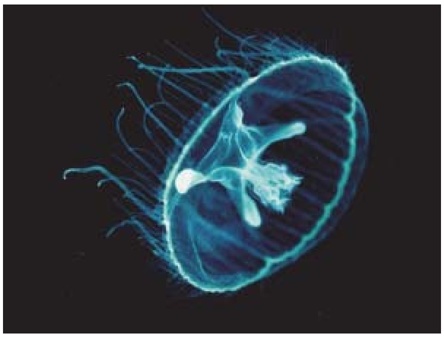
Hybridisation is also an impact associated with invasion by the only aquatic bird species considered to be an invasive alien in South Africa (Picker and Griffiths 2011), namely *Anas platyrhynchos* (Mallard Duck) – a species that interbreeds with indigenous waterfowl such as Yellow Billed Ducks.

Other invasive alien taxa recorded in South African rivers include six freshwater snail species (*Pomacea diffusa, Aplexa marmorata, Physa acuta, Gyraulus chinensis, Helisoma duryi* and *Tarebia granifera* (Picker and Griffiths 2011), with *T. granifera*, for example, being linked to an increase in the spread of diseases, by serving as hosts for parasitic flukes that cause disease in humans (Miranda et al. 2010). Three alien flukes that occur in South African waters, and are variously associated with impacts to aquatic and human hosts, have also been listed by Picker and Griffiths (2011), namely *Pseudodactylogyrus anguillae* (Eel gill fluke), *Gyrodactylus kherulensis* (Fish skin fluke) and *Gyrodactylus kobayashii* (Fish gillworm).

More recent invasions of South African waters by alien fauna include the establishment of four species of crustacean, namely *Cherax destructor* (Yabby) (Free State), *Cherax quadricarinatus* (Australian redclaw) (Crocodile River), *Cherax tenuimanus* (Marron) (Western Cape) and *Procambarus clarkia* (North American red swamp crayfish) (Crocodile River) (Picker and Griffiths 2011). Of these, De Moor (2002) describes *P. clarkia* as a destructive burrower, causing destabilisation of river banks and thus potentially of significance as a cause of erosion and general riverine degradation in areas in which it occurs. *C. destructor* is also a bank burrower, but although currently held captive in Free State aquaculture farms, is not believed to have established populations in the wild as yet (Picker and Griffiths 2011) although MacDonald et al. (2003) comment that it must be assumed that these species will eventually become naturalised.

Most of the alien invasive fauna that have established in South African rivers have been deliberately released, or accidentally introduced in association with some other deliberate introduction (e.g. the fish louse *Argulus japonicus*, introduced from South East Asia with koi carp (and now established in water bodies in Gauteng, where it impacts on the survival of both farmed and native fish populations (Picker and Griffiths 2011). In their review of alien and invasive animals of South Africa, these authors list 38 alien freshwater faunal species known to be invasive in South African rivers and other water bodies, four of which have been imported deliberately as bio-control agents to act against other faunal or floral invaders (e.g. *Orthogalumna terrebrantis* (waterhyacinth mite) and *Niphograpta albiguttalis* (waterhyacinth moth), both introduced as biocontrol agents for *Eichhornia crassipes* (water hyacinth).

In addition to the invasive alien species described above, potentially large numbers of taxa are altering their natural ranges, as a result of landscape and climate level changes, as well as so-called human-mediated jump dispersal (Tolley et al. 2008). These authors cite the approximately 500km westward expansion in range undertaken in recent years by *Hyperolius marmoratus* (Painted Reed Frog), the ecological consequences of which are not yet known, but are considered of concern by various conservationists (e.g. CAPE (http://www.capeaction. org.za/index.php/strategic-objectives/integrated-management/invasive-alien-species)). Davies et al. (2013) cite unspecialized habitat requirements, rapid spread and high local population sizes as factors that suggest that these frogs could be well-suited to competition with co-occurring endemic frogs in the Western Cape winter rainfall area into which they have been introduced, and hamper the conservation of indigenous range-restricted amphibians.



Craspedacusta sowerbyi (freshwater jelly fish) is another alien invertebrate species that has established itself in many freshwater dams and lakes in South Africa (Picker and Griffiths 2011). Imported into this country from China, presumably in aquatic plants, these organisms can at times attain high densities in their free swimming medusa stage, although since they prefer standing water, significant populations are unlikely to occur in rivers. They feed on zooplankton, and might compete with other aquatic predators, although adverse ecological effects of these invasive

Similar so-called jump-dispersal by *Amietophrynus gutturalis* (Guttural Toad) into the suburbs of Cape Town(**Figure 3.11**), presumably transported accidentally in plant material from Durban is also considered of concern, particularly since this species shares habitat and diet preferences with the closely related but Endangered *Amietophrynus pantherinus* (Western Leopard Toad) (e.g. Measey and Davies 2011). While *A. gutturalis* is not strictly river-associated, it may breed in seasonally inundated pools associated with valley bottom wetlands in the Cape Town area.

Figure 3.11: The Endangered *Amietophrynus pantherinus* (Western Leopard Toad) (left) may be threatened by the introduction of *Amietophrynus gutturalis* (Guttural Toad) (right), in urban areas of Cape Town (photo: Charles Griffiths)

4 WHAT IS REHABILITATION?

4.1. Rehabilitation, restoration and remediation

Although there is no wide international consensus on the strict definitions of the descriptions and distinctions between river restoration, rehabilitation and remediation, all these terms nevertheless indicate activities undertaken to improve or enhance river ecosystems in some way, and are all addressed in various parts of the overall River Rehabilitation Manual. Below is a short summary of the definitions adopted in this document, and as generally understood in the rehabilitation environment of South Africa. **Figure 4.1** illustrates the different concepts diagrammatically.

Rehabilitation is defined as *promoting the recovery of ecosystem functions and values in a degraded system in order to regain some of the value the system previously had to society* (Dunster and Dunster 1996, Grenfell et al. 2007). Rehabilitation is not the same as **restoration**, *which is the manipulation of a site in order to revert the watercourse back to its full range of natural (historic) processes and functions* (National Ocean Service and National Marine Fisheries Service 2002; US EPA 2003). Restoration therefore is the attempt to restore habitats back to their natural (historic or so called Reference State) conditions. In the South African context, this would mean restoring rivers back to an A (Reference State) Ecological Category. Rehabilitation, by comparison, only aims to improve aspects of the degraded state (such as some of the identified assets and processes of a system), and although this should be a reversion back towards the natural state, it does not purport to achieve the Reference or natural historical state, but rather improve watercourse condition and functions for the benefit to society and the environment.

In many cases, irretrievable changes to the system may preclude restoration or rehabilitation activities. In these cases, a suitable alternative is **remediation** (Bradshaw 1996). The aim of remediation is *simply to improve the ecological condition of the system, but without the focus of restoring the system to its historical state*. Remediation is where a river is managed along a different vector of ecosystem improvement (Fryirs and Brierley 2000), and this concept is most appropriate in urban watercourses and in highly degraded streams where restoration back to, or even towards, the natural condition is no longer possible due to fundamental changes in ecosystem drivers (hydrology, geomorphology and/or water quality).

The River Rehabilitation Manual includes all of the above approaches. It is the objectives and scope of work undertaken for a specific project that would however determine if the activities constitute restoration (full reversion of the system back to the natural historic condition), rehabilitation (manipulation of the system back towards a more natural state by reinstating some lost or impaired functions or ecosystem components) or remediation (improving the current condition of the system through improved ecological services, albeit not necessarily in a manner which reinstates the natural morphology or processes that existed historically).

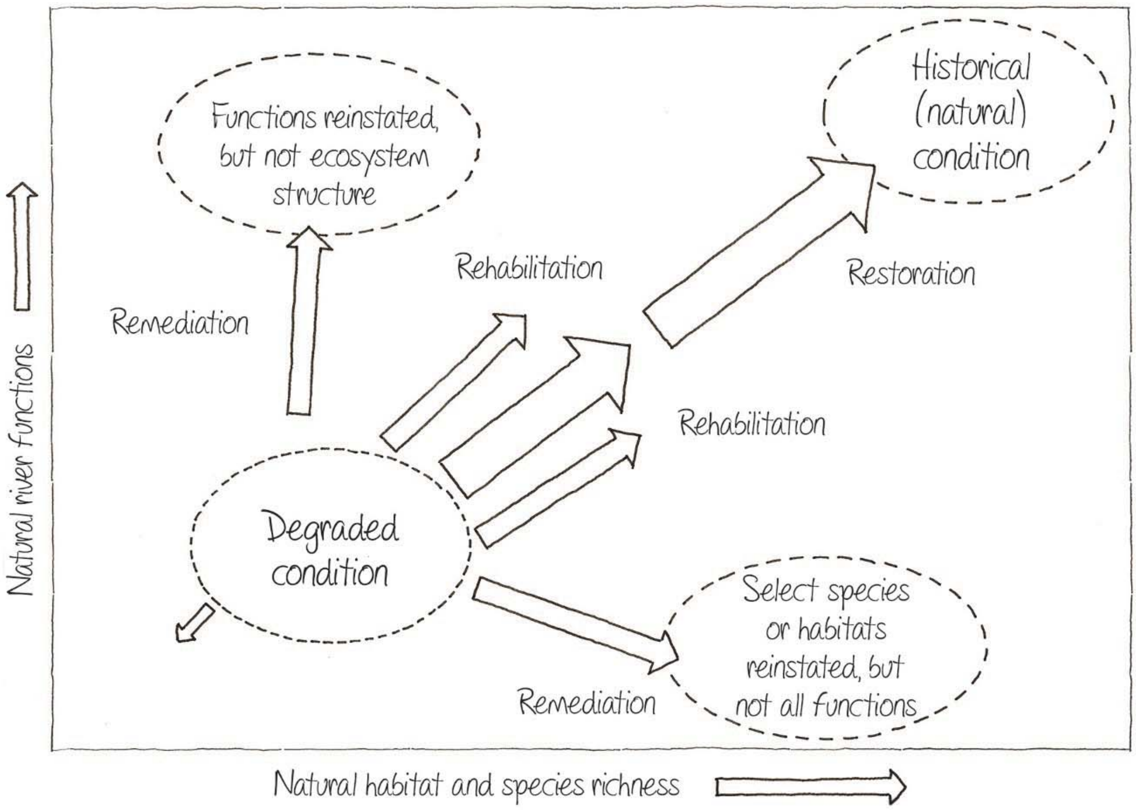


Figure 4.1: The distinction between rehabilitation (towards natural), restoration (the achievement of the natural or historical condition) and remediation (select mitigation of degradation) can all achieve an improvement of the condition of a degraded river (modified from Williams et al. 1997 and Woolsey et al. 2005).

4.2. Principles of rehabilitation

Rehabilitation is necessary because at disturbed sites, natural processes may not be able to achieve sufficient ecosystem recovery. There are many guidelines that identify key principles for rehabilitation, and these include (King et al*.* 2003), who recommend that:

> Remember that rehabilitation does not need to result in restoration of a system to its natural state. Such an objective is often neither achievable nor even desirable in some cotexts. Rehabilitation can simply be about improving some aspect of river function or condition to a more sustainable and/or more natural state.

- The **objectives** for rehabilitation should be clear, explicit and be defined by the principles listed above.
- Rehabilitation should direct the system back towards a more natural state, and work in harmony with the major abiotic drivers of ecosystem;
- Undertaking rehabilitation should be seen as an interdisciplinary activity, recognising that rehabilitation may be necessary over a range of spatial and temporal scales;
- Rehabilitation should aim at treating causes rather than symptoms;
- Given that ecosystems are dynamic and can naturally exist in alternative metastable states, it should be remembered that it is easier to cross a degradation threshold than to return over it;

- Monitoring should be an essential component of rehabilitation.

The above principles are discussed in the following sections.

4.2.1. Rehabilitation objectives need to be clear and explicit

This is the most important consideration for any proposed rehabilitation action. Objectives for interventions need to be clear, explicit and acceptable to all stakeholders involved. Defining broad endpoints for the rehabilitation outcomes, as well as considering and choosing the most desirable intervention option to achieve this endpoint, need to be guided by clear and explicit objectives that are agreed to by all relevant stakeholders. For large projects or programmes, it would be useful to list or organise the objectives hierarchically, from broad statements of the desired outcome of the rehabilitation project, down to specific technical aspects to be achieved at intervention sites (Rogers and Bestbier 1997), as this ensures that the small scale site aspects remain aligned within the overall objectives.

4.2.2. Rehabilitate back towards a more natural state

In Section 4.1, the concepts of restoration, rehabilitation and remediation were discussed. Ideally, activities motivated on ecological grounds should at least promote a move back towards a more natural state (rehabilitation), and if possible back to the historic natural state (restoration back to the Reference Condition). This is not however always possible. Underlying drivers of the riverine ecosystem (e.g. water quality and flow regimes arising from developed catchments), or even deep erosion on a former floodplain system), may have fundamentally altered the ecosystem processes and preclude the potential for moving the system back towards its historic condition. Streams and rivers in urban areas may have been historically drained or canalised to be managed for water supply, flood mitigation and disposal of wastewater (Walsh 2000; Paul and Meyer 2001; Morley and Karr 2002), or upstream dams and water demands may mean that floods that once maintained large wetlands or floodplains no longer occur. In the South African context, the reinstatement of key flows for environmental purposes is possible through the determination and implementation of the Ecological Reserve (see Section 3.7 above).

Where a move back towards natural is not possible, remediation (reversing or limiting environmental damage – see Section 4.1) is the only practical option available. Remediation allows for engineering or modification of watercourses to enhance ecosystem services and possibly in-channel habitat diversity, but not through altering the form of the watercourse back towards its natural condition. Therefore, although rehabilitation activities should undertake to restore watercourses back towards a more natural (historic) condition, sometimes this is not possible where the underlying drivers have been fundamentally altered.

In urban rivers, Wolman (1967) observed that a cycle of sedimentation and erosion was often associated with the construction and development stage of urban catchments. Clearing of slopes and the initial stages of urban development result in large increases in catchment erosion and sediment delivery to watercourses, followed by erosion caused by the increase in flood peaks and frequencies as runoff increases, with progressive densification. The increased rate of erosion of the stream does not necessarily mean that the urban stream is inherently unstable, but is merely adjusting to the new catchment conditions (Neller 1988). The changes in the rate and magnitude of sediment delivery often cause urban stream systems to adjust their slopes, channel width and depths. Although rivers are inherently disturbance-driven environments (Schumm and Lichty 1963; Stevens et al. 1975; Hughes and Rood 2001), rehabilitation plans should attempt to identify the trajectory of change and work in sympathy with this. It is highly unrealistic to expect a return to the historic, non-impacted condition because the irreversible changes of catchment conditions (e.g. impervious surface area, hydrology, vegetation cover) preclude this. Urban stream health is moreover often limited by available habitat (Moses and Morris 1998) due to stream modifications and channel engineering/simplification, so many urban rehabilitation schemes focus on reinstating habitat on a localised level, rather than restoring natural, historic river forms (Rosgen 1994; Morris and Moses 1999; Brierley and Fryirs 2000; Gregory and Chin 2002).

In an urban context, river rehabilitation programs are often forced to focus on remediation because of the extent of permanent change and the limitations imposed in terms of space.

It is critically important to understand that the "natural condition" of a site or reach is represented by a range of conditions*. For rivers, this range of conditions is usually a function of the recovery time from the last major flood and sediment events at that site. Vegetation succession also plays an important role in the changing biophysical condition of the reach. The idea of what constitutes the "natural" (sometimes also referred to as Reference) condition of a watercourse provokes passionate arguments among researchers but forms the backbone of rehabilitation practice for managers and stakeholders (Fryirs and Brierley 2009). Naturalness should be considered as a functional condition whereby the river is able to adjust its character and behaviour in response to flow, sediment, and vegetation fluxes (Brierley and Fryirs 2005, Hughes* et al*. 2005). Historical records, such as anecdotal evidence, old maps or aerial photographs, or even historical Google Earth imagery, can be used to generate some understanding of the original historical condition and dynamics of the river reach under investigation. The historic morphology (channel patterns) of the reach can inform to a large degree the underlying natural dynamics of a river system.*

4.2.3. Rehabilitation as an interdisciplinary activity

Understanding and managing the behaviour of rivers as ecosystems requires holistic, interdisciplinary approaches (Dollar et al. 2007 and see Section 2.1), but rehabilitation activities are often undertaken in response to small-scale visible impacts of disturbance, such as erosion of a river channel, or may be narrowly focused on maximizing habitat for one species of concern. The visibility of abiotic physical disturbance impacts, or the desire to focus on a single species, should not however overshadow an appreciation for the interconnected biological and ecosystem service aspects of the watercourse. Rehabilitation activities and their outcomes affect multiple disciplines and stakeholders and practitioners should consider biotic as well as abiotic factors that, across a range of spatial and temporal scales, are necessary to achieve the desired ecological condition. It is important to note that, although there are parallel hierarchies (or levels of organisation) of hydrological, geomorphological and ecological components in a river system, these different parts may operate at different frequencies of occurrence and/or rates of change (Dollar et al. 2007).

Focusing on improving a single aspect of a watercourse is not the same as re-creating the biotic structure and biophysical functioning of a stream ecosystem – the impacts of rehabilitation activities on all components of the ecosystem should be considered.

4.2.4. Focus on treating causes rather than symptoms

Ideally the ultimate cause of the problem that is to be remedied should be addressed, rather than the symptom. Understanding the scales of interactions of hydrology, geomorphology and ecological responses to these underlying drivers is critical to identifying the correct spatial and temporal aspect of interaction (Frissell et al*.* 1986; Montgomery and Buffington 1998; Thomson et al*.* 2001; Brierley and Fryirs 2005; Thorp et al*.* 2006; Dollar et al*.* 2007 and Beechie et al*.* 2010). Whilst the focus of a perceived problem may be at a small (site) scale, the catchment-level processes that could affect the local form and function should also be considered. Assessment and rehabilitation planning should start at the catchment scale, or at least larger spatial scales than simply the site, to ensure that the underlying causes of the problem seen at the site can be identified and cognisance of these can be taken in to account during the planning.

4.2.5. Recognise that ecosystems are dynamic with alternative, [2]metastable states

Natural ecosystems are not static systems (Wu and Loucks 1995). River ecosystems are dynamic, patchy environments (van Coller et al*.* 2000) and the responses of small patches (Parsons et al*.* 2006), larger river reaches (Rountree et al*.* 2001) or even whole river systems (Carter and Rogers 1995) to the same or similar disturbance regimes are can be non-uniform. There is thus a range of natural conditions that a river can be in, and these are usually dependent on historical disturbance patterns, natural trajectories of vegetation succession (Rountree et al*.* 2000) and the antecedent (previous) flow conditions.

River interventions may have multiple, not always predictable, outcomes. It is essential that they are approached with an understanding of the natural underlying dynamics of the river, and selected in sympathy with this.

4.2.6. Remember that monitoring is essential

"There are a lot of people harming rivers. There are also people who are improving them. But we do not know who is doing what. We are all trying as best we know how to do effective maintenance and improvement work. But there is no attempt to learn from each other. No doubt mistakes are repeated. No doubt success goes unnoticed ... successes in field restoration are little known, while mistakes are repeated indefinitely." This telling statement from Leopold (1997) demonstrates that the lack of monitoring is limiting the expansion of success stories and enabling repetition of ill-advised approaches.

Monitoring of rehabilitation activities is essential, not only because of uncertainty in terms of understanding the cause-effect relationships in river ecosystems, in underlying dynamic conditions of rivers themselves, and in the ability of selected rehabilitation options to successfully achieve the stated outcomes, but also from an adaptive management perspective, that relies on "learning by doing" development and refinement of rehabilitation practices.

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[2] metastable – that is, stable provided it is subjected to no more than small disturbances

5 ASSESSING THE SITE

5.1. What is the problem?

Section 3 of this report describes many of the typical problems encountered within river systems. Typically river rehabilitation initiatives are initiated through a desire to address one or more of these problems which manifest at a site. These problems are usually caused by issues at the site, or within the reach, and occasionally from perhaps an upstream river reach or even arise due to issues within the larger upstream catchment.

A clear understanding of the specific problem/s which is of concern and is intended to be addressed through the rehabilitation activity is essential when considering any intervention. Problems are typically symptoms of other issues – the causes – at the site, upstream of the site or within the broader catchment. In this manual, problems have been grouped in to the following categories:

- Invasive vegetation within the channel or within the riparian zone;
- Flooding risks at the site;
- River bank erosion (the bank of the active channel or macro-channel is eroding laterally);
- Channel downcutting, when the river is incising and creating headcuts or gullies (dongas);
- Problems with excess sedimentation within the river channel;
- Problems with weirs;
- Problems with water quality;
- Problems with flows necessary to maintain the ecosystem;
- Problems with habitat and biodiversity within rivers;
- Problems with indigenous vegetation establishment; and
- Conflicting needs of river processes and local residents or broader societal needs in urban areas, especially in lower income suburbs.

Each of these problem types, and a range of potential solutions to address each of them, are summarised in Section 7 of this report and discussed in detail in Volume 2 (the Technical Manual). When considering rehabilitation interventions to address a problem in a river, it is important to understand that ***the problem you see may be a "symptom" or result of another problem area on the opposite bank, upstream of the site or at large within the upstream catchment***. An understanding of the root cause of the problem (symptom) – the visible degradation impact – is important if appropriate rehabilitation interventions are to be selected.

5.2. Identifying causes versus symptoms of river degradation

The most frequently perceived problems in rivers are the visible impacts of erosion and deposition processes associated with floods, but there are a wide range of causes of such impacts. The underlying causes of erosion and deposition may simply be the normal, natural processes of erosion and deposition in watercourses, but these can also be exacerbated by site-specific factors, such as impacts from bridges, weirs, dams, landuse practices adjacent to the watercourse, or direct transformation of floodplains and riparian zones through agriculture or urban development, through to catchment-wide landuse changes and associated changes in hydrology, water quality and sediment flows to the watercourses.

Other types of river degradation include declining water quality, the impacts of invasive alien biota and flow changes caused by interbasin transfers. All these factors influence the ecological condition of a watercourse, as well as the functional aspects of the ecosystem (**Figure 5.1**). Longitudinal connectivity (the ability of organisms, water, nutrients and sediment to connect to up- and downstream reaches of watercourses) and lateral connectivity (the ability of organisms, flood flows and sediment to move from the channel in to the riparian areas and up on to the floodplains) (**Figure 5.2**) can be altered directly by structures in the channel and bank, as well as indirectly by flow changes resulting from widespread catchment landuse changes. These problems need to be evaluated within the context of the site, reach and catchment conditions of the river system. If necessary, consider some directed studies or research in the morphological or ecological aspects in which you are attempting to address (**Figure 5.1**).

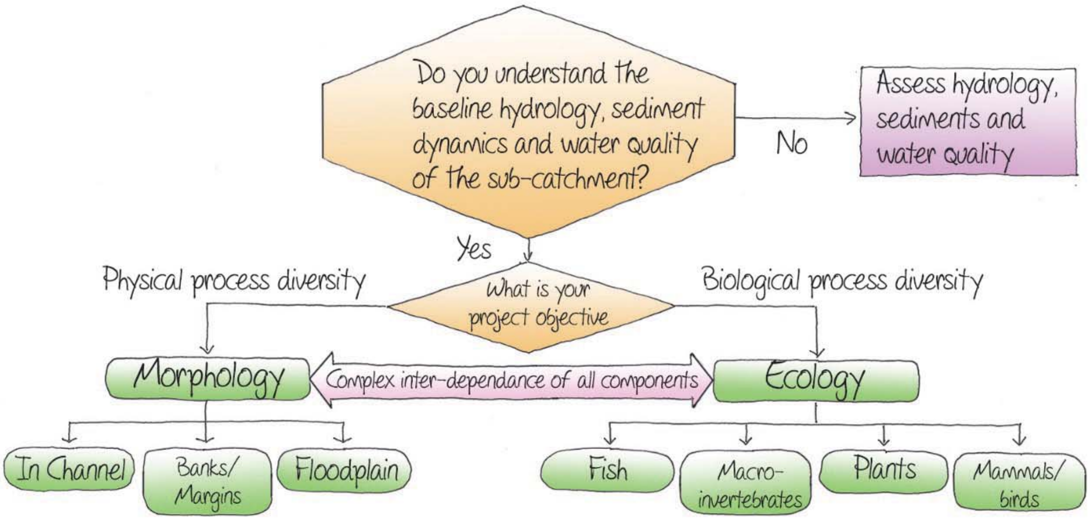

Figure 5.1: An understanding of the problem (or initial impact or objective which is trying to be addressed) should ideally be based within aat minimum a reach-based, and ideally catchment scale, context of the natural ("baseline") hydrology, sediment and water quaity dynamics of the system. Any problems of objecrives to be addressed can then be further investigated by either geomorpholigical (in-channel, banks, river bed and floodplain) issues or ecological (plants, fish, invertebrates, mammals and other fuana) focussed specialsit studies.

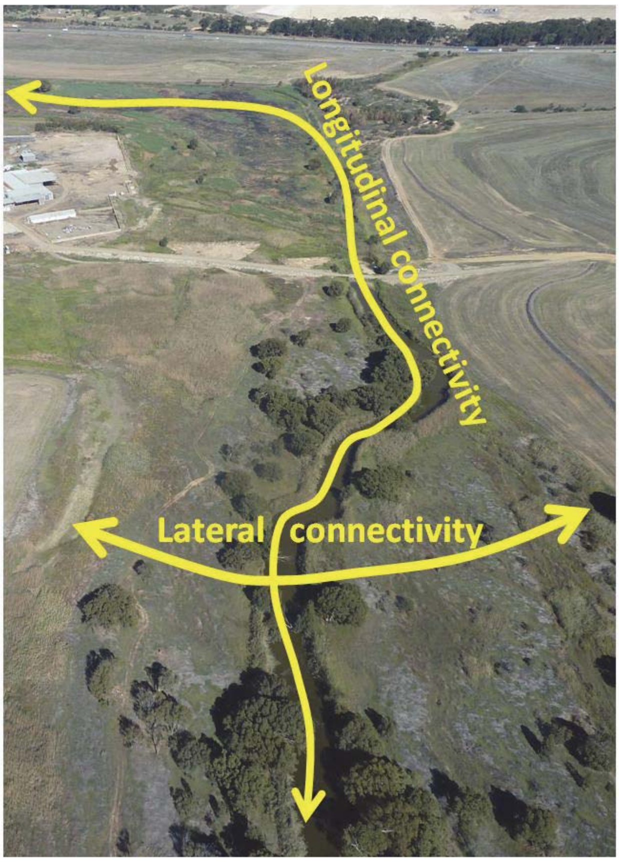

Figure 5.2: In addition to the ecological condition of a reach, the lateral (between the channel, riparian and floodplain within the reach) and longitudinal connectivity (between the reach and the up- and downstream reaches) are important functional attributes to consider in river ecosystems.

5.3. Understanding the direction of change and the risk of further degradation

Once the problem is identified, and some understanding of the site, reach and upstream catchment has been developed, the history and rate of change of the problem should be investigated.

This can be undertaken through anecdotal means – discussing with longtime residents or farmers within the area to obtain information on the size and rate of change of the problem site – and/or through the use of historical data sources:

- Historical aerial photographs (often for South Africa, dating back to the 1930s or 1940s for most areas of the country) are a suitable data source for the evaluation of relatively large scale geomorphological and vegetation problems, such as erosion or invasive alien vegetation. Google Earth can also provide more recent imagery for the last 10 to 20 years for some areas.
- Historical flow data (obtainable online from the DWS) can provide indications of long term flow changes where gauging weirs have sufficiently long records of flow;

- Historical water quality monitoring data, or comparison of the water quality of a river site in question with a nearby "Reference" site within a more unimpacted catchment, can provide an indication of likely Reference Condition water quality conditions.

These various data sources can be used to identify the size of the problem, but more importantly, the rate at which change or degradation is taking place. The faster the rate of change (degradation) within the channel or riparian zones, the higher the risk of further degradation of the system.

An analysis of the site, reach and catchment context of the problem, and understating of the historical extent and rates of change, will provide important understanding of

- The implications of not undertaking any rehabilitation intervention: how large the problem is now, how recently (or not) it began and thus how rapidly the problem is deteriorating, and what the likely projections of deterioration would be on a 1, 2, 5 and 10 year time frame for example, will all inform the rate and risk of further deterioration should nothing be done to address the problem.
- In most instances, the problem cannot be effectively or sustainably addressed without dealing with the underlying casual factors. For most water quality problems in rivers, for example, it is often point sources of pollution (such as the many non-compliant

6 PLANNING A REHABILITATION ACTIVITY

Planning is an essential tool that enables effective rehabilitation interventions to be implemented (Rutherford et al. 2000). When planning is neglected or only superficially addressed, projects tend to fail in achieving the original intentions, or projects provide little benefit to society or the aspects of ecosystem functioning they were meant to improve. Many river restoration projects fail because of inadequate planning due to:

- Setting overly ambitious goals;
- Selecting inappropriate sites and techniques;
- Losing stakeholder motivation;
- Poor implementation of the selected rehabilitation activity; and
- Neglecting to monitor, assess, and document projects.

Box 6.1 summarises the benefits of effective rehabilitation planning.

Box 6.1: The power of planning

Planning enables one to:

- Clearly define the purpose of rehabilitation;
- Focus on the most important issues relating to the project;
- Identify and focus on the causes of problems rather than the symptoms;
- Identify and understand the domains of scale of the problem;
- Prioritise problems and thus optimise the cost-effectiveness of addressing them;
- Set clear and measurable objectives that will enable the evaluation of the success of the completed project; and

A good plan is as important to the rehabilitation process as the technical skill required for defining, identifying and designing measures for rectifying problems in the system. Many projects start by focusing on design and implementation rather than sound planning, with unintended consequences. Some rehabilitation structures, for example, built in dongas within wetlands to address erosion, have ended up exacerbating erosion through accelerated incision downstream of the new structures due to sediment starvation of the lower reaches.

In the South African context, rehabilitation is very costly (often enabled through the use of public money), and thus, in addition to the potentially ineffective ecological outcomes, the social implications of wasteful spending of public money must be considered. The legal and criminal implications of couching river landscaping or engineering efforts under the pretext of rehabilitation should also be considered.

For these reasons, planning needs to be transparent, ensuring wide stakeholder support for the vision as well as accountability with respect to the costs, selection of the rehabilitation option/s and the implementation and outcome of the project. Rutherford et al. (2000) expand upon four key points about planning rehabilitation projects, all of which are applicable to South Africa. These are:

- Rehabilitation projects should follow a hierarchy of spatial and governance scales that provide a framework for meeting national, regional and local objectives. This can allow any plans to link in, where appropriate, with national, regional and/or catchment management strategies relating to water resource management;
- An understanding of the cause of the problem being addressed- how the problem site relates to the catchment and what the rehabilitation potential of the site is;
- There needs to be an understanding of the ecological value and the types of goods and services that are provided to society or contribute towards meeting key objectives for the management of the catchment. The enables one to evaluate one rehabilitation option another.
- The rehabilitation plan must have the support of stakeholders affected by the proposed rehabilitation. Ideally therefore, rehabilitation activities should receive input and support from local stakeholders and communities and, wherever possible, also form part of an overall national strategy. The advantages of having a national strategy is that it encourages the identification and establishment of priorities, the coordination of programmes to set and meet public expectations, as well as the development and application of uniform standards to meet common goals.

Despite a rich literature defining the components of restoration project planning, there is often a lack of an explicit, logical process or method to move from the initial project vision to successful selection and implementation of on-ground strategies (Brooks et al. 2010). Rutherford et al. (2000) proposed a 12 step procedure to follow when undertaking rehabilitation projects, divided into four man phases:

- Establish a vision,
- Develop a plan,
- Implement the plan, and
- Monitor and review.

These plans, and others for ecosystem management (e.g. Rogers and Bestbier 1997), incorporate aspects of adaptive management to allow for ecosystem dynamics and uncertainty, as well as the consideration of innovative (sometimes untested) strategies and options to address the problem. A modification of Rutherford et al. (2000)'s 12 step planning procedure for undertaking river rehabilitation activities (**Figure 6.1**) is described below, with full acknowledgements to these authors for the basic structure of the approach. The procedure incorporates the principles and recommendations already made in Sections 4 and 5, and can be used as a direct guide in a rehabilitation project.

Step 1: Develop a Vision (set objectives)

The first step is to establish a vision for the watercourse. The most important question in planning rehabilitation activities is to therefore ask stakeholders "***what do you want***?[3]" The vision that the stakeholders (local communities and authorities) set for the site, reach or catchment must guide the entire project. This broad vision may not necessarily be quantitative or very scientific, but this can be disaggregated in to clearly defined measurable objectives (Rogers and Bestbier 1997), against which the outcomes of options for management or rehabilitation can be assessed. This process of planning

[3] Acknowledgment to the late Alan Batchelor, who would start any discussion on rehabilitation planning with this statement.

should be undertaken for small projects (i.e. at the site) as well as large catchment level studies. Rehabilitation actions can be contemplated at a variety of spatial scales, but a vision and associated clear objectives should drive the process from the beginning.

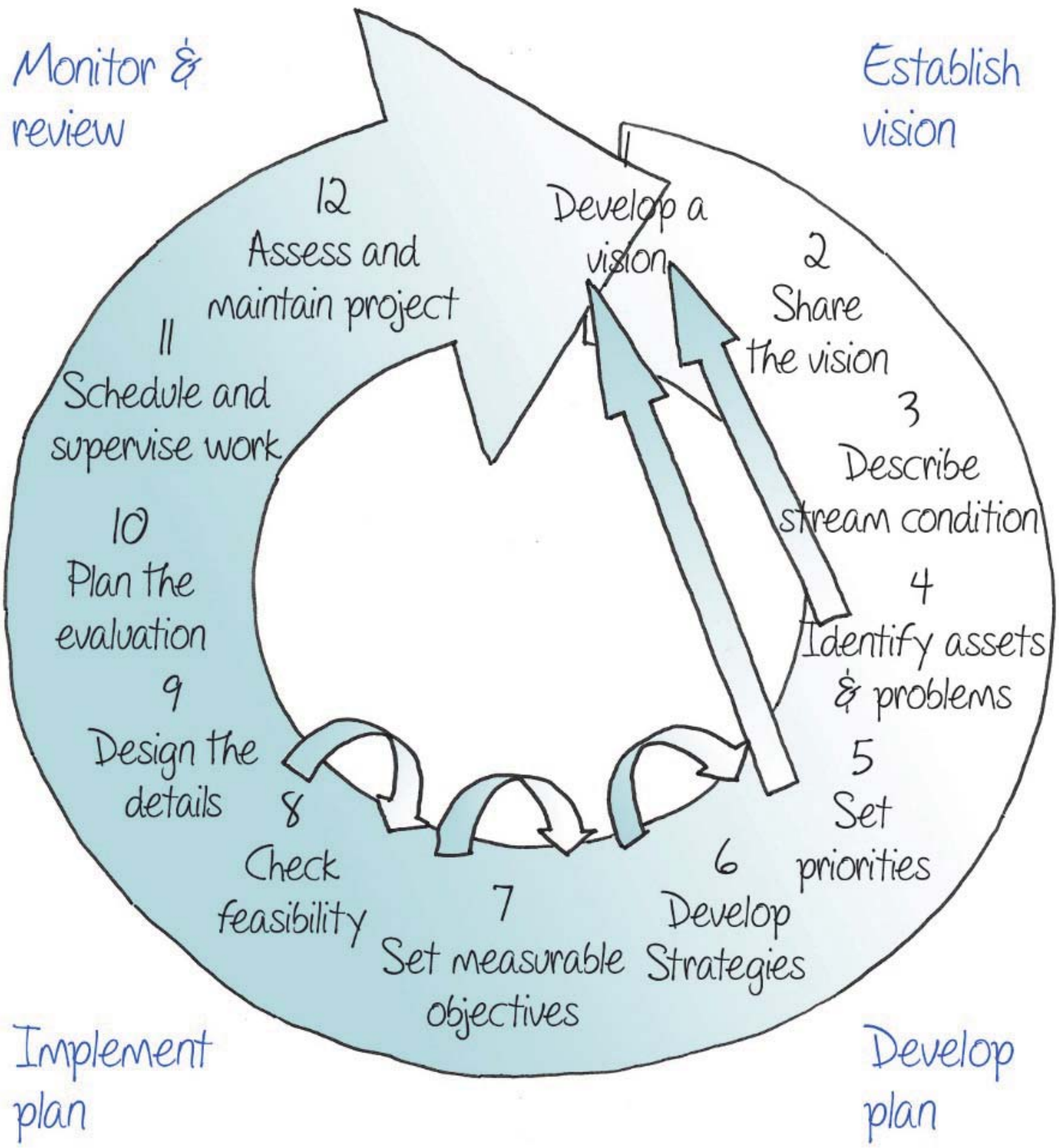

Figure 6.1: 12 step process for river rehabilitation (after Rutherford et al. 2000).

Rehabilitation planning should also allow for multiple users and enable input and entry in to the process from a variety of stakeholders, from organisations involved in national planning down to a specific individual proposing activities at a specific site. A common future vision for the river, or river reach, representative of all stakeholders' desires, should be developed.

The vision for the rehabilitation plan should thus encompass the future desired state that the stakeholders wish to be achieved for the watercourse. Rutherford et al. (2000) list a number of techniques that can be used to assist with the task of winning support for the desired vision. These are:

1. Make sure that the rehabilitation plan is developed as a co-operative venture between authorities and other relevant stakeholders from the outset (setting of the vision). If this is achieved, then it has a much better chance of success than if it is simply imposed from above;
2. Instead of dictating the problems based on a specific agenda, provide stakeholders with the opportunity to identify the problems for themselves. For example, take people into the catchment and explain the perceived problems and consequences of these. Demonstration of the problem is often far more convincing than theory or perceptions;
3. Describe the future desired state when agreeing on a vision for the site (or catchment). Make sure that this vision is clear, and that all stakeholders are committed to it, and have the same understanding of what it entails. Remember the first rule of selling: "If you don't love the product – nobody else will". Stakeholders must be as committed to the vision they are to some of their private interests. In order to articulate the vision, it is also important to: a.) be well informed; b.) be passionate with respect to commitment to the vision; and yet c.) remain open-minded and capable of seeing the interests and perspective of other role players and stakeholders;
4. Involving the local stakeholders in identifying the problem, describing the vision and evaluating and choosing appropriate solutions together fosters relations and helps to develop commitment to the rehabilitation project from the outset. It is more likely that a community with a sense of ownership will take responsibility for the project;
5. Anderson (1999) describes the importance of having a strong, inspirational stakeholder or community leadership in any project (a champion). This person can also act as a go-between with the community and government agencies in many instances and actually act as a stalwart.

Step 2: Share the vision (get support)

From the very beginning of a project you need to identify the important people and groups who support the vision for the stream. Stream rehabilitation projects can be as much about people as they are about the science and technical methods. Share and refine the vision of the river with stakeholders to increase the support and convert the opponents, as opposition may reflect areas where the initial vision does not cater for some stakeholders or, in the case of opposing authorities, some legislative requirements. Be prepared to work on a common vision for the river reach. An adversarial legislative route (see van Niekerk and Taljaard 2003) to force rehabilitation to be undertaken is likely to increase tensions and stifle any long-term stewardship or buy-in from those stakeholders who are alienated, so effective buy in and support is critical.

It is also important to remember that the process of developing the rehabilitation plan is not linear, but iterative, and loops back in an adaptive manner as problems are redefined and a range of solutions evaluated. If there is insufficient support for the vision of the rehabilitation project as originally conceived, one may need to redefine the vision based on stakeholder interests. It must also be stressed that **maintaining support** is as important as winning support in the initial stages of the rehabilitation plan. Among the greatest dangers of rehabilitation are unrealistic expectations (Rutherfurd et. al. 2000). It can take decades, or even centuries, for some types of disturbance to recover and it is therefore important to keep people informed of what is happening in order to maintain their interest, involvement and commitment. The inclusion of project evaluation in the overall procedure can go some way towards making this possible. However, continued communication with stakeholders is essential.

Step 3: Assess and understand the stream condition and site / reach characteristics

This step requires you to answer the question of how your river has changed, and to what extent such changes are part of the natural river dynamic, and to what extent they reflect human-induced disturbance? You need to be able to describe its pre-disturbance condition, present condition and rate of change. Look for independent evidence, anecdotal and historical information, including historical aerial and other photographs and GOOGLE imagery. As well as describing the present condition, estimate the potential for recovery or deterioration of the stream and make sure that you understand the physical and biological processes at play in the stream.

Depending on the scope and nature of your project, you will need to bring together the skills, advice and support of a number of specialists. It is important to work with these experts at the start of a project so that its full possibilities can be achieved, and to make sure that the professionals themselves work together in a cohesive, collaborative manner (see also Section 2.1).

Remember to identify other aspects about the site, and the broader river and its catchment that may affect the success of rehabilitation measures. These issues include:

- Soil type – does the site include "problem" soils, that may require special treatment or particular approaches (e.g. sodic soils, humic or peat soils)

Problem soils for rehabilitation

Some soil types require additional caution and consideration when undertaking rehabilitation interventions. This is the case when the soils are particularly erodible (such as sodic and other dispersive soils) or where the properties of the soil structure require more careful consideration of structure designs (such as in peat soils).

- **Dispersive soils** are those soils with a high concentration of sodium in the clays. These soils can effectively be dissolved by water due to the charged clay particles. Because these layers of clay can occur below the surface (i.e. at depth), the effects of soil erosion may not be immediately visible as gullies, but could manifest through tunnel erosion and small sinkholes. Dispersive soils have soil clods which appear to dissolve or go in to solution in water, and tend to have high turbidity runoff water.
- **Sodic soils** are highly dispersive soils, associated with a *very* high excess of sodium salts relative to calcium and magnesium. The upper soil horizon becomes highly dispersive and in some cases may be largely eroded from the site. In the underlying soil horizons, the sodium ions change the clay structures within soil, causing them to inhibit infiltration and prevent root growth through soil. Low vegetation cover and typically high grazing pressure (due to the high salt content of the vegetation) further promotes erosion.
    - Sodic and dispersive soils are highly erodible and need special care, especially when considering the construction of structures within such soils as the failure risks will be higher.
    - Depending on the pH, it is possible to mitigate the effects of sodicity or dispersive soils through the application of gypsum or lime, as this helps to correct the calcium imbalance within the soil.
- **Peat** is a highly organic rich soil which forms slowly over centuries in very wet environments through the accumulation of organic material. In Southern Africa, peats are typically associated with wetland environments. Hard, compacted peats can be impermeable, but are highly susceptible to desiccation and, if allowed to be drained or dry out, to fire which can burn off metres of the soil surface. Special care in peat environments must be undertaken to ensure that the peats are maintained wetted, and that no fire is permitted to encroach.

- Is the upstream catchment heavily invaded with woody alien vegetation, likely to wash downstream and cause debris dams / changes in river function;

- Are there significant upstream sources of sediment?
- What threats are there to the present water quality and flow regime (e.g. are big dams planned upstream, or outflows of waste water?).

Input from all or any of the following kinds of specialists may be necessary to inform rehabilitation planning and implementation, depending on the complexity of the project:

- Archaeologist/ heritage professional: Shares knowledge of local heritage and culture to help guide project planning and restoration;
- Biologist/ecologist: Checks that project approach and restoration techniques benefit habitats and species found at the site and within the catchment. They also help shape the design;
- Community contact: A trusted locally based contact between the project team and the public, and decision-making;
- Construction contractor: Makes sure the project is completed on time and budget. Inputs into designs and is available to answer any questions on-site to steer works;
- Geomorphologist: Provides advice on river channel and floodplain regarding morphology, sediment and natural river processes. Also advises on project design;
- Hydrologist: Expert knowledge about river flow, floods, drought and groundwater systems and how these interrelate;
- Landscape architect: Gives direction on project design, landscape and planting;
- Landscaper: implements the landscape architect's plan;
- River engineer: to undertake design of structures and assess hydraulic characteristics of the site and, if necessary, impacts of the proposed structures;
- Project Manager: Has overall responsibility for the project, day-to-day management, controlling budgets and communicating with specialists and the public;
- Site supervisor: Makes sure everyone meets their health and safety responsibilities on- and off-site.

Step 4: Identify assets and limitations

This step requires identification of your stream's main natural assets and problems.

Rehabilitation is about protecting natural stream assets and improving or creating other assets. An asset is any aspect of the stream already in good enough condition to meet your goal. Many stream assets are threatened or have already been degraded. In this step, you identify the main assets, degraded assets and problems impacting on your stream.

In addition, you need to identify factors that will limit the ability to address these impacts – for example if river water quality is highly impacted as a result of upstream catchment-scale land-use, this may impose significant limitations on what can and cannot be achieved at a site or reach level.

Step 5: Set priorities

Here, you need to answer the question of which reaches and problems should be addressed first.

If you have an extensive reach of river to work with, do not automatically start rehabilitation at the most damaged reaches. Remember that it is usually more effective to protect reaches of stream that remain in good condition, than to spend large amounts of money trying to rehabilitate reaches that are already damaged. When the major assets of the stream have been protected, then you can begin to improve the stream condition.

Step 6: Develop strategies

In this step, you need to consider the different strategies that are available, both to protect assets and improve your river. Volume 2 of the River Rehabilitation Manual (that is, The Technical Manual) provides a large selection of rehabilitation approaches and these would form the basis for considering this step. A summary of the options available that could potentially address each of the main problem types or objectives to be addressed is presented in Chapter 7. There may be other innovative techniques or approaches outside of this document that could be considered, bearing in mind that new approaches need to be carefully weighed up in terms of all of their implications.

Using the Technical Manual as a source of information and approaches, identify and list the things that you can do to protect and improve the important assets in the reaches that you identified as a high priority, making sure that they meet your key objectives in terms of what they are realistically likely to be able to achieve. Note that many strategies will also involve changing the behaviour of people who use the stream.

When considering the expected outcomes of implementing different rehabilitation approaches, it is also important to remember that rehabilitation brings change, including sometimes unanticipated knock-on effects. These should be identified as far as possible, so that their consequences can be thoroughly understood, before they occur, noting however that there is often an element of unpredictability in river rehabilitation, and unexpected consequences of rehabilitation are likely to persist until such time as rehabilitation activities are informed by a much greater resource of data, expertise and shared rehabilitation experiences.

Examples of knock-on effects of rehabilitation include the short-term occurrence of nuisance plagues of midges (adult life stages of *Chironomid* dipterans) in a water body following rehabilitation measures focusing on removal of alien Carp.

Safety, security and aesthetic issues should also be considered. In some cases, implementation of the preferred approach from an ecological perspective may result in the creation of areas where safety and security are compromised (e.g. as a result of dense reedbeds, deep waters or trees promoting areas for criminal elements to lurk (see Day et al. 2005). The social, aesthetic and economic effects of rehabilitation measures need to be considered in conjunction with their ecological outcomes, and vice versa, to avoid outcomes that are potentially surprising or shocking to user groups.

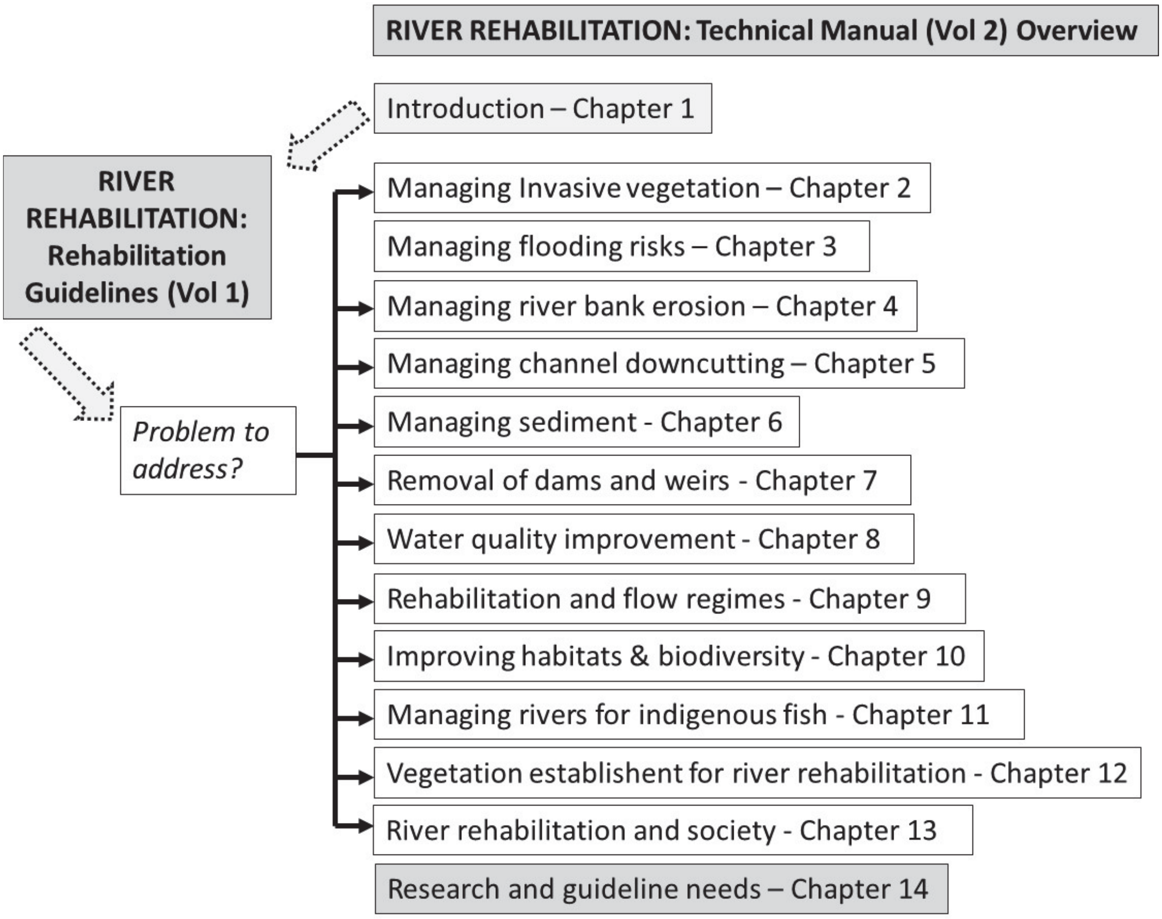

Figure 6.2: Develop strategies to address the priorities or problems that you wish to address through selecting poosible options for rehabilitation actions from the suite of options presented in each of the chapters in the Technical Manaul (Volume 2). A summary of the options for each main objective type is presented in Chapter 7 of this document.

Step 7: Set measurable objectives

An essential step in developing a rehabilitation plan is to specify exactly what will be achieved. Your general strategy for rehabilitation has to be turned into clear, measurable objectives that specify exactly what you want to achieve in your rehabilitation project. These objectives will become the core of your stream rehabilitation plan. Some questions which can be used to clarify the purpose would be:

- Is the main aim of the project to improve the physical processes of the river or increase the biological diversity of your section(s)?
- If the focus is to increase river forms and processes, what will be the specific expected benefit for the ecology (specific fauna and flora and, where appropriate, part(s) of life cycle(s))?
- If the focus is to increase ecological (habitat) diversity for a range of fauna and/or flora, which parts of the life cycle are expected to be restored and what physical river features are expected to be developed to support this?

An essential step in developing a rehabilitation plan is to specify exactly what will be achieved. Specific and measurable objectives for the intended intervention must be identified. Objectives should be SMART (Kotze 2000):

- **S**pecific: *Clear and unambiguous, and specify clearly what will be achieved*
- **M**easurable: *One will not know what has been achieved if it cannot be measured*
- **A**chievable: *Realistic and attainable with the resources that are available*
- **R**elevant: *Must be a key part of the vision and problems being addressed*
- **T**ime-bound: *Must have a starting point, ending point and a time frame for objectives to be met*

For some projects, for example, a SMART approach may be as clear-cut as stating: "the new sewage works will not discharge wastewater into the river". Most of the time, however, the intervention will probably require objectives that are not as clear-cut. For example, one could set objectives for sediment trapping simply to improve the current situation. This is unlikely to be quantified and may lie somewhere between the best one can expect and a result that is at least acceptable but not ideal.

Alternatively, objectives may need to be set in terms of maintenance rather than improvement. That is, when protecting an existing service, the objective may need to be based on maintaining a certain condition rather than allowing it to deteriorate. It is also important to specify the scale applicable to each objective where this is not implicit in the objective. For example, specifying certain water quality criteria for a point source input may only be applicable to a river reach a few hundred metres downstream of the point of input. **Box 6.2** highlights the benefits of effective objective setting in project planning and implementation.

Box 6.2: The benefits of setting objectives:

- It forces one to work out exactly what would be considered a success;
- Having measurable objectives is a prerequisite for designing specific intervention strategies and for evaluation;
- It allows one to set the scope and scale of the project;
- It also reveals where objectives are contradictory or in conflict with one another. For example, re-creating certain habitats for one species may not allow one to meet the objectives with respect to another; and
- Defining measurable objectives adds rigour and accountability to the rehabilitation process.

In order to be able to evaluate the rehabilitation project, one should also set the time over which improvements are expected to occur and objectives are intended to be met. One should describe the range between what would be considered a very disappointing result, and what would be considered a great success. This will depend largely on the problems being dealt with. Since there are no guidelines available for this, it is likely that this approach will need to be predictive and based on the current levels of understanding about wetland systems. It is also likely that the understanding around these issues will be developed incrementally as experience is developed. A key aspect of this is ensuring that the time periods against which results can be expected are short enough in order to keep the stakeholders who bought into, or who are involved in, the project interested. It is also important that the objectives set are achievable and can realistically be met. According to Rutherford et al. (2000), experience has shown that nothing kills the enthusiasm of stakeholders and participants in a project more quickly than objectives that can never be met. A successful project can appear unsuccessful because of over-ambitious objectives.

Since most recovery is measured in years, and thus it is essential that objectives reflect the time that it is likely to take for recovery, and that all participants are fully aware of that time. Objectives should therefore include a time frame within which they will be achieved. Having a series of objectives may help with this since these can be used to track the recovery of the system. One may set the objectives based on, for example, an improvement in water quality after one year, and further improvements after three years and so on. Alternatively, two complementary objectives might be to complete any work on the system in a year, and to measure the effects of that work (outcomes) after five years.

Step 8: Assess feasibility

This important step requires you to ask whether your rehabilitation objectives are feasible.

Many of the interventions that you would like to include in your stream rehabilitation plan may not be feasible because of cost, legislative or administrative constraints or the side-effects of your work (see also Section 9). By examining each of your objectives to check whether or not they are feasible, you will arrive at a final list of problems that can realistically be treated.

Step 9: Design the details

In this step you move from the general methods that you would use to treat problems to a detailed design for your river. You need to identify the specific activities interventions/approaches that need to be carried out to achieve your objectives. These can range from doing nothing, to the planning and design of erosion control structures, flow manipulation, or complete channel reconstruction.

Note that in some circumstances, legal authorization may necessary for the planned interventions (see Section 10) and the necessary applications and associated public and stakeholder participation processes would need to be considered at this stage, if not before. The timescales and financial costs inherent in obtaining such legal authorization should not be under-estimated (see Section 9).

Step 10: Plan the evaluation

Every river rehabilitation project should have some form of evaluation as without it, you will never know if your project was worth the effort or achieved its objectives. Evaluations also allow lessons learned from rehabilitation projects to be shared with a broader audience of rehabilitation scientists, planners and implementing agents, to ensure that rehabilitation as a science continues to grow.

The measurable objectives worked out in Step 7 become the basis for evaluating the project. Practical evaluation procedures emphasise that not all evaluation needs to be detailed and expensive, and cost-effective, robust evaluation approaches should be worked out in advance.

Step 11: Implement and supervise works

A detailed plan needs to be worked out and implemented, including developing a time line that includes consideration of natural rainfall and other phenomena likely to affect rehabilitation success unless adequately factored into timelines; allocating responsibilities; finalising funding; actually implementing the planned works; and organising the evaluation schedule. This can be both the most exciting and the most stressful phase of the project – the more attention is paid to the details of the plan, and to addressing Steps 1-10, the less likely the project is to fail in implementation.

Step 12: Maintenance and monitoring

The final step of the planning process is to maintain the work that has been done, and to set a point in the future at which the project will be formally assessed using the information gathered by the evaluation plan. Lessons learned and retrospective changes that might have been made in planning, design or implementation to avoid subsequent problems should be documented in this monitoring and evaluation phase.

The above 12 stages of rehabilitation planning, design and implementation are summarized in **Figure 6.1** (after Rutherford et al. 2000).

7 OPTIONS FOR REHABILITATION

7.1. Overview of options

This section provides an overview of the options for rehabilitation that are considered in more detail in the Technical Manual (Volume 2). While it is necessary to review the Technical Manual for a detailed evaluation of each approach, as well as recommendations for its applicability or desirability in different situations, the material presented here is intended to provide a rapid overview of the rehabilitation options that are available to address specific problems. The relationship between the Rehabilitation Guidelines (this document) and the contents of the Technical Manual (Volume 2) is shown in **Figure 7.1.**

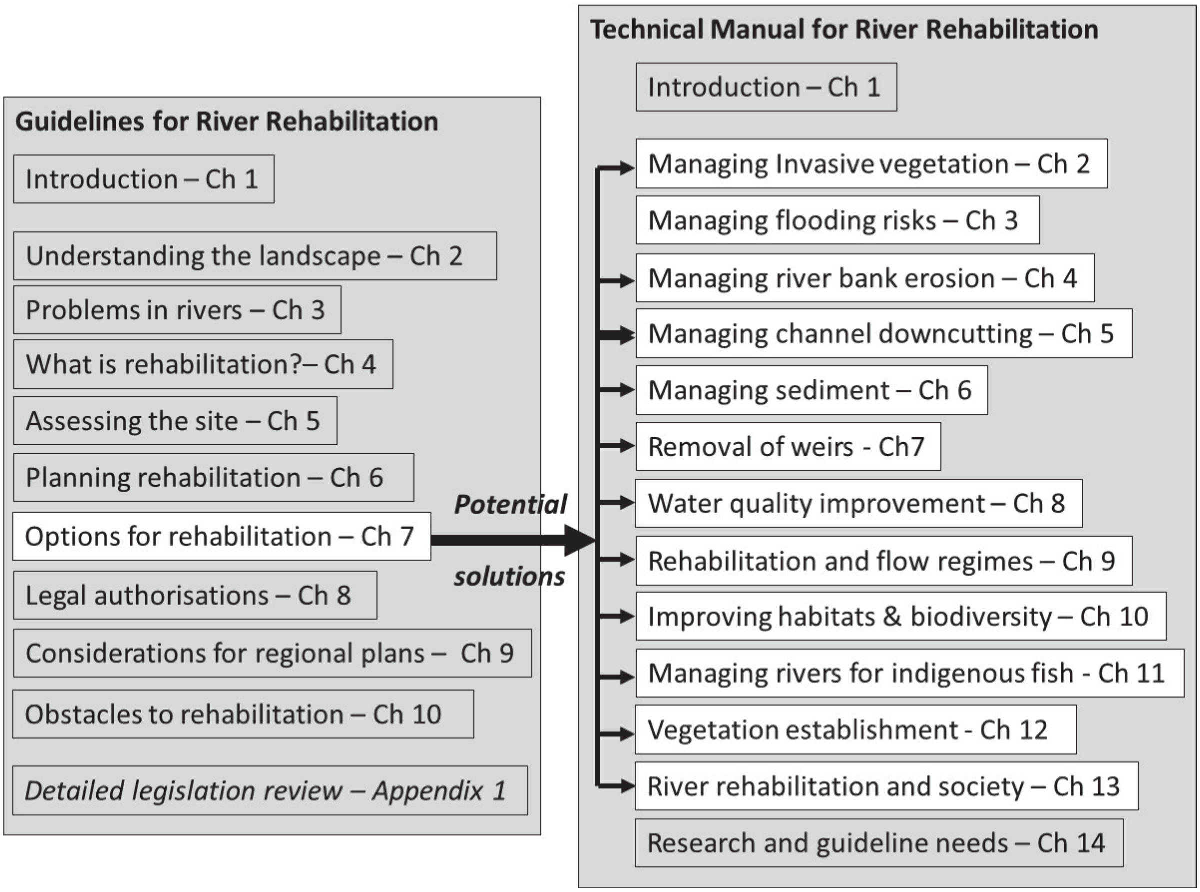

Figure 7.1: Relationship between the Rehabilitation Guidelines and the contents of the Technical Manual

Costs of not rehabilitating

Although most of this document focuses on the ecological, biodiversity and financial costs of rehabilitation, it should be stressed that in many cases, failure to implement appropriate rehabilitation activities timeously can also have tremendous costs, often orders of magnitude greater than the costs of early intervention, and resulting at best in stabilizing the degradation process, with no chance of returning the system to its original condition. Remember that "*it is easy, fast and cheap to damage natural streams, but difficult, slow and expensive to return them to their natural conditions*" (Rutherford et al. 2000). Some of the implications of not rehabilitating are documented in the Case Study Assessments (Volume 3).

7.2. Options to manage invasive vegetation

Section 3.2 described the effects that invasive alien (and even in some circumstances indigenous and/or cosmopolitan vegetation) can have on rivers, often leading to severe degradation and associated direct and indirect ecological and economic costs.

7.2.1. Legal Classification of invasive vegetation

The National Environmental Management: Biodiversity Act (Act 10 of 2004) (NEMBA) categorises invasive species into four categories of so-called "Listed Invasive Species", as published in August 2014 (GN 599 of 2014, Gazette No 37886). These categories comprise:

- **Category 1a** – these comprise invasive species requiring compulsory control, and all such plants are to be removed and destroyed; this Category equates to Category 1 in terms of CARA (see above);
- **Category 1b** – These invasive plants require control as part of an invasive species management programme, and no increase in their extent or density may take place.
- **Category 2** – Such species may only be kept with a permit, and in a specified area of land; except when they occur in a riparian zone or a protected area where they need to be controlled
- **Category 3** – these invasive species are exempt from the requirements for control. However, where they occur in aquatic and/or riparian areas, they are considered as Category 1b species and need to be controlled.

A second piece of legislation (subordinate to the NEMBA legislation) is also relevant to alien clearing, namely the **Conservation of Agricultural Resources Act** (CARA) (Act 43 of 1983), which classifies invasive alien plants into three categories, each of which allow for different levels of approach, as follows:

- **Category 1** species – these invader plants must be destroyed immediately, and may not be traded. This category equates to Category 1a in terms of NEMBA (see previous);
- **Category 2** species – these invader plants have a commercial or utility value, with useful qualities, including commercial use for timber, food, animal fodder, soil stabilisation, etc. Permission can be gained to grow these species commercially in demarcated areas but otherwise they must be removed. This category equates to Category 1b in terms of NEMBA (see previous);
- **Category 3 species** – these plants are primarily ornamental or 'exotic' horticultural plants that have escaped from gardens. They can be maintained on a landowner's property if they were already growing at the time of promulgation of these regulations. All other Category 3 plants must be removed. This category equates to Category 1b in terms of NEMBA (see previous) and the plants must be controlled.

Note that irrespective of the category, the above Act stipulates that all declared (invasive) plants growing within 30 m of the 1:50 flood line of a river or water body must be removed.

Since this manual approaches invasive plant removal as one of a suite of rehabilitation approaches, it follows however that the legal classification of invasive plants is less important than

> **How does one know what plants can be removed without a permit ?**
> A combined list of Declared Weeds and Invasive Alien Plant Species addressed by both CARA and NEMBA has been provided in Volume 3 (Technical Manual).

identification of their individual effects on river function. However, an understanding of their classification is important from the perspective of carrying out legally defendable rehabilitation activities, without running foul of legislation. From this perspective, it is noted that removal of alien vegetation requires a permit in terms of NEMBA (Section 65 (1)).

However:

- Removal of Category 1a, 1b, 2 & 3 invasive alien plants is mandatory in terms of NEMBA where such plants occur within a riparian area (32 metres of the edge of a river, lake, dam wetland or estuary, or within the 1:100 year floodline, whichever is the greater);
- Alien species regulated in terms of CARA as weeds and invader plants (i.e. Categories 1-3) are exempt from the requirement for a permit for their removal in terms of NEMBA.

This means that removal of all Category 1-3 listed plant species may be carried out legally, without a permit. Note that this is not the case in the control of indigenous invasive plant species – as outlined in Section 2.3.

7.2.2. Identifying situations where alien plants are drivers of river degradation

A number of factors may indicate that invasion by alien plants is a contributing or primary cause of river degradation, noting that they do not need to occur on the site or even in the affected reach to result in problems, but may be upstream or upslope of the affected area. Look for signs of the following:

- Increased sediment in the river channel
- Lining of the river bank by alien trees, that might confine flows in flood conditions
- Extensive alien invasion at a catchment or sub-catchment level – use tools such as GOOGLE historical imagery to note changes in extent over time
- Obstruction of the river bed with felled trees / large branches
- The presence of large logs / branches along the river bank, deflecting stream flows onto the opposite bank or increasing stream velocities
- Decreases in dry season stream flows over time, and possible encroachment of terrestrial plant species into flood channels and the river margins
- Debris dams against bridges or culverts, characterized by large sediment loads and/or woody debris comprising alien trunks and branches
- Smothering of riverine vegetation by alien plants, including weedy creepers
- Establishment of young trees on islands and sand bars, previously non-existent or temporary features that washed away in floods.

7.2.3. Establishing a structured approach to alien plant control

Once alien plants have been identified as problematic, the following steps need to be considered (see more detailed technical specifications and recommendations outlined in the Technical Manual (Volume 2: Section 2.1)):

Step 1: Planning alien control, including considerations around:

- Setting objectives
- Deciding on focus areas
- Planning and preparation
- Addressing alien clearing impacts

Step 2: Deciding on Alien clearing and control methods, including:

- **physical** (or mechanical) control
- **chemical** control
- biocontrol
- a combination of approaches.

Details as to the most appropriate method in different circumstances are again included in the Technical Manual (Volume 2: Section 2.1).

Step 3: Methods for the disposal of alien plant material

Step 4: Maintenance / How to follow-up on alien clearing

Step 5: Alien clearing monitoring

Step 5: The need for trained implementers – who should do this work?

Step 6: Considering legal issues and permitting

Step 7: Guidelines for the removal of specific alien plant species.

7.2.4. Control of other plant species

Since alien vegetation is not the only type of vegetation that can be invasive and affect perceived or real river function, the Technical Manual also includes specifications around the removal of some common problematic indigenous or cosmopolitan species.

7.3. Options to reduce flooding risks by improving flood conveyance or flood attenuation

Floods damage agricultural infrastructure along the river, and occasionally overtop the river channel, cause bank erosion and may inundate large areas of productive agricultural land. This puts agricultural production and job security in the valley periodically at risk. Maintaining productive agricultural areas is thus essential for the economy of the country, to secure employment and food security, but similarly maintaining and where possible improving the ecological condition of the river can ensure sustained provision of ecosystem goods and services.

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Main principles for managing flooding risks at the site

The guiding principles to managing flooding risks along a river should be:

1. to allow the river as much lateral space as possible to allow floodwater to spread and thereby reduce velocities and minimize erosion and safety hazard,
2. to restrict floodplain activities to those compatible with occasional flooding (such as for pastures or recreation), and
3. to keep rivers and riparian zones clear of invasive vegetation in order to preserve their conveyance function and reduce flood heights.

Floods are naturally occurring events and a range of floods is important for river ecosystems. Large floods are responsible for channel formation and smaller floods control and maintain instream and riparian habitats and biota. In southern Africa, the very large or extreme (1:50 to 1:100 year return interval) floods are responsible for scouring sediment and vegetation from the channels and redistributing that sediment across the reach. Infrequent moderate and large floods can be expected to overtop the river channel, but when regular small floods begin regularly to overtop the channel, this can be caused by

- Increased vegetation cover (often invasive alien vegetation, especially woody trees) growing on the channel bed or banks. The increased vegetation slows down the flow velocities and caused higher flood levels;
- Sedimentation of the river channel, possibly due to upstream catchment erosion, but also often in response to the slower flow velocities caused by vegetation growth in the channel;
- Encroachment in to the channel, with the result that the smaller, narrower channel is too small to convey large floods; and
- Cutting off of the secondary channels and floodplain, which causes larger volumes of water to be confined to less flow area, and resulting in higher water levels during floods.

Where it is practicable and desirable from the stakeholders' perspectives, flood attenuation of a river reach and the ecological condition of the floodplain can and should be improved through reconnecting the floodplain, riparian areas and secondary channels to the main channel through levee removal. Other options for increasing flood attenuation, but reducing flood heights, include the widening of the channel and stabilisation of the resloped channel banks with a variety of simple vegetation, green engineering or harder engineering options. Widening of the channel is only possible where there is sufficient available adjacent land to undertake this. The widening of formerly encroached rivers and reconnection of floodplains and riparian areas enhances ecosystem functions and services in river reaches and should be promoted wherever possible.

However, in many river reaches, the lateral expansion of watercourses needed for flood attenuation enhancement is constrained by existing infrastructure and landuse activities, and remediation measures rather than rehabilitation are often the only practical approach to an intractable problem. To manage flooding risks in reaches where there is insufficient available lateral space to widen the channel, the direct removal of sediment and/or effective deepening of the channel through levee creation could be considered. These solutions should however only be undertaken in areas where there is existing uses immediately adjacent to the river channel and where, following invasive vegetation removal, excessive sedimentation continues to cause channel aggradation.

Channel straightening is another option for reducing flood heights in a reach, as straightened channels convey floods more effectively, but also then result in larger flood peaks delivered to downstream river reaches.

There are thus a variety of rehabilitation options which can be employed to address overbank flooding risks through improved flood conveyance and increased flood attenuation where appropriate. These options are tabulated in Table 7.1. In **Figure 7.2**, intervention options are summarized along the x axis by those requiring increasing areas of lateral space, and costs for implementation, and along the y axis by, from top to bottom, options which generally represent the rehabilitation towards increasingly natural conditions of the river reaches.

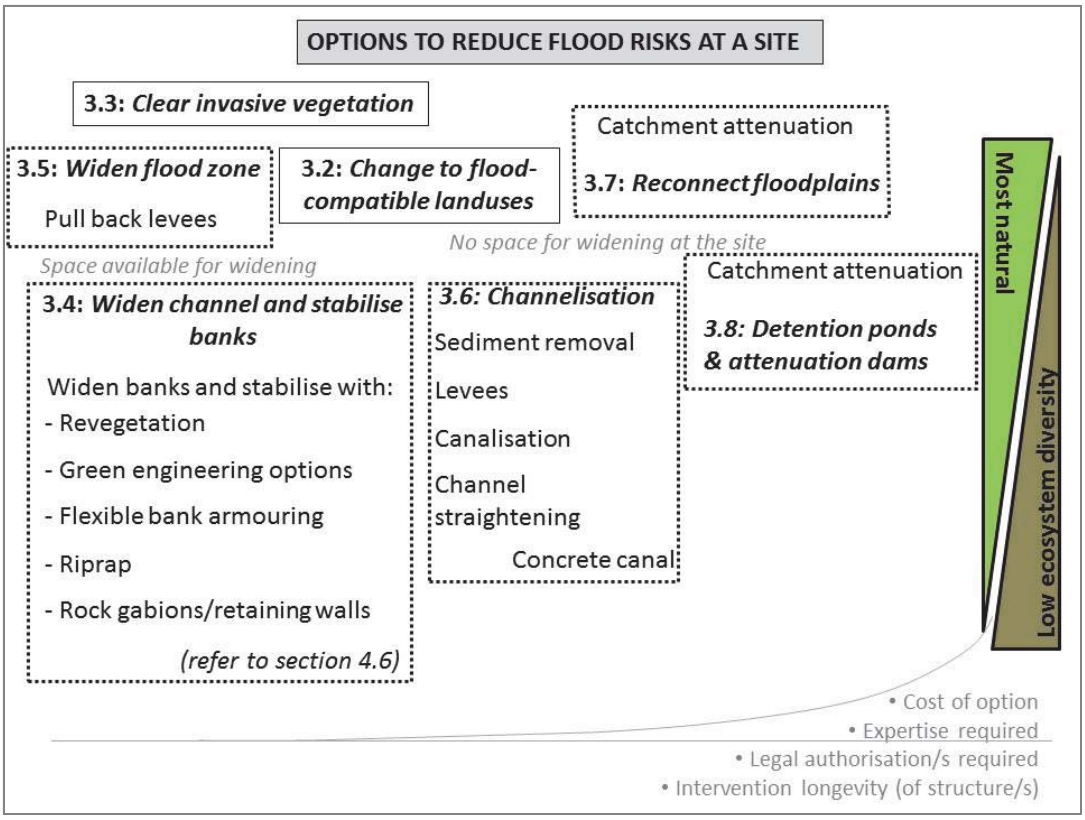

Figure 7.2: A summary of the rehabilitation options available for reducing flooding risks at the site scale. Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed in detail.

Table 7.1: Summary of the options to reduce flooding risks. Options described in more detail in text – presented largely in order of most to least ecologically benign options – within groups of broad objectives (conveyance, attenuation, etc.). Sections indicated refer to the section of the Technical Manual (Volume 2 of this series) which can be referred to for more information.

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
Avoidance approaches						
No interventions	**Do nothing (Vol 2, Section 3.1)**	No intervention	0	None, but risk of further loss of ecosystem degradation may be high	None	Do not consider if rate of degradation is fast and/or risk of widespread impacts is high.
Minimise the impact of flooding	**Change landuses to flood-compatible activities (Vol 2, Section 3.2)**	Within flood- prone areas, employ landuse activities (e.g. sports fields, flood tolerant crop, parklands) which are compatible with occasional flooding.	++	Some ecological benefit may occur where the new landuse activities allow for more natural vegetation and flooding processes to be reinstated.	NEMA, NEMBA and CARA authorization may be required for some instances of landuse change	The most fertile soils tend to be found on floodplains, and abandonment or relocation of existing agricultural landuses to other sites will not always be possible. Moreover, the cost of relocating fixed infrastructure (irrigation, dwellings, roads, bridges, etc.) will present an enormous cost to society and may preclude this option in many cases.
Conveyance approaches (aimed at increasing discharge through the site)						
Increase flow velocity	**Clear invasive vegetation (Vol 2, Section 3.3)**	Removal of invasive vegetation from river and banks	+ (R4k-R15k/ ha)	Can be beneficial if more natural conditions are being created – note that functions such as water quality improvement through sediment and nutrient trapping may be reduced and erosion may increase.	None unless species are protected	Some indigenous species are protected and clearing requires additional authorizations – Refer to Section 2 of this document. All debris should be removed from the channel and riparian area. Costs of clearing, based on 2014 SANBI data, range from R4000-R8000 per ha for Acacias and R10 000-R15 0000 per ha for large bluegums. In addition, follow up clearings (from R2000 to R4500/ha) must be budgeted for.

[4] Costing estimates kindly provided by Ms. Heidi Niewoudt (SANBI) are indicated primarily for comparative purposes. Site specific factors, such as access, available materials, environmental authorisations and method of construction will determine final costing. These costs based on 2014 data only.

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
Increase cross-sectional area of the channel	**Widen channel and stabilize new banks (Vol 2, Section 3.4)**	Widen the channel, reshape the banks and stabilise with either: • vegetation, • green engineering options, • Riprap, • Flexible armouring mats, • Rock retaining walls (gabions;	+ ++ (+++) +++ +++ +++++	**Revegetation** with a variety of indigenous species may improve habitat diversity and quality, as well as longitudinal and lateral connectivity, while reducing erosion; Important positive component is that it allows the low flow channel to be relatively natural, and unlined, supporting habitat quality, diversity and low flow water quality amelioration **Green engineering options** usually provide better habitat diversity over harder options. If design allows for establishment of plants other than grasses, and with vertical diversity, then could be ecologically improved **Riprap and flexible armouring mats** tend to offer poorer ecological condition of the banks (but riprap can be appropriate for boulder streams and can be adapted to support vegetation) **Gabions** offer even lower habitat diversity, but planting of lower wetted gabions may provide improved river bank habitat	NWA: Section 21 c and i; NEMA applies unless very small (<5 m^3) sediment volumes are moved.	**Revegetation**: Only applicable to low energy sites where vegetation will be sufficient to stabilise reshaped banks. Revegetation costs are estimated at R16-35 per m^2. **Green engineering options**: May only be applicable to moderate energy sites where green options adequate to stabilise reshaped banks – note that if used in high energy areas, may result in significant ecological and other risk and/or damage **Riprap and flexible armouring mats**: In boulder and cobble streams, riprap would be preferable over armourflexing. If armourflexing is used, the cells must be left open for vegetation establishment. **Gabion**: Engineer is required to design structures

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
Increase cross-sectional area of the floodplain/ riparian area	**Widen the flood zone by pulling back levees (Vol 2, Section 3.5)**	Pull back existing levees from the bank or water's edge.	++	Ecological impact reduced (but not avoided) by setting levees back as far from the top of the bank as possible – where levees set back to include high flow area, this allows for low flow habitat to be undisturbed and increases conveyance through the site.	NWA: Section 21 c and I (General Authorisation should apply); NEMA Activity 19 will apply unless very small (<5 m^3) sediment volumes are moved.	Pulling back existing levees should be encouraged wherever practicable.
Increase flow velocity	**Channelisation : excavation, levees and channel straightening (Vol 2, Section 3.6)**	**Channel straightening** (excavated, unlined) whereby a narrow, deep, straighter channel is created to speed up the rate of flow, especially in rivers with a highly meandering or braided pattern, where channel straightening allows for more effective, rapid flood conveyance	++	High in-channel disturbance, but in cases of aggradation (i.e. where sedimentation is raising the level of the river bed), this approach may be essential. If carried out infrequently, high levels of ecosystem recovery may be possible; disturbance and steepening of river banks often associated with dredging sediment	NWA: Section 21 c and I (GA may be applicable in some cases); NEMA applies unless very small (<5 m^3) sediment volumes are moved.	May be applicable for high sediment rivers where adjacent landuses are at unacceptable risk (***Refer to Chapter 6***). Engineer should design the channel straightening to planform to identify the minimum amount of channel straightening to achieve the required reduction in flood risk. Note that significant downstream impacts may result as a result of receipt of increased volumes of flow, potentially resulting in the need for extended canalization / channelization and its associated negative impacts
		Levees: where new levees are constructed on the channel banks to constrain flood flows	+++	***None in the case of new levees.*** <u>New levees definitely not recommended from an ecological perspective</u>	NEMA Activity 19, NWA: Section 21 c and i	Loss of floodplains and/or riparian areas as the floods become restricted by levees. Downstream flood peaks may increase.

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
		Canalisation (excavated, lined) whereby a narrow, deep, lined channel is created to speed up the rate of flow , especially floodwaters	+++++	Unless water quality is seriously impacted, benefits in terms of ecological function are very limited for lined (concrete or other) canals. New canalisation definitely not recommended from an ecological perspective	NEMA Activity 19, NWA: Section 21 c and i	Engineer should design the canal dimensions to meet the flood conveyance objectives. Unlined canals are cheaper than lined canals (concrete structures in the region of R7500/m^3) but require more regular maintenance actions. Once in place, channelized or canalised system are difficult to undo, and are often associated with socio-economic ills, such as littering, poor water quality, invasion by alien vegetation, poor habitat quality and reduced property values
Attenuation approaches: decrease flood peaks into downstream areas						
Reduce flood peaks from the catchment	**Reconnect upstream riparian areas and floodplains (Vol 2, Section 3.7)**	**Reconnection of riparian areas and floodplains** to maximize flood attenuation through the removal of berms, pulling back levees and/or through construction of weirs to raise water levels to floodplain height. Even in reaches without floodplains, pulling back existing levees to positions farthest from the river channel will widen flood zones in upstream areas, increase attenuation and decrease flood peaks in downstream areas.	+ (++)	Pulling back or reducing levee heights on existing levees to reconnect riparian areas and floodplains would aid in river rehabilitation by promoting a shallower and wider flow area, thus reducing flow velocities and the sediment transport capacity of the river) and creating riverine habitat subject to extreme disturbance on a less frequent basis. Upstream attenuation may create an opportunity for reconnection of floodplains,	NWA: Section 21 c and I (GA should apply); NEMA applies unless very small (<5 m^3) sediment volumes are moved.	Floodplains may be rendered un suitable for economic uses and therefore costs may be very high. Economic and social costs should be weighed against benefits. Practitioners should be aware of risks of erosion. Where structures are necessary (e.g. weirs to raise water levels in incised channels), an engineer is required to design structures.

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
	Attenuate flows in upstream dams (Vol 2, Section 3.8)	**Attenuation of stormwater** within urban drainage network [i](numerous options including small attenuation ponds)	+++++	Where floods are unnaturally high (e.g. downstream of urban areas or where the catchment has changed its function as a result of loss of wetlands or climate change), reduced flood peaks may improve the likelihood of ecosystem recovery between flood disturbance events; small attenuation ponds may provide opportunities to create seasonal wetlands in urban areas – provided that water quality and socio-economic impacts do not over-ride these benefits.	NEMA, NWA: Section 21 b, c and i	The cost and expertise to retrofit attenuation options and structures within the existing urban environment could be challenging, and this is not a viable solution for an individual downstream landowner with site-specific flooding problems; It is however a viable option for "Friends of Rivers" groups or local authorities seeking to improve flood management without impacting on river ecosystems.
		Large (catchment-scale) flood attenuation dam/s	+++++++	Reduced flood peaks may reduce flooding downstream, but sediment starvation (causing enhanced erosion) and the barrier effect of the dam would possibly outweigh these benefits in some catchments.	NEMA, NWA (numerous)	Large dams would be needed to attenuate floods, and these dams would need to be designed or operated to maximize temporary storage of flood peaks. This would be a very expensive option and is ***not recommended as a river rehabilitation intervention*** , both from an environmental perspective of dam impacts and due to the prohibitive costs which make this unviable for individual landowners

7.4. Erosion: Managing eroding banks (lateral erosion)

Options for the management of river erosion at a site level fall into two broad categories. The first category is **managing eroding banks**, which is where usually only one bank, or a short section of both river banks, are eroding. This issue is addressed in **Section 7.4**. The second category of erosion involves managing sites and reaches which are **downcutting or incising**, which is when the river bed is eroding down into itself and resulting in donga or gulley formations and steep, vertical banks for extensive lengths along both banks of the river. This erosion type is also sometimes called headcut erosion, and management options are outlined in **Section 7.5.**

One group of river bank erosion protection options involves longitudinal protection where a structure or bank treatment is provided down the length of the bank, often just on one bank. This could also be seen as direct protection of the river bank. Here, options for addressing bank erosion include retaining walls (or river training walls), riprap, prefabricated concrete block structures, landscaping and re-vegetating (**Figure 7.3**). Of these, the so-called "hard" engineered options such as riprap and retaining walls leave little scope for biological connectivity between the channel and the flood plain, so are environmentally undesirable, but in urban areas they have the advantage of providing a maximum sized flow channel with the space available.

A second group of river ban erosion protection options can be referred to as "transverse protection" where structures are placed on the river bed to modify the flow of the river and in doing so protect the bank. This could also be seen as a means of "indirect protection". This includes groynes, Iowa vanes, bendway weirs and micro-groynes. These techniques have the advantage that there are large stretches of river bank between the structures that may be landscaped and re-vegetated, so enhancing the biological connectivity between the river channel and the flood plain. In addition to this, all these techniques promote the re-establishment of wider and shallower rivers which with slower flow velocities, are generally more stable.

A range of options for bank stabilization, from hard engineered solutions through to small scale "soft" or so-called green options are presented in this section (green options including bank landscaping and re-vegetation, informal erosion control structures, the armoring of banks with erosion mats and re-vegetation, and the use of groynes with re-vegetation in the space between the groynes).

A general rule is that informal structures can be used to address small areas of low risk in lower energy rivers, but with increasing risk, flood volumes and flow velocities, increasingly harder options would need to be considered.

Identifying situations where vegetation can be used for active bank management or stabilization, and selecting appropriate species, requires understanding the ways in which banks can fail and their causes, as well as the ways in which vegetation reduces erosion and strengthens the soil (see Section 3.4). The appropriate vegetation properties can then be matched with the potential failure mode.

Chapter 10 of the Technical Guidelines (Volume 2) also provides broad guidelines around plant traits that should be considered in determining their suitability for bank stabilization.

Wherever possible, a realistic assessment of expected discharges in the river, flow heights and velocities, the erosion resistance of the various parts of the river, and the consequence of the failure of the structure and maintenance requirements should be taken into account when comparing and selecting rehabilitation options.

It should however be remembered that river bank erosion can be a natural process and before proceeding with the perceived need for rehabilitation of the eroded bank, the cause of the bank erosion should first be determined to assist in deciding whether there is a need for rehabilitation. Furthermore, it should be noted that the banks on outer bends of rivers will naturally erode in alluvial, meandering river reaches, but that this process may be artificially accelerated, or erosion on previously stable river banks initiated by, invasive vegetation diverting flows, by deposition of high sediment loads or by poorly designed structures up or downstream of the eroding bank.

If both banks are eroding, and there is evidence of erosion of the river bed, then the reader should examine options presented for the management of incising (downward eroding) streams (see Section 7.4.2). If river bank erosion is caused by river incision, then the stability of the river bed must be investigated and stabilized if necessary, otherwise it will lead to the failure of bank protection measures.

It is particularly important that ***the cause rather than the symptom of erosion must be addressed wherever possible.*** Once unnatural erosion has taken place in a river and the sediment load has been increased unnaturally, fresh erosion sites can be expected downstream as the extra sediment accelerates the meandering process, leading to bank erosion. In other words if initial erosion symptoms may direct a person to focus on a particular site, if the cause of the bank instability is due to a problem at a site upstream, then consideration must be given to resolving the upstream site first. This is however not always possible due to the risks, land-ownership and rate of erosion in question.

Rehabilitation options for addressing bank erosion are tabulated in **Table 7.2** and summarised in **Figure 7.3**, with the y axis, from top to bottom, showing options that generally represent rehabilitation towards increasingly natural conditions of the river reaches, at the top.

Table 7.2: Summary of options considered in this chapter for addressing eroding banks

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
Non-invasive intervention	Do nothing	0	None, but risk of further loss of ecosystem degradation may be high	None	Do not consider if rate of degradation is fast and/or risk of widespread impacts is high.
	Removal of invasive vegetation	+ (R4k-R15k/ ha)	Allows endemic vegetation to re-establish	None (notify authorities)	All debris should be removed from the channel and riparian area. Costs of clearing, based on 2014 SANBI data, range from R4000-R8000 per ha for Acacias and R10 000-R15 0000 per ha for large bluegums. In addition, follow up clearings (from R2000 to R4500/ha) must be budgeted for.
Indirect intervention for bank stabilization	Removal of sedimentary bars from the channel	**	Temporarily increases flow channel capacity and reduces flood heights Facilitates movement of water straight down river without being directed into the bank	NEMA DWS	Should not be considered unless source of sedimentary bar addressed (otherwise bar will form again).
	Permeable groynes	*	Structures can retard the flow velocity along a bank, promote the deposition of sediment, create a zone where revegetation of the river can take place Structures usually made of natural materials (timber poles and branches)	NEMA DWS	Should structures be washed out the poles and branches could cause a blockage in the river or at a bridge pier, and cause infrastructural damage. The layout of the structures should be planned / checked by a suitably qualified person to ensure that the structures will not direct the flow of the river into the opposite bank.

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Solid groynes	+++	Structures can retard the flow velocity along a bank, promote the deposition of sediment, create a zone where revegetation of the river can take place Structures usually made of natural materials (timber poles and branches)	NEMA DWS	The layout of the structures should be planned / checked by a suitably qualified person to ensure that the structures will not direct the flow of the river into the opposite bank.
	Iowa vanes and micro-groynes	+++	Structures reverse the helical flow of water around bends, which reduces the tendency for the band to erode faster than the rest of the canal.	NEMA DWS	The structures are experimental and untried in South Africa
Direct interventions for bank stabilization	Bank reshaping and re-vegetation	+	By reducing the soil slope and increasing the hydraulic roughness with vegetation it is possible to stabilize some river banks	NEMA DWS	Only applicable in slow flowing rivers
	Bank reshaping and erosion control mats	++	By reducing the soil slope and increasing resistance to erosion by means of a mat it is possible to stabilize some river banks	NEMA DWS	
	Bank reshaping with concrete grass-blocks	++	By reducing the soil slope and increasing resistance to erosion by means of a concrete blocks and vegetation it is possible to stabilize some river banks	NEMA DWS	

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Bank stabilization with flexible bank armouring	+++	By reducing the soil slope and increasing resistance to erosion by means of a flexible bank armouring it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with riprap	+++	By reducing the soil slope and increasing resistance to erosion by means of a heavy rock layer it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 1/7: Root wads	+	By increasing resistance to erosion by means of a stack of tree trunks it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 2/7: Green gabions (TerraMesh)	+++	By increasing resistance to erosion by means of a soil filled gabion mesh structure (Green Terramesh) it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 3/7: Interlocking concrete blocks (Loffelstein)	+++	By increasing resistance to erosion by means of interlocking concrete blocks (Loffelstein) it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 4/7: Pre-cast concrete blocks	+++	By increasing resistance to erosion by means of dry stacked precast concrete blocks it is possible to stabilize some river banks	NEMA DWS	

Rehabilitation objective	***Description of options***	***Cost***	***Ecological benefits***	***Legal authorizations***	***Technical limitations and cautions***
	Bank stabilization with retaining walls 5/7: Rock filled gabions	+++	By increasing resistance to erosion by means of rock filled gabions it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 6/7: Concrete walls	+++	By increasing resistance to erosion by means of a reinforced concrete wall it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 7/7: Used car tyres	+	By increasing resistance to erosion by means of used car tyres it is possible to stabilize some river banks	NEMA DWS	This intervention is not recommended because of the tendency for the structures to fall apart and block culverts and bridges during floods.
Canalization	Semi-canalization: Hardened base of canal	+++	Vertical erosion in a confined channel may be controlled by hardening the base of the canal. This in turn limits the height of the banks, and the tendency of the banks to erode.	NEMA DWS	
	Semi-canalization: Hardened river bank	+++	Horizontal erosion (meandering) in a confined channel may be controlled by hardening the banks of the channel.	NEMA DWS	

Rehabilitation objective	***Description of options***	***Cost***	***Ecological benefits***	***Legal authorizations***	***Technical limitations and cautions***
	Full canalization	++++	All erosion is controlled by full canalization as long as the canal section is large enough to contain any given flood. Full canalization increases the flow velocity and discharges more water through a confined space.	NEMA DWS	Sediment should not be allowed to wash into the canal. The flow capacity of the canal must be large enough to contain a reasonably expected flood. Very careful control of the slope of the canal must be exercised during construction.

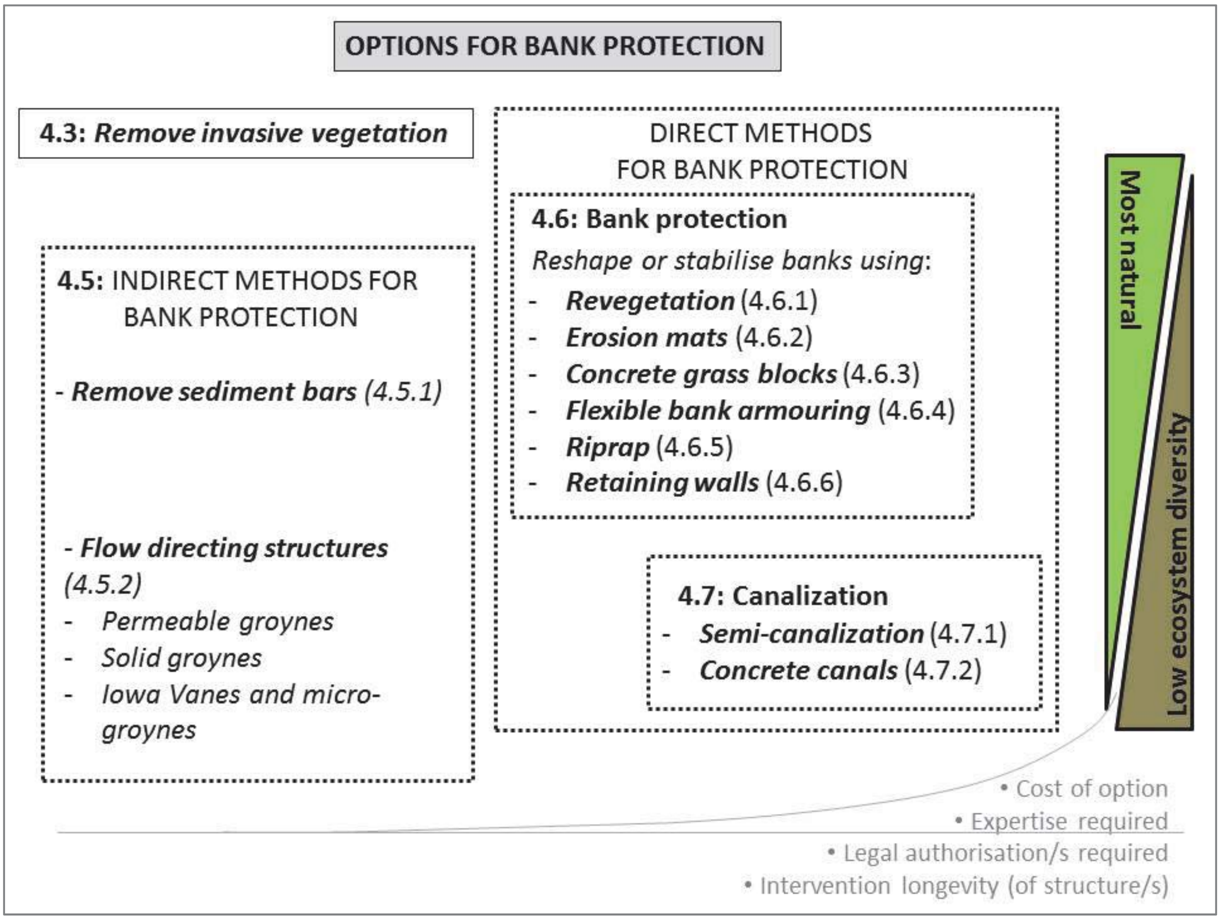

Figure 7.3: Options for addressing lateral or bank erosion in rivers. Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed

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Using vegetation for bank stablisation

Vegetation is able to stabilise bank soil through various processes. Vegetation reduces stream bank erosion above ground as shoots bend and cover the surface and reduce the velocity at the soil/water interface, whilst below ground, roots mechanically restrain or hold soil particles in place (Gray and Sotir 1996). These factors mean that vegetation can be used to address (1) bank instability arising from slumping (mass failure) or (2) direct surface erosion.

The position of vegetation up the bank also may significantly influence bank stability – ***the stabilizing effects of vegetation are maximized when placed at the bank toe/base*** (van der Wiel and Darby 2007).

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Using plants to achieve stabilization against surface (runoff) erosion

Vegetation can also provide protection against erosion on the banks. It provides a softer option than riprap for the bank zones, and is as effective for a wide range of conditions. Emergent vegetation for example provides good protection against erosion in the toe zone or permanently inundated zone of the channel through the reduction of flow velocity and bed shear stress by the stems and foliage.

Further work is however required to provide quantitative guidelines as to acceptable thresholds for the use of vegetation as opposed to harder, engineered structures in effecting stabilisation of surface erosion of both river beds and banks (refer to Chapter 12 in Volume 2 – the Technical Guidelines – for further information on utilising vegetation for river rehabilitation).

THINK GREEN

Using plants to prevent bank slumping: the contribution of plant roots to slope stability

Root growth into soils can result in a reinforced soil structure with increased soil shear strength (De Baets et al. 2008) and reduce the risk of slumping; but the roots must deeper than the failure surface (that is, extend deeper than the depth of potential slumping) to have a significant effect (Gray and Sotir 1996).

The mechanical effects of plant roots are the most beneficial in increasing bank stability as roots anchor themselves into the soil. The binding effect on the soil by the plant roots increases the soil shear strength by an additional apparent cohesion (Coppin and Richards 1990). As a general rule, plants are more effective in protecting slopes from slumping when:

1) bank slopes are flatter rather than steep;
2) plant roots high up the bank extend deep into the soil horizon (i.e. through the zone of potential slumping or failure surface);
3) plant cover protects against surface erosion and
4) where banks are low.

In the event that that vegetation alone is not considered a suitable stabilization technique against slumping, further guidance must be sought by geotechnical specialists. In such cases it may be recommended to first reduce the bank slope before vegetation would be considered a suitable riverbank stabilization technique. Alternatively, a combination of hard engineering with soft engineering may be recommended, or it may be recommended to use hard engineering alone to stabilize the bank. These decisions usually need to take cognisance of the level of risk / consequences of failure to life and / or property, as well as costs and available space

As a guideline, when bank height is 3 m or more, input from a specialist engineer should always be sought prior to implementing any stabilisation attempts.

Maximising opportunities for the use of plants in addressing bank erosion

The potential for surface erosion of a river bank depends on the nature of the soil, the gradient of the channel, the slope of the bank and the water depth. These factors therefore also determine the level of protective cover required. ***The flatter the channel gradient, the gentler the bank slope and the shallower the water depth under flood conditions, the more likely plants can be used to effect stabilisation***. Where these factors can be manipulated on site (e.g. by flattening steep river banks), vegetation may be able to achieve similar levels of erosion protection to hard structures.

Guidelines for using plants to stabilise against bank slumping

Preliminary guidelines for the use of vegetation in preventing bank slumping (mass failure) of river banks have been developed by van der Haar (2015) and are presented in Day et al. (2015). The details of this study should be consulted for additional information, but as further research is required to calibrate laboratory-based thresholds with those relating to field conditions, the data are not presented here.

7.5. Erosion: Managing river downcutting (incision)

Options for the management of river erosion at a site level fall into two broad categories. The first category is **managing eroding banks**, which is where usually only one bank, or a short section of both river banks, are eroding. This issue is addressed in **Section 7.4**. The second category of erosion involves managing sites and reaches which are **downcutting or incising**, which is when the river bed is eroding down into itself and resulting in donga or gulley formations and steep, vertical banks for extensive lengths along both banks of the river. This erosion type is also sometimes called headcut erosion, and management options are outlined in **Section 7.5.**

When addressing bed erosion protection, as with bank erosion protection, the cause of erosion must be understood before effective remedial measures can be planned. Often bed erosion takes place when a river is constricted and subjected to abnormally high flood levels and flow velocities during floods, but this must be verified, or an alternative explanation sought.

The types of intervention that address riverbed incision directly vary in decreasing environment friendliness, from re-vegetation of the river bed, to grade control structures such as block ramps or vertical drop weirs, and finally to full canalization of the river. Additional options include the concept of off-channel stormwater detention ponds, to reduce the size of flood peaks passing down the river.

Rehabilitation options for addressing river bed incision are tabulated in **Table 7.3** and summarised in **Figure 7.4**, with the y axis, from top to bottom, showing options that generally represent rehabilitation towards increasingly natural conditions of the river reaches, at the top.

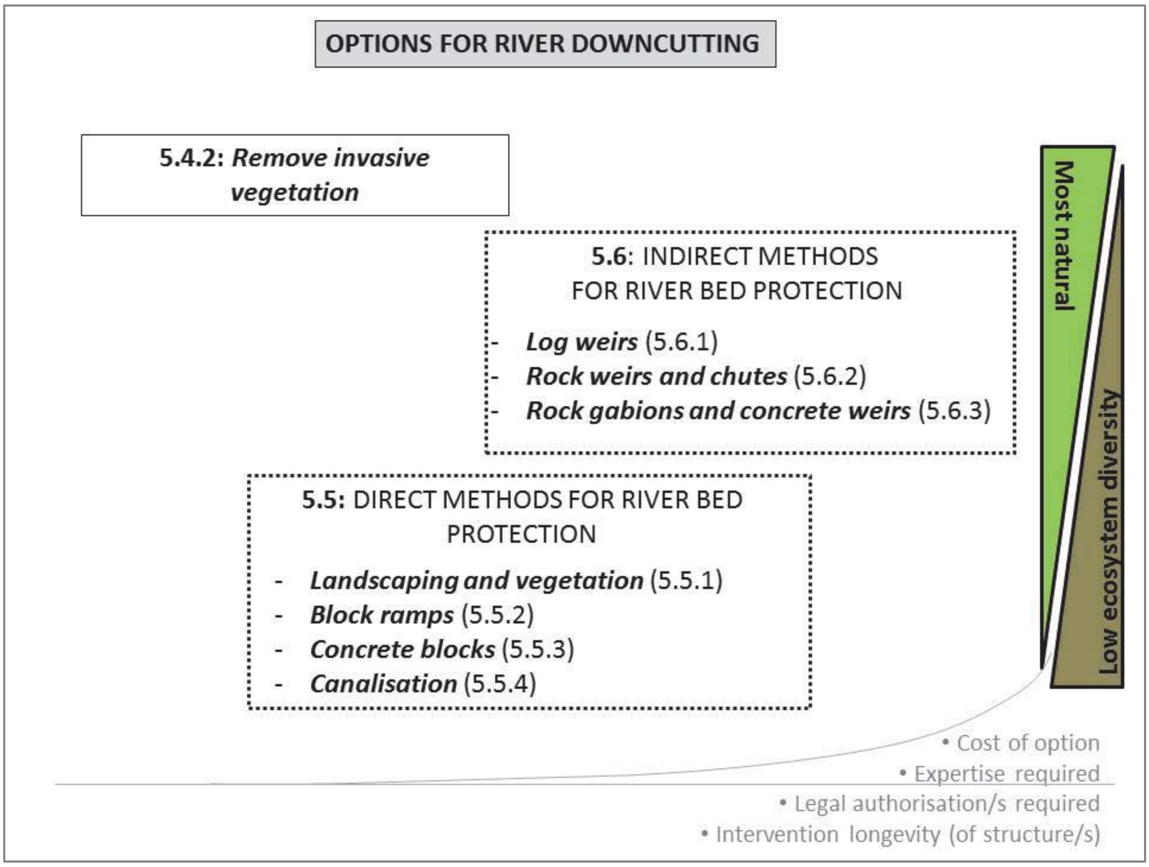

Figure 7.4: Options for addressing channel incision / downcutting in rivers. Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed.

Table 7.3: Summary of options considered in this chapter for addressing river downcutting / channel incision

Rehabilitation objective	***Description of options***	***Cost***	***Ecological benefits***	***Legal authorizations***	***Technical limitations and cautions***
Non-invasive intervention	Do nothing	0 - +++++	None, but risk of further loss of ecosystem degradation may be high	None	Do not consider if rate of degradation is fast and/or risk of widespread impacts is high.
	Removal of invasive vegetation	+ (R4k-R15k/ ha)	Allows endemic vegetation to re-establish	None (notify authorities)	All debris should be removed from the channel and riparian area. Costs of clearing, based on 2014 SANBI data, range from R4000-R8000 per ha for Acacias and R10 000-R15 0000 per ha for large bluegums. In addition, follow up clearings (from R2000 to R4500/ha) must be budgeted for.
Indirect intervention for bank stabilization	Log weirs	+	Log weirs could possibly slow flow velocity in the river and retard incision. A more significant use is for creating fish habitat.	NEMA DWS	These structures are not sustainable, and are likely to fail during floods. They are very likely to cause more harm to the ecosystem than good.
	Rock weirs and chutes	++	Rock weirs could possibly slow the flow velocity in a river and retard incision.	NEMA DWS	These structures are not sustainable, and are likely to fail during floods. If there is not proper provision for the protection of the banks adjoining the structure during floods, the bank will wash away and the structure will be outflanked. If the structure rock size is not adequate they will wash away during floods. These structures are very likely to cause more harm to the ecosystem than good.
	Rock gabion weirs	+++	Rock gabion weirs can be used as slope control weirs in rivers to stop incision. Being flexible structures they can best accommodate the foundation settlement often experienced in alluvial soils.	NEMA DWS	The wires of gabion weirs need special consideration to protect them from abrasion and corrosion. The structures are 'gravity' structures and require a lot of rock to be stable. All weirs have the problem that they are barriers to the migration of biota up and down the river.

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Concrete weirs	++++	Concrete weirs can be used as slope control weirs in rivers to stop incision. Being concrete they have the potential to be the longest lasting of construction materials.	NEMA DWS	Concrete weirs can be constructed on ‘floating foundations’ – i.e. they may be constructed on soft sediments if need be, but rock foundations are much more desirable. All weirs have the problem that they are barriers to the migration of biota up and down the river.
Direct interventions for bank stabilization	Bank and bed reshaping and re-vegetation	+		NEMA DWS	
	Block ramps	+++	Block ramps can be used as slope control structures in rivers to stop incision	NEMA DWS	The design of rock size and distribution to achieve a specific level change objective is in a developmental stage. The erosion protection of the river banks adjacent to the block ramp requires consideration.
	Concrete blocks	+++	Concrete blocks (with or without cables stringing them together) can be placed on a river bed to prevent the incision of the channel.	NEMA DWS	Hardening the river bed will interfere with sediment movement and then impact negatively on instream habitat diversity. The erosion protection of the river banks adjacent to the lined bed requires consideration.
	Full canalization	++++	All erosion is controlled by full canalization as long as the canal section is large enough to contain any given flood. Full canalization increases the flow velocity and discharges more water through a confined space.	NEMA DWS	Sediment should not be allowed to wash into the canal. The flow capacity of the canal must be large enough to contain a reasonably expected flood. Very careful control of the slope of the canal must be exercised during construction.

7.6. Managing sediment

Sediment erosion, transport and deposition are important processes that create habitat diversity in rivers. However, where sediment deposition rates are very high, the increased sediment stored in the river reach increases the chance of flooding through increased channel roughness and reduced channel depth. Excessive sediment deposition is thus sometimes perceived as a problem in some river reaches.

Assessing whether sediment removal is appropriate

In general, removal of sediment from a watercourse is not a good idea due to risks of initiating instability (incision and bank erosion) and the loss or degradation of habitat diversity associated with widespread sediment removal. However, in some cases, effective management of the watercourse and mitigation of risk for adjacent landuses is not possible without some sediment management actions. Each case must therefore be considered based on the reach-specific evidence and understanding of sediment processes for that site or reach.

For cases where the removal of sediment is found to be justified, best practice must be used to carry out the necessary work to minimise adverse effects on the environment (Environment Agency 2004).

The following situations represent scenarios where sediment removal could be justifiably considered as part of true rehabilitation or restoration actions for a river system:

- In reaches where there is excess sediment erosion upstream (such as of the catchment, or of a large upstream wetland or of extensive lengths of the river banks) and this has resulted in a perceptible higher river bed level within the river reach in question;
- At sites where there has been excess sediment deposition related to reduced conveyance – such as upstream of a bridge where culverts are insufficient to convey floods, resulting in a backup of floodwaters, reduction of velocity and increased sediment deposition upstream of the constriction;
- At sites or reaches where there has been excess sediment deposition related to increased flow resistance – such as where a reach has been invaded by invasive vegetation, causing a reduction in flood velocities and increased sediment deposition due to the reduced water speeds;
- Reaches downstream of areas which have recently been cleared of invasive vegetation may also experience enhanced sediment deposition. This is because sediment previously trapped in the invasive alien vegetation stands upstream becomes mobilised following clearing activities.

There are however, other situations where the removal of sediment may be considered by a landowner or river manager due to the risks to infrastructure, or additional erosion, which sediment deposits present. ***Removal of sedimentary bars*** (in-channel sediment deposits) is often undertaken to reduce flooding risks and prevent secondary (deflected) currents from causing erosion of the banks of the river. ***Excavation of river reaches*** is usually undertaken to reduce the risk of overbank flooding through increasing channel depth and therefore competency. The demand for sediment in construction activities can also lead to large reaches of rivers being targeted for sediment mining.

The options for addressing the management of sediment in rivers are summarized in **Table 7.4** and presented visually in **Figure 7.5**.

THINK GREEN

Bars and secondary channels are very important ecological habitats

Often the backwaters and secondary channels provide important habitats for instream biota – secondary channels are important for juvenile fish and bars provide protected resting and nesting areas from predators. The small bars and riparian vegetation slow down flood velocities, increasing flood attenuation and sediment deposition. These physical environments and their associated ecosystem services are reduced or lost during the removal of mid-channel bars and the straightening and deepening of river channels. Unless the risks are absolutely unacceptable, bars and the secondary channels which they create should as far as possible be left to remain in river systems for the benefit of instream ecology (especially fish habitats).

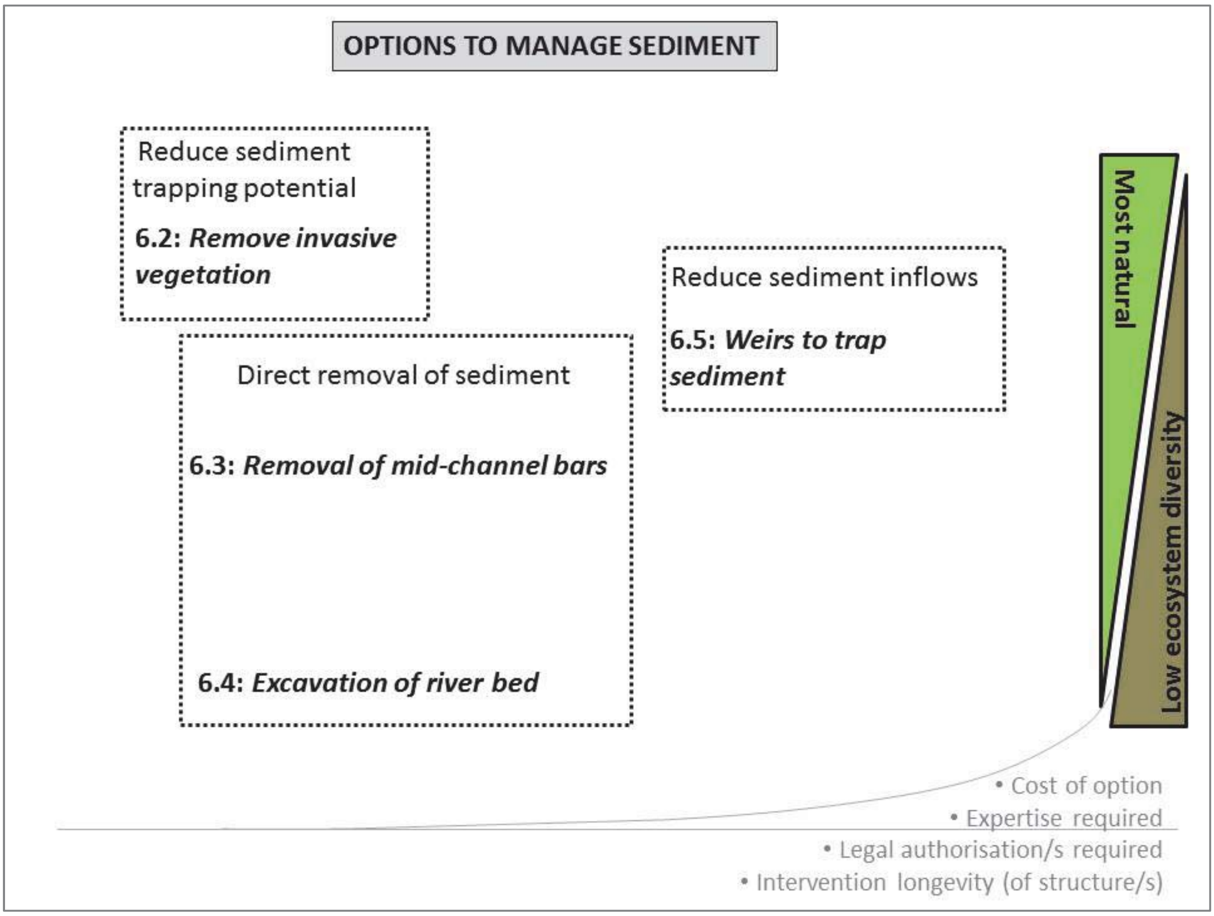

Figure 7.5: Options for managing sediment. Numbers refer to sections in Volume 2: Technical Manual, where these options are presented in detail.

Table 7.4: Summary of options considered for addressing eroding banks

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions[5]*
No intervention	**Do nothing (Vol 2, Section 6.2)**	No intervention undertaken.	0	No direct disturbance to the channel.	None	Assess impacts of increased sedimentation on smothering of habitats, increased flood risks and potential impacts downstream (if lots of sediment is being trapped in the reach).
Reduce sediment trapping potential	**Removal of invasive vegetation (Vol 2, Section 6.3)**	Invasive vegetation from the channel and riparian zone (banks and flood zone) is removed.	+ (R4k-R15k/ ha)	Can be beneficial if more natural conditions are being created – endemic vegetation permitted to re-establish. Note that sediment trapping can be reduced, but functions such as water quality improvement through nutrient trapping may also be reduced.	None unless species are protected	Some indigenous species are protected and clearing requires additional authorizations – Refer to Section 2 of the Technical Manual. All debris should be removed from the channel and riparian area. Costs of clearing, based on 2014 SANBI data, range from R4000-R8000 per ha for Acacias and R10 000-R15 0000 per ha for large bluegums. In addition, follow up clearings (from R2000 to R4500/ha) must be budgeted for.
Direct intervention to remove sediment	**Removal of mid-channel bars (Vol 2, Section 6.4)**	Small scale removal of individual sedimentary bars at sites where the bars divert flood waters in to eroding outer banks.	++	None.	NWA: Section 21 c and i; NEMA applies unless very small (<5 m^3) sediment volumes are moved.	Facilitates movement of water straight down river without being directed into the bank. This should only be contemplated for small-scale interventions (less than 100 m of river length disturbed).
	Excavation of river reaches (Vol 2, Section 6.5)		+++	None. This approach is associated with widespread bed and bank disturbance.		Widespread channel excavation may initiate channel destabilization and require regular maintenance actions. Once in place, canalised watercourses are difficult to undo, and are often associated with socio-economic ills, such as littering, poor water quality, invasion by alien

[5] Costing estimates kindly provided by Ms. Heidi Niewoudt (SANBI) are indicated primarily for comparative purposes. Site specific factors, such as access, available materials, environmental authorisations and method of construction will determine final costing. These costs based on 2014 data only.

Objective	Intervention Option	Description of approaches	Cost	Ecological benefits	Legal authorizations	Technical limitations and cautions[5]
						vegetation, poor habitat quality and reduced property values
Reduce sediment inflows	**Upstream weirs to trap sediment (Vol 2, Section 6.6)**		+++++	In reaches subject to excessive, highly unnatural, sedimentation rates, upstream weirs can reduce habitat smothering and bed aggradation.	NEMA, NWA	Dams or weirs will need to be designed by an engineer, and these must specifically allow for sediment trapping and the easy removal of accumulated sediment. This option should be considered with caution, both (1) from an environmental perspective w.r.t. dam/weir impacts and (2) due to the prohibitive costs and extensive authorisations which may limit the practicality of this option.

7.7. Removal of weirs

Dams and weirs often have very definite negative impacts on the environment and sometimes removing dams is a rehabilitation option for a river. The removal of dams can restore free-flowing river conditions, reinstate migration routes for instream biota, and restore more natural flows and sediment delivery to downstream reaches. Despite the potential benefits to be obtained through the removal of weirs, their removal or decommissioning is often a major exercise and should not be undertaken lightly as there are significant potential negative consequences, such as:

- smothering of downstream habitats through the pulsed release (and increased overall) sediment loads as accumulated sediment from upstream of the weir structure is flushed downstream;
- increased downstream flooding due to increased bed levels (aggradation from sediment influx);
- release of contaminated sediments downstream (in the cases where sediment may be trapping pollutants, such as mine tailings); and
- flushes of nutrients and anoxic conditions associated with the mobilisation of accumulated sediments in the impounded river upstream of the structure.

Due to the high risks and specialist insight required, ***qualified environmental practitioners and engineers should be consulted prior to considering the potential for the removal of dams.***

7.8. Water Quality Improvement

General overview

Water quality, particularly in urban areas can be a major limitation to effective rehabilitation, especially downstream of Waste Water Treatment Works where nutrient levels are dramatically increased. Acid mine drainage, industrial effluent, general runoff from urban and industrial areas, agricultural return flows as well as the more diffuse runoff from agricultural areas, are also sources of water quality problems. ***Efforts to improve water quality in rivers and wetlands should focus as far as possible on preventing grossly elevated nutrient levels from reaching the watercourses***. Although rivers and wetlands have some assimilative capacity to absorb and process nutrients, often the enormous volumes introduced in concentrated form at point sources (such as waste water discharge points) overwhelms the dilution capacity of the baseflow of the receiving stream and the assimilative capacity of the river ecosystem. Focused efforts at significant sources of pollution (such as waste water treatment works), effective catchment management the use of vegetated swales and buffers and sediment and litter traps in the contributing tributaries can aid in reducing nutrient loads in rivers and wetlands.

Water quality constituents of concern (see Section 3.6)

Rutherford et al. (2000) categorise water quality into six key components of ecological significance, namely

- turbidity and fine sediments at levels that restrict photosynthesis and/or clog gills and smother habitat
- nutrients at concentrations that will promote algal growth
- low dissolved oxygen
- high and low temperatures, affecting dissolved oxygen and/or metabolic rates
- salinity
- toxicants (heavy metals, oils, pesticides).

From a human health perspective, **bacteriological and pathogenic pollutants** also need to be considered, particularly in rivers where full or partial contact recreation activities take place

Biedenharn et al. (1997) note however that the rehabilitation process itself (for example, bank stabilisation activities) can also result in short-term water quality impacts to the river, and existing biota need to be able either to survive through such periods or to be re-colonised from elsewhere, in cases where biodiversity impacts are an objective of rehabilitation activities.

Steps to consider in decision-making around the need for / approach to water quality rehabilitation

The following steps should be taken in any rehabilitation project, before deciding on the need to embark on a water quality amelioration project, or the risks / costs of not doing so:

1. Characterise the river's water quality, drawing on information provided in Section 3.6 and Section 3.6 (as well as Table 8.2 of Volume 2 in the Technical Manual), as to likely indicators of particularly problematic variables (e.g. excessive algal growth, blanketing sediments, unnatural salt crusting, organic sediments);
2. If this process suggests particular water quality problems, or you have other reasons to suspect poor water quality (e.g. smells, discoloured water, dead fish or bleached plants, vigorous plant growth, presence of black, foul-smelling muds / organic sediments and in extreme circumstances, the presence of deformed aquatic organisms such as frogs and tadpoles) then collect once-off or (preferably) a series of water quality samples, and have them analysed at an approved laboratory;
3. Consider the water quality that the river of concern would be expected to display in its natural (or "reference") condition, remembering to consider what natural seasonal variability in water quality might have been expected due to wet season dilution and dry season elevated temperatures, for example. Ask an aquatic specialist or local Department of Water and Sanitation for assistance, or consult River Health Programme documents or personnel for assistance/information;
4. Compare water quality data obtained from laboratory analyses with expected reference conditions, and highlight areas of concern;
5. Identify (if possible) the source(s) of variables of concern – useful approaches could include:
    a. using GOOGLE Maps imagery to identify changes in landuse that might be linked to changes in water quality;
    b. walk upstream along the river banks, and look for pipe inlets or visible signs of changes in water quality (plumes of discoloured water, erosion, seepage from irrigated lands, leaking pipes or overflowing manholes);
6. Assess the degree to which water quality amelioration is realistically achievable, and consider the importance of doing so – consultation with a river / freshwater specialist may be useful;
7. Consider the rehabilitation options in **Table 7.5** with regard to the river reach in question.

Techniques to improve water quality that are addressed in the Technical Manual include:

- Measures to address specific variables of concern;
- Managing diffuse runoff;
- Managing point source pollution;
- Instream measures to improve water quality.

These options and key considerations in choosing the most appropriate option, if any, are summarized in **Table 7.5**.

Table 7.5: Symptoms of particular water quality problems and how to address them. This table to be read in conjunction with information in subsequent sections (information adapted from Rutherford et al. 2000). See Section 3.6 for a discussion of why these variables can be problematic.

Water quality constituent	Problem Signs	Rehabilitation approaches
Nutrients – phosphorus and nitrogen	• Excessive growths of algae in the channel, adhering to stones and even sediment in shallow water; • Establishment of alien aquatic weeds (e.g. water hyacinth) in slow flowing deeper open water areas; • Rapid rate of growth of reeds and other plants in shallow marginal areas; • Algal blooms in slow flowing / standing water – the water will appear turbid or green with algal scums in extreme cases; • Smells and/or accumulation of black organic scums on the river bed; • In extreme cases of ammonia toxicity there may be visible fish deaths – usually though, fish death are attributable to low oxygen; • Sustained extremely high levels of nitrites and (less commonly) nitrates can lead to deformities in frogs / tadpoles and affect fish and aquatic invertebrates ; • **Remember**: • There may still be nutrient enrichment downstream even if there are no signs of it at your site – particularly if it is a deep, fast flowing channel. • Certain algal species occur to some degree even in low nutrient water	- Focus on nutrient removal at source; - Trap sediments entering the river (see section below) – phosphorus often binds to inorganic sediments (e.g. fine sands and clays) and can be removed with sediment; - Remove enriched sediments from in-channel weirs in dire circumstances; - Establish vegetated filter strips along seepage or runoff zones into the channel to improve water quality; - Harvest plant material to remove nutrients bound in plants – noting that most of the nutrients are usually in root / soil / microbe zones rather than in the stems and leaves, except in the case of floating (non rooted) plants (usually aliens).
Salinity	• Very clear water, as high salts cause clay	- Very difficult to address at a site scale - Usually requires catchment-level interventions that look at landuse practice and salt

 *Sarcocornia* spp. (above) are typical salt-tolerant plants.	particles to drop out of the water column; • Presence of salt-tolerant species – e.g. *Phragmites australis* is more tolerant of brack conditions than *Typha capensis* • Visible salt crusts on the edges of channels, particularly ones with high seasonal variation in stream flow • Changes in water palatability and / or poor crop and/or livestock condition.	sources; - Preferential abstraction of freshwater inflows / tributaries may make naturally saline streams much more saline and this issue could be pursued with local authorities.
Toxicants	• These may include heavy metals, un-ionised ammonia (NH_3), oils (hydrocarbons), herbicides and pesticides	- Heavy metals may be bound to sediments (but not all forms) and thus river beds, reedbeds and river sediments in contaminated watercourses should be handled with care as disturbance of the beds, banks, wetlands and sediment sorted in weirs can potentially remobilise otherwise stable contaminants; - Hydrocarbons should be separated out at source, using bunding and oil/ grease traps where possible; - Aeration may be effective where ammonia concentrations are elevated – this is most likely where pH > 8 (DWAF 1996) as the proportion of potentially toxic NH_3 : non-toxic NH_4^+ increases significantly as pH increases above 8.
Turbidity and fine sediments	• Most river systems have some fine material (silt, mud) included in their habitats. However, if silts or muds blanket the stream bed, completely fill in the spaces between cobbles and gravels, or smother plants it is likely that turbidity and/or fine sediments are a problem in the river reach. Suspended sediments can also be visually recognized to some degree, as a cloudy or murky layer, although depth does influence perception and such assessments are not accurate. • Remember that the volume of suspended sediments can vary enormously,	- Addressing sources of turbidity / fine sediment (usually erosion) – this usually requires catchment level interventions and is beyond the scope of this manual, but in small catchments, or high up in the catchment, this may be more feasible. A survey of the river in conditions of high flow and low flow may be useful to identify sources of sediment, using water turbidity as a guide, and noting that at times, single road crossings or runoff from un-contoured agricultural areas may be the main cause of turbidity. In such cases, remedial action would include provision of vegetated buffer strips; - Sediment trapping upslope of the river / stream, using devices such as buffer strips and sediment traps, noting that sediment traps are less effective for fine sediments (especially clays) and other approaches (e.g. dams, detention ponds and vegetated buffer strips) may be more useful for addressing suspended clays; - Sediment trapping within the stream – such approaches may include vegetation of eroded channels; widening of artificially narrowed channels to accommodate shallower

	depending on flow velocity and volume. Also – too little sediment can be as bad as too much, leading to channel. • You need to be able to distinguish between high-flow and low-flow sources of turbidity.	flows at lower velocities conducive to sedimentation; encouraging the growth of reeds in channels to trap fine sediment, construction of sediment dams or traps. Of these, the latter would not usually be recommended instream, but would be useful in addressing sediment in inflows.
Low dissolved oxygen	- In severe cases, fish gulping at the water surface or fish deaths may occur; • Signs of nutrient enrichment (see above) particularly black muds in shallow, warm water; • Inflows of known nutrient enrichment in warm conditions – e.g. downstream of waste water inflows;	- Ideally, address at source; - Create instream structures (e.g. low weirs) to aerate water (see Liesbeek Canal case study); - Plant the riparian zone to create shaded, cooler areas; - Design inflows of polluted water for maximum aeration – e.g. channel over rock-lined open channel, rather than piping).
Temperature	• High temperatures: • -Shallow, unshaded waters in areas with high air temperatures may be prone to overheating at times. - Effluent inflows may have high temperatures. • Low temperatures – Often from deepwater discharges from large dams. • **Note** • High temperatures may occur only during short periods of the day, but may result in oxygen reaching critically low thresholds	- Address warm effluent inflows at source, or by extending time to discharge; - Plant the riparian zone to create shaded, cooler areas – usually using indigenous species; - Where a significant problem, dam design may need to be considered – this is only likely to be feasible if dam undergoing upgrading / structural maintenance.
Acid mine drainage		- Ideally treat through a centralised treatment facility whereby the mine water levels are maintained below the point/s of decant. - Treatment at the points of decant is the next best option, but probably more expensive and difficult to manage due to more numerous and potentially unpredictable localities of decant points; - All of these options require specialist technical input.

7.9. Rehabilitation and flow regime

It has long been recognised that river flow is the defining element of river habitats and that this gives rise to the patterns and processes commonly associated with fluvial environments. Indeed, river flow is so strongly correlated with the physical (geomorphological), chemical and biological processes in rivers that it is considered the 'master variable' (Power et al. 1995, Resh et al. 1988, Poff et al. 1997). Not surprisingly, therefore, a crucial component of river condition is the extent to which its natural flow regime is maintained. Indeed, USDIBR (2006) comments on the importance of instituting natural flows and sediment processes in effecting real river rehabilitation while Tourbier et al. (2004) stress that the setting of rehabilitation objectives must take into account what is realistically achievable in light of existing flow regimes in the system

Although the setting of adequate flow regimes for rehabilitated rivers is beyond the scope of this Manual, it is essential that all rehabilitation projects are undertaken with a full understanding of the extent to which the natural flow regime has been altered in any river undergoing rehabilitation, and the implications of such changes for:

- Riverine fauna and flora
- Short- and long term disturbance processes, and associated river "maintenance" functions (e.g. flushing, scouring, channel formation)
- River morphology
- Riparian quality and function
- Water quality.
- Options for addressing flow regime changes are not addressed in the Rehabilitation Manual, other than indirectly in terms of the removal of alien plants, and the removal of dams where appropriate. Flow regime changes require the reallocation of scare water resources and are therefore difficult, and often economically unfeasible, to implement.

7.10. Improving riverine habitat quality and biodiversity

USDIBR (2006) stress the importance of rehabilitation planning and design that overtly considers the habitat requirements and biological interactions of the riverine biota that would be desired in a rehabilitated river system, noting that the statement "if you build it, they will come" can be applied to channel restoration efforts. They continue, observing that the physical conditions constructed are the invitation to colonization by the biologic communities associated with that niche. If the desired conditions are not correctly diagnosed and replicated, biological communities can also disappear at a rapid rate. Thus it is important to consider the target communities or species in the project area and determine how physical features can be optimized to promote desirable habitat. Consideration should also be given to issues of competition between species. For example, backwater habitats may be of more benefit to some fish species than others, and the establishments of backwater habitats may help some species to the ultimate detriment of others. Holmes et al. (2008) note however that in some severely degraded systems, colonisation of the full natural species complement required may be unlikely without active intervention and the introduction of target flora and/ or fauna, with faunal introductions usually centering on larger taxa (fish, birds, medium to large mammals).

Chapter 10 of the Technical Manual provides a number of options that have the primary objective of increasing instream and/or riparian and floodplain habitat diversity. They should be read in the context of the more general information around assessing river condition and rehabilitation opportunities and constraints on the site / river reach that you are working on (see Section 5, this volume), bearing in mind that in most cases, rehabilitation towards a more natural condition should be the preferred option. In some cases, however, the extent of permanent, often catchment-level changes to river functioning and condition mean, however, that such an approach may not be feasible, and interventions around improving river condition would rather be considered remedial activities, that largely ignore natural condition.

It should be remembered, moreover, that efforts to improve biodiversity by addressing physical habitat types at the level of a site or reach will not succeed if the river is affected by over-arching problems of water quality, water quantity and flow regime, erosion or sedimentation.

USDA (2001) further comment that although it is often much easier to implement individual in-channel structures, aimed at increasing a single component of habitat diversity, an "ecosystem restoration" or "ecosystem management" approach that focuses design resources on the chemical, hydrologic, and geomorphic functions of the stream corridor are more likely to achieve real rehabilitation or restoration objectives. Such an approach assumes that communities will recover to a sustainable level if the stream corridor structure and functions are adequate. It is important that, before embarking on any structural interventions aimed primarily at increasing habitat diversity, the degree to which they actually address real problems and are appropriate to the affected river reach should be considered, paying particular attention to the following issues (after USDA 2001):

- Structures should never be viewed as a substitute for good riparian and upland management;
- Defining the ecological purpose of a structure and site selection is as important as construction technique;
- Scour and deposition are natural stream processes necessary to create fish habitat. Overstabilisation therefore limits habitat potential, whereas properly designed and sited structures can speed ecological recovery;
- Use of native materials (stone and wood) is strongly encouraged;
- Periodic maintenance of structures will be necessary and must be incorporated into project planning.

The most important factors that usually determine the usefulness / relevance of each potential intervention to a particular site / project comprise, in order:

- Availability of space – apart from water quality improvement options, the most effective rehabilitation interventions usually require space along the river corridor;
- Cost;
- Attitude of local communities and local authorities – the socio-economic background of each proposed rehabilitation is critically important in determining the degree to which different interventions are likely to be appropriate, desirable or sustainable (see Section 10-14).

Taking cognisance of these factors, the interventions and approaches for general aquatic habitat improvement that are included in this chapter have been critically summarised / rated in Table 7.6, with comments on desirability, usefulness, applicability, maintenance requirements, sustainability and cost, bearing in mind that, unlike other chapters in the manual, all of the options included in this chapter have ecological merit. Figure 7.6 provides a conceptual summary of these options.

Table 7.6: Descriptions of interventions and approaches used to improve habitat quality and biodiversity (note: cost estimates are relative only and likely to vary widely on a scale- and site-specific basis).

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
1. Do nothing option	No gains – may waste opportunities	None	None – unless wasted funding opportunity	Consider this option if ecological gains from interventions minor compared to costs / effort
2. **Increasing habitat diversity in unlined, but channelised rivers**				
2.1 Removal of alien vegetation	Positive if carried out properly	None – notify authorities	+ (R4k-R15k/ ha)	Long-term maintenance usually required; Stabilisation of cleared areas necessary
2.2 Management of invasive indigenous vegetation	Management often symptomatic and usually needs to be ongoing – ensure that natural function is not being destroyed by process	NEMBA; NEMA, NWA	+	Make sure that implications of removal are clearly understood
2.3 Reshaping and planting of banks *with guidelines around the selection of plants for these purposes*	Good ecological option	NEMA (if > 5 m^3) NWA (21c and i)	+ - ++	Check that infrastructure not threatened
2.4 Creating riffle/pool sequences	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i)	+ - +++	May have low real ecological impact and will probably require ongoing replacement; check water quality impacts do not negate habitat diversity impacts
2.5 Other interventions				
Creating pools	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i)	+	
Creating instream rock and boulder habitat			+=++	
Rehabilitating or recreating meanders	Usually good ecological option		+-++++	Needs land and high levels of technical input
2.6 Creating artificial valley bottom wetlands	May provide useful ecosystem function and amenity value n otherwise sterile usually urban landscape		+-+++	Needs land and high levels of technical input

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
3. **Increasing habitat diversity in lined canals**				
3.1 Adding hydraulic diversity and providing instream cover	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+-++	Hydraulic implications must be checked
3.2 Creation of planting ledges in canals				
Retro-fitting canals with planted gabions	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	++	Hydraulic implications must be checked
Retrofitting canals with ledges stabilised with airblock, brick or retaining block walls			+-++	
Use of bagwork and pilings			++	
Use of floating vegetated islands	**Not recommended for rivers**		+	
3.3 Canal removal and/or daylighting of piped river flows				
Partial canal removal **–** *Diversion of canalized low flows*	Recommended where possible; full or partial canal removal preferred	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+++	Hydraulic implications must be checked
Partial canal removal – removal of canal base and / or walls and the establishment of plants and rock substrate	Excellent approach where technically feasible and where water quality not major issue		+++	Hydraulic implications must be checked; Water quality issues may over-ride benefits of habitat creation; Should be reconsidered when through area with poor servicing and high levels of poverty
4. **Improving floodplain and off-channel habitat function and diversity**				
4.1 Retain existing floodplain areas	Best approach	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+ (but lost development costs)	
4.2 Breaching levees	May provide limited opportunities for habitat creation and (importantly) prevents the need for erosion control structures in alternative confined channel		+	Hydraulic implications must be checked
4.3 Channel excavation to reconnect existing relict	Better option than 4.2 in terms of		+++	Hydraulic implications must be

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
floodplains	habitat improvement as provides active habitat reconnection			checked; May provide useful urban stormwater attenuation and filtration options
4.4 Creating off-channel wetlands	Localised ecological value – may be important nodes in highly urbanized area		++	Hydraulic implications must be checked; Desirability of receipt of river flood water to be checked (in terms of quality and quantity / timing)
5. **Improving habitat quality in existing erosion control structures**				
Facilitating plant establishment	Best option in case where use of stabilising structures unavoidable	No additional, if approvals for structures already in place	+	Need for structures to be carefully motivated by engineers; Allowance for planting essential, unless size of structure small in relation to area rehabilitated (e.g. there is no need to plant a stabilizing weir)
6. **Removal of weirs to rehabilitate aquatic habitat**				
	May provide opportunities to redress past impacts of impoundment, sediment trapping and erosion – but should be carefully motivated and real ecosystem benefits should not be exaggerated	NEMA (if > 5 m^3) NWA (21c and i)	++-++++	Hydraulic and geomorphological implications must be checked; Effects on indigenous fish populations to be checked
7. **Design and management of riparian buffer areas**				
	Critically important aspect of river management and ensuring rehabilitation outcomes are sustainable	NEMA if excavations within 32 m of river bank outside of urban areas	+-++ (land costs)	Must be implemented and managed in the long term

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
8. **Managing alien fish species**				
8.1 Preventing alien fish introductions	Preferred ecological approach	Required in terms of NEMBA	+	Requires long-term education and consistent management / auditing / control effort
Managing aquaculture facilities	Important to prevent introductions where catchment not invaded already			
Protecting barriers to movement	Important where indigenous fish populations remain			
Education and Policing	Important and should be ongoing			
8.2 Alien fish eradication			+++	
Piscicides	Effective – but targets all gill-breathing fauna; highly specialist application	NEMBA; NWA; notify authorities	+-+++	Full ecological assessment and motivation required with input from multiple stakeholders including anglers, conservation authorities and river ecologists
Manual clearing	Less effective but reduced indirect effects		+-+	
9. **Managing other alien fauna**				
	Prevention is referred approach Conservative attitude required	Required in terms of NEMBA	+-++++	Requires long-term education and consistent management / auditing / control effort

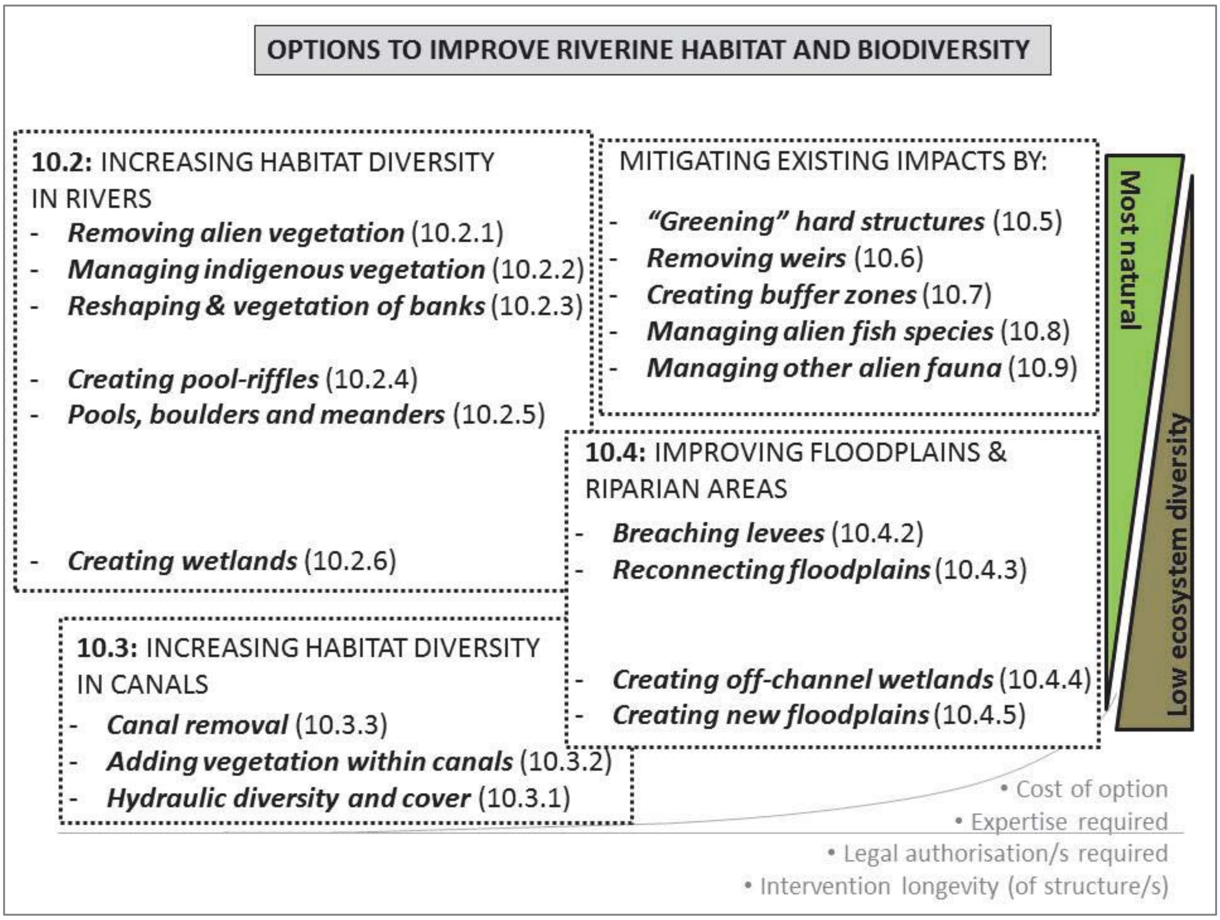

Figure 7.6: Options for improving habitat quality and diversity. Numbers refer to sections in Volume 2: Technical Manual, where these options are discussed

7.11. Managing rivers for indigenous fish

The freshwater fishes of South Africa

South Africa has at least 108 species of primary freshwater fishes inhabiting its inland waters, comprising 91 indigenous species and 17 established alien species (Skelton 2001). More than a third (33 of the 91) of the indigenous fish species is endemic to South Africa (Skelton 2001). Ongoing genetic and morphological work indicates a higher fish diversity than currently recognised, with several species recently being described, including the giant redfin *Pseudobarbus skeltoni* from the Breede River System (Chakona and Swartz 2013). Over 30 taxa are regarded as threatened, more than half of which are listed as Critically Endangered or Endangered (IUCN Red Data website). Most endemic and threatened fish species are found in the Cape Fold Mountain (Fynbos) aquatic eco-region (Tweddle et al*.* 2009).

Freshwater fishes are an integral part of most aquatic ecosystems and associated food-webs, and comprise a substantial component of the vertebrate biomass of such systems. Removal or reduction of fish biomass has knock-on effects that negatively affect other components of the ecosystem.

Fish are of great value to South African society, through recreational, competitive and subsistence angling (McCafferty et al*.* 2012). Recreational angling for freshwater fishes is of major economic significance and the value of fish to our poorer sections of society, especially in rural areas, cannot be over emphasized (Ellender et al*.* 2009).

Different species of fish, and different life history stages of fish, use a wide range of habitat in rivers, and their relative importance in any river rehabilitation intervention will depend on the species occurring in the river reaches under consideration. Adequate knowledge of the depth, substratum, river gradient, velocity and vegetation requirements of the species is essential (Welcomme 2001).

Ecological guilds are classification systems that group species according to their morphological, physiological, behavioural and life history adaptations and an ecological guild classification system has been devised (Welcome et al. 2006) specifically with environmental flow restoration and river rehabilitation in mind.

Major threats to fishes

South Africa fishes are increasingly threatened by a "cocktail" of threats, i.e. a combination of threats working together that reduce the population size and distribution range of the species under consideration (Bruton 1986). The numbers of threatened species has unfortunately increased substantially since 1978 when the first Red Data Book for fishes was produced.

Threats to these fishes can be divided into three groups – physical, chemical and biological. The significant physical threats include water abstraction, dams and weir construction, and sedimentation. Chemical threats include point source (e.g. malfunctioning waste water treatment works, mineral acid drainage) and non-point source pollutants (e.g. pesticides and fertilisers from agriculture). These are all increasing in severity in South Africa, culminating in polluted urban rivers (e.g. Hennops and Mzinduzi) and dams, the latter often with unsightly and hazardous algal blooms (e.g. Hartbeespoort Dam). Elevated pollution has led to fish kills and increased rates of parasite infestation on fishes (Grant et al*.* 2014), and the disappearance of pollution sensitive species from affected rivers (Allanson et al*.* 1990). Biological threats include invasive fishes, invasive plants and fish parasites. The negative impacts of invasive fishes, especially black bass and trout, are most severely felt in the Cape Fold eco-region with its high concentration of small endemic fishes (Tweddle et al*.* 2009). Carp are found in most rivers and public dams and can have severe impacts on water quality when abundant (Roberts and Tilzey 1997). In polluted waters, fish often suffer from more serious parasite loads, which can have lethal and sub-lethal impacts (Grant et al*.* 2014), with new diseases such as Epizootic Ulcerative Syndrome (EUS), causing large fish kills in rivers and dams in southern Africa (Huchzermeyer and van der Waal 2012). The negative impacts of invasive plants in riparian zones must also not be ignored – these can have serious impact on small rivers, especially on reducing their dry season base-flows (see Section 3.2 of this Volume).

River rehabilitation for fish

Indigenous fish require ecologically healthy rivers to thrive – rivers that are in a good to excellent River Health status. The smaller endemic Cape species require ecological healthy rivers where alien fish are absent. All river rehabilitation actions that are soundly planned and implemented should be of benefit to fish, because of the way aquatic ecosystems work. However, sometimes the focus of the river rehabilitation exercise is on fish, and mitigating the threats to fish. Technical approaches for rehabilitating rivers for fish are dealt with in the fish section of the Technical Manual.

In consideration of the major threats to indigenous fishes, rehabilitation from a national perspective should focus on the fish “sanctuaries” that are also national Freshwater Ecosystem Priority Areas (Nel et al. 2011). However, many rehabilitation actions will take place outside of fish “sanctuaries” in areas where fish are present, and it is important that such actions include consideration of the fish community present.

Using successful fish rehabilitation approaches in Australia as a guide, the approach to fish rehabilitation projects outlined in **Figure 7.7** is recommended. This approach focusses on a variety of actions and objectives that can lead to river rehabilitation.

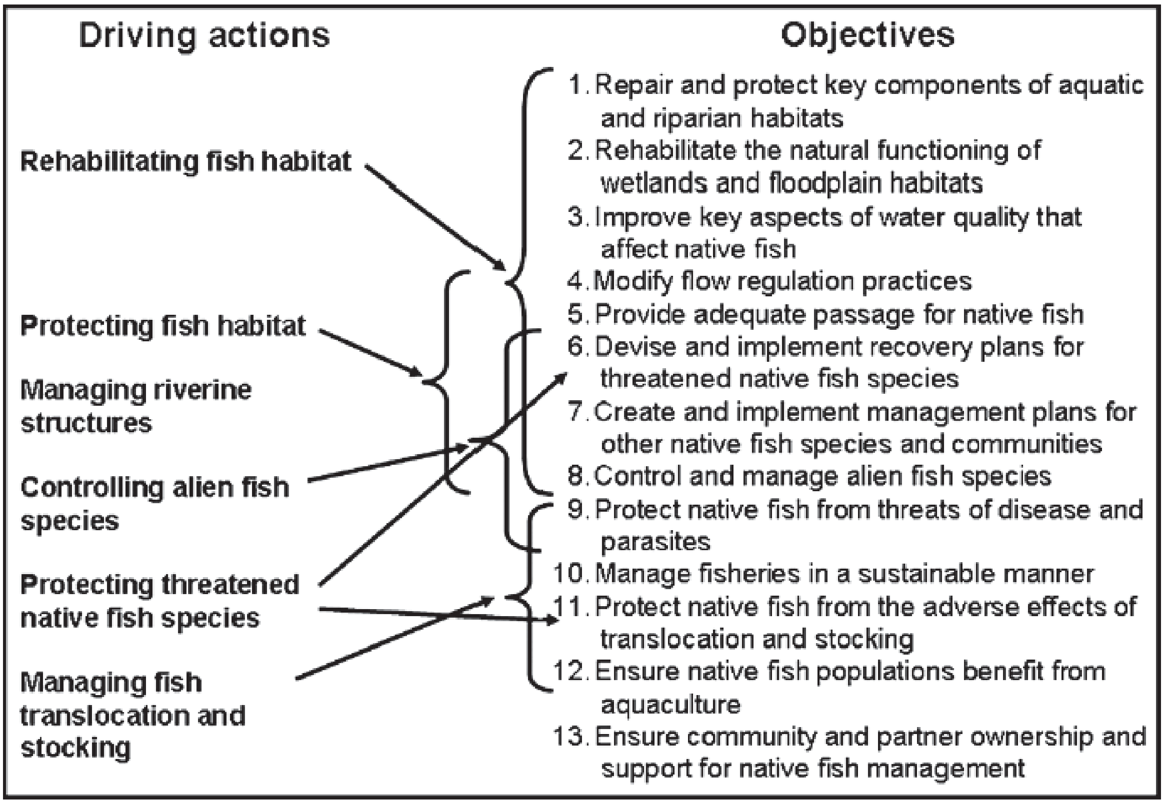

Figure 7.7: Thirteen key objectives and 6 actions identified for the recovery of fish populations in Australia’s Murray-Darling River Basin (Koehn and Lintermans 2012).

The focus of instream habitat rehabilitation is on ensuring that fish have good habitat quantity and quality for all indigenous fish species present and for all life history stages. This requires the input of fish ecologists who have good knowledge of the species present and their biology and ecology. Good habitat requires adequate pool and riffle depth, cover for fish (rocks, logs, aquatic macrophytes), maintenance of fish migration to enable successful spawning and recruitment, and ensuring suitable water quality. Fish passage facilities should be considered a key component of any rehabilitation project designed to restore fish populations on rivers where instream barriers are present, since many freshwater fishes depend on movement between different habitats in river systems to complete all phases of their life cycle. Fishways are structures incorporated, or added, to an instream barrier (weir or dam), so as to allow the upstream migration of fish. Fishways are usually very expensive to construct and thus need the input of appropriate specialists, including engineers, before being designed or built. A protocol and scoring scheme has been developed in South Africa for assessing the need for providing a fishway at an instream barrier (Bok et al. 2007).

The principals of riparian habitat restoration are dealt with elsewhere in this document. It should be stressed though that in terms of fish populations, the presence of healthy indigenous aquatic and emergent vegetation in and alongside rivers is very important for ameliorating water quality impacts, reducing sediment loads, as habitat for fish, as well as for maintaining the quality of instream habitat.

Invasive alien fishes are a serious threat to indigenous fishes, especially in the Cape Fold Ecoregions, and can also be a major problem to water quality (e.g. carp). Generally, it is not possible to eradicate an invasive fish from a whole river system because of the complexity of the task. However, they can be successfully eradicated from parts of rivers (usually between two barriers e.g. waterfall and weir) as well as dams using piscicides. This has been confirmed through many successful projects in the USA, England, Norway and Australia (Lintermans 2000, Finlayson et al. 2005, Britton and Brazier 2006), as well as the recent Rondegat River project in the Cederberg undertaken by CapeNature and partners (Impson et al. 2014, Weyl et al. 2014). Piscicide projects can be challenging and are frequently controversial (Finlayson et al. 2009, Marr et al. 2012), because the piscicide not only kills fish but can have impacts on non-target fauna such as aquatic insects (Vinson et al. 2010, Woodford et al. 2013). Two piscicides are commonly used – rotenone and anti-mycin. They are naturally occurring chemicals, with the bulk of projects having used rotenone because it is readily available and effective under a wider range of conditions. Piscicide projects must be well planned and carefully implemented to maximise benefits and minimise risks. There are comprehensive American manuals to guide the effective use of both rotenone (Finlayson et al. 2010) and anti-mycin (Moore et al. 2008). Key components of a piscicide project are explained in more detail in the Technical Manual

It is sometimes essential to re-introduce indigenous fishes to a river area for a variety of reasons. There may be loss of the species in the affected area because of alien fish impacts or pollution or loss of habitat (e.g. excessive abstraction, extensive bulldozing). Alternatively, the species may have been reduced to a very low density, and may need augmentation to overcome genetic constraints that can affect small populations. Before re-introduction can be considered, the threat which caused the fish to disappear must be reduced and preferably removed, and legal considerations (e.g. permits to stock fish need to be addressed.

The IUCN has developed very useful guidelines (IUCN 2012), explained in more detail in the Technical Manual, to assist organisations wanting to re-introduce indigenous fish species into inland waters, and these should be consulted and used before any re-introduction is considered. Obviously, stocking or introduction of alien species into rivers needs very careful consideration. No alien fish may be introduced into any rivers without a permit from the Department of Natural Resource Management Programmes of DEA. The proposed introduction of any alien fish into a river where it does not occur requires the proponent to undertake a Risk Assessment to motivate for the introduction.

7.12. Vegetation establishment for river rehabilitation

The appropriate establishment of plants as a means of improving habitat diversity, providing specific habitat types for species of concern, managing issues such as water temperature and shading and, in particular, for addressing issues of bank and bed erosion is a critical part of most river rehabilitated projects. Virtually all of the previous chapters of this manual have referred to the need to undertake replanting as part of meeting overall rehabilitation objectives. This chapter provides guidance and specifications for the actual planting process, and should be read in conjunction with whichever other chapters address particular sources of river degradation.

Chapter 11 of the Rehabilitation Manual has been structured to guide readers through planning of the planting process, to implementation and maintenance activities.

The following phases are addressed and illustrated in the chapter:

- Planning Phase, with guidelines on the following:
    - Develop a Project Brief:
    - Finalise the Project Concept
    - Identification of climatic region and planting season
    - Plant species selection
    - Programming
    - Choosing plant density
    - Plant material – size and source
    - Paths
        - Pathway alignment
        - Pathway widths
        - Pathway materials
    - Lighting
- Implementing Phase, , with guidelines on the following:
    - Excavating the plant hole
    - Soil preparation – including (imported) topsoil, compost, fertilisers
    - Planting the plants into the prepared hole
    - Planting in artificial structures
    - Irrigation
- Establishment and Maintenance phases.

The chapter also provides listings of typical indigenous plants associated with rivers in different provinces of South Africa, and

7.13. River rehabilitation and society

This chapter provides brief recommendations around the following important issues:

- Social and security considerations in river rehabilitation projects
- Effects of river rehabilitation on human health
- The need for effective resource prioritisation.

8 LEGAL AUTHORISATIONS NECESSARY FOR RIVER REHABILITATION

There is a plethora of legislation and authorisations which are potentially applicable to individuals or organisations wishing to undertake river rehabilitation initiatives (see Appendix 1 and Braid 2014). The two most important and overarching pieces of legislation are the National Environmental Management Act (NEMA) and the National Water Act (NWA).

Appendix 1 provides a detailed overview of the aspects of existing legislation which are applicable in terms of river and wetland rehabilitation activities. At all times, it is recommended that the

1) ***Relevant provincial Department of Environmental Affairs, and***
2) ***Regional Department of Water and Sanitation or relevant Catchment Management Agency***

be contacted prior to undertaking any rehabilitation activities in order to confirm that the most up to date NEMA and NWA requirements and authorisation processes are adhered to.

8.1. NEMA

Of most importance for any activities within and around rivers and watercourses is the awareness of Activity 19 of NEMA (as updated in Government Gazette No 38282 (4 December 2014). Activity 19 relates to

"*The infilling or depositing of any material of more than 5 cubic metres into, or the dredging, excavation, removal or moving of soil, sand, shells, shell grit, pebbles or rock of more than 5 cubic metres from-*

(i) a watercourse;
(ii) the seashore; or
(iii) the littoral active zone, an estuary or a distance of 100 metres inland of the high-water mark of the sea or an estuary, whichever distance is the greater but excluding where such infilling, depositing, dredging, excavation, removal or moving-
(a) will occur behind a development setback;
(b) is for maintenance purposes undertaken in accordance with a maintenance management plan; or
(c) falls within the ambit of activity 21 in this Notice, in which case that activity applies."

Whenever this activity is triggered, a Basic Assessment must be undertaken and authorisation for the activity obtained from the relevant provincial Environmental Affairs Department prior to undertaking the activity.

8.2. National Water Act- Water Use Authorisation

Activities that modify the beds or banks of a watercourse, or which divert flow in a watercourse, normally required a Section 21 Water Use Licence from the Department of Water Affairs in terms of the National Water Act (NWA).

Section 390 of the NWA offers relief from having to apply for a water license in the form of a General Authorisation (GA) (Government Notice 1199 of 18-12-2009) if it can be demonstrated that the activities:

- will not have significant environmental impacts;
- are > 500 m from a wetland;
- will have no detrimental effect on biota; and that
- that adequate provision has been made for environmental management and rehabilitation.

At present this GA does not apply to any activities within 500 metres of wetlands (see FEPA layer for an indication of possible wetlands in your area). A Water Use License Application (WULA) is required for activities which are not eligible for the GA. The landowner should contact the regional Dept. of Water Affairs and Sanitation prior to commencement of works to clarify the application process.

Contact details for the national and provincial DEA and DWS offices

Office	DEA	DWS
National	+27 86 111 2468 callcentre@environment.gov.za	012 336 7500 0800 200 200 https://www.dwa.gov.za/contactus/
KwaZulu-Natal Province	Department of Agriculture, Environmental Affairs and Rural Development http://www.kzndae.gov.za/	Tel: (031) 336 2862
Limpopo Province	Department of Economic Development, Environment & Tourism http://www.ledet.gov.za/	Tel: (015) 290 1215 Private Bag X6101 Kimberley, 8300
Mpumalanga Province	Department of Economic Development, Environment and Tourism http://www.mpumalanga.gov.za/dedt/	Tel: (013) 759 7310 Private Bag X11259 Nelspruit, 1200
Northern Cape Province	Department of Environmental Affairs and Nature Conservation http://denc.ncpg.gov.za/	Tel: (053) 830 8803
North West Province	Department of Economic Development, Environment, Conservation and Tourism http://www.nwpg.gov.za/Agriculture/	Tel: (018) 387 9547 Private Bag X5 Mmabatho, 2735
Eastern Cape Province	Department of Economic Development and Environmental Affairs http://www.dedea.gov.za/	Tel: (043) 604 5406 Private Bag X7485 King William's Town, 5600
Western Cape Province	Department of Environmental Affairs and Development Planning https://www.westerncape.gov.za/dept/eadp	Tel: (021) 941 6000 Private Bag X16 Sanlamhof, 7532
Gauteng Province	Gauteng Department of Agriculture and Rural Development http://www.gdard.gpg.gov.za/	Tel: (012) 336 8065/392 1301 Private Bag X995 Pretoria, 0001
Free State Province	Department of Economic Development, Tourism and Environmental Affairs http://www.edtea.fs.gov.za/	Tel: (051) 405 9281 Po Box 528 Bloemfontein, 9300

9 CONSIDERATIONS FOR REGIONAL AND NATIONAL REHABILITATION INITIATIVES

In terms of national and regional rehabilitation programmes, aside from identifying systems in need of rehabilitation, a key aspect of rehabilitation planning is the protection of those systems that are still in good condition (Rutherford, et al. 2000). This important principle – ***conserving what is still in good condition before trying to fix what has deteriorated*** – is often overlooked in rehabilitation exercises, but should form a key component of any rehabilitation strategy (National Ocean Service and National Marine Fisheries Service 2002).

The South African National Working for Wetlands Programme published several documents and guidelines providing guidance for rehabilitation planning, and much of this information (see **Box 9.1**) can be applied in the river rehabilitation context.

Box 9.1: Guidelines for identifying sites for rehabilitation:

- Focus on sites that are rare or represent rare types;
- Focus on sites that are in good condition before those that are in poor condition;
- Focus on deteriorating before stable or improving reaches;
- Focus on problems that are easiest to fix;
- Focus on those sites that will generate a guaranteed immediate positive benefit before those that have potentially longer-term, but less certain, positive benefits;
- Focus on those problems or sites perceived to be important by local communities and stakeholders before those not perceived to be important;
- Recognise lost causes for what they are, and focus effort problems and sites where there is more chance of success; and
- Focus on those problems known to have tried and tested remedies;
- Incorporate a broader(catchment or sub-catchment) level assessment to identify any causes that may be outside of the river channel/floodplain itself;
- Consider the recovery potential; and
- Consider the willingness and capacity for local people and local structures to become involved and address the causes of degradations.

(adapted from Rountree et al. 2007)

10 OBSTACLES TO THE REHABILITATION OF RIVERS

That river rehabilitation is not undertaken more widely can be partly attributed to the lack of readily available technical information and guidelines for undertaking rehabilitation activities, and this manual hopes to address some of that information gap. However, there are several other, probably more critical, reasons for the relatively limited extent of river rehabilitation in South Africa. In this chapter, the authors have highlighted some of the limitations that prevent or inhibit landowners and other organisations from undertaking more river rehabilitation. The key obstacles which prevent river rehabilitation activities are outlined in the sections below.

10.1. Onerous legislation and authorisation processes

There is a plethora of Acts which can potentially be triggered when undertaking river rehabilitation activities (see Appendix 1). Proponents of river rehabilitation activities need to be to be aware and comply with the potential multitude of applicable pieces of legislation, and the actual process of applying for authorisation can be slow and expensive as sometimes a large number of specialist studies and assessments need to be undertaken to support the application. The onerous legislation and authorisation processes are a hindrance and huge deterrent to undertaking rehabilitation.

In addition, the *interpretation* of the legislation is sometimes inconsistent within the various branches of the authorising agencies and therefore it is not always possible to obtain consistent opinion from the relevant Departments on what needs to be complied with when. This presents a huge risk for landowners given the large fines associated with contravention of the Acts.

HOW CAN AUTHORISING AGENCIES (DWS & DEA) PROMOTE RIVER REHABILITATION?

It is recommended that the Dept of Water and Sanitation, together with DEA, consider developing a BEST PRACTICE GUIDELINE FOR RIVER AND RIPARIAN MANAGEMENT. This guideline must identify river rehabilitation actions which can be nationally supported and endorsed, and streamline or remove necessary approvals for undertakeing these nationally supported, low risk rehabilitation objectives. Such a guideline would reassure landowners that they have the support of the DWS and DEA and encourage them to take more responsibility for the management and rehabilitation of their watercourses. A clear and streamlined authorisation process such as this would thus enable, rather than inhibit, landowners from undertaking river rehabilitation actions.

Activities which are Generally Authorised in terms of the NWA *should* be able to be immediately undertaken, instead, as is currently the case, the need for additional information or specialist studies. This cost saving will enable more money to be spent on actual rehabilitation actions; and the reduced administrative burden on government would save time and money for DWS staff and enable them to allocate more time to the processing of other Water Uses (which are currently running within a 300 day approval process). This year-long or more delay in approvals of water use activities could be shortened if the GA process is streamlined.

The two main pieces of overarching legislation, NEMA and the NWA, provide some relief in that some small scale activities can be undertaken without prior authorisation (NEMA) or are eligible for General Authorisation (under the NWA). In the case of General Authorisations however, the cost of requested supporting information and specialist studies even where the General Authorisations apply can be prohibitive, running in to tens or hundreds of thousands of rands. These costs can entirely prohibit any rehabilitation actions from being undertaken, whereas the time delays can allow for greatly accelerated degradation, and further increased costs of rehabilitation, to develop (See Volume 3: Cast Studies; Case Study #8).

10.2. Cost and the large scale of interventions

Available budgets for financing rehabilitation interventions is a frequent constraint to undertaking rehabilitation of rivers. The costs for rehabilitation arise from:

1. Applications for legal authorisations and specialist studies or application processes required to support these;
2. Costs of design for structures and any specialist modelling (such as catchment hydrology or local hydraulic modelling) which may be required in the process of design;
3. The actual material and labour costs for implementation – the building of the structure or rehabilitation activity itself; and
4. Occasionally budget must also be allocated for monitoring and follow up maintenance of the structure or activity. *This is critically important in the case of invasive alien clearing*, where a lack of follow up clearing can lead to even word invasive plant conditions in the first year or two after clearing than had no clearing been undertaken in the first place. A confirmed commitment follow-up clearing is therefore essential.

The costs of design and the material and labour costs can appear to be disproportionate to the size of the problem which is being addressed. This is because sometimes small interventions within the riparian or floodplain area of a river can create disproportionally large problems (See Volume 3: Cast Studies; Case Study #7) which require large and very expensive structures or interventions to address. Such large costs would not be feasible for a single landowner to provide for. It is perhaps a consideration for the state to dedicate a fund, generated from fines levied for water resource transgressions, to assist landowners in such cases. Thus fines incurred for water resource degradation within each province can be used to enable rehabilitation of rivers within the same province.

Caution

Pros and Pitfalls of project phasing (Day et al. 2007)

Project phasing is often a component of river rehabilitation projects, on the basis of the following points:

- Phasing allows funds to be sourced over time, making the full cost of the project less daunting;
- It allows uncertainties to be clarified during the course of the project, without delaying the whole implementation;
- It allows for learning and evolution of ideas, as approaches that do not work or could be improved on can be developed iteratively and integrated into design.

Phased projects can however also be risky, because:

- If funds earmarked for rehabilitation are allocated elsewhere, the project may be permanently halted, potentially wasting funds in unachievable outcomes (see Langevlei Case Study: Volume 3: Case Study 16);
- Projects that materialize only very slowly may result in local communities losing enthusiasm for issues for which they had initial buy-in.

10.3. Issues which are beyond the control of individual landowners

In Section 10.2 above, the large costs of intervention approaches are noted as a limitation to rehabilitation, but in addition to cost, some solutions to river degradation are physically beyond the effective control of individual landowners. These include:

- ***Catchment-wide erosion***, where widespread landuse degradation has caused an increase in sediment runoff from the catchment and increased sediment loads within the river;
- ***Changes in flow*** arising from the upstream catchment, such as increased flood peaks from urban areas or deceased flows due to abstraction or dams. The management of river flows requires effective catchment management and the determination and provision of environmental flows where necessary. Such actions are the responsibility of the Department of Water and Sanitation and cannot be achieved by individual landowners.
- A major and increasing risk for rivers is that of ***water quality***. The management and remediation of water quality in rivers is almost always beyond the control of individual landowners because the water quality problems in rivers is a reflection of the entire catchment. Point source pollution sources, such as the discharge point from waste water treatment works, interact with more diffuse sources of pollution (such as the nutrient, herbicide and pesticide runoff from agricultural areas, or untreated sewage and waste from poorly serviced informal settlements within urban areas). Where downstream landowners are on the receiving end of these water quality problems, effective management and remediation of these problems at the downstream site is ineffectual. Widespread implementation of vegetated buffer strips in agricultural areas together with careful and constrained application of fertilisers, herbicides and pesticides, or the improved treatment of waste water at municipal waste water treatment works, would be required, and such actions are beyond the control of downstream landowners. In these cases, support for rehabilitation interventions, and enforcement of the appropriate environmental and water legislation, should be obtained through provincial DEA officials and the relevant DWS or local Catchment Management Agency (CMA) respectively.

10.4. Data limitations and poor objective setting

Problems and limitations to effective river rehabilitation also arise through limited information regarding the natural (or "reference") condition of the watercourse. Where such information is limiting or poorly understood, this can create a situation where unsuitable objectives are selected and inappropriate options for rehabilitation implemented (See Text Box of Section 6.6.3). These shortcomings can be limited by developing as clear a picture of the likely historic pre-development condition of the watercourse as possible (for example, using anecdotal information for the river reach, such as verbal accounts from longtime residents; and historical maps or aerial photographs of the site) and carefully screening proposed rehabilitation options to ensure that those selected will replicate or at least restore some of the natural processes, habitats and morphologies to the site.

> Remember that rehabilitation does not need to result in restoration of a system to its natural state. Such an objective is often neither achievable nor even desirable in some cotexts. Rehabilitation can simply be about improving some aspect of river function or condition to a more sustainable and/or more natural state.

In some cases, rehabilitation may not be possible or desirable. This can be the case in urban settings, where remediation rather than rehabilitation is required. For example, some urban wetlands are now channelized watercourses and must, for the safety of local residents, be managed in a canalised, "river" conduit form (See Volume 3: Case Studies; Case Study #2). In these cases, the historic reference conditions are not appropriate rehabilitation objectives, but rather the local social uses of the riparian zones must be taken in to consideration when developing objectives and selecting rehabilitation options to ensure that the objectives selected do not ignore the needs and risk the safety of local residents (See Volume 3: Case Studies; Case Study #20).

11 REFERENCES

Abernethy, B., and Rutherford, I. D.1999. Guidelines for Stabilising Streambanks with Riparian Vegetation. Technical Report 99/00. Cooperative Research Centre for Catchment Hydrology. Monash University, Clayton, Victoria, Australia.

Abernethy, B., and Rutherford, I. D. 1998. Where along a river's length will vegetation most effectively stabilise stream banks? Geomorphology, 23, 55-75.

Allanson, B.R., Hart, R.C., O'Keefe, J.H. and Robarts, R.D. 1990. Inland Waters of southern Africa. An ecological perspective. Khiwe Academic Publishers, London. 458 pp.

ASCE Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment, 1998. River Width Adjustment. I: Processes and Mechanisms. Journal of Hydraulic Engineering, p881-902.

Baker, V.R. 1977. Stream-channel response to floods, with examples from central Texas. Geol. Soc. Am. Bull., 88: 1057-1071.

Beechie, T.J., Sear, D.A., Olden, J.D., Pess, G.R., Buffington, J.M., Moir, H., Roni, P. and Pollock, M.M. 2010. Process-based Principles for Restoring River Ecosystems. BioScience, 60 209-222.

Biedenharn, D.S., C.M. Elliott and C.C. Watson. (1997). The WES Stream Investigation and Streambank Stabilization Handbook. Vicksburg, Mississippi: ASACE.

Bok, A., Kotze, P., Heath, R., and Rossouw, J. 2007. Guidelines for the planning, design and operation of fishways in South Africa. WRC Report No. TT 287/07.

Booth A.J., Traas G.R.L. and Weyl O.L.F. 2010. Adult African sharptooth catfish, Clarias gariepinus, population dynamics in a small invaded warm-temperate impoundment. African Zoology 45: 299-308.

Bourke, M.C. & Pickup, G. 1999. Fluvial Form and Variability in Arid Central Australia. In Miller, A.J. and Gupta, A. (eds), Varieties of Fluvial Form. Wiley and Sons, Chichester, U.K, 249-272.

Bradshaw, G. A., and J. G. Borchers. 2000. Uncertainty as information: narrowing the science-policy gap. Conservation Ecology 4(1): 7. [online] URL: http://www.consecol.org/vol4/iss1/art7/.

Braid, S. 2014. Tools to determine enforcement driven rehabilitation objectives on urban river reaches. WRC Report No: TT 593/14, Water Research Commission, Pretoria. Bray, D I and Davar, K S. 1987. Resistance to flow in gravel-bed rivers, Canadian Journal of Civil Engineering, Vol. 14, pp 77-86.

Brierley G J and Fryirs K 2000 River Styles, a Geomorphic Approach to Catchment Characterization: Implications for River Rehabilitation in Bega Catchment, New South Wales, Australia Environmental Management 25(6) 661-679

Brierley, G. J., and K. A. Fryirs, editors. 2008. River futures: an integrative scientific approach to river repair. Island Press, Washington, D.C., USA.

Brierley, G. J., and K. A. Fryirs. 2005. Geomorphology and river management: applications of the River Styles framework. Blackwell, Oxford, UK.

Brierley, G. J., K. A. Fryirs, A. Boulton, and C. Cullum. 2008. Working with change: the importance of evolutionary perspectives in framing the trajectory of river adjustment. Pages 65-84 in G. J. Brierley and K. A. Fryirs, editors. River futures: an integrative scientific approach to river repair. Island Press, Washington, D.C., USA.

Britton, J.R. and M. Brazier. 2006. Eradicating the invasive topmouth gudgeon, Pseudorasbora parva, from a recreational fishery in northern England. Fisheries Management and Ecology 13: 329-335.

Bromilow, C. 2001. Problem Plants of South Africa: A Guide to the Identification and Control of more than 300 Invasive Plants and other Weeds. Briza Publications, Afrika. pp 258

Brooks, K. Fryirs, M. Leishman, M. Sanders, A. Arthington, R. Creese, M. Dahm, C. Miller, B. Pusey, and A. Spink. 2010. Inside the "black box" of river restoration: using catchment history to identify disturbance and response mechanisms to set targets for process-based restoration. Ecology and Society 15(4): 8. (http://www.ecologyandsociety.org/vol15/iss4/art).

Brown, C. and Fowler, J. 2000. Breede River Basin Study. Preliminary Assessment of the Breede River Basin. Southern Waters Report to the Department of Water Affairs and Forestry (DWAF).

Bruton, M.N. 1986. Have fishes had their chips? The dilemma of threatened fishes. Environmental Biology of Fishes 43, 1-27

Cadman, M., Petersen, C., Driver, A., Sekhran, N., Maze, K. and Munzhedzi, S. 2010. Biodiversity for Development: South Africa's landscape approach to conserving biodiversity and promoting ecosystem resilience. Pretoria: South African National Biodiversity Institute.

Cambray, J. A. 2003. The need for research and monitoring on the impacts of translocated sharptoothed catfish, Clarias gariepinus, in South Africa. African Journal of Aquatic Science 28(2): 191-195.

Cambray, J.A. and Jubb, R.A. 1977. Dispersal of fishes via the Orange-Fish tunnel, South Africa. Journal of the Limnological Society of Southern Africa 3: 33-55.

Carter, A.J. & Rogers, K.H. 1995. A markovian approach to investigating landscape change in the KNP rivers. Report no. 2/95, CWE, University of the Witwatersrand, Johannesburg.

Chakona, A. and Swartz, E.R. 2013. A new redfin species Pseudobarbus skeltoni from the Cape Floristic Region, South Africa. Zootaxa 3638: 565-575.

Coppin, N J and Richards, I. G. 1990. Use of vegetation in civil engineering, Butterworths, London.

Dallas HF. 2007. The influence of biotope availability on macroinvertebrate assemblages in South African rivers: implications for aquatic bioassessment Freshwater Biology 52: 370-380

Davies, B.R. and J.A. Day .1998. Vanishing Waters. University of Cape Town Press. Cape Town, South Africa.

Davies, S., Clusella-Trullas, S., Hui, C. and McGeoch, M. 2013. Farm dams facilitate amphibian invasion: Extra-limital range expansion of the painted reed frog in South Africa. Austral Ecology. Ecological Society of Australia.

Day, E. (Liz). 2013c. Central Breede River maintenance and management plan (MMP): Freshwater ecosystems assessment of proposed activities. Report to BolandEnviro for the Central Breede River MMP.

Day, E. (Liz). 2013a. Paardevlei. Operational Phase Environmental Management Programme. Report submitted to Heartland Properties (Pty) Ltd.

Day, E. and Snaddon, K. 2000. A conceptual plan for the proposed widening of the Keysers River, Retreat, between Tokai Road Extension and Military Road. Report by the Freshwater Research Unit to South Peninsula Municipality.

Day, E. (Liz), Rountree, M. and King, H. 2013. The development of a comprehensive manual for river rehabilitation in South Africa. Literature Review (unpublished report). WRC Project KSA2: K5/2270

Day, E., Ractliffe, G. and Wood, J., 2005. An audit of the ecological implications of remediation, management and conservation or urban aquatic habitats in Cape Town, South Africa, with reference to their social and ecological contexts

De Baets S, Poesen J, Reubens B, Wemans K, De Baerdemaeker J and Muys B (2008) Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength, Plant Soil 305: 207-226.

De Moor, I.J and Bruton, M.N. 1988.Atlas of alien and translocated indigenous aquatic animals of southern Africa. South African National Scientific Programmes Report 144: 78-133.

De Moor, I.J. 2002. Potential impacts of alien freshwater crayfish in South Africa. African Journal of Aquatic Science 27: 125-139.

Dollar, E.S.J. 2002. Fluvial Geomorphology. Progress in Physical Geography 26: 123-143.

Dollar, E.S.J., James, C.S., Rogers, K.H. and Thoms, M.C. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. Geomorphology, 89, 147-162.

Dollar, E.S.J. 2002. Fluvial Geomorphology. Progress in Physical Geography, 26: 123-143.

Driver, A., Maze, K., Lombard, A.T., Nel, J., Rouget, M., Turpie, J.K., Cowling, R.M., Desmet, P., Goodman, P., Harris, J., Jonas, Z., Reyers, B., Sink, K. & Strauss, T. 2004. South African National Spatial Biodiversity Assessment 2004: Summary Report. Pretoria: South African National Biodiversity Institute.

Dunster J. and Dunster K. 1996. Dictionary of natural resource management. University of British Columbia.

DWAF. 1996. South African Water Quality Guidelines, Volume 1-7. Department of Water Affairs and Forestry, Pretoria.

DWAF. 2005. A practical field procedure for identification and delineation of wetland riparian areas. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF. 2008a. Updated Manual for the Identification and Delineation of Wetlands and Riparian Areas, prepared by M. Rountree, A. L. Batchelor, J. MacKenzie and D. Hoare. Unpublished Draft Report on Stream Flow Reduction Activities, Department of Water Affairs and Forestry, Pretoria, South Africa.

Ellender, B.R, Weyl, O.L.F. and Winkler, H. 2009. Who uses the fishery resources in South Africa's largest impoundment? Characterising subsistence and recreational fishing sectors on Lake Gariep. Water SA 35(5): 677-682.

FCG (Freshwater Consulting Group) and Wetland Solutions. 2011a. Aquatic Weed Management Plan for the City of Cape Town. Framework for Aquatic Weed Management Plans for the City of Cape Town. Ref No: R031000114. Report to the City of Cape Town.

FCG (Freshwater Consulting Group) and Wetland Solutions. 2011b. Aquatic Weed Management Plan for the City of Cape Town. Pilot Project: Sand River Catchment. Report to the City of Cape Town. Ref No: R031000114. Report to the City of Cape Town.

Federal Interagency Stream Restoration Working Group, 2001. Stream corridor Restoration: principles, processes and practices. USDA. ISBN-0-934213-59-3.

Finlayson, B., R. Schnick, D. Skaar, J. Anderson, L. DeMong, D. Duffield, W. Horton, and J. Steinkjer. 2010. Planning and standard operating procedures for the use of rotenone in fish management. American Fisheries Society, Bethesda, Maryland.

Finlayson, B., Somer, D. Duffield, D. Propst, C. Mellison, T. Pettengill, H. Sexauer, T. Nesler, S. Gurtin, J. Elliot, F. Partridge, and D. Skaar. 2005. Native inland trout restoration on National Forests in the Western United States: time for Improvement. Fisheries 30: 10-19.

Finlayson, B., W. Somer, and M.R. Vinson. 2009. Rotenone toxicity to rainbow trout and several mountain stream insects. North American Journal of Fisheries Management 30: 102-111.

Frissell, C.A., Liss, W.J., Warren, C.E. and Hurley, M.D. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management, 10. 199-214.

Fryirs K and Brierley G 2000 A Geomorphic Approach to the identification of river recovery potential Physical Geography 21 244-277

Fryirs, K., and G. J. Brierley. 2009. Naturalness and place in river rehabilitation. Ecology and Society 14(1): 20. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art20/

Fryirs, K., G. J. Brierley, N. J. Preston, and M. Kasai. 2007. Buffers, barriers and blankets: the (dis)connectivity of catchment-scale sediment cascades. Catena 70:49-67.

Graf, W.H., 1971. Hydraulics of Sediment Transport. McGraw-Hill, New York.

Grant, B., Huchzermeyer, D. and Hohls, B. 2014. Mammal for fish kill investigations in South Africa. WRC Report TT 589/14. Water Research Comm. 109 pp with appendices.

Gray, D H and Sotir, R B (1996) Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control, John Wiley & Sons, Canada.

Gregory K J and Chin A 2002 Urban stream channel hazards. Area 34(3) 312-321

Grenfell, M.C., Ellery, W., Garden, S.E., Dini, J. and van der Valk, A.G. 2007. The language of intervention: A review of concepts and terminology in wetland ecosystem repair. Water SA, 33: 1, 43-50.

Picker, M. and Griffiths, C. 2011. Alien and Invasive Animals: A South African Perspective. Struik Publishers. pp 248Picker, M. and Griffiths, C. 2011. Alien and Invasive Animals: A South African Perspective. Struik Publishers. pp 248

Grimm, N. B., Grove, J. M., Pickett, S. T. A. and Redman, C. L. 2000. Integrated approaches to longterm studies of urban ecological systems. BioScience 50:571-584.

Groffman, P. M., Bain, D. J., Band, L. E. Belt, K. T., Brush, G. S., Grove, J. M., Pouyat, R. V., Yesilonis, I. C. and Zipperer, W. C. 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and the Environment 1:315-321.

Gupta, A., Kale, V.S. & Rajaguru, S.N. 1999. The Narmada River, India, through space and time. In Miller, A.J. and Gupta, A.(eds), Varieties of Fluvial Form. Wiley and Sons, Chichester, U.K, 113-144.

Hockey, P. 2008. Impacts of proposed developments at Fernwood Estate on Knysna Warblers (Bradypterus sylvaticus.) Unpublished report to Chand Environmental Consulting.

Holmes, P.M., Esler, K.J., Richardson, D.M. and Witkowski, E.T.F. 2008. Guidelines for improved management of riparian zones invaded by alien plants in South Africa. South African Journal of Botany 74 (2008) 538-552

Huchzermeyer, K.O.A. and Van Der Waal, B.C.W. 2012. Epizootic ulcerative syndrome: Exotic fish disease threatens Africa's aquatic ecosystems. J. S.A. Veterinary Association 83(1). http: 11dx.doi.org/10.4102/jsava.v83il.204.Impson, N.D., van Wilgen, B. & O. Weyl. 2013. Co-ordinated approaches to rehabilitating a river ecosystem invaded by alien plants and fish. S.A. J. Science 109 (11/12), 3-6.

Hughes F M R and Rood S B 2001 Floodplains in Warren A and French J R eds Habitat conservation: managing the physical environment John Wiley and Sons 103-121

Hughes, F. M. R., A. Colston, and J. O. Mountford. 2005. Restoring riparian ecosystems: the challenge of accommodating variability and designing restoration trajectories. Ecology and Society 10(1): 12. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art12.

Impson, D. 2012. Eradicating Invasive Alien Fish – It can be done, project shows. Water Wheel. December 2012. Pp 20-25

Impson, N.D., Bills, R.I. and Cambray, J.A. 2000. State of Biodiversity: Western Cape Province, South Africa: freshwater fishes.

Jordaan, M., Impson, D. and van der Walt, R. 2012. Freshwater Fishes. In: Turner, A. A. (ed.) Western Cape Province State of Biodiversity. Chapter 4. Stellenbosch: CapeNature Scientific Services. 68-86 pp.

King, J.M., ACT Scheepers, RC Fisher, MK Reinecke and LB Smith. 2003. River Rehabilitation: Literature Review, Case Studies and Emerging Principles. WRC Report No. 1161/1/03, Water Research Commission, Pretoria.

Kleynhans C.J. Thirion C and Moolman J (2005) A Level 1 Ecoregion Classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria.

Kochel, R.C. 1988. Geomorphic Impact of Large Floods: review and new perspectives on magnitude and frequency. In Baker, V.R., Kochel, R.C. and Patton, P.C. (eds) Flood Geomorphology. Wiley-Interscience, New York, 169-87.

Koehn, J.D. and M. Lintermans. 2012. A strategy to rehabilitate fishes of the Murray-Darling Basin, south-eastern Australia. Endangered Species Research, 16: p161-181.

Kotze, D.C. 2000. Wetlands and People. Wetland-use Booklet 1. A Share-net resource. ISBN. NO. 1-874891-44-3.

Kotze, D. 2012a. An assessment of the wetlands of the Central Breede River. Report to BolandEnviro for the Central Breede River MMP.

Kotze, D. 2012b. A broad-scale fluvial geomorphological assessment of the central Breede River catchment. Report to BolandEnviro for the Central Breede River MMP.

Kotze, D., Ellery, W., Rountree, M. Grenfell, M., Marneweck, G., Nxele, I., Breen, C., Dini, J., Batchelor, A. and Sieben, E. 2009. WET-RehabPlan: Guidelines for planning wetland rehabilitation in South Africa. WRC Report No TT 336/09. Water Research Commission. Pretoria.

Lane, E.W. 1955. The Importance of Fluvial Morphology in Hydraulic Engineering, American Society of Civil Engineering, Proceedings, 81, paper 745: 1-17.

Leopold, L. 1997. Let rivers teach us. Presentation by Luna B. Leopold on November 18. 1997.

Lintermans, M. 2000. Recolonization by the mountain galaxias Galaxias olidus of a montane stream after the eradication of Rainbow Trout Oncorhynchus mykiss. Marine and Freshwater Research 51: 799-804.

Macdonald, I.A.W., J.K. Reaser, C. Bright, L.E. Neville, G.W. Howard, S.J. Murphy and G. Preston (eds.). 2003. Invasive alien species in southern Africa: national reports and directory of resources. Global Invasive Species Programme, Cape Town, South Africa.

Manders, P., Godfrey, L. and Hobbes, P. 2009. Acid Mine Drainage in South Africa. CSIR Briefing Note 2009/02.

Marr, S.M. (2011). Conservation of the native freshwater fishes of the Cape Floristic Region (South Africa): Management of non-native species. PhD Thesis. University of Cape Town, Cape Town. 358 pp.

Marr, S.M., N.D. Impson, and D. Tweddle. 2012. An assessment of a proposal to eradicate non-native fish from priority rivers in the Cape Floristic Region, South Africa. African Journal of Aquatic Science 37: 131-142.

McCafferty, J.R., Ellender, B.R., Weyl, O.L.F. and Britz, P.J. 2012. The use of water resources for inland fisheries in South Africa. Water SA 38(2): 327-343.

McMahon, T.A, Finlayson, B.L., Haines, A.T. & Srikanthan, R. 1992. Global runoff: continental comparisons of annual flows and peak discharges. Catena Paperback. Cremlingen-Destedt.

Miranda, N.F., Perissinotto, R. and Appleton, C.C. 2010. Salinity and temperature tolerance of the invasive freshwater gastropod Tarebia granifera. South African Journal of Science. 106: 3/4.156

Montgomery, D.R. and Buffington, J.M. 1998. Channel processes, classification and response potential. In: River ecology and management. (Eds R.J. Naiman and R.E. Bilby), pp. 13-42. Springer-Verlag Inc., New York.

Moore, S., Kulp, M., Rosenlund, B., Brooks, J. and Propst, D. 2008 A Field manual for the use of Anti-Mycin A for restoration of native fish populations. USA Department of the Interior, Fort Collins, Colorado.

Morley, S. A. and Karr, J. R. 2002. Assessing and restoring the health of urban streams in the Peuget Sound Basin Conservation Biology 16(6) 1489-1509

Morris S and Moses T 1999 Urban Stream Rehabilitation: A Design and Construction Case Study Environmental Management 23(2) 165-177

Moses, T. and Morris, S. 1998. Environmental constraints to urban stream restoration, part 1. Public Works 129(12) 45-48.

Nanson, G.C. 1986. Episodes of vertical accretion and catastrophic stripping: a model of disequilibrium flood-plain development. Geol. Soc. Am. Bull., 97: 1467-1475.

National Ocean Service and National Marine Fisheries Service (NOSNMFS). 2002. A national strategy to restore coastal and estuarine habitat. Restore America's estuaries, USA.

Nel, J.L., Driver, A., Strydom W.F., Maherry, A., Petersen, C., Hill, L., Roux, D.J., Nienaber, S., Van Deventer, H., Swartz, E. and Smith-Adao, L.B. 2011. Atlas of freshwater ecosystem priority areas in South Africa. WRC Report No. TT 500/11.Roberts, J. and Tilzey, R. 1990. Controlling carp: exploring the option for Australia. CSIRO, Griffith NSW, Australia. 129 pp.

Neller, R. J. 1988. A comparison of channel erosion in small urban and rural catchments, Armidale, New South Wales. Earth Surface Processes and Landforms 13 1-7.

NEMBA 2004. National Environmental Management Biodiversity Act No. 10, Government Gazette No. 26436, 7 June 2004. South African Government.

NFA 1998. National Forests Act No. 84, Government Gazette No. 34595, 16 September 2011. South African Government.

Parsons, M., C. A. Mcloughlin, M. W. Rountree and K. H. Rogers. 2006. The Biotic and Abiotic Legacy of a Large Infrequent Flood Disturbance in the Sabie River, South Africa. River Research and Applications 22: 187-201.

Partridge, T. C. , Dollar, E. S. J. , Moolman, J. and Dollar, L. H.(2010) 'The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists', Transactions of the Royal Society of South Africa, 65: 1, 1 — 47Partridge, T.C. & Maude, R.R. 1987. Geomorphic evolution of southern Africa since the Mesozoic. South African Journal of Geology, 4: 179-208.

Paul, M. J. & Meyer, J. L. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics, 32: 333-365.

Paxton, B.R., Clark, B.M. and Brown, C.A. 2002. An assessment of the effects of habitat degradation and exotic fish species invasions on the distribution of three endemic cyprinids: Barbus capensis, Barbus serra and Labeo seeberi in the Olifants and Doring Rivers, Western Cape. DWAF Report No. PB E000-00-1302. Prepared for the Department of Water Affairs and Forestry and Department of Agriculture by Southern Waters Ecological Research and Consulting cc. 53 pp.

Picker, M. and Griffiths, C. 2011. Alien and Invasive Animals: A South African Perspective. Struik Publishers. pp 248.

Poff, N.L.R., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C. 1997. The natural flow regime. Bioscience, 47: 769-784.

POLLEN, N., 2007: Temporal and spatial variability in root reinforcement of streambanks: Accounting for soil shear strength and moisture. Catena 69: 197-205.

Power, M.E., Sun, A., Parker, G., Dietrich, W.E. and Wootton, J.T. 1995. Hydraulic food-chain models. Bioscience, 45: 159-167.

Ractliffe, S.G. 2009. The hydrological character of the Berg River. Transactions of the Royal Society of South Africa 64(2): 96-118.

Ractliffe, G., Ewart-Smith, J., Day, E.(Liz) and Görgens, A. 2003. External Evaluation of the Working for Water Programme: Water Resource Theme. Addendum 1: Review of the Effects of Alien Invasive Plants on Freshwater Ecosystems. Final Report to Common Ground Consulting for client: DWAF.

Resh, V.H.; Brown, A.V.; Covich, A.P.; Gurtz, M.E.; Li, H.W.; Minshall, G.W.; Reice, S.R.; Sheldon, A.L.; Wallace, J.B. and Wissmar, R.C. 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society: 433-455.

RHP (River Health Programme) 2011. State of Rivers Report: Rivers of the Breede Water Management Area. Department of Water Affairs, Western Cape, Republic of South Africa

Rinaldi, M., and S. E. Darby (2008), Modelling river-bank-erosion processes and mass failure mechanisms: Progress towards fully coupled simulations, in Gravel-Bed Rivers 6—From Process Understanding to River Restoration, Dev. Earth Surf. Processes, vol. 11, edited by H. Habersack et al., pp. 213-239, Elsevier, New York.

Roberts, J., and R. Tilzey, editors. 1997. Controlling carp: exploring the options for Australia. Proceedings of a workshop 22-24 October 1996, Albury. Commonwealth Scientific and Industrial Research Organization and Murray Darling Basin Commission, Canberra, Australia.

Rogers, K. and Bestbier, R. 1997. Development of a protocol for the definition of the desired state of riverine systems in South Africa, Department of Environmental Affairs and Tourism, Pretoria.

Rosgen, D. L. (1994). A Classification of Natural Rivers, Catena, Vol. 22, pp. 169-199.

Rountree, M. 2012. Geomorphology Assessment of the Central Breede River: Reach delineation and Ecological Objectives for riverine habitat management. Report to BolandEnviro for the Central Breede River MMP. 36pp.

Rountree, M. W. and K. H. Rogers. 2004. Channel Pattern Changes in the Mixed Bedrock/Alluvial Sabie River, South Africa: Response to and Recovery from Large Infrequent Floods. In D.G. de Jalon and P. Vizcaino (editors): Proceedings of the Fifth International Symposium on Ecohydraulics, p318-324, IAHR, Madrid, Spain.

Rountree, M.W., Heritage, G.L. & Rogers, K.H. 2001. In-channel metamorphosis in a semi-arid, mixed bedrock/alluvial river system: Implications for Instream Flow Requirements In M.C. Acreman (ed) Hydro-ecology, IAHS Publ. no. 26.

Rountree, M.W., Rogers, K.H. & Heritage, G.L. 2000. Landscape change in the semi-arid Sabie River in response to flood and drought. South African Geographical Journal, 82(3): 173-181.

Rowntree K.M. and Wadeson R.A. 1999. A hierarchical geomorphological model for the classification of selected South African river systems. Water Research Commission. Report No. 497/1/99.

Rutherford, I.; Jerie, K. and Marsh, N. (2000). A rehabilitation manual for Australian streams. Canberra: Land and Water Resources Research and Development Corporation.

SANBI. 2013. Development of a National Wetland Classification System for South Africa. Primary Project Report (Final Draft). Prepared by the Freshwater Consulting Group for the South African National Biodiversity Institute (SANBI).

Schumm, S.A. & Litchy, R.W. 1963. Channel widening and flood-plain construction along Cimarron River in south-western Kansas. Geol. Surv. Prof. Paper, 352D: 71-88.

Simons, D.B. and Sentürk, F. 1992. Sediment Transport Technology, Water Resources Publications.

Skelton, P.H. 2001. A complete guide to the freshwater fishes of southern Africa. Struik Publishing, Cape Town. 395pp.

Stevens M A Simons D B and Richardson E V 1975 Nonequilibrium River Form Journal of the Hydraulics Division 101(5) 557-566

Thomson, J.R., Taylor, M.P., Fryirs, K.A. and Brierley, G.J. 2001. A geomorphological framework for river characterization and habitat assessment. Aquatic Conservation-Marine and Freshwater Ecosystems, 11, 373-389.

Thorne, C. R., Amarasinghe, I., Gardiner, J. L., Gardiner, C., & Sellin, R. (1997). Bank protection using vegetation with special reference to the use of willows. Nottingham, U.K. 85 pp.

Thorne, C. R. (1990). Effects of vegetation on riverbank erosion and stability. Vegetation and Erosion: Processes and Environments. J. B. Thornes (Ed.) John Wiley and Sons, Chichester, UK. pp. 125-144.

Thorp, J.H., Thoms, M.C. and Delong, M.D. 2006. The riverine ecosystem synthesis: biocomplexity in river networks across space and time. River Research and Applications 22, 123-147.

Tolley, K., Davies, S. and Chown, S. 2008. Deconstructing a controversial local range expansion: conservation biogeography of the painted reed frog (*Hyperolius marmoratus*) in South Africa. *Diversity and Distributions*. Volume 14, Issue 2, pages 400-411

Tooth, S. and McCarthy, T.S. (2004), Anabranching in mixed alluvial-bedrock rivers: the example of the Orange River above Augrabies Falls, Northern Cape Province, South Africa, Geomorphology, 57 (3-4), pp.235-262.

Tooth, S. 2000. Process, form and change in dryland rivers: a review of recent research. Earth Surface Reviews, 51: 67-107.

Tourbier, J.T., Gersdorf, I., Schwager, T. 2004 Urban River Basin Enhancement Methods. 5th Framework Programme, Key Action 4 "City of tomorrow and cultural heritage: Existing Urban River Rehabilitation Schemes. Work package 2. Final Report. Dresden University of Technology (TU Dresden)

Tweddle, D., R. Bills, E. Swartz, W. Coetzer, L. Da Costa, J. Engelbrecht, J. Cambray, B. Marshall, D. Impson, P. Skelton, W.R.T. Darwall, and K.G. Smith. 2009. The status and distribution of freshwater fishes. Pages 21-37 in W.R.T. Darwall, K.G. Smith, D. Tweddle, and P. Skelton, editors. The status and distribution of freshwater biodiversity in Southern Africa. International Union for Conservation of Nature, Gland, Switzerland, and South African Institute for Aquatic Biodiversity, Grahamstown, South Africa.

US EPA (United States Environmental Protection Agency). 2003. River Corridor and Wetland Restoration. Definitions and distinctions. www.epa.gov/owow/wetlands/restore.

USDA: Natural Resources conservation Service. 2010. Understanding Fluvial Systems: Wetlands, Streams, and Flood Plains, Technical Note No. 4, February 2010.

USDIBR. 2006. United States Department of the Interior: Bureau of Reclamation. Erosion and Sedimentation Manual. Denver. Colorado. United States of America.

van Coller, A.L., Rogers, K. and Heritage, G.L. 2000. Riparian vegetation-environment relationships: complimentarity of gradients versus patch hierarchy approaches. International Association of Vegetation Science, Vol 11 (3), p337-350.

van der Haar, M. 2015. Guidelines for the stabilization of banks using the functional traits of roots. Summary document produced for WRC Project KSA2: K5/2270 as part of a mini-thesis produced in partial fulfilment of an MSc thesis. University of the Witwatersrand. In: Day, E. (Liz), Rountree, M. and King, H. 2013. The development of a comprehensive manual for river rehabilitation in South Africa. Literature Review. Appendices. WRC Project KSA2: K5/2270

van der Wiel, M. J. and S.M. Darby. 2007. A new model to analyse the impact of woody riparian vegetation on the geotechnical stability of river banks. Earth Surf. Processes Landforms. 32: 2185-2198. van Niekerk, A.W., Heritage, G.L. & Moon, B.P. 1995. River classification for management: the geomorphology of the Sabie River. South African Geographical Journal, 77(2): 68-76.

van Niekerk, A.W., Heritage, G.L. & Moon, B.P. 1995. River classification for management: the geomorphology of the Sabie River. South African Geographical Journal, 77(2): 68-76.

Vannote R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Versfeld, D.B., Le Maitre, D., and Chapman, R.A. 1998. Alien Invading Plants and Water Resources in South Africa: A preliminary Assessment WRC Report No TT/99/98)

Vinson, M.R., Dinger, E.C. and Vinson, D.K. 2010. Piscicides and Invertebrates: over 70 years, does anyone really know? Fisheries 35 (2): 61-71.

Walsh, C. J. 2000. Urban Impacts on the Ecology of receiving waters: a framework for assessment, conservation and restoration. Hydrobiologia. 431: 107-114.

Walsh, C. J. 2004. Protection of in-stream biota from urban impacts: to minimise catchment imperviousness or to improve drainage design? Marine and Freshwater Research 55 317-326

Walsh, C. J., Fletcher, T.D. and Ladson, A. R. 2005. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. Journal of the North American Benthological Society 24:690-705.

Welcomme, R. and Halls, A. 2001. Some considerations of the effects of differences in flood patterns on fish populations. Ecohydrology & Hydrobiology, 1: 313-321.

Welcomme, R.; Winemiller, K. and Cox, I. 2006. Fish environmental guilds as a tool for assessment of ecological condition of rivers. River Research and Applications, 22: 377-396.

Weyl, O.L.F, Finlayson, B., Impson, N.D., Woodford, D.J. and J. Steinkjer. 2014. Threatened endemic fishes in South Africa's Cape Floristic Region: a new beginning for the Rondegat River. Fisheries 39 (6), 270-279.

Weyl, O.L.F. and Booth, A.J. 2008. Validation of annulus formation in otoliths of a temperate population of adult African sharptooth catfish Clarias gariepinus using fluorochrome marking of wild fish. Journal of Fish Biology 73: 1033-1038

Weyl OLF, Finlayson B, Impson ND, Woodford DJ, Steinkjer J. 2014. Threatened endemic fishes in South Africa's Cape Floristic Region: a new beginning for the Rondegat River. Fisheries 39: 270-279.Williams, J.E., C.A. Wood & M.P. Dombeck. 1997. Understanding watershed-scale restoration. pp. 1-13. In: J.E. Williams, C.A. Wood & M.P. Dombeck (ed.) Watershed restoration: principles and practices, American Fisheries Society, Bethesda, Maryland.

Wolhuter, L. and Impson, N.D. 2007. The State of Yellowfish in South Africa. WRC Report TT302/07. Water Research Commission, Pretoria. 186 pp.

Wolman M G 1967 A Cycle of Sedimentation and Erosion in Urban River Channels Geografiska Annaler 49A 2-4

Wolter, C. 2013. Modifying rivers: ecological responses to hydromorphological degradation and restoration. River Restoration Conference, Vienna, 12.09.2013

Womack, W.R. & Schumm, S.A. 1977. Terraces of Douglas Creek, northwestern Colorado: an example of episodic erosion. Geology, 5: 72-76.

Woodford, D.J., Impson, N.D., Day, J.A. and Bills, I.R. 2005. The predatory impact of invasive alien smallmouth bass, Micropterus dolomieu (Teleostei: Centrarchidae), on indigenous fishes in a Cape Floristic Region mountain stream. African Journal of Aquatic Science, 30: 167-173.

Woodford, D.J., H.M. Barber-James, T.A. Bellingham, J.A. Day, F.C. de Moor, J. Gouws, and O.L.F. Weyl. 2013. Immediate impact of piscicide operations on a Cape Floristic Region aquatic insect assemblage: a lesser of two evils? Journal of Insect Conservation 17: 959-973.

Woolsey, S., C. Weber, T. Gonser, E. Hoehn, M. Hostmann, B. Junker, C. Roulier, S. Schweizer, S. Tiegs, K. Tockner & A. Peter. 2005. Handbook for evaluating rehabilitation projects in rivers and streams. Publication by the Rhone-Thur project. Eawag, WSL, LCH-EPFL, VAW-ETHZ. 108 pp.

Wu, J, and Loucks, O. 1995. From balance of nature to hierarchical patch dynamics: a paradigm shift in ecology. Quarterly Review of Biology 70: 439-466.

APPENDIX 1: Legislative requirements for river rehabilitation in South Africa

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A.1. Introduction

Rehabilitation suggests the “fixing or repair” of something that is damaged or degraded. River rehabilitation is thus the repairing or fixing of degraded rivers. The activities of rehabilitation fall within the ambit of the environmental legislation and principles of environmental management. The legislative framework surrounding river rehabilitation in South Africa is discussed further.

This Appendix provides a detailed overview of the aspects of existing legislation which are applicable in terms of river and wetland rehabilitation activities. At all times, it is recommended that the

1) **Relevant provincial Department of Environmental Affairs, and**
2) **regional Department of Water and Sanitation or relevant Catchment Management Agency**

be contacted prior to undertaking any rehabilitation activities in order to confirm that the most up to date NEMA and NWA requirements and authorisation processes are adhered to.

A.2. Legislative framework

There is a myriad of environmental legislation that could apply to river rehabilitation activities. Depending on the cause for rehabilitation, different activities of rehabilitation may need to be carried out, and these can require different approvals. Table A.1 summarises the different potential activities identified in legislation requiring approval for implementation.

Table A-1 Summary of potential rehabilitation activities requiring environmental approvals

Legislation	Regulation	Sections	Institution	Process
National Water Act, Act 36 of 1998 (NWA)	Act	4, 21, 27, 32, 36, 39, 40, 41, 42, 53, 54, 55, 151	Department of Water and Sanitation (DWS)	WULA Application in terms of section 40.
	GN R1352 in (Government Gazette) GG 20606 of 12 November 1999: Registration of a water use			Registration in terms GNR 1352
	GN R519 in GG 32209 of 6 May 2009: Registration of section 21(f) and (g) water uses			
	GN R399 in GG 26187 of 26 March 2004: Revised GAs *inter alia* relating to the water uses contained in sections 21(a) and (b).			
	GN R1199 of 18 December 2009, with effect from 1 January 2010: Revised GAs relating to the water uses contained in sections 21(c) and (i).			
	GN R1198 of 18 December 2009: For the Purpose of Rehabilitating a Wetland for Conservation Purposes			
	GN R665 in GG 36820 of 6 September 2013: Revised GAs relating to the water uses contained in sections 21(f) and (g)			

National Environmental Management Act, Act 107 of 1998 (NEMA)	Act	23A, 24, 24C, 24E, 24G, 24O 28, 30, 30A 31L, 34	Department of Environmental Affairs (DEA) if the project is applied nationally or across more than one province, however if the scale of the project falls within provincial boundaries, the competent authority will be the provincial DEA. If one of the mining activities (i.e. 20, 21 or 22 of Listing Notice 1 or 17, 18 or 19 of Listing Notice 2) is triggered, the competent authority becomes the Department of Mineral Resources (DMR).	BAR, EIA, EMP Application in terms of section 24
	GN R982 in GG 38282 of 4 December 2014: Environmental Impact Assessment Regulations	Chapter 4 (16-26), Chapter 6 (39-44)		
	GN R983 in GG 38282 of 4 December 2014: Listing Notice 1, Activities:	9, 13, 15, 17, 18, 19, [20,21,22], 27, [30], 45, 48, 49, 50, 54, 55, 63, 66		
	GN R984 in GG 38282 of 4 December 2014: Listing Notice 2, Activities:	11, 15, 16, [17, 18, 19], 24, 26,		
	GN R985 in GG 38282 of 4 December 2014: Listing Notice 3, Activities	11, 14, 16, 23		
	Please note that a fourth listing notice is currently pending (GN 737 in GG 37951 of 29 August 2014)	*Currently pending* 1, 2 and 3		
National Heritage Resources Act, Act 25 of 1999 (NHRA)	Act	34(1), 35, 36, 38, 45, ~~50~~, 51	South Africa Heritage Resources Agency (SAHRA) Provincial Heritage Authorities	Permit in terms of section 48
National Environmental Management: Waste Act, Act 59 of 2008 (NEM:WA)	Act	16, 19, 20, 21, 22, 26(1), 27, 45, 45, 47, 48, 49, 50, 56, 67, 68, 74, 75, 76	Department of Environmental Affairs (DEA) Local Government	Licence in terms of section 45
	GN 718 in GG 32368 of 3 July 2009	2,3,4		

National Environmental Management: Biodiversity Act, Act 10 of 2004 (NEM:BA)	Act	52, 53, 56, 57, 65, 66, 67, 69, 70, 71, 73, 75, 76, 88, 89, 90, 91, 92, 93, 101, 102	Department of Environmental Affairs (DEA) Directorates of Conservation	Permit in terms of section 91
	GN R1002 GG 34809 of 9 December 2012	List of Ecosystems that are threatened and in need of protection		BAR, EIA refer NEMA
	GN R506 in GG 36683 of 19 July 2013 Not operational yet	Regulations		Permit in terms of Section 23 of GNR 506
	GN R507 in GG 36683 of 19 July 2013	National list of invasive species		
	GN R507 in GG 36683 of 19 July 2013	Prohibited alien species		
	GN R509 in GG 36683 of 19 July 2013	Exempted Alien Species and CARA managed species		
National Environmental Management: Protected Areas Act, Act 57 of 2003 (NEM:PAA)	Act	9, 48, 50, ~~51~~, 89	Department of Environmental Affairs (DEA) Directorates of Conservation Local Government	
	GN R1061 in GG 28181 of 28 October 2005 Regulations for the proper administration of special nature reserves, national parks and world heritage sites	4, 25(1), 39, 40, 41, 42, 45, 46, 47		
	GN R99 in GG 35021 of 8 February 2012 Regulations for the proper administration of Nature Reserves	33, 36, 39, 40, 43, 44, 51, 52, 54		
Mountain Catchment Areas Act, Act 63 of 1970	Act	2, 3, 4(1), 11, 14, ~~15~~	Department of Environmental Affairs (DEA) Directorates of Conservation Local Government	Refer to NEM:PAA
Conservation of Agricultural Resources Act, Act 43 of 1983 (CARA)	Act	6, 7, 12	Department of Agriculture, Forestry, and Fisheries (DAFF)	Application for consent section 12
	GN R1047 in GG 9238 of 25 May 1984	6		
	GN R1048 in GG 9238 of 25 May 1984	Control measures: 3,4,6,7,8,9(1),13,14,15A, 15B, 15C, 15E, 16		
Mineral and Petroleum Resources Development Act, Act 28 of 2002 (MPRDA)		5A, 22, 23, 27, 38A, 98, 99, 106	Department of Minerals Resources (DMR)	Permit in terms of section 27 or right in terms of section 23

A.3. Environmental Approvals

Rehabilitation activities may require different types of approvals prior to commencement, such as licences, environmental authorisations, permits or rights. The various types of environmental approvals are discussed below.

Water Use Licences

Section 4 of the National Water Act, Act 36 of 1998 (NWA) states amongst others, as follows:

(1) "A person may use water in or from a water resource for purposes such as reasonable domestic use, domestic gardening, animal watering, firefighting and recreational use, as set out in Schedule 1.

(2) A person may continue with an existing lawful water use in accordance with section 34.

(3) A person may use water in terms of a general authorisation or licence under this Act".

Section 21 of the NWA deals with "water uses" and the following water uses could be applicable to river rehabilitation:

- 21(a) taking water from a water resource;
- 21(b) storing water;
- 21(c) impeding or diverting the flow of water in a watercourse;
- 21(d) engaging in a stream flow reduction activity contemplated in section 36;
- 21(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
- 21(g) disposing of waste in a manner which may detrimentally impact on a water resource;
- 21(i) altering the bed, banks, course or characteristics of a watercourse;

The NWA defines existing lawful water use as a water use:

- (a) Which has taken place at any time during a period of two years immediately before the date of commencement of the NWA; or
- (b) Which has been declared an existing lawful water use under section 33, and which –
  - i. was authorized by or under any law which was in force immediately before the date of commencement of the NWA;
  - ii. Is identified as a stream flow reduction activity in section 36(1); …"

If a water use is deemed to be an existing lawful use, as defined above, it must be registered with the Department of Water Affairs.

It is also important to note that any entitlement granted to a person by or under the NWA replaces any right to "use water" which that person might otherwise have been able to enjoy or enforce under any other law –

- (a) to take or use water;
- (b) to obstruct or divert a flow of water;
- (c) to affect the quality of any water;

(d) to receive any particular flow of water;
(e) to receive a flow of water of any particular quality; or
(f) to construct, operate or maintain any waterwork.

If the proposed water use

- is not permissible in terms of Schedule 1,
- is not an existing lawful water use, or
- does not fall within the parameters as set out in the relevant general authorisations (referred to in detail below), in which case such water use is either registered, or not, as required by the general authorisation,

then a water use licence is required to undertake that water use. More information about how water uses licences are processed can be found at
http://www.dwaf.gov.za/WAR/authorised.aspx.

Note that section 22(3) of the NWA provides that "[a] responsible authority may dispense with the requirement for a licence for water use if it is satisfied that the purpose of this Act will be met by the grant of a licence, permit or other authorisation under any other law". Section 22(4) further provides that "[i]n the interests of cooperative governance, a responsible authority may promote arrangements with other organs of state to combine their respective licence requirements into a single licence requirement".

ENVIRONMENTAL AUTHORISATION

Section 24 of National Environmental Management Act, Act 107 of 1998 (NEMA) provides for certain listed activities that may not commence without an environmental authorisation, which require some form of environmental impact assessment to be undertaken. The first set of regulations published under NEMA repealed the environmental impact assessment (EIA) regulations contained in sections 21, 22 and 26 of the Environment Conservation Act 73 of 1989, (ECA) and the regulations promulgated thereunder on 21 April 2006, with effect from 3 July 2006. On 18 June 2010 a new set of regulations to replace these was published[6] and came into operation on 2 August 2010. These 2010 regulations were repealed and replaced with a new set of regulations which were promulgated on 4 December 2014[7]. Refer to the Table A.1 above for a list of listed activities that may be triggered when undertaking river rehabilitation.

The Listing Notices indicate who the competent authority will be that will consider and decide on applications for environmental authorisation. Section 24C of NEMA, which determines the procedure for identifying the competent authority, states that the national Minister of Environmental Affairs will be the competent authority where a listed activity is undertaken, or is to be undertaken, by a provincial department responsible for environmental affairs or any other organ of state performing a

[6] Published under Government Notices R543, R544, R545 and R546 in *Government Gazette* 33306 of 18 June 2010

[7] Published under Government Notices R982, and corresponding Listing Notices R983, R984 and R985 in *Government Gazette* 38282 of 4 December 2014

regulatory function and reporting to the MEC; or a statutory body, excluding any municipality, performing an exclusive competence of the national sphere of government; or will take place within a national proclaimed protected area or other conservation area under control of a national authority. The Minister and the MEC may however agree that applications for environmental authorisations with regard to any activity or class of activities as indicated above may be dealt with by the MEC. Should the activity trigger a prospecting, exploration or extraction and primary processing action in terms of the Minerals and Petroleum Resources Development Act (MPRDA) then the competent authority becomes the Minister responsible for Mineral Resources.

The process of obtaining an environmental authorisation is either through a Basic Assessment Report (BAR) or a detailed Scoping and Environmental Impact Assessment (EIA). The listing notices differentiate which activities are required to follow which processes. If an activity on listing notice 1 and/ or 3 is triggered, a BAR will be required. An activity triggered on listing notice 2 would require a full Scoping and EIA process. In general a BAR process is shorter and less detailed than an EIA. Such application and specialist studies as required for both processes, must be compiled at the cost of the person proposing the development, by a person or persons approved by the responsible authority with relevant qualifications and experience and professional standing in environmental resources management.

The 2014 EIA regulations have made provision for some exclusions to the listing activities should an activity be triggered for maintenance purposes. These exclusions are only applicable to the following activities and do not negate the approval of other activities requiring approval both in terms of NEMA and/or other legislation. Furthermore, a maintenance management plan must still be approved by the competent authority. The following listed activities provide for this exclusion:

Table A-2: Exclusion activities with maintenance management plans

GN R983: 18	The planting of vegetation or placing of any material on dunes or exposed sand surfaces of more than 10 square metres, within the littoral active zone, for the purpose of preventing the free movement of sand, erosion or accretion, excluding where – (i) The planting of vegetation or placement of material relates to restoration and maintenance of indigenous coastal vegetation undertaken in accordance with a maintenance management plan; or (ii) Such planting or placing of material will occur behind a development setback.
GN R983: 19	The infilling or depositing of any material of more than 5 cubic metres into, or the dredging, excavation, removal or moving of soil, sand, shells, shell grit, pebbles or rock of more than 5 cubic metres from – (i) A watercourse; (ii) The seashore; or (iii) The littoral active zone, an estuary or a distance of 100 metres inland of the high-water mark of the sea or an estuary, whichever distance is the greater But excluding where such infilling, depositing, dredging, excavation, removal or moving – (a) Will occur behind a development setback'

	(b) Is for maintenance purposes undertaken in accordance with a maintenance management plan; or (c) Falls within the ambit of activity 21 in this Notice, in which case that activity applies.
GN R983: 27	The clearance of an area of 1 hectare or more, but less than 20 hectares of indigenous vegetation, except where such clearance of indigenous vegetation is required for – (i) The undertaking of a linear activity; or (ii) Maintenance purposes undertaken in accordance with a maintenance management plan.
GN R984: 15	The clearance of an area of 20 hectares or more of indigenous vegetation, excluding where such clearance of indigenous vegetation is required for – (i) The undertaking of a linear activity; or (ii) Maintenance purposes undertaken in accordance with a maintenance management plan.
GN R984: 24	The extraction or removal of peat or peat soils, including the disturbance of vegetation or soils in anticipation of the extraction or removal of peat or peat soils, but excluding where such extraction or removal is for the rehabilitation of wetlands in accordance with a maintenance management plan.
GN R985:12	The clearance of an area of 300 square metres or more of indigenous vegetation except where such clearance of indigenous vegetation is required for maintenance purposes undertaken in accordance with a maintenance plan. *The rest of this activity is area specific per province.*

HERITAGE PERMITS AND SECTION 38 OF THE NHRA

Section 38 of the National Heritage Resources Act, Act 25 of 1999 (NRHA) provides that any person who intends to undertake a development categorised as the construction of a road, wall, power line, pipeline, canal or other similar form of linear development or barrier exceeding 300 m in length, must at the very earliest stages of initiating such a development, notify the responsible heritage resources authority and furnish it with details regarding the location, nature and extent of the proposed development.

If there is reason to believe that heritage resources will be affected by such development, the responsible heritage resources authority must notify the person who intends to undertake the development to submit an impact assessment report. Such report must be compiled at the cost of the person proposing the development, by a person or persons approved by the responsible heritage resources authority with relevant qualifications and experience and professional standing in heritage resources management; or notify the person concerned that this section does not apply.

The responsible heritage resources authority will consider the report and determine whether or not the development may proceed and any limitations or conditions to be applied to the development.
In terms of section 38(3) of the NHRA, the provisions of this section do not apply to a development if an evaluation of the impact of such development on heritage resources is required in terms of any

other legislation: Provided that the consenting authority must ensure that the evaluation fulfils the requirements of the relevant heritage resources authority and any comments and recommendations of the relevant heritage resources authority with regard to such development have been taken into account prior to the granting of the consent. In effect, where listed activities in terms of NEMA are triggered for river rehabilitation, the provisions of section 38(8) apply and the heritage impact assessment, where required, is done as part of the Basic Assessment or full Environmental Impact Assessment process.

Additional permits may also be required if the river rehabilitation will impact on any heritage resource, for example, for the disturbance of any archaeological or palaeontological sites[8] . If river rehabilitation activities will affect burial grounds or graves, a permit will be required in terms of section 36 of the NHRA.

In addition, some structures such as bridges and canals, for example a lei water, may be older than 60 years, in which case any upgrading or construction related thereto would require a permit in terms of section 34 of the NHRA. Note that section 34 requires a permit where a structure that is older than 60 years will be altered or demolished. The definition of “alter” is very wide and is defined as meaning “any action affecting the structure, appearance or physical properties of a place or object, whether by way of structural or other works, by painting, plastering or other decoration or any other means”.

WASTE MANAGEMENT LICENCES

National Environmental Management: Waste Act, Act 59 of 2008 (NEM:WA) commenced on 1 July 2009 (unless otherwise indicated), and repealed large portions of the Environment Conservation Act 73 of 1989 (ECA). Section 20 of the NEM: WA provides that no person may commence, undertake or conduct a waste management activity listed in NEM: WA unless a licence is issued in respect of that activity. A list of waste management activities was also gazetted[9]. Some of these activities require that a BAR be undertaken prior to a licence, if any, being issued, (“Category A activities”), and others require a full EIA to be undertaken prior to a licence, if any, being issued, (“Category B activities”).

“Waste” is defined in the NEM: WA as meaning any substance, whether or not that substance can be reduced, re-used, recycled and recovered-

(a) that is surplus, unwanted, rejected, discarded, abandoned or disposed of;
(b) which the generator has no further use of for the purposes of production;
(c) that must be treated or disposed of; or
(d) that is identified as a waste by the Minister by notice in the Gazette,
and includes waste generated by the mining, medical or other sector, but -
  (i) a by-product is not considered waste; and
  (ii) any portion of waste, once re-used, recycled and recovered, ceases to be waste;

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[8] Section 35 of the NHRA

[9] Published under Government Notice 718 in *Government Gazette* 32368 of 3 July 2009.

There are a few waste management activities that could be triggered in undertaking river rehabilitation, for example stockpiling of excavated material, and will therefore require a waste management licence.

However, there is provision in section 74 for the issuing of exemptions by the Minister. Any person may apply in writing for exemption from the application of a provision of this Act to the Minister or, where the MEC is responsible for administering the provision of the NEM: WA from which the person or organ of state requires exemption, to the MEC. An application must be accompanied by an explanation of the reasons for the application and any applicable supporting documents. The Minister or MEC, as the case may be, may request an applicant to furnish additional information where such information is necessary for the purposes of informing the Minister or MEC's decision.

If the rights or interests of other parties are likely to be adversely affected by the proposed exemption, the Minister or MEC, must, before deciding on the application, request the applicant to-

(a) bring the application to the attention of relevant organs of state, interested persons and the public by conducting a public participation process indicated by the Minister or MEC; and
(b) to submit any comments received from the public following such process to the Minister or MEC".

PERMITS IN TERMS OF BIODIVERSITY

Section 57(1) of the National Environmental Management: Biodiversity Act, Act 10 of 2004 (NEM:BA) prohibits the carrying out of a restricted activity involving a specimen of a "listed protected or threatened species" without a permit. "Listed threatened or protected species include those listed by the Minister in terms of section 56(1) and include species described as critically endangered, endangered, vulnerable and protected".

"Restricted activity" in relation to a specimen of a listed threatened or protected species, is defined as including:

(i) ...;
(ii) gathering, collecting or plucking any specimen of a listed threatened or protected species;
(iii) picking parts of, or cutting, chopping off, uprooting, damaging or destroying, any specimen of a listed threatened or protected species;
(iv) ...;
(v) ...;
(vi) having in possession or exercising physical control over any specimen of a listed threatened or protected species;
(vii) ...;

conveying, moving or otherwise translocating any specimen of a listed threatened or protected species..."

Section 65(1) prohibits the carrying out of a restricted activity involving a specimen of an "alien species" without a permit. A permit may however, only be issued only after a prescribed assessment of risks and potential impacts on biodiversity is carried out. In terms of section 67 however, the Minister may publish a list of those alien species[10] in respect of which a permit may not be issued[11].

"Alien species" is defined in the Biodiversity Act as

(a) "a species that is not an indigenous species; or

(b) an indigenous species translocated or intended to be translocated to a place outside its natural distribution range in nature, but not an indigenous species that has extended its natural distribution range by natural means of migration or dispersal without human intervention".

"Restricted activity" in relation to a specimen of an alien species or listed invasive species, is defined as including-

(i) ...;

(ii) having in possession or exercising physical control over any specimen of an alien or listed invasive species;

(iii) growing, breeding or in any other way propagating any specimen of an alien or listed invasive species, or causing it to multiply;

(iv) conveying, moving or otherwise translocating any specimen of an alien or listed invasive species...".

Section 71(1) prohibits the carrying out of a restricted activity involving a specimen of a "listed invasive species" without a permit. A permit may however, only be issued only after prescribed assessment of risks and potential impacts on biodiversity is carried out.

If the rehabilitation activities involve a restricted activity relating to any listed protected or threatened species, alien species, or listed invasive species, a permit must be obtained from the issuing authority. The issuing authority is usually the provincial organ of state responsible for conservation. Note however, that regulation 3 of the Threatened or Protected Species Regulations, 2007 makes provision for various instances in which the issuing authority is the National Minister of Environmental Affairs.

Note that both the CARA and the Biodiversity Act have a gazetted list of alien species. However, on 19 July 2013, the Minister of Environmental Affairs published a list of exempted alien species in which alien species regulated in terms of CARA as weeds and invader plants are exempted from compliance with the Biodiversity Act.

[10] Published under Government Notice R509 in Government Gazette 36683 of 19 July 2013

[11] Published under Government Notice R508 in *Government Gazette* 36683 of 19 July 2013, Publication of prohibited alien species.

In addition to the above, any planning instruments[12], such as the National Biodiversity Framework, bioregional plans, biodiversity management plans and identified threatened or protected ecosystems will also be relevant to river rehabilitation activities, as well as in relation to the determination of whether listed activities in terms of NEMA are applicable.

APPROVALS IN TERMS OF PROTECTED AREAS

The National Environmental Management: Protected Areas Act, act 57 of 2003 (NEM:PAA) is the primary statute for the regulation and administration of protected areas, as it provides for the manner in which the different statutes governing protected areas should interact. The NEM: PAA not only deals with national parks, but also with other protected areas. The NEM: BA primarily regulates the management of biodiversity, but the Protected Areas Act must, in relation to any protected area, be read, interpreted and applied in conjunction with the Biodiversity Act[13].

The following types of protected areas are recognised by the Protected Areas Act[14]:

- Special nature reserves;
- National parks;
- Nature reserves;
- Wilderness areas;
- Protected environments;
- World heritage sites;
- Marine protected areas;
- Specially protected forest areas, forest nature reserves and forest wilderness areas declared in terms of section 8 of the NFA[15]
- Mountain catchment areas are areas so declared in terms of the Mountain Catchment Areas Act 63 of 1970[16].

The management authority of a protected area is the organ of state or other institution or person in which the authority to manage the area is vested.
Should river rehabilitation activities take place within a protected area, as identified above, the requirements of the NEM:PAA will apply in conjunction with any other identified legislation.

Section 45(1) provides that no person may enter, reside in, or perform any activity in a special nature reserve. This prohibition does not, however, apply to an official of the Department or another organ of state designated to monitor conservation or biodiversity, or a person acting in terms of an exemption granted under the Act.

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[12] Please refer further to paragraph 6 above and the activities listed in terms of section 24 of NEMA.
[13] Section 6 of the Protected Areas Act.
[14] Section 9 of the Protected Areas Act
[15] See section 15 of the Protected Areas Act. Only Chapters 1 and 2 and section 48 of the Protected Areas Act apply to such areas.
[16] See section 16 of the Protected Areas Act.

Section 48(1) prohibits commercial prospecting or mining in a special nature reserve, national park or nature reserve, as well as in world heritage sites, marine protected areas and specially protected forest areas, forest nature reserves and forest wilderness areas. It also prohibits such activities in a protected environment without permission from the Minister (of Water and Environmental Affairs) and the cabinet member responsible for minerals and energy.

Section 50(5) prohibits development, construction and farming in a national park, nature reserve and world heritage site unless prior written approval has been obtained from the management authority.

CONTROL MEASURES IN TERMS OF AGRICULTURAL RESOURCES

In terms of section 6(1) of the Conservation of Agricultural Resources Act, Act 43 of 1983 (CARA), the Minister may, in order to achieve the objects of this Act, prescribe control measures that must be complied with by land users to whom they apply. Rather than a formal licence or environmental authorisation as contemplated in the NWA or NEMA respectively, a control measure may contain a prohibition or an obligation.

Control measures that have been prescribed by the Minister in the Regulations promulgated under CARA, which relate to potential impacts on or from riparian areas include the following:

- (a) Protection of cultivated land against erosion through the action of water;
- (b) The prevention of waterlogging and salination of irrigated land;
- (c) The utilization and protection of vleis, marshes, water sponges, water courses;
- (d) The regulating of the flow pattern of run-off water;
- (e) The utilization and protection of veld;
- (f) Restoration or reclamation of eroded land;
- (g) Restoration and reclamation disturbed or denuded land;
- (h) Declaration of weeds and invader plants;
- (i) Indicators of bush encroachment.

Various other approvals in terms of other legislation may be required in order to undertake a control measure, such as a water use licence in terms of the NWA or an environmental authorisation in terms of NEMA.

MINING PERMITS/RIGHTS

Section 5(4) of the Mineral and Petroleum Resources Development Act, Act 28 of 2002 (MPRDA) provided, until the amendments that took effect on 7 June 2013, that no person may remove or mine any mineral without an approved environmental management programme or plan and the required permission, right or permit from the Minister of Mineral Resources. This section has however been deleted.

The newly inserted section 5A provides that “[n]o person may prospect for or remove, mine, conduct technical co-operation operations, reconnaissance operations, explore for and produce any mineral or petroleum or commence with any work incidental thereto on any area without-

(a) an environmental authorisation;

(b) a reconnaissance permission, prospecting right, permission to remove, mining right, mining permit, retention permit, technical co-operation permit, reconnaissance permit, exploration right or production right, as the case may be; and

(c) giving the landowner or lawful occupier of the land in question at least 21 days written notice."

"Mineral" is defined in the MPRDA as "any substance, whether in solid, liquid or gaseous form, occurring naturally in or on the earth or water and specifically includes sand, stone, rock, gravel and soil". In the context of river rehabilitation, this applies to the excavation of sand, stone, rock, gravel or soil from a river.

In terms of section 106 of the MPRDA, any landowner or lawful occupier of land "who lawfully, takes sand, stone, rock, gravel or clay for farming or for effecting improvements in connection with such land or community development purposes, is exempted" as long as the sand, stone, rock, gravel or clay is not sold or disposed of.

However, should any "mineral" be removed during river rehabilitation activities[17] and sold or disposed of, a mining permit or right will still be required[18] [19]. Note also that the disposal of such materials may also require a waste licence in terms of the NEM:WA.

Mining permits are granted in terms of section 27 of the MPRDA and are valid for the period specified in the permit, which may not exceed a period of two years, and may be renewed for three periods each of which may not exceed one year. Mining permits may also "*not be transferred, ceded, let, sublet, alienated or disposed of, in any way whatsoever, but may be encumbered or mortgaged only for the purpose of funding or financing of the mining project in question with the Minister's consent*" [20] .

Mining permits are only granted for small scale mining activities which must be capable of being mined optimally within two years and which must not mine over an area of more than 5 hectares.

Mining rights are granted in terms of section 23 of the MPRDA, and the requirements for the granting of such rights are more onerous than for the granting of mining permits. A mining right may

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[17] Note that section 48(1) of the Protected Areas Act, prohibits mining in a special nature reserve, national park or nature reserve, as well as in world heritage sites, marine protected areas and specially protected forest areas, forest nature reserves and forest wilderness areas. It also prohibits such activities in a protected environment without permission of the Minister of Environmental Affairs and the cabinet member responsible for minerals and energy.

[18] In addition, approval from the Minister of Mineral Resources may be required in terms of section 53 of the MPRDA to "use the surface of any land in any way that may be contrary to any object of this Act or which is likely to impede any such object".

[19] Note that a rezoning may also need to be obtained in order for mining activities to be undertaken.

[20] Section 27(8) of the MPRDA.

only be granted if, among others, the mineral can be mined optimally in accordance with the mining work programme, and the mining will not result in unacceptable pollution, ecological degradation or damage to the environment.

A mining right is valid for the period specified in the right, which period may not exceed 30 years.

INTEGRATED AUTHORISATIONS

Some of the statutes make reference or provision for integrated authorisations. However in practice, the necessary procedures and policies are not yet in place to support this and the roles and responsibilities of due process such as appeals, compliance monitoring and enforcement, have not been thought through. The closest “streamlining” of environmental authorisations is in terms of section 24 of the NWA, that allows for a water use licence to be waived provided that DWS is satisfied that the EIA process has adequately covered their issues; the activity must still however be registered with DWS. However, this “streamlining” is only applicable where an environmental authorisation is issued.

A.4. GENERAL AUTHORISATIONS IN TERMS OF THE NATIONAL WATER ACT AND REGISTERING WATER USES

In order to improve access to water resources for utilization, section 39 of the NWA enables the Minister, after public consultation, to permit the use of water by publishing general authorisations (GAs) in the Gazette. A general authorisation may be restricted to a particular water resource, a particular category of persons, a defined geographical area or a period of time and is usually where they are deemed to have little or negligible impact on the water resource or environment. Compliance with all other relevant legislation is still required.

The applicability of any GA (or not, as the case might be), to any given area in question depends inter alia on whether or not lawful access to such land on which the water use is to take place, has been obtained.

Where activities fall outside of the parameters of a GA, or are excluded from the GA, the water use is subject to the standard section 21 water use licence requirements.

GNR 1352 in GG 20606 of 12 November 1999 provides that any person who uses water in terms of section 21 of the NWA must register such water use as required under a general authorisation promulgated in terms of section 39 of the NWA or when requested by the responsible authority. This helps the resource managers understand all the activities the water resources are being utilised for and incorporate these requirements into the resource planning strategies. All uses affecting water resources should be registered, unless specifically excluded in the relevant GA.

In terms of GN R519 in GG 32209 of 6 May 2009, the Minister determined that inter alia section 21(f) and (g) water uses must be registered.
GAs relating to various water uses were issued in terms of section 39 of the NWA in GNR 1191 of 1999:

GNR 399 SECTION 21 (A) AND (B)

GNR 399 in GG 26187 of 26 March 2004 has been extended in validity by Government Notice 970 in Government Gazette 35909 of 30 November 2012 for a further period until it is withdrawn by notice in the Government Gazette.

The General Authorisation replaces the need for a water user to apply for a licence in terms of the NWA for the taking or storage of water from a water resource, provided that the taking or storage is within the limits and conditions set out in this authorisation.

This authorisation does not apply-

(a) to any lawful taking and storage within a government water control area, a government water work, a catchment control area or an irrigation district as defined in the Water Act, 1956 (Act No. 54 of 1956) prior to its repeal;
(b) to a person who does not have lawful access to any waterwork or water resource;
(c) to wetlands, the dewatering of mines or storage of water underground;
(d) to an exclusion zone of 750 metres inland from the high water mark; and
(e) to an area where the limits of taking and storage of water were reduced in terms of section 9B (1C) of the Water Act, 1956 (Act No 36 of 1956).
(f) Further, this authorisation does not-
    a. apply to any water use under Schedule 1 of the National Water Act;
    b. replace any existing authorisation that is recognised under the National Water Act; or
    c. exempt a person who uses water from compliance with any other provision of the National Water Act unless stated otherwise in this notice, or any other applicable law, regulation, ordinance or by-law.

(2) In the case of the taking of water for industrial purposes the provisions of section 7 of the Water Services Act, 1997 (Act No. 108 of 1997), must be met.
(3) A person who uses water in terms of this authorisation is exempt from compliance with section 22(2)(e) of the National Water Act.

GN 665, SECTION 21(E), (F), (G) AND (H)

Published under Government Notice 399 in Government Gazette 26187 of 26 March 2004 and amended by GNR 665 of Government Gazette 36820 of 6 September 2013 and is applicable for a period of five years from the date of publication of this notice, unless-

(a) it is amended by the responsible authority at any review period;
(b) the period is extended by a notice in the Gazette;
(c) it is replaced with a general authorisation in relation to a specific water resource or within a specific area; or
(d) the water user is instructed in writing by the responsible authority to apply for a licence in terms of the Act

This general authorisation replaces the need for a water user to apply for a licence in terms of the Act, provided that the water use is within the limits and conditions as set out in this general authorisation. This GA applies to the following water use activities:

- engaging in a controlled activity, identified as such in section 37(1)(a): irrigation of any land with waste or water containing waste generated through any industrial activity or by a waterwork (section 21(e));
- discharge of waste or water containing waste into a water resource through a pipe, canal, sewer or other conduit (section 21(f));
- disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process (section 21(h));
- disposing of waste in a manner which may detrimentally impact on a water resource (section 21(g)); and
- removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people (section 21(j)).

GN 1198, SECTION 21 (C) AND (I) WETLAND REHABILITATION BY ORGANS OF STATE

A "General authorisation in terms of Section 39 of the National Water Act, 1998 (Act No 36 of 1998) in terms of Section 21(c) and (i) for the Purpose of Rehabilitating a Wetland for Conservation Purposes" was published under Government Notice 1198 in Government Gazette 32805 of 18 December 2009.

However, this general authorisation is only applicable to "the category of persons who are organs of state in terms of the Constitution and who are undertaking water use 21 (c) and (i) of the Act for the purpose of rehabilitating a wetland for conservation purposes". Section 239 of the Constitution defines "organs of state" as follows:

(a) any department of state or administration in the national, provincial or local sphere of government; or

(b) any other functionary or institution –

 (i) exercising a power or performing a function in terms of the Constitution or a provincial constitution; or

 (ii) exercising a public power or performing a public function in terms of any legislation, but does not include a court or a judicial officer".

"Wetland" is defined in the NWA as meaning "land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil".

Please take note that this GA 1198 is **ONLY** for organs of state for wetland rehabilitation purposes **ONLY**. The moment when other activities are linked to this wetland rehabilitation then it needs to follow the GA 1199 or licence route. Therefore should a Local Government wish to use this GA in their future planning processes, systems and resources (human & financial) and standardised EIM Reports (align to DWS legislation and information requirements) must be in place as per the conditions of the GA 1198. It is not a GA that can be applied immediately without having certain processes, documentation and financial controls in place [21]. Also note that this GA does not exempt the organ of state from having to obtain environmental authorisation in terms of NEMA for activities that have the potential to impact a wetland in terms of NEMA.

Further, this GA also does not apply where the water user must in any event make an application for a licence for any other section 21 water use. It further does not allow for the storage of water as a result of the impeding or diverting the flow or altering the bed, banks, course or characteristics of a watercourse and there are also various areas to which this GA does not apply. Use of water in terms of this GA also requires registration with the responsible authority.

GN 1199, SECTION 21 (C) AND (I) GENERAL

This Notice (published in Government Gazette 32805 of 18 December 2009) replaces Government Notice No. 398 dated 26 March 2004 as published in Government Gazette No 26187 for water use 21(c) and (i) as set out in this Notice. This General Authorisation is valid from the 01 January 2010 for a period of 20 (twenty) years unless –

- (a) the period is extended for a further period by a Notice in the Gazette;
- (b) it is replaced by another general authorisation; or
- (c) the water user is required to apply for a licence in terms of the Act.

This GA does not exempt the water user from compliance with any other provision of the Act or from any other applicable legislation, regulation, ordinance or by-law.

This GA outlines the conditions for impeding or diverting the flow or altering the bed, banks, course or characteristics of a watercourse without requiring a water use licence. Should activities exceed those identified in this GA then a water use licence contemplated in terms of section 21 of the NWA will be required.

The GA specifically states that this Notice does not-

- (a) apply to the use of water in terms of section 21(c) and (i) for the rehabilitation of a wetland;
- (b) apply to the use of water in terms of section 21(c) and (i) within a 500 metre radius from the boundary of any wetland;
- (c) apply if the water user must make an application for a licence for any other water use in terms of section 21 of the Act;
- (d) apply to any sewerage pipelines, pipelines carrying hazardous materials and to water and wastewater treatment works;

[21] Email of 19 June 2013 from Valerie Killian, Scientific Manager: Environment & Recreation, Directorate: Water Abstraction and Instream Use, Department of Water Affairs.

(e) allow for the storage of water as a result of the impeding or diverting the flow or altering the bed, banks, course or characteristics of a watercourse; and

(f) apply to the areas set out in Table 1 of paragraph 4.

NOTE: Information on the method of delineation of a wetland is contained in the Department of Water Affairs and Forestry, 2005 publication: A Practical Field Procedure for Delineation of Wetlands and Riparian Areas, which is available on the Department's website http://www.dwaf.gov.za

A.5. MAINTENANCE AND UPGRADING OF EXISTING LAWFUL USE STRUCTURES

As stated above, section 4(2) of the NWA provides that *"[a] person may continue with an existing lawful water use in accordance with section 34*". Section 32 of the NWA provides the following definition of existing lawful water use:

(1) "An existing lawful water use means a water use -

(a) which has taken place at any time during a period of two years immediately before the Commencement date of this Act and which -

(i) was authorised by or under any law which was in force immediately before the Commencement date[22] of this Act;

(ii) is a stream flow reduction activity contemplated in section 36 (1); or

(iii) is a controlled activity contemplated in section 37 (1); or

(iv) which has been declared an existing lawful water use under section 33.

(2) In the case of -

(a) a stream flow reduction activity declared under section 36 (1); or

(b) a controlled activity declared under section 38, existing lawful water use means a water use which has taken place at any time during a period of two years immediately before the date of the declaration".

Section 34 provides the authority to continue with existing lawful water use and states as follows:

(1) A person, or that person's successor in title, may continue with an existing lawful water use, subject to -

(a) any existing conditions or obligations attaching to that use;

(b) its replacement by a licence in terms of this Act; or

(c) any other limitation or prohibition by or under this Act.

(2) A responsible authority may, subject to any regulation made under section 26 (1) (c), require the registration of an existing lawful water use".

No licence is therefore required to continue with an existing lawful water use until a responsible authority requires a person claiming such an entitlement to apply for a licence. If a licence is issued it becomes the source of authority for the water use. If a licence is not granted the use is no longer regarded as a permissible use.

Even if a water use is regarded to be an existing lawful water use in terms of the NWA, if the rehabilitation activities relating to existing lawful water uses fall within the parameters of any of the

[22] The commencement date of the NWA was 1 October 1998.

other environmental approvals described above, such approvals will have to be obtained for maintenance or upgrading activities related to river rehabilitation. However, with regard to the activities listed in terms of NEMA, one may not necessarily require environmental authorisation. NEMA and the EIA regulations do not contain a definition of "maintenance". However, the EIA regulations do not apply where commencement of an activity listed in terms of section 24 of NEMA was "commenced" prior to the coming into effect of the EIA regulations. Such "commencement" must however, have been lawful.

"Commence" is defined in NEMA as meaning "the start of any physical activity, including site preparation and any other activity on the site in furtherance of a listed activity or specified activity, but does not include any activity required for the purposes of an investigation or feasibility study as long as such investigation or feasibility study does not constitute a listed activity or specified activity".

"Construction" is defined as "the building, erection or establishment of a facility, structure or infrastructure that is necessary for the undertaking of a listed or specified activity but excludes any modification, alteration or expansion of such a facility, structure or infrastructure and excluding the reconstruction of the same facility in the same location, with the same capacity and footprint".

Therefore, if activities related to river rehabilitation are regarded as existing lawful water uses in terms of the NWA, and the activities will result in the same capacity and footprint, then environmental authorisation in terms of NEMA will not be required. However, there may still be other environmental approvals as described above that will need to be obtained prior to commencement.

In terms of section 35 of the NWA, the responsible authority may, in order to verify the lawfulness or extent of an existing water use, by written notice require any person claiming an entitlement to that water use to apply for a verification of that use.

In addition, in terms of section 33 of the NWA, a person may apply to a responsible authority to have a water use which is not one contemplated in section 32 (1) (a), declared to be an existing lawful water use. In terms of section 33(2) of the NWA a responsible authority may, on its own initiative, declare a water use which is not one contemplated in section 32 (1) (a), to be an existing lawful water use. A responsible authority may only make a declaration under subsections 32(1) or 32(2) if it is satisfied that the water use -

- (a) took place lawfully more than two years before the date of commencement of this Act and was discontinued for good reason; or
- (b) had not yet taken place at any time before the Commencement date of this Act but -
  - (i) would have been lawful had it so taken place; and
  - (ii) steps towards effecting the use had been taken in good faith before the Commencement date of this Act".

GN R1352 requires all water uses to be registered.

A.6. Rectification of unlawful activities

Section 24G of NEMA provides for a process where upon the payment of an administrative fine, a person who has committed an offence may apply for rectification and after consideration of such application, an environmental authorisation may be granted. "Environmental authorisation", when used in Chapter 5 of NEMA, means "*the authorisation by a competent authority of a listed activity or specified activity in terms of this Act, and includes a similar authorisation contemplated in a specific environmental management Act*".

The offence relates to the commencement of an activity listed or specified in terms of section 24(2)(a) or (b) of NEMA. This therefore includes the activities listed in terms of section 24 of NEMA. However, it does not include the waste management activities that were listed[23] in terms of section 19(1) of the Waste Act, the restricted activities as determined in the Biodiversity Act, or the water uses declared in terms of the Water Act.

There also do not appear to be any provisions relating to rectification of illegal activities in the context of river rehabilitation in any of the other legislation referred to above, other than provision in the NWA for a directive in terms of section 53 to compel rectification measures, but it does not include an "authorising" process as with section 24G. However, there are currently amendments proposed to NEMA that will widen the scope of section 24G to allow for the rectification of more than just illegally undertaken listed activities[24].

A.7. Conflicts and issues arising in the legislation

The Agricultural Resources Act

As described above, there are a number of control measures contained in the Regulations promulgated under CARA[25] affecting riparian areas that have been prescribed by the Minister of Agriculture which either contain a prohibition or an obligation, and which must be complied with by land users to whom they apply.

Where such control measures contain obligations, the potential for conflict arises where such activities also require other approvals in terms of the environmental legislation, such as environmental authorisations under NEMA or water use licences in terms of the Water Act. An example is control measure 13 in relation to the restoration and reclamation of eroded land, which requires that "[e]very land user shall by means of as many of the measures set out in regulations 4, 5 and 9 as are necessary in his situation, effectively restore or reclaim the land on his farm unit on which excessive soil loss due to erosion occurs or has occurred". Regulations 4, 5 and 9 contain various measures which in themselves constitute activities listed in terms of section 24 of NEMA and/or water use licences.

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[23] Published under Government Notice 718 in *Government Gazette* 32368 of 3 July 2009

[24] National Environmental Management Laws Second Amendment Bill [B13-2013].

[25] Published under Government Notice R1048 in *Government Gazette* 9238 of 25 May 1984

Control measure 16(2) regarding bush encroachment provides that "a land user of an area in which natural vegetation occurs and that contains communities of indicator plants shall follow practices to prevent the deterioration of natural resources and to combat bush encroachment where it occurs". The issue that arises is that many of the indicator plants listed are indigenous plants. This may be in contrast with the principles of the Biodiversity Act, and may trigger additional listed activities for the clearing of indigenous vegetation (e.g. Listing Notice 3, activities 12, 13. Activity 14 specifically excludes for agricultural purposes).

Control measure 15F deals with the application of other laws and provides that "[n]othing contained in this regulation shall derogate in any way from any obligation imposed on any land user in terms of any other law". This should be amended to refer to all the control measures and not just control measures contained in section15.

The definition "waterway" contained in the CARA Regulations should be included in the definition of "watercourse" in both NEMA and the Water Act. The GN 1048 Regulations of CARA define a waterway as meaning "an artificial flow path constructed on land in order to carry away run-off water without causing excessive soil loss". However, the definition of a "watercourse" in terms of the Water Act means -

(a) a river or spring;
(b) a natural channel in which water flows regularly or intermittently;
(c) a wetland, lake or dam into which, or from which, water flows; and
(d) any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse,
(e) and a reference to a watercourse includes, where relevant, its bed and banks".
(f) The transition from a watercourse to a waterway is "lost" between the two Acts. For example, the transfer canals in Clan William or Kamanassie, which are used for transferring water from a resource to farmers for agricultural uses, technically fall out of the definition in the NWA, but were built and operated by Department of Water Affairs, and now by Water User Associations in terms of the NWA. It is understood that irrigation furrows on a farm fall into the definition of "waterways". The effect hereof is that the canals or whatever is used to transfer the water from the watercourse to the waterway, is excluded from both CARA and the NWA.

It should be noted that neither soil conservation works nor irrigation improvement schemes fall within the realm of activity 18 listed in Listing Notice 1, i.e. NEMA Listing Notice 1, Activity 18 cannot be used to get around having to obtain an environmental authorisation in terms of NEMA.

While Activity 18 in Listing Notice 1 allows for an exemption from obtaining environmental authorisation if the activity is done for maintenance purposes in terms of an approved management plan, it will not be possible to request the Department of Water Affairs to dispense with the requirements for a water use licence in terms of section 22(3) of the NWA. Section 22(3) of the NWA requires some form of authorisation that will meet the purposes of the NWA, and we are of the opinion that the management plan referred to in Activity 18 will not be sufficient to qualify as such.

Activity 18 and section 21 of the NWA: you can remove 4,99 m^3 of soil and deposit it on the banks of the watercourse, if it is approved in terms of a management plan and you will require a water use license. However this activity will likely lead to channelling of the watercourse (the dumped material forming levees). In terms of NEMA, this activity will only require an approved management plan, which is not necessarily an Environmental Management Plan (which has minimum requirements in the NEMA), and the impact of the channelling of the watercourse may not be addressed in the Management Plan.

The CARA Regulations need to be updated: Control measure 7 refers to the old Water Act 54 of 1956, while Control measure 15 refers to the current NWA.

Public participation should be required for the approved management plan referred to in Activity 18 of Listing Notice 1.

There is no definition of “maintenance” as opposed to “expansion” in the NEMA Regulations. Maintenance cannot always be like-for-like. For example, where gabion baskets protecting a river bank have failed, the site may require the implementation of a concrete toe base first, then the re-construction of the gabion baskets. This is not necessarily an upgrade, i.e. the capacity or the area of impact has increased slightly, but the activity has not changed. However, if all the gabion baskets were replaced with a solid concrete embankment over the same reach of river, would this still fall under maintenance or would it be an upgrade?

THE WATER ACT

Additional authorisations from other legislation affected by NEMA activity 18 have already been discussed above. Activity 18 includes the infilling of 5 m^3. The composition of this material may trigger the Waste Act and the resultant impeding/diverting of the watercourse will require a water use licence, the cumulative impact of this action, which could include the complete impediment (daming) of a river, will only be assessed within the jurisdiction of the Water Act and not within the broader environment contained in the principles of NEMA if it is done in terms of the approved management plan.

WASTE ACT

As stated above, the temporary storage of material such as sediment that is removed from a river during maintenance and/or management would require a waste management licence. However, if the material that is removed from the river is “disposed” of to the land, it will also require a waste management licence unless one can show that the material is not “surplus, unwanted, rejected, discarded, abandoned or disposed of”, or for “which the generator has no further use of for the purposes of production”. Stockpiling or storage of the soil on the banks of the river is discussed above and is not recommended.

Should the sediment contain solid waste materials, whether from the site or washed from within the catchment, there may be additional issues arising such as: issues of littering (municipal bylaws) and environmental health (section 83(1) of the National Health Act 61 of 2003).

MINERAL AND PETROLEUM RESOURCES DEVELOPMENT ACT

In terms of the MPRDA prior to the coming into effect of the Mineral and Petroleum Resources Development Amendment Act 49 of 2008, ("the 2008 Amendment Act"), an applicant for a mining right had to prepare an environmental management programme ("EMPR") to assess the potential impacts of its operations on the environment and propose mitigation measures to minimise those impacts. However, on 7 June 2013, the 2008 Amendment Act came into effect[26], repealing and replacing various provisions. The Minister issued a further proclamation[27] on 6 June 2013 in which various sections of the 2008 Amendment Act were excluded from coming into effect, most notably, section 38B. The effect thereof inter alia is that section 39 of the MPRDA was deleted, being the section relating to environmental management programmes ("EMPRs"). If an application for a mining right is accepted in terms of section 22(4), the applicant is required to submit an EMPR "in terms of section 39".

Although section 39 has been repealed, as well as the definitions of EMPR, it appears that the DMR are still applying the section as if it had not been repealed and have apparently justified this with reference to section 11 of the Interpretation Act 33 of 1957, which states as follows: "When a law repeals wholly or partially any former law and substitutes provisions for the law so repealed, the repealed law shall remain in force until the substituted provisions come into operation". The debate however, is whether section 38B of the MPRDA, which has not yet come into effect, is a substitute provision for the repealed section 39.

In addition, section 38A which was inserted by the 2008 Amendment Act, is in effect and states inter alia that an "environmental authorisation issued by the Minister shall be a condition prior to the issuing of a permit or the granting of a right in terms of this Act". (Own emphasis). "Environmental authorisation" is defined as having "the meaning assigned to it in section 1 of National Environmental Management Act, 1998 (Act No. 107 of 1998)", ("NEMA"). In NEMA, "environmental authorisation when used in Chapter 5, means the authorisation by a competent authority of a listed activity or specified activity in terms of this Act, and includes a similar authorisation contemplated in a specific environmental management Act". The relevance hereof is that the activities listed in terms of section 24 of NEMA referring specifically to mining, are not yet in effect.

However, should any other activities listed in terms of section 24 of the National Environmental Management Act 107 of 1998 ("NEMA") that are currently in effect be undertaken in the course of mining activities related to river management and/or maintenance, or any other approvals be required in terms of any of the specific environmental management Acts, an "environmental authorisation" would be required for such activities.

[26] Proclamation No. 14 of 2013, Government Gazette No. 36512 of 31 May 2013.
[27] Proclamation No. 17 of 2013, Government Gazette No. 36541 of 6 June 2013.

Section 38A of the MPRDA also provides that the Minister is the responsible authority for implementing environmental provisions in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) as it relates to mining or activities incidental thereto on a mining area. Section 24C(2A) of NEMA states that "[t]he Minister of Minerals and Energy must be identified as the competent authority in terms of subsection (1) where the activity constitutes mining or a related activity occurring within a mining area". (Own emphasis)

It appears as though the Minister of Mineral Resources is therefore intended to be the responsible authority for the other activities listed in terms of section 24 of NEMA if such activities will also be undertaken during mining activities, as such activities could be regarded as being "activities incidental thereto on a mining area". The issue therefore is whether the Minister of Mineral Resources is therefore the authority that must consider and decide upon any applications for environmental authorisation that are incidental to any river rehabilitation and/or management where material will be removed from such river and sold, irrespective of whether a mining right or permit is applied for.

EMERGENCIES AND DISASTERS

The NWA, NEMA and the Disaster Management Act, Act 57 of 2002 (DMA) all provide for emergency and/or disaster situations. However, they all contain different definitions as well as different lead agents in the event of an emergency and/or disaster.

Section 28 of NEMA places a general duty of care on "[e]very person who … may cause significant pollution or degradation of the environment" to take reasonable measures "to prevent such pollution or degradation from occurring, continuing or recurring, or in so far as such harm is authorised by law, or cannot reasonably be avoided or stopped, to minimise and rectify such pollution or degradation of the environment". "Environment" in the MPRDA means "the environment as defined in the National Environmental Management Act, 1998 (Act No. 107 of 1998)".

"Pollution" is defined as meaning "any change in the environment caused by -

> (i) substances;
> (ii) radioactive or other waves; or
> (iii) noise, odours, dust or heat,
>
> emitted from any activity, including the storage or treatment of waste or substances, construction and the provision of services, whether engaged in by any person or an organ of state, where that change has an adverse effect on human health or wellbeing or on the composition, resilience and productivity of natural or managed ecosystems, or on materials useful to people, or will have such an effect in the future".

The measures required in terms of the above section (28(3)) include but are not limited to the following:

- investigate, assess and evaluate the impact on the environment;

- inform and educate employees about the environmental risks of their work and the manner in which their tasks must be performed in order to avoid causing significant pollution or degradation of the environment;
- cease, modify or control any act, activity or process causing the pollution or degradation;
- contain or prevent the movement of pollutants or the causant of degradation;
- eliminate any source of the pollution or degradation; or
- remedy the effects of the pollution or degradation.

Section 28(4) provides further that the Director-General, the Director-General of the department responsible for mineral resources, or a provincial head of department, may, after having given adequate opportunity to affected persons to inform him or her of their relevant interests, direct any person who is causing, or may cause significant pollution or degradation of the environment to-

(a) cease any activity, operation or undertaking;
(b) investigate, evaluate and assess the impact of specific activities and report thereon;
(c) commence taking specific reasonable measures before a given date;
(d) diligently continue with those measures; and
(e) complete them before a specified reasonable date".

If urgent action is necessary for the protection of the environment, the Director-General or a provincial head of department may issue such a directive, and consult and give such opportunity to inform as soon thereafter as is reasonable.

Section 30[28] of NEMA could also apply in a situation that is regarded to be an emergency "incident". Section 30(6) provides that the responsible authority can issue such a directive where the person responsible for the incident fails to fulfil its obligations in terms of the prescriptions contained in section 30(4) and (5). The term "emergency" is not defined, but according to the definition in NEMA, an "incident" must satisfy the following cumulative requirements:

- It must be unexpected, (not expected/surprising) sudden, (without warning/abrupt) occurrence (of which major emissions, fires and explosions are three examples); and
- It must lead to serious danger to the public; or
- It must lead to potentially serious pollution of or detriment to the environment;

irrespective of whether the above effects are immediate or delayed.

The "responsible person" to whom the directive can be issued includes any person who:

- is responsible for the incident;
- owns any hazardous substance involved in the incident; or

[28] Note that there are proposed amendments in the National Environmental Management Laws Second Amendment Bill (B13-2013) that will affect this section.

- was in control of any hazardous substance involved in the incident at the time of the incident.

The relevant authorities that can issue such a directive include a municipality with jurisdiction over the area in which an incident occurs. It can also be issued by the provincial head of department or any other provincial official designated by the MEC, the Director-General of DEA, or any other Director-General of a national department, as they are all included in the definition of "relevant authority". This will therefore include the Director-General of the DWS and the Director-General of the DMR. In terms of section 30(2) such a directive can however, only be issued by these other authorities in some instances. The Director-General of a national department can only issue such a directive where all the other parties mentioned have failed to do so.

A directive may be issued where an emergency incident took place and the responsible person failed, as soon as reasonably practicable after knowledge of the incident, to:

- take all reasonable measures to contain and minimise the effects of the incident, including its effects on the environment and any risks posed by the incident to the health, safety and property of persons;
- undertake cleanup procedures;
- remedy the effects of the incident;
- assess the immediate and long-term effects of the incident on the environment and public health;

  and/or

- where an emergency incident took place, and the responsible person failed, within 14 days of the incident, to report to the relevant authority such available information so as to enable an initial evaluation of the incident, including:
  - the nature of the incident;
  - the substances involved and an estimation of the quantity released and their possible acute effect on persons and the environment and data needed to assess these effects;
  - initial measures taken to minimise impacts;
  - causes of the incident, whether direct or indirect, including equipment, technology, system, or management failure; and
  - measures taken and to be taken to avoid a recurrence of such incident.

On 18 December 2014, sub section 30A was included to provide direction for emergency situations. Here emergency situation was described (30A(7)) as a situation that has arisen suddenly that poses an imminent and serious threat to the environment, human life or property, including a 'disaster' as defined in section 1 of the DMA, but does not include an incident referred to in section 30 of NEMA. This provision states that "the competent authority may, on its own initiative or on written oral request from a person, direct a person verbally or in writing to carry out a listed or specified activity, without obtaining and environmental authorisation contemplated in section 24(2)(a) or (b), in order to prevent or contain an emergency situation or to prevent, contain or mitigate the effects of the emergency situation".

To this extent, the person requesting permission must at least include, where known –

(a) the nature, scope an possible impact of the emergency situation;
(b) the listed or specified activities that will be commenced with in response to the emergency situation;
(c) the cause of the emergency situation; and
(d) the proposed measures to prevent or to contain the emergency situation or to prevent, contain or mitigate the effects of the emergency situation.

The consideration of the above, along with the principles indicated in section 2 of the Act and the associated risks of the impact on the environment, shall result in the competent authority directing the person to undertake specific measures within a specific time period in order to prevent or contain an emergency situation or to prevent, contain or mitigate the effects of the emergency situation. Should this occur verbally, the directive must be confirmed in writing as soon as possible, within seven days. If the competent authority decides not to issue a directive as described above, then the activity may not commence without an environmental authorisation.

Section 19 of the NWA deals with prevention and remedying the effects of pollution, creates a general duty of care similar to the one contained in section 28(4) of NEMA and provides as follows:

"An owner of land, a person in control of land or a person who occupies or uses the land on which -

(a) any activity or process is or was performed or undertaken; or
(b) any other situation exists,

which causes, has caused or is likely to cause pollution of a water resource, must take all reasonable measures to prevent any such pollution from occurring, continuing or recurring".

The measures may include measures to –

- cease, modify or control any act or process causing the pollution;
- comply with any prescribed waste standard or management practice;
- contain or prevent the movement of pollutants;
- eliminate any source of the pollution;
- remedy the effects of the pollution; and
- remedy the effects of any disturbance to the bed and banks of a watercourse.

This directive may be issued where any person on whom the general duty described above fails to take reasonable measures to prevent pollution of a water resource from occurring, continuing or recurring. The person may be directed to:

- commence taking specific actions before a given date that are measurable;

- diligently continue with those actions; and
- complete them before a given date.

Note that there must be pollution before such a directive may be issued but that the threshold is lower than that of NEMA that requires the pollution to be "significant". Directives in terms of section 20 of the NWA however, may be issued for potential as opposed to actual pollution, or where there is likely to be a detrimental effect on a water resource.

"Pollution" is defined differently in the NWA (as opposed to NEMA and the MPRDA) as meaning "the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it -

(a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or

(b) harmful or potentially harmful -

(aa) to the welfare, health or safety of human beings;

(bb) to any aquatic or nonaquatic organisms;

(cc) to the resource quality; or

(dd) to property".

This directive may be issued by the relevant catchment management agency or the Regional Director of the appropriate Regional Office as delegated by the Minister of Water Affairs in terms of section 63 of the NWA. Section 72 states that in areas for which a catchment management agency is not established or, if established, is not functional, all powers and duties of a catchment management agency, vest in the Minister of Water Affairs.

Part 5 of the NWA deals with pollution of water resources following an emergency incident, such as an accident involving the spilling of a harmful substance that finds or may find its way into a water resource. The responsibility for remedying the situation rests with the person responsible for the incident or the substance involved.

The following definitions are relevant:

- "incident" includes any incident or accident in which a substance pollutes or has the potential to pollute a water resource; or has, or is likely to have, a detrimental effect on a water resource.
- "responsible person" includes any person who –
  - is responsible for the incident;
  - owns the substance involved in the incident; or
  - was in control of the substance involved in the incident at the time of the incident.

This directive may be issued in terms of section 20 of the Water Act where there is an incident, i.e. any incident or accident in which a substance –

- pollutes or has the potential to pollute a water resource; or
- has, or is likely to have, a detrimental effect on a water resource.

This directive may be issued by the relevant catchment management agency or the Chief Director of the appropriate Regional Office as delegated by the Minister of Water Affairs in terms of section 63. Section 72 states that in areas for which a catchment management agency is not established or, if established, is not functional, all powers and duties of a catchment management agency, vest in the Minister of Water Affairs. The Minister has delegated the power to issue these directives in terms of section 63:

- The Regional Deputy Director has been delegated the power to issue a verbal directive;
- The Regional Director has been delegated the power to confirm a verbal directive; and to issue a written directive in terms of section 20(4)(d).

The responsible person can be directed verbally or in writing to take any measures that the catchment management agency may either verbally or in writing direct, within the time specified by such institution. This would typically include:

- All reasonable measures to contain and minimise the effects of the incident;
- Undertaking cleanup procedures; and
- Remedying the effects of the incident.

The NEMA now includes a definition of "emergency" however it is not defined in the NWA. Both Acts however define "incident". There does not appear to be a conflict between these definitions, which would allow both directives in terms of Section 20 of the NWA and Section 30 of NEMA to be issued simultaneously if necessary. However, the conflict could arise as to what is stipulated in such directives as to what the person(s) being directed, must do, and there is a difference as to who issues these directives. The issuing authorities must ensure that they consult with each other first to a) ensure that they do not issue conflicting directives, and b), not inadvertently contain a provision in such directives that would first require some form of authorisation from another department/Organ of State, without first consulting with such Organ of State.

Section 67 of the NWA provides that in an emergency situation, or in cases of extreme urgency involving the safety of humans or property or the protection of a water resource or the environment, the Minister may dispense with the requirements of the NWA relating to prior publication or to obtaining and considering public comment before any instrument contemplated in section 158(1) of the Water Act is made or issued. This includes the issuing of any directives, including an urgent directive in terms of Section 20 of the NWA, and the provisions that may be disregarded, including provisions as to public participation as well as any time periods that may be required. In effect, Section 67 allows the Minister to authorise the authority issuing an emergency directive to dispense with the requirements for public participation. NEMA's emergency directive does not explicitly allow for these requirements to be dispensed with but does provide that it is a defence to an offence under Section 24F if a listed activity was undertaken without an environmental authorisation if it was undertaken in response to an emergency, so as to protect human life, property or the environment. If read with the Promotion of Administrative Justice Act 3 of 2000, ("PAJA") there would still have to be some form of public participation even after an urgent directive is issued. We are not convinced that Section 67 of the NWA doesn't conflict with PAJA – which was promulgated after the NWA.

The whole of the Disaster Management Act 57 of 2002 ("DMA") is relevant, and makes provision inter alia for disaster management frameworks, disaster management plans and strategies to be drafted, the contents of which could potentially conflict with the requirements of, for example NEMA, if a listed activity needs to be undertaken urgently without an EIA, because as stated above, as NEMA does not make provision for the undertaking of listed activities in emergency situations.

However, section 2 states that the DMA does not apply inter alia " to an occurrence falling within the definition of "disaster" in section 1", which defines "disaster" as "a progressive or sudden, widespread or localised, natural or human-caused occurrence which-

(a) causes or threatens to cause-
  - (i) death, injury or disease;
  - (ii) damage to property, infrastructure or the environment; or
  - (iii) disruption of the life of a community; and

(b) is of a magnitude that exceeds the ability of those affected by the disaster to cope with its effects using only their own resources…to the extent that that occurrence can be dealt with effectively in terms of other national legislation-
  - (i) aimed at reducing the risk, and addressing the consequences, of occurrences of that nature: and
  - (ii) identified by the Minister by notice in the Gazette.

It is clear from the above that there are different definitions, and also that there could be confusion surrounding who the lead department would be in such a situation.

The development of a comprehensive manual for river rehabilitation in South Africa

VOLUME 2:

TECHNICAL MANUAL

Report Prepared by:

Liz Day (The Freshwater Consulting Group)

Hans King (Department of Agriculture in the Western Cape)

Mark Rountree (Fluvius Environmental Consultants)

FCG

Western Cape Government
Agriculture

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Managing water for the environment

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- Mr B Madikizela (Water Research Commission) – Chair of Reference Group
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- Mr Chris Brooker (Chris Brooker and Associates)
- Ms L Hill (CSIR NRE)
- Ms SM Braid (AURECON)
- Mr IP Bredin (INR)
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ACRONYMS

IAP	Invasive alien plants
CMA	Catchment Management Agency
DEA	Department of Environmental Affairs
DEADP	Western Cape Dept. of Environmental Affairs and Development Planning
DWA	Department of Water Affairs (name change from DWAF applicable after April 2009)
DWAF	Department of Water Affairs and Forestry (until 2009)
DWS	Department of Water and Sanitation (Name change from DWA applicable after May 2014)
EIA	Environmental Impact Assessment
MAR	Mean Annual Runoff
MASL	Metres Above Sea Level
NFEPA	National Freshwater Ecosystem Priority Area
NWA	National Water Act
PES	Present Ecological State
SANBI	South African National Biodiversity Institute
SASS	South African Scoring System (an instream invertebrate biomonitoring tool)
WfWetlands	Working for Wetlands
WMA	Water Management Area
WULA	Water Use Licence Application – relating to Section 21 Water Uses in the National Water Act

GLOSSARY

Active channel bank: the bank of the channel(s) that has been inundated at sufficiently regular intervals to maintain channel form and to keep the channel free of established terrestrial vegetation.

Alluvial soil: a deposit of sand, mud, etc. formed by flowing water, or the sedimentary matter deposited thus within recent times, especially in the valleys of large rivers.

Anastomosing: a river reach pattern or type where multiple channels flow along faults or weaknesses of underlying bedrock. These steep channels are separated by large, stable, vegetated islands which are very seldom inundated**Bar**: accumulations of sediment associated with the channel margins or bars forming in meandering rivers where erosion is occurring on the opposite bank to the bar.

Base flow: long-term flow in a river that continues after storm flow has passed.

Braided: a river reach pattern or type characterised by high sediment deposition rates, where multiple channels flow across a usually wide valley, separated by alluvial eye or teardrop shaped sedimentary bars. These bars may be bare or vegetated. Most would be inundated by annual floods, and the pattern would be fairly dynamic in that channels would move and switch, driven by the deposition of sediment

Buffer: a strip of land surrounding a wetland or riparian area in which activities are controlled or restricted, in order to reduce the impact of adjacent land uses on the wetland or riparian area.

Catchment: the area contributing to runoff at a particular point in a river system.

EcoClassification: This is a procedure to determine and categorise the ecological state of various biological and physical attributes compared to the reference state. The procedure of EcoClassification describes the health of a water resource and derives and formulates management targets / objectives / specifications for the resource. This provides the context for monitoring the water resource within an adaptive environmental management framework. The classification ranges from A (natural) to F (highly impacted).

EcoRegions: "Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources", and are designed to serve as a spatial framework for the research, assessment, management and monitoring of ecosystems and ecosystem components (US EPA). Several levels or scales of EcoRegions can be delineated (e.g.: Level I low resolution/detail; Level III high resolution and detail). In South Africa, EcoRegions form the basis of the River Health monitoring assessments.

EcoStatus: The overall PES or current state of the resource. It represents the totality of the features and characteristics of a river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and its capacity to provide a variety of goods and services. The EcoStatus value is an integrated ecological state made up of a combination of various PES findings from component Ecostatus assessments (such as for invertebrates, fish, riparian vegetation, geomorphology, hydrology and water quality).

Ephemeral stream: a stream that has transitory or short-lived flow.

Floodplain: a relatively level alluvial (sand or gravel) area lying adjacent to the river channel, which has been constructed through deposition of alluvial (water-transported) sediments by the watercourse. Typical floodplains generally have a meandering river channel which overtops its banks during flood events resulting in the floodplain being saturated for extended periods of time. Meandering usually develops upstream of a local (e.g. resistant dyke) base level, or close to the mouth of the river (upstream of the ultimate base level, the sea) . Ox-bows or cut-off meanders – evidence of meandering – are often present on the floodplain.

Groundwater: Subsurface water in the zone in which permeable rocks, and often the overlying soil, are saturated under pressure equal to or greater than atmospheric pressure

Habitat: the natural home of species of plants or animals.

Hydrology: the study of the occurrence, distribution and movement of water over, on and under the land surface.

Infilling: dumping of soil or solid waste onto the wetland surface. To fill in a wetland (or riparian area) in order to raise the ground level above the flooding or saturated zone; usually for the purposes of construction. Infilling generally has a very high and permanent impact on wetland functioning and is similar to drainage in that the upper soil layers are rendered less wet, usually so much so that the area no longer functions as a wetland.

Macro channel: Over much of southern Africa, uplift in the recent geological past and subsequent incision has caused many rivers to flow within an incised 'floodplain', outside of which flood flows have no recorded influence. This incised feature (essentially a "restricted floodplain") has been termed the macro-channel.

Mid-channel bar: single bar(s) formed within the middle of the channel; flow on both sides.

Peat: a dark brown or black organic soil layer, composed of partly decomposed plant matter, and formed under permanently saturated conditions.

Perched water table: The upper limit of a zone of saturation in soil, separated by a relatively impermeable unsaturated zone from the main body of groundwater

Platform: The elevated surface of an infilled area of wetland or riparian zone. Platforms are often constructed using ex-situ material which is used to increase the ground level height in order to reduce flooding or saturation of the soils. Platforms can then be used for construction of residential or commercial properties, or for cultivation of crops.

Reference State (also Reference Condition): The natural or pre-impacted condition of the system. The reference state is not a static condition, but refers to the natural dynamics (range and rates of change or flux) prior to development.

Rehabilitation*:* an intervention that promotes the recovery of ecosystem functions and values in a degraded system in order to regain some of the value the system previously had to society (Dunster and Dunster 1996)

Remediation: Improving the current state of an ecosystem without reference to its initial state (Petts *et al.* 2000)

Restoration: manipulation of a site in order to revert the watercourse back to its full range of natural (historic) processes and functions (National Ocean Service and National Marine Fisheries Service 2002; US EPA 2003)

Riparian habitat (as defined by the National Water Act): includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils (deposited by the current river system), and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas.

Runoff: surface runoff from rainfall which can then enter in to the stream channel network.

Sedges: grass-like plants belonging to the family Cyperaceae, sometimes referred to as nutgrasses. Papyrus is a member of this family.

Terrace: area raised above the level regularly inundated by flooding (infrequently inundated).

Watercourse (as defined by the National Water Act): means

a) a river or spring;
b) a natural channel in which water flows regularly or intermittently;
c) a wetland, lake or dam into which, or from which, water flows; and
d) any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes where relevant, its bed and banks.

Wetland (as defined by the National Water Act): land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which under normal circumstances supports or would support vegetation typically adapted to life in saturated soil.

1 INTRODUCTION

1.1. Background and objectives

Recognising that an integrated guideline to identify locally appropriate river rehabilitation objectives and structures would enable more effective protection of watercourses, the WRC has funded a project to develop national guidelines for river rehabilitation, in the form of a technical **River Rehabilitation Manual**, a Decision Support system, presented as **Rehabilitation Guidelines**, to guide would-be rehabilitation implementers in the selection of the most appropriate and legally compliant rehabilitation approach to a particular problem, and a selection of **Rehabilitation Case Studies**, illustrating particular aspects of river rehabilitation that are discussed in the previous two documents.

This document comprises the ***Technical Manual for River Rehabilitation***. It is intended to provide clear, practical guidelines to the implementation of a wide range of rehabilitation and remediation activities that are of relevance in South Africa, and which take cognisance of legal, social, economic and ecological issues and aspects that affect river management options and opportunities. The Technical Manual is intended for use by readers who have already accessed the Rehabilitation Guidelines (Volume 1), and used the latter to arrive at an informed, rational decision as to which is the most practical, financially affordable, legally defensible and ecologically acceptable option or options for their particular circumstances, as well as an understanding of the advantages, trade-offs and opportunity costs implicit in the selection.

The Rehabilitation Guidelines constitute **Volume 1** of the overall River Rehabilitation Manual outputs, while the Technical Guidelines (the present document) comprise **Volume 2**.

1.2. Manual structure

Figure 1.1 provides a schematic overview of the contents of this document (the Technical Manual – Volume 2), and its links to the Rehabilitation Guidelines (Volume 1).

Figure 1.2 provides a similar schematic to show how the various chapters in both the Rehabilitation Guidelines and the Technical Manual link to Volume 3 (Rehabilitation Case Studies), and which Case Studies are most relevant in illustrating principles, concepts and approaches in different chapters.

1.3. Intended users of the Technical Manual

The Technical Manual, like the Rehabilitation Guidelines, is intended for use by a range of groups / individuals involved in rehabilitation activities, from private landowners, usually operating at the site or reach level of a river, through to the various river "Friends" groups, often operating on whole rivers or at least the reach scale, to organisation / institutions engaged in rehabilitation planning, design and implementation, including Working for Wetlands and Working for Water groups, Land Care, the Department of Agriculture, Forestry and Fisheries, various municipalities engaged in activities affecting rivers, some of which lend themselves to opportunistic or other rehabilitation approaches, and enforcement officers (Department of Water and Sanitation (DWS), Department of Environmental and Development Planning / other Departments of Environmental Affairs) required to assess or recommend rehabilitation activities and/or objectives.

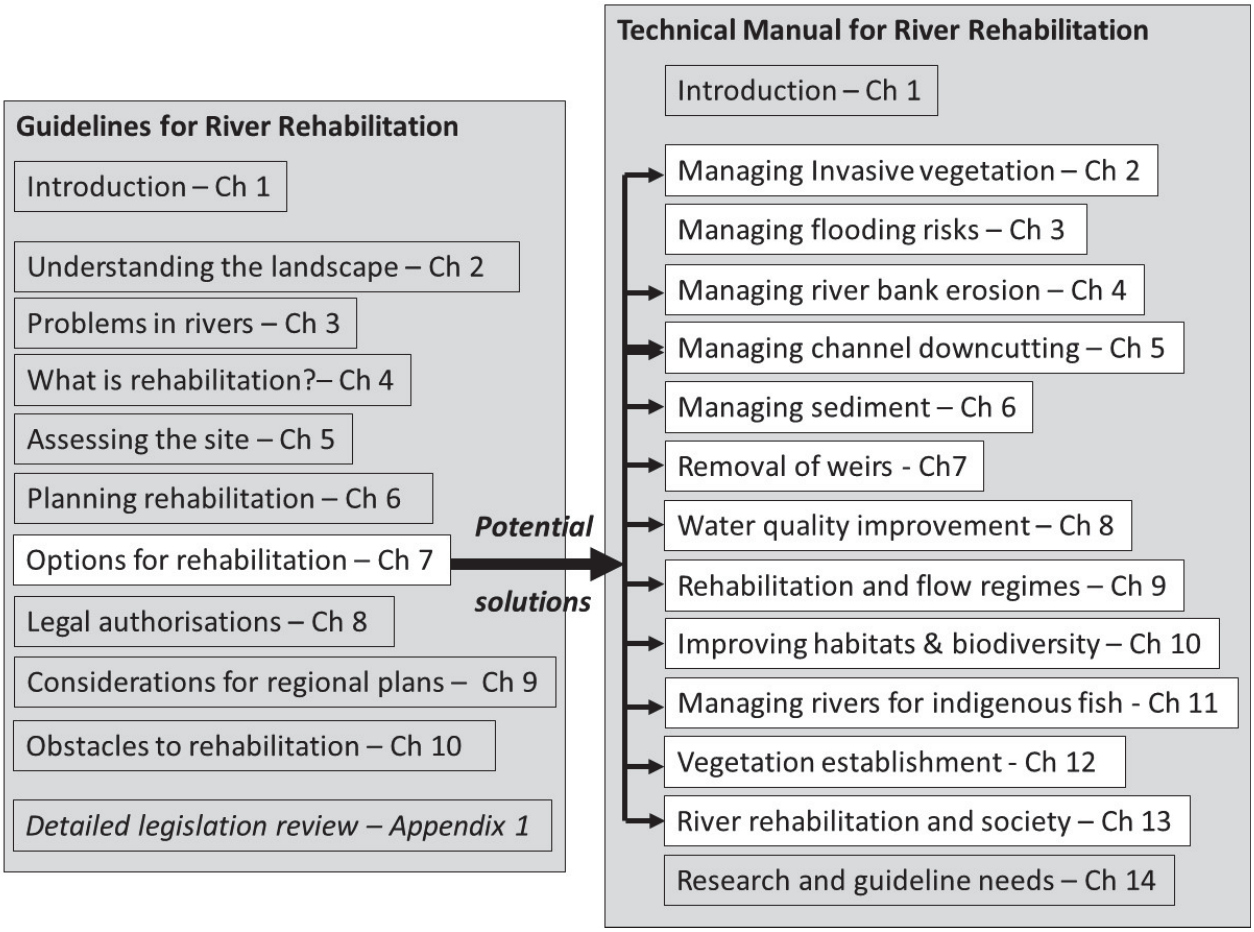

Figure 1.1: Structure of the Technical Manual (this document) and its links to Rehabilitation Guidelines

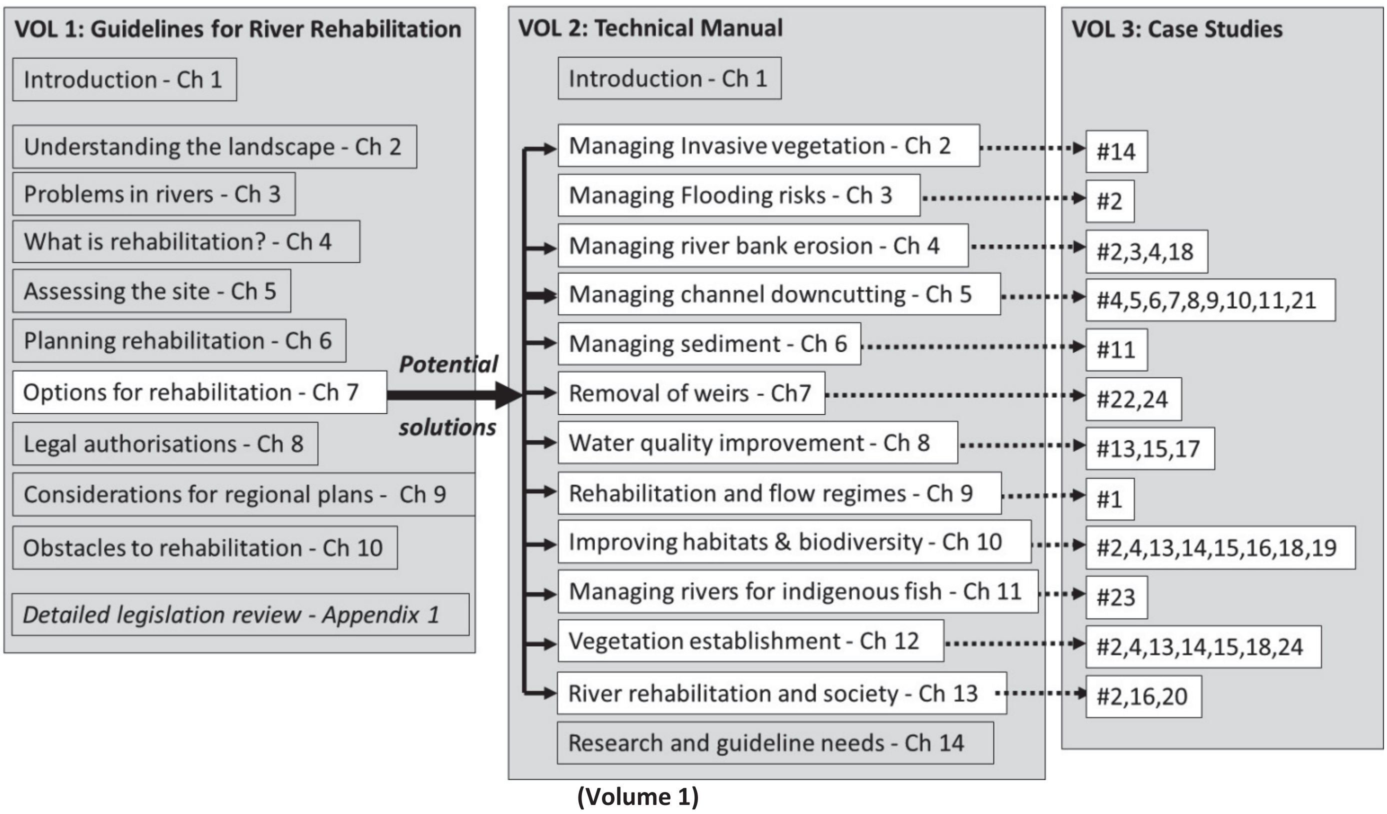

Figure 1.2: Links between the Technical Manual (this document), the Rehabilitation Guidelines (Volume 1) and the Rehabilitation Case Studies (Volume 3)

1.4. How to use this manual

The Technical Guidelines are intended to be referred to in the context of the information provided in the Guidelines (Volume 1) regarding natural river function and dynamics, the key problems affecting river condition, and principles and considerations to apply when planning and implementing rehabilitation. The main idea underlying this approach is to provide end users with sufficient background information for them to be able to make reasonable assessments of the cause of the problem(s) affecting a particular river, and to make informed decisions as to the most feasible and ecologically acceptable approach(es) to addressing it.

The Rehabilitation Case Studies (Volume 3) should be referred to for illustrations of some general river rehabilitation approaches, as well as to assist in finding common ground between a particular problem encountered by a reader, and various sites, problems and approaches that are reflected in the Case Studies.

1.5. Aquatic Ecosystems addressed in the Manual

The overall project addresses rehabilitation with regard to rivers, rather than to wetlands. The National Water Act (Act 98 of 1998) does not however define rivers, other than to include them in the general definition of a watercourse, cited as meaning:

> *(a)* a river or spring;
> *(b)* a natural channel in which water flows regularly or intermittently;
> *(c)* a wetland, lake or dam into which, or from which, water flows; and
> *(d)* any collection of water which the Minister may, by notice in the *Gazette,* declare to be a watercourse.

The scope of systems covered in the project has been assumed to extend to all channeled and channelised inland aquatic ecosystems, including channeled valley bottom and floodplain wetlands, as defined by the National Wetlands Classification System (SANBI 2013). To some extent it also covers artificial stormwater drains and canals, where some level of aquatic ecosystem function is attainable for these systems.

1.6. Important limitations

The Technical Guidelines presented in this Manual have been formulated on a fairly generic basis, and without reference to particular sites or river systems. Users are urged to consult with specialists with the appropriate (recommended) level of skills and experience when deciding on rehabilitation options or preparing and implementing detailed designs. Where there is any doubt with regard to identification of river condition, drivers of degradation, or the most appropriate rehabilitation approach, implementers are furthermore urged to consult more widely with experienced personnel.

The three manuals together aim to introduce the reader and potential implementers to issues which should be considered when planning to undertake rehabilitation activities (Volume 1), a range of potential interventions that should be evaluated for their potential to address the rehabilitation objective/s being addressed (Volume 2 (this volume)) and examples of past case studies.

The manuals in no way dispense with the need for legal authorisations that are required to implement rehabilitation actions (See Chapter 10 and Appendix 1 of the Guidelines Document for further detail), nor with the need for specialist insight or engineering design where these specialist skills are necessary. The Guidelines and Technical Manuals attempt at all times, however, to indicate where such advice and authorisations should be obtained.

1.7. Costs of not rehabilitating

Although most of this document focuses on the ecological, biodiversity and financial costs of rehabilitation, it should be stressed that in many cases, failure to implement appropriate rehabilitation activities timeously can also have tremendous costs, often orders of magnitude greater than the costs of early intervention, and resulting at best in stabilizing the degradation process, with no chance of returning the system to its original condition.

Remember that it is easy, fast and cheap to damage natural streams, but difficult, slow and expensive to return them to their natural conditions (Rutherford et al. 2001).

Chapter 2:

Managing Invasive Plants

Author: Liz Day (Freshwater Consulting Group)

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Introduction

This section has been divided into recommended approaches for the management of invasive **alien** plant species (Section 2.2) and guidelines for the management of invasive **indigenous** plant species (Section 2.3). This separation stems primarily from the fact that although the objectives of invasive plant control are usually the same for alien versus cosmopolitan and indigenous plant species, the legal imperatives affecting such activities are often quite different. In addition, the factors driving invasion by alien plants are also often very different to those resulting in actual or perceived invasion by indigenous species and as a result, best practice approaches to these issues may also be different. For all of these reasons, the issues have been separated.

> **Useful functions performed by riverine plants**
>
> Although this section focuses on the need to remove various riverine plants, remember that indigenous plants play important roles in and along rivers, and should not be removed unless it is quite certain that they are exerting a deleterious effect on natural river function. Plants stabilise the river bank and bed, slow down floods, provide shade, cover and habitat for riverine fauna and can contribute functions such as trapping of sediment and the trapping or uptake of heavy metals and nutrients.

Relevance of plant control

Section 3.2 of the Rehabilitation Guidelines (Volume 1 of this Manual) describes how invasive alien vegetation can result in the following impacts to river systems, often associated with ecological, economic, management and landuse opportunity costs:

- Decreased stream flow
- Promoting seasonal rather than perennial rivers
- Increasing sediment supply to rivers
- Increasing channel and bed erosion in high flows
- Altering channel shape through
- Reducing plant and animal biodiversity by altering habitat type
- Changing soil and water chemistry including nutrient availability
- Promoting invasion by alien animals (e.g. alien fish species) by changing habitat
- Increasing instream shading, creating cooler water and increasing shelter for alien (or indigenous) fauna.

> DID YOU KNOW?
>
> **Ecological effects of streamflow reduction**
>
> The ecological effects of streamflow reduction are generally most apparent during the dry season, when particularly smaller systems are naturally water stressed.
>
> Streamflow reduction as a result of invasive (indigenous and alien) plants can reduce dry season flows to the point where the river changes from a perennial to a seasonal system – a fundamental distinction in ecosystem type, and one that can have tremendous impacts on instream biodiversity, particularly in naturally perennial rivers where indigenous fauna often lack adaptations to survive / escape from periodic drying out of the river.
>
> Even where dry season baseflows remain, reduced flows may alter temperature regime and result in the encroachment into the channel of other weedy and/or alien plant species.

Control of Invasive Alien Plant Species

Identifying situations where invasive alien plants are drivers of river degradation

A number of factors may indicate that invasion by alien plants is a contributing or primary cause of river degradation, noting that they do not need to occur on the site or even in the affected reach to result in problems, but may be upstream or upslope of the affected area. Look for signs of the following:

- Increased sediment in the river channel
- Lining of the river bank by invasive alien trees, that might confine flows in flood conditions
- Extensive invasive alien invasion at a catchment or sub-catchment level – use tools such as GOOGLE historical imagery to note changes in extent over time
- Obstruction of the river bed with felled trees / large branches
- The presence of large logs / branches along the river bank, deflecting stream flows onto the opposite bank or increasing stream velocities
- Decreases in dry season stream flows over time, and possible encroachment of terrestrial plant species into flood channels and the river margins
- Debris dams against bridges or culverts, characterized by large sediment loads and/or woody debris comprising alien trunks and branches
- Smothering of riverine vegetation by invasive alien plants, including weedy creepers
- Establishment of young trees on islands and sand bars, previously non-existent or temporary features that washed away in floods.

Which invasive alien plant species are of most concern?
Appendix 2.1 lists the river and wetland associated invasive alien plant species as included in the NEMBA AIS lists (see Section 8, Volume 1), their growth form, modes of dispersal and main means of control.

More details on the effects of invasive alien plants on river function can be found in Volume 1 (Section 3.2).

A structured approach to invasive alien plant control

2.1.1. Planning Invasive Alien Plant Removal

Setting objectives

As with any rehabilitation process (see Volume 1: Section 6), the objectives of invasive alien plant clearing must be clear at the start. This requires an understanding of the extent of the invasion, the different species invading the area and the effects of invasive alien plants on the river in the particular river reach under consideration. In addition, although most landowners are unlikely to be able to undertake clearing of invasive alien plants at a catchment scale, an understanding of the role and extent of invasive alien vegetation in the broader catchment is also important in planning an approach to clearing invasive alien plants at a site or reach level.

Common aims in removal of invasive alien vegetation in river rehabilitation include:

- To create space in which to address bank erosion (see Chapters 4 and 10);
- To increase space for flood alleviation (see Chapter 3);
- To rehabilitate a more natural river flow regime by releasing trapped sediments and allowing erosion processes to restore natural river levels (Chapters 6 and 10;
- To prevent erosion as a result of channel confinement and bank undercutting (Chapters 5 and 10);

- To improve biodiversity by allowing the establishment / generation of natural indigenous riverine flora (Chapters 10 and 12);
- To improve dry season stream flow (Chapter 9);
- To improve access to the river bank or water;
- To revitalise the natural disturbance regime of a river, and allow natural erosion of sediments that otherwise accumulate against encroaching alien plants.

Rember – Avoidance is the best form of control!

Preventing invasion of riverine areas by alien plants is by far the most cost-effective manner of invasive alien plant management. Prevention methods include:

- Ensure that planting / landscaping of riverine and adjacent areas does not make use of species that are likely to be invasive and create management problems later – check a plant guide before purchasing or establishing new species, to ensure that it is not invasive in your area;
- Familiarise yourself with invasive alien species in your area, to help with early recognition;
- Acquire a comprehensive guide to invasive alien plant species, to assist with species identification;
- Ensure that any new species appearing and apparently thriving in riverine areas on your property is properly identified – use local expertise such as botanists or conservationists, to assist;
- When an emerging invasive alien plant is identified on your site, prioritise activities to ensure its removal before it reaches a stage of establishment where it sets seed or starts to alter habitat;
- Be vigilant in controlling activities associated with high levels of risk of accidental importation and introduction of invasive alien plant propagation material. Such activities include:
    - Imports of soils / other material for infill – unless the source area can be shown to have been uncontaminated by invasive alien plants, it should be as assumed that such material includes invasive alien propagation material
    - Imports of potted or bagged plants for landscaping projects
    - Compost or mulch.

Where to begin? Deciding on focus areas for invasive alien plant clearing

Invasive plant management includes the systematic control of invasive plants on a site or a reach over a period of time until the objectives are achieved. It also includes a species approach where species are prioritized for control. Some invasive plants are more aggressive and damaging than others and should be controlled at shorter intervals than the schedule for other invasive plants at the site or reach where they occur (e.g. *Ageratina adenophora* (Crofton weed)).

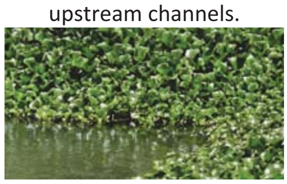
Clearing of the following areas should be prioritized (eThekwini 2014):

- Woody invasives that pose fire risks to houses or infrastructure (e.g. water pipelines, pylons, etc.) – fire breaks should first be created between invasive alien plant stands and such areas;

Clear more not less!

While this Manual focuses on river rehabilitation, it is emphasized that alien clearing should not be limited to riverine areas, as some species are able to invade across both terrestrial and riparian areas. If only riverine areas are cleared, they will be subject to ongoing re-invasion from adjacent zones.

Similarly, clearing of invasive water hyacinth from lakes and river channels is most successful when a catchment approach is taken, and the plant is cleared from all upstream channels.



Invasive water hyacinth

- Riparian areas, starting from the head of the catchment / most upstream extent of the valley on the site and moving downstream – clearly such measures are most effective when invasive alien plant clearing is undertaken at the level of a catchment rather than a site;
- Riparian areas, moving from upwind to downwind – this applies to plants that are spread primarily by windblown seeds (e.g. most *Acacia* species);
- Areas of light infestation should be tackled before areas of heavy infestation, to minimise net habitat alteration.

[1]*Planning and preparation*

Essential to effective invasive alien plant clearing is adequate planning and preparation, incorporating the following aspects:

- Surveying of the site / area to be addressed, to allow accurate identification and, in the case of large sites, mapping of infected areas – such surveys should be carried out by an experienced person, competent to identify alien and indigenous species;
- Identifying priority invasive plant species for control;
- Identification of sensitive indigenous vegetation that should be protected during invasive plant clearing operations – again, a suitably experienced person with botanical knowledge should make this assessment. Marking of individual trees or stands of vegetation should take place to guide workers on site during invasive alien plant clearing and prevent accidental damage. Danger tape or paint markings can be used for marking;
- Identification of areas that should be protected from mechanical disturbance – in some areas (e.g. fynbos renosterveld), areas that have high levels of alien plant infestation may retain valuable seedbanks of indigenous plants, that will be destroyed if the soil surface is ploughed or churned up during mechanical removal of invasive alien plants. <u>In order to prevent this, areas that do not have a history of ploughing or cultivation should be redflagged, and the applicability of this concern specifically considered;</u>
- Identification of the most appropriate clearing method or combination of methods, that take account of the species requiring control, the specific conditions of the site and the circumstances of the landowner;
- Identify and obtain the necessary field and personal protective equipment for the selected clearing method(s), including herbicides;
- Identify training needs for clearing workers and supervisors (e.g. herbicide application, use of chain saws, etc.);
- Identify approaches and areas for the disposal of cleared plant material;
- Prepare an accurate estimate of the financial costs of clearing, and ensure that there are sufficient funds to achieve a successful outcome. Rather clear a smaller area and ensure resources are available to follow up and maintain the area than clearing a large area and abandon clearing due to a lack of funding for follow up and maintenance. Initial clearing operations are the most costly and control cost gradually reduce over time.

Phasing

Where alien vegetation is valued for its aesthetic appeal or other useful functions (e.g. windbreak, view shielding / privacy) phased invasive alien removal should be considered, with suitable indigenous (or at least non-invasive alien) plants being planted beneath or around clusters of invasive alien trees ear marked for removal, and invasive alien trees only being removed once indigenous vegetation has established and is providing similar levels of function.

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[1] Note that this section has been adapted from the eThekwini Municipality's guideline document for General Invasive Alien Plant Control (c)

Phasing of invasive plant alien clearing activities does however carry risks, and should be discouraged if the following apply:

- When invasive alien trees are highly invasive and remnant stands will spread into cleared areas, negating such efforts
- Where invasive alien trees are contributing to ongoing river degradation – e.g. constricting river flows and leading to bank or bed erosion (see Box 2.5);
- Where later removal or felling of invasive alien vegetation will negatively affect re-established or remnant indigenous vegetation;
- Where retention of invasive alien vegetation along the river bank / riparian area prevents other rehabilitation activities (e.g. bank reshaping and planting);
- When phasing results in additional and unacceptable costs that may make subsequent removal of plants unlikely.

Addressing alien clearing impacts – Erosion control and rehabilitation of disturbed areas

Despite the good intentions that usually drive invasive alien plant clearing programmes in riverine areas, invasive alien plant clearing itself is often associated with extensive damage to riverine ecosystems, in some cases arguably more severe and longer-lasting than the presence of the invasive vegetation themselves (see Volume 3: Langtou and Berg River Bridge case studies). Such impacts are almost always the result of either a failure to stabilize cleared slopes adequately, and manage increased runoff from these areas immediately following clearing activities, and / or a failure to remove / dispose of cleared material, leading to the debris dams and flood blockages both in the channel and on the floodplain during flood events.

The following measures must be considered when invasive alien plant clearing in riverine and floodplain areas:

- The branches, stumps and trunks of all felled woody invasive alien vegetation must be stockpiled and /or otherwise disposed of above the 1:100 year floodline of the river and, if this floodline is not known, no closer than 50 m from the river bank and outside of any areas known to be flooded during large storm events. This will prevent such material from being washed downstream;
- Where alien plant invasion has been extensive, and little vegetation remains in the river bed or banks after invasive alien clearing, stabilisation of the banks through re-shaping, planting and, potentially, inclusion of other bank stabilisation options outlined in Sections 4 and 5 must form part of the invasive alien plant clearing programme, with priority being given to the rapid establishment of plants along the wetted edge of the channel, as well as up the banks, where erosion is most likely to be an ongoing issue;
- Cleared areas must be carefully monitored for signs of erosion, and bank reshaping, planting and/or temporary stabilisation methods implemented as appropriate (See Sections 5 and 8) at the first signs of erosion.

Consequences of failing to rehabilitate after alien clearing

In the absence of real rehabilitation and, in particular, attention to the establishment of non-invasive plant species along areas cleared of woody alien plants, the risk of river bank and bed erosion will be high, and if triggered by heavy rainfall can result in dire consequences for river morphology, often off-setting the benefits of alien clearing.

Erosion of the Berg River following alien clearing
(Photo: Justine Ewart-Smith)

Issues around the removal of stumps

Clearing of woody invasive alien species usually entails removing surface plant material (i.e. the trunk, branches and leaves). Along rivers, it may however sometimes be necessary to remove the root / tree stump itself, usually by mechanical means. Although costly, stump removal is a requirement when:

- The presence of stumps prohibit the level of bank reshaping needed to achieve stability;
- Protruding stumps in the channel or river bank continue to deflect or constrict river flows, even after surface material has been removed.

Note that unless the above scenarios apply, removal of stumps is not recommended, as it is both costly and entails high levels of soil destabilisation and disturbance, potentially increasing the vulnerability of slopes to erosion.

Notes on protecting rivers from clearing invasive alien plants in upslope areas

Rivers are often affected by destabilisation and erosion from adjacent hillslopes that have been denuded of their alien vegetation cover. The following measures (taken from the eThekwini Alien Plant Control Guidelines) should be applied to such areas upslope, not only as best management practice, but in the context of river rehabilitation activities, to prevent knock-on effects to river systems:

- All areas of exposed soil should immediately be protected by placing packed brush on the slope, or creating erosion control barriers using branches, sticks or logs placed horizontally across the slope at 1 m intervals (the steeper the slope the closer the barriers should be placed to each other);
- If the soil remains relatively undisturbed and the area has some indigenous vegetation left intact, the natural regeneration processes of the indigenous vegetation on the site should be managed, through regular follow-ups to remove emergent alien plants, protecting the area from other forms of disturbance (uncontrolled fire, heavy grazing, etc.) while the vegetation re-establishes naturally;
- Grassland restoration may be supported by controlled burning at the correct time of year, under the guidance of an ecological professional, noting that if the area has been cleared of Black Wattle (*Acacia mearnsii*), burning will stimulate germination of the seeds and a significantly increased alien clearing follow-up requirement;
- Forest and woodland regeneration will be supported by keeping fire out of the area and limiting grazing/browsing pressure in the area until the trees have reached 1.5-2 m in height.

Further information regarding re-establishment of vegetation on cleared areas is provided in Chapter 12.

2.1.2. [2]Invasive alien plant clearing and control methods

Overview

Invasive alien plant clearing methods are generally divided into three main categories, namely **physical** (or mechanical) control, **chemical** control and **biocontrol**. A combination of approaches may however be recommended in the case of some invasive plant species. Appendix A2.1 provides summary recommendations for current control measures for the most prevalent problem species. The following sections provide a brief overview of these approaches, which are broadly compared in Table 2.2

Physical control: Manual and mechanical methods

These approaches generally entail the complete removal or destruction of plants and where used in dense infestations, must be accompanied by effective rehabilitation measures (see above) to avoid triggering severe erosion and other ecological damage.

Physical control methods include the following:

- Hand pulling
- Hand pulling using tools (e.g. tree poppers)
- Ring- barking
- Cutting
- Slashing
- Strip barking
- Frilling
- Brush-cutting
- Felling using a chainsaw
- Burning

A brief comparative description of these approaches is provided in **Table 2.1**.

To fell or not to fell

Note that single invasive alien trees that are not actively contributing to river degradation through channel or floodplain construction or the diversion of flows, may be addressed by ring-barking or frilling (see Table 2-1) rather than felling, and left standing until they collapse naturally over time. While this approach may be cheaper than felling, it should be undertaken with caution in riverine environments, noting that:

- ➢ Falling boughs may pose a safety risk
- ➢ Fallen debris in the floodplain of the river may increase flood damage, if it contributes to debris dam formation on the floodplain or in-channel

Table 2.1: Physical control methods used in invasive alien plant control

Approach	Description and comments	Application
Hand pulling	This entails pulling the whole plant out, including roots. Care must be taken to remove all the plant material – especially when removing plants that sprout readily from pieces of stem or root material. Results in soil disturbance but insignificant if invasion sparse. If hand-pulling required in follow-up	This approach is effective for small plants (seedlings, small shrubs) and plants in soft or sandy soils. Recommended for sparse invasion only.

[2] Note that this section has also been adapted from the eThekwini Municipality's guideline document for General Invasive Alien Plant Control (eThekwini Municipality's Environmental Planning and Climate Protection Department: 2014: http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications)

Approach	Description and comments	Application
	programmes, care should be taken to ensure that the timing of activities does not result in plants being too big or deep-rooted to pull by hand, or so small that identification among other foliage is hard.	
Hand pulling using tools (e.g. poppers)	Tree poppers are hand-held tools used to gain leverage on young saplings and allow them to be pulled out relatively easily.	Effective for deep-rooted invasive aliens in their early sapling stages Not recommended for dense infestations
Ring- barking or strip barking	The method entails removing (with an axe or knife) a band of the tree's bark and cambium (top layer of live material below the bark) in a band some 30 cm wide, running round the full circumference of the tree, some 50 cm above the ground. Strip barking entails complete removal of bark from the base to a height of about 1 m, from a growing tree, using a knife or axe	Useful for killing large trees Not applicable if trees left *in situ* will pose an erosion threat as a result of deflecting stream flow, or prevent rehabilitation such as bank re-shaping and planting. These methods are effective on some species however other trees may re-sprout from the stump or roots and therefore require herbicides.
Cutting	This method involves cutting relatively large plants (stem > 10 mm) as close to the ground as possible, with a saw or lopper/secateurs.	Useful for young plants. Not suitable for plants that coppice rapidly
Slashing	Cane knives, slashers or similar can be used for clearing the branches young plants before they set seed	Useful where there are large stands of non-sprouting plants, e.g. hakea or pine. Not recommended for species requiring herbicides because herbicide application require clean cuts to be effective
Frilling	An angled grove is cut into the bark and cambium, around the full circumference of the tree. Herbicide is applied as soon as possible to the groove and kills the tree. as it seeps into the cambium. It is important to make sure no portion of the cambium is left untreated.	Again, not applicable if trees left in situ pose an erosion threat as a result of deflecting stream flow, or prevent rehabilitation such as bank re-shaping and planting
Brush-cutting	Depending on blade size, brush cutters can be used to control low-growing thickets such as bramble, tackling stems up to 15 cm in diameter.	Not recommended where herbicides required for application to cut stems, unless labour availability such that workers can move in teams, identifying and immediately applying herbicide to cut stems; cut stems may be easy to miss. Non-target plants may be affected by this method of herbicide application.

<table>
<tr><th>Approach</th><th>Description and comments</th><th>Application</th></tr>
<tr><td>Felling</td><td>Chainsaws are ideal for felling large trees and reducing log size to a transportable size and weight, allowing removal of material from the cleared riverine zone.</td><td>Ideal where large woody trees need clearing.
Operators must be certified and competent in all safety and technical aspects of chainsaw usage.</td></tr>
<tr><td>Burning</td><td>Burning can be a quick method of clearing old foliage and reducing litter loads, and also an excellent control for invasive alien annual grasses and weeds.
The timing of burning is critical, and dependent on where the site is situated. If burning occurs too long before the wet season, newly sprouting plants will exhaust their resources before the start of the rain, and recovery may not take place adequately (note that this can be used as a strategy to effect die-off of alien seedlings after fire, if there is inadequate water for their initial survival – D. Gibbs, City of Cape Town, pers. comm.).
As a guideline for timing of burning, where regeneration of seeds is desirable:
➢ In Summer rainfall areas, fires should ideally be lit in September / October;
➢ In winter rainfall areas, fire should be lit from late February through to March / April;
➢ The above time frames also avoid bird and other animal nesting and breeding times, in riverine environments.
See Burning Guidelines – Appendix A2.2</td><td>Burning requires a permit, and is seldom allowable in urban areas.
High levels of control are required (see Appendix A2.2), and it is not recommended in:
➢ Peatbed wetlands, where there is some risk that peat, particularly if degraded and dried, will catch alight;
➢ Drought years, where the water table is low, and fires may burn plant roots, heightening erosion risk;
➢ Areas where access is limited or resources for fire control are limited;
➢ Seep wetlands, where fires remove organics, removing primary "sponge" mechanism for these systems.</td></tr>
</table>

Biocontrol

Biocontrol (or biological control) is an approach to invasive alien plant control that makes use of the natural enemies of these species (e.g. pathogens, grazers) to control them in the foreign environments in which they occur. The underlying principle is a simple one, namely that one of the main reasons that invasive alien plants thrive in their new environments is because they have escaped the pests and diseases that form natural controls in their native habitats. The safe introduction of such pests to areas that have been invaded allows their competitive advantage over indigenous species, subject to their own attacks by pests and disease), to be reduced. Biological control agents include insects, mites, fungi and bacteria. They are usually highly specific in the part of the plant that they target – e.g. seeds, flowers, stems or fruit. Tight controls are kept on the selection and release of biocontrol agents into natural ecosystems, as they themselves are alien species and it is important that there is no risk that these species will affect local vegetation as well as the targeted aliens.

Biocontrol success story

South Africa is the only country in the world to date that has implemented biocontrol measures against *Acacia* species, despite these being problematic in many countries. A review of the efficacy of ten biocontrol agents released in South Africa for the biocontrol of ten invasive Australian *Acacia* species showed, amongst other findings, that weevils feeding on *Acacia longifolia* seeds achieved an average damage level of 72.5% (range 57.8-94.6 %) per season, while a different species targeting *Acacia melanoxylon* achieved a mean of 90.5% damage (range 55-100%). Along with the results of aerial surveys, such data suggest that biocontrol agents are slowly bringing invasion of these pest species under control. The study stressed however that biocontrol measures are most effective used in conjunction with other control measures, such as clearing. Information from Impson et al. (2011).

Although often highly effective, biocontrol does not allow for complete control of the problem plant, as the agent is entirely dependent on its host plant. Fluctuations in the weed and agent populations are common, with a time lag in some cases between the onset of invasion of a water body and the time for colonisation by an appropriate control.

Where not already present in an invaded areas, biocontrol agents are available free of charge from distributing authorities.

External factors such as climate, watershed management, nutrient enrichment and herbicide control can moreover have an effect on the bio-control agents and reduce their effectiveness. For instance, bio-control agents for water hyacinth (*Eichornia crassipes*) and *Myriophyllum aquaticum* are less effective where high nutrient levels in the water stimulate plant growth (City of Cape Town 2005).

Cross references

Appendix A2-1 lists the biocontrol agents available in South Africa as of 2011 (Klein 2011) and their target species, with comments as to their efficacy.

In addition to this reference, and to keep abreast of new biocontrol agents and how to source/ disperse them, landowners should contact the following organisations for information:

- Provincial representatives of the Working for Water Programmes (http://www.arc.agric.za
- Agricultural Research Council – Plant Protection Research Institute (ARC- PPRI) (http://www.arc.agric.za)
- Rhodes University – Department Zoology & Entomology (https://www.ru.ac.za/zoologyandentomology)
- City of Cape Town Invasive Species Unit – biocontrol (http://www.capetowninvasives.org.za; email invasive.species@capetown.gov.za)

Chemical control (herbicides)

> **Chemical control** involves the application of registered herbicides at prescribed rates using suitable equipment and appropriately trained and skilled labour.

Chemical controls are used to target many invasive alien plant species. Their application requires some understanding of basic herbicide function, to ensure that the correct type, dose and application approach is applied, and that both human and ecosystem health risks from the application are minimised.

In river environments, particular care must be taken to ensure that the selected herbicide will not be washed downstream and remain effective, or will not exert a long-term effect on soils, thus preventing future rehabilitation. The herbicide Roundup® for example is a non-selective herbicide, but is deactivated on contact with soil and thus its residual (or long-term) effect can be controlled and it does not affect plants that have not been sprayed or painted with it. It is used in many riverine invasive alien applications.

> **Defining broad and narrow leafed plants**
> Broad leaved (also called broad-leaf) plants have **broad, flat leave**s as opposed to the **needle-like** leaves of some evergreens (e.g. pines) or the **narrow, blade-like** leaves of grasses.

Herbicides are generally classified as **selective** or **non-selective.** Of these, the former are usually specific to a particular group of plants. Broad-leaf plant herbicides for example will not act on narrow-leaved plants such as grass and can thus be used where alien vegetation occurs in mixed stands with indigenous vegetation. By contrast non-selective herbicides will target all plants and are inappropriate for application where indigenous or otherwise desirable species occur and are intended to remain after clearing.

> **Drifting into danger**
> During application of herbicides by spray, chemical drift can occur, whereby droplets of the herbicide blow or waft onto adjacent areas. While this is not problematic if adjacent areas are also being targeted, where they support non target species, significant unintended die-offs can occur. Drift can be controlled for by paying particular attention to application techniques in windy conditions or where high importance is attached to adjacent areas. The use of high velocity, low volume sprays for misting and low velocity high volume sprays for drenching are recommended to reduce problems of drift and (similar) accidental splash (eThekwini 2014).

> **Safe application of herbicides in rivers**
> Herbicides used to target invasive alien plant species in rivers must be selected carefully to ensure that they are unlikely to affect downstream users or ecosystems. The following should be considered:
> - Applications should preferably be made while moving upstream to avoid accidental concentration of chemicals in the water;
> - Only emergent, exposed plant foliage should be sprayed and open water areas should be avoided;
> - Only herbicides registered as suitable for application in water bodies should be used.

Table 2.2 provides comparative information on various chemical application techniques, with comments on each approach.

Table 2.2: Comparison of different chemical control application methods.
Information sourced from the eThekwini Municipality's guideline document for General Invasive Alien Plant Control
http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications

Technique	Description	Application	Level of Training required	Notes and cautions
Foliar spraying	Knapsack sprayer	Plants below 1 m in height	Training and certification	Cheaper than cut stump treatment because requires fewer workers Can only be used where water available as requires large amounts of clean water for mixing with herbicides
Handheld spraying	Usually a small (e.g. 1.5 L) sprayer with adjustable nozzle	Applied after cut stumping, ring barking, frilling and strip-barking	Training in safe use of sprays	Equipment is cheap and application method is accurate. Requires more workers than foliar spraying.
High pressure spraying	Needs tank and high pressure pump; usually carried out from a boat but equipped vehicles can also be used	Used where high densities of invasive alien plants and no indigenous vegetation (often used for invasive water weeds)	Training in safe use of sprays	Very difficult to spray selectively
Aerial spraying	Herbicides sprayed from aeroplane or helicopter	Used where sites are inaccessible (e.g. dams) and where invasive plants are at high densities	Highly trained pilots, registered as crop sprayers	Expensive but effective technique. Selectivity is impossible. Herbicide type and dilution / mix must be considered carefully to prevent ecosystem damage (e.g. to fish and other fauna). Other ecological effects (e.g. eutrophication and low oxygenation following death and decay of large volumes of plant material)

In addition to paying attention to selection of an appropriate application approach, it is critical that the correct herbicide is selected for the required environment and purposes, and that it is correctly applied / treated. The following issues should inform herbicide selection (eThekwini 2014):

- Herbicides should be selected with the correct active ingredient for the specified plant and environment (i.e. near water), noting that different brand names may use the same active

ingredient, but at different concentrations, meaning that mixing or dilution ratios may differ between brands;
- Only herbicides registered for use in South Africa on the target species may be used – avoid waste of money and resources, as well as potential ecological or human health damage, by using only appropriate approved herbicides on the correct manner, and ensure that the product used carries a South African registration number;
- The residual effect of the herbicide must be considered – the shorter the residual time, the less likely non-target species will be affected;
- The need for "wetters" (adjuvants) to apply some herbicides to specific targets should be checked, to ensure efficacy – dyes are sometimes used to differentiate between herbicides mixed with different adjuvants or different herbicides, and allows for ready identification of sprayed areas on site. Care should be taken to ensure that any dyes used are compatible with both the adjuvant and the herbicide.

Different herbicide application methods:

- **Foliar:** Herbicide is applied to the foliage
- **Cut-stump**: Applied to the freshly cut stumps
- **Basal**: Applied to the lower stem of standing trees
- **Soil:** Applied to the soil around the plant

Chemical suppliers

The names of key herbicides currently in use in the control of listed invasive alien plants in South Africa are provided in Appendix A2.1. It should however be borne in mind that, as with all such information, these approaches may become outdated in time, and the user should ensure that up-to-date information informs choice of herbicide control, by referring to www.invasives.org.za or other websites listed in Section 2.2 for updated information.

Reputable suppliers should be able to provide the required information about their products – saving the financial and environmental costs of wasteful or harmful applications of the wrong products, or the right products incorrectly.

Remember that overdosing is expensive and not likely to be more effective than dosing correctly – it may also affect the surrounding environment negatively.

Timing of herbicide applications

As a rule, herbicide applications are most effective if they occur during the growing season of the targeted species, when uptake is most effective. However, in some species (e.g. *Arundo donax* (Giant reed) (see **Table A2.1.2**)) herbicide application is best in early winter, when nutrient transfer from surface stems and leaves to the root mass occurs, and toxin transfer thus passes into the roots where it can achieve systemic effects, cited by Basson (2013) as 100% effective in monospecific stands of this species.

Comparison of control methods

Table 2.3 summarises the main advantages and disadvantages of different invasive alien plant control methods, noting that available literature suggests that the most effective control measures often entail a combined approach.

Integrating control measures

Several researchers suggest that short-term approaches to invasive alien plant control should centre on **prevention** of new invasion, while chemical and mechanical controls are most applicable in short to medium term clearing objectives (e.g. van Wilgen et al. 2001).

Biological controls by contrast are considered as long-term control measures, and an integrated approach involving all of these approaches is often advocated, noting that **early detection and immediate management intervention is critical in controlling aquatic species invasion by preventing them from becoming established**.

Table 2.3: Comparison of different alien clearing methods

Advantages	Disadvantages
Biocontrol	
Most environmentally friendly and sustainable of all control methods	Generally slow, especially initially and may thus be an issue of concern in areas where fast-growing invasive alien plants may out-compete clearing rates
Usually does not require high or long term maintenance – periodic re-stocking or introductions of species with low dispersal abilities is however necessary	Low levels of infestation by alien invasives with occasional outbreaks will remain a feature of systems under biological control
Relatively low cost implementation over the long term	Use of chemicals around biocontrol agent colonies may adversely affect the potency of this method
Biocontrol typically causes less risk of damage to river beds and banks	Cannot be used where the biocontrol agent would threaten commercial populations of the target species that exist nearby (e.g. commercial plantations)
	Not available for all invasive alien plant species
Chemical (herbicide) control	
Achieve results over a short period (within 6 weeks of application)	Herbicides are expensive
Large areas can be treated quickly	Herbicides may contaminate sites used for drinking water, washing or fishing and may affect general river ecosystem health
Complements mechanical control methods increasing invasive alien plant control effectiveness – in addition, mechanical controls using booms or cables to contain invasive alien vegetation, so that it can be chemically or otherwise treated, are used successfully in some systems	May kill non-target species
	Specialised training and certification required for use of herbicides
Manual removal using mechanical tools	
Dense stands of invasive alien plants can be cleared	Cost of equipment, fuels and servicing may be high (but labour costs reduced)
May be possible to clear large areas quickly	Possible pollution from oil
In some circumstance may provide a means of	May damage sensitive areas by compaction and removal of top soil and/or important seedbanks

Advantages	Disadvantages
removal of layers of alien seedbank or plant material (e.g. kikuyu grass).	
	May result in steepening of river banks and potential creation of berms along river banks with dredged material
	May result in short-term turbidity in disturbed aquatic environments
Manual removal using hand labour	
Effective in areas with low infestations	Not effective for dense infestations as the cost of clearing is high, with little impact on the problem
High job creation and associated poverty relief potential as uses largely unskilled labour	Time consuming – may be slower than other forms of control
No contamination of water with herbicides as these are applied directly to the tree / plants	If no herbicides used, then manual methods must be very well executed to ensure success

A decision-support tool to assist in the approach to clearing of invasive alien aquatic species is illustrated in **Table 2.4 (after** FCG and Wetland Solutions (2011b)).

Table 2.4: Decision-support tool to assist in the approach to clearing of alien aquatic species. Table after FCG and Wetland Solutions (2011b)

Criteria	Bio-Control	Chemical	Mechanical	Manual
Access to site on foot	Foot access not necessarily important	Easy to access on foot	Easy to access on foot	Easy to access on foot
Machine access to site	Machine access not important	Machine access not important	Easy to access with machinery	Machine access not important
Ecosystem type	Any	Standing or isolated water-bodies may be preferred	Any	Any
Flow conditions	Any	Any	Not fast flow	Any
Water depth	Any	Any	Sufficiently deep to warrant use of machinery	Shallow to moderately deep (too deep would be inaccessible on foot)
Biodiversity value	Any	Low	Low to moderate	Any
Water quality	Not important, but may take longer in eutrophic systems	Poor water quality may be preferable	Not important	Not important, but may be too slow for rapidly reproducing large infestations
Method effective for the following species	*Azolla, Eichhornia, Myriophyllum, Pistia, Salvinia*	*Commelina, Eichhornia, Lythrum, Pontederia, Salvinia*	*Egeria, Eichhornia*	*Ceratophyllum, Commelina, Egeria, Ludwigia, Lythrum, Myriophyllum (only with bio-control), Nasturtium, Persicaria, Pistia, Pontederia*

Criteria	Bio-Control	Chemical	Mechanical	Manual
Infestation size	Moderate to large	Moderate to large	Small to large	Small to moderate

2.1.3. Disposal of cleared material

Disposal options for woody material

Disposal of cut invasive alien plant material must be considered carefully, with options raised by the eThekwini Invasive Alien Plant Control Guidelines (eThekwini 2014) including:

- Burning on site – this is often a cheap alternative to carrying material off site and out of flood zones, particularly in inaccessible areas. It reduces fuel loads, and removes material that might otherwise end up in the rivers as log jams. However, burning requires careful consideration, and implementation of a number of safety precautions. The following issues should be considered when selecting this option for disposing of cut alien material:
  - Fire permits are required in terms of The National Veld and Forest Fire Act, 1998 (Act No. 101 of 1998);
  - Fires must be carefully controlled – see Appendix A2.2 for detailed fire management guidelines;
- The effects of hot fires on underlying seedbanks must be considered – where regeneration of an indigenous seedbank is a desired and realistic outcome of alien clearing, it might be negated by burning of cut material. Burning also stimulates release or rapid germination of seeds in some alien plants (e.g. Pine trees and Black Wattle, respectively) and allowance must be made for early clearing or spraying of seedlings;
- Stack burning is usually the preferred approach to using fire to manage fuel loads, as it affects a defined area and is usually easier to control than burning of a wide area. Note however that where maintaining low levels of nutrients in the soil (e.g. many fynbos areas) is desirable, burning vegetation may re-introduce nutrients to the soils, altering habitat type;
- Chipping – this also poses a threat, if chipped material includes seed material or other viable propagules. For this reason, cut plants should only be chipped for re-use in riverine areas if they were cut outside of seeding phases, or in cases where the alien seedbank remaining in the soil after alien clearing is already likely to be so high that additional seeds will not affect the outcome;
- Composting (if material includes softer leaf material);
- Use in charcoal manufacture;
- Disposal at a garden refuse or landfill site.

Disposal options for non-woody material

Options for the disposal of non woody alien material include:

- Mulching or chipping (unlikely to success if material is soft and wet)
- Composting
- Disposal of at a garden refuse or landfill site.

Don't spread the problem

Some invasive alien plant species (e.g. *Commelina benghalensis* Wandering Jew) are highly effective at propagating from even small portions of their stems. Mulching and re-use of such material is thus not a useful approach, whereas composting can effectively destroy the plant, and can be speeded up by the placement of wetted, cut plant material in a closed black garbage bag, in the sun.

2.1.4. Maintenance / How to follow-up on invasive alien plant clearing

Proper follow-up after initial alien plant clearing is essential to the sustainability of any clearing plan, and without it, the positive effects of invasive alien removal may disappear over a very short period of time. Implementation of a maintenance programme that allows for regular revisiting of the site, and removal or other treatment (e.g. foliar spraying – see Table 2.2) of emerging seedlings before they effect habitat transformation or become so large that the cost of their removal increases. Thorough, consistent follow-up maintenance activities should result in a pronounced decrease over time in maintenance effort and expense.

Remember- it is important to determine whether invasive alien clearing maintenance should be tied to active rehabilitation measures to ensure that indigenous plant species can be established as quickly as possible.

2.1.5. Monitoring

Monitoring is important to:

- Highlight areas where treatment has been inadequate and additional measures are required
- Highlight areas where indirect impacts such as erosion may need to be addressed
- Allow learning from past practices, so that ongoing invasive alien plant clearing initiatives are constantly improving.

The following monitoring suggestions should be considered:

- A fixed-point photographic record should be collected, showing the river in its affected reaches before, during and at regular time periods after initial alien clearing has taken place;
- Historical GOOGLE images should be used over time, to provide a spatial record of clearing extent and effects;
- Records should be kept of the time and costs required for each clearing intervention, and the approximate volume and life stage (e.g. seedling or mature plant) of the bulk of material removed on each occasion. This information will allow quantification of the costs of invasive alien removal, show landscape changes resulting from invasive alien removal and potentially inform decisions that are required around changes in clearing frequency, area or approach.

In addition to the above, monitoring of other aspects such as flow regime, soil moisture in riverine wetlands (e.g. valley bottom wetlands), soil and water nutrients and turbidity as a result of erosion, could all be included in a more rigorous monitoring programme, depending on the interest and requirements of the auditing or monitoring agency.

2.1.6. Technical expertise required / Who should do this work?

It is critically important in invasive alien plant clearing programmes that those undertaking implementation are adequately trained, so that they are able to work safely and effectively.

Note also that formal certification is required for any workers involved in the application of chemical controls, as well as in the use of some mechanical tools (e.g. chain saws and vehicles), and supervisors must also be trained and proficient in what safety measures and devices are required in different situations and approaches (e.g. the need for gloves, helmets, masks, etc.). Each team should have a trained first-aid representative and Safety Health & Environmental (SHE) representative

The following websites should be sourced for more information on training and certification requirements, and where such training might be acquired:

- https://www.invasives.org.za.
- https://www.environment.gov.za/wfw

2.1.7. Checks and balances

While the material presented in this section has tried to provide a comprehensive overview of invasive alien plant control measures and approaches, it is stressed that methods may be updated over time, new biocontrol agents may be found for some species, and herbicides and /or their application may also change. It is recommended that people undertaking regular or large-scale invasive alien plant control projects should periodically check that the most up-to-date invasive alien plant clearing methods are being utilised. This can be achieved through liaison with relevant organisations (e.g. Working for Water) or websites (e.g. www.invasives.org.za).

Legal classification and required treatment of invasive vegetation

The **National Environmental Management: Biodiversity Act (Act 10 of 2004) (NEMBA)** categorises invasive species into four categories of so-called “Listed Invasive Species”, as published in August 2014 (GN 599 of 2014, Gazette No 37886). These categories comprise:

- Category 1a – these comprise invasive species requiring compulsory control, and all such plants are to be removed and destroyed; this Category equates to Category 1 in terms of CARA (see above);
- Category 1b – These invasive plants require control as part of an invasive species management programme, and no increase in their extent or density may take place.
- Category 2 – Such species may only be kept with a permit, and in a specified area of land; except when they occur in a riparian zone or a protected area where they need to be controlled
- Category 3 – these invasive species are exempt from the requirements for control. <u>However, where they occur in aquatic and/or riparian areas, they are considered as Category 1b species and need to be controlled.</u>

A second piece of legislation (subordinate to the NEMBA legislation) is also relevant to alien clearing, namely the **Conservation of Agricultural Resources Act (CARA)** (Act 43 of 1983), which classifies invasive alien plants into three categories, each of which allow for different levels of approach, as follows:

- Category 1 species – these invader plants must be destroyed immediately, and may not be traded. This category equates to Category 1a in terms of NEMBA (see previous);;

- Category 2 species – these invader plants have a commercial or utility value, with useful qualities, including commercial use for timber, food, animal fodder, soil stabilisation, etc. Permission can be gained to grow these species commercially in demarcated areas but otherwise they must be removed. This category equates to Category 1b in terms of NEMBA (see previous);
- Category 3 species – these plants are primarily ornamental or 'exotic' horticultural plants that have escaped from gardens. They can be maintained on a landowner's property if they were already growing at the time of promulgation of these regulations. All other Category 3 plants must be removed. This category equates to Category 1b in terms of NEMBA (see previous) and the plants must be controlled.

Note that irrespective of the category, the above Act stipulates that all declared plants growing within 30 m of the 1:50 flood line of a river or water body must be removed.

Note that removal of invasive alien vegetation requires a permit in terms of NEMBA (Section 65 (1).

However:

- Removal of Category 1a, 1b, 2 & 3 invasive alien plants is mandatory in terms of NEMBA where such plants occur within a riparian area (32 metres of the edge of a river, lake, dam wetland or estuary, or within the 1:100 year floodline, whichever is the greater);
- Invasive alien species regulated in terms of CARA as weeds and invader plants (i.e. Categories 1-3) are exempt from the requirement for a permit for their removal in terms of NEMBA.
- This means that removal of all Category 1-3 listed plant species may be carried out legally, without a permit. Note that this is not the case in the control of indigenous invasive plant species.

How does one know what plants can be removed without a permit?
A combined list of Declared Weeds and Invasive Alien Plant Species addressed by both CARA and NEMBA has been provided in Appendix A2.1.

Environmental legislation

In addition to the above legislation, note that:

- The use of machinery in a wetland (including valley bottom wetlands) or river may require authorisation in terms of NEMA and the NWA, as it is likely to result in movement of bed material and /or changes in the bed or banks of the river channel.
- The use of Fire as a control method requires authorization in terms of The National Veld and Forest Fire Act, 1998 (Act No. 101 of 1998).ire control requires a permit
- Refer to Section 10 "*Legal authorisations necessary for river rehabilitation*".

Useful reference material

Croudace 1999: The Alien Clearing Handbook for the Western Cape. Pub Bo-Kloof Fynbos Conservation and Environmental Information Trust.
Provides: 40 page, simple, step-by-step guide to the life cycle characteristics, spread, habitat and removal techniques (double spread per species) for 17 of the province's pervasive invasive alien species.

CSIR 2000. Guidelines for indigenous vegetation restoration following invasion by alien plants. Prepared for the Working for Water Programme. CSIR Report No ENV-S-C-2000-144
Provides: Brief, South African based working guide prepared for Working for Wetlands implementers, including information on alien plant control protocols, principles of indigenous vegetation restoration and management guidelines for alien plant clearance and restoration.
The guide includes regionally-based tabulated guidelines for initial clearance, fire management and restoration actions in different ecosystems, including specific guidelines for work carried out in grassland and savanna riparian areas, and along drainage lines and in riparian areas in Arid Zones.
The appendices provide information regarding the method of propagation of different alien species, their seed storage zone and seed longevity, and recommended initial and follow-up treatment regime for different alien plant species that have been prioritised for clearing in KwaZulu-Natal.

Freshwater Consulting Group and Wetland Solutions (2011): Aquatic Weed Management Plan for the City of Cape Town
Provides: Detailed specifications for the identification, biology and control measures for key invasive alien aquatic plants in watercourses in the City of Cape Town.

eThekwini Municipality – Environmental Planning and Climate Protection Department. 2014. General Invasive Alien Plant Control. Insight into Best Practice, Removal Methods, Training & Equipment. **Guideline** Document produced by eThekwini Municipality.
Provides: Detailed step-by-step guide to invasive alien plant management and eradication methods

2.1.8. Technical guidelines for the removal of specific invasive alien plant species

The following sections provide brief guidelines only as to methods currently being utilized for invasive alien plant control in South Africa, (A) with regard to different ecosystems, and (B) with regard to individual plant species

A Area-specific guidelines (after Holmes et al. 2008)

These guidelines were developed to assist in the removal and rehabilitation of invasive alien plant species in specific ecosystems, differentiating between Fynbos, and Grassland and Savanna ecosystems, as outlined in Tables 2.5 and 2.6.

Table 2.5: Guidelines for invasive alien plant removal and subsequent rehabilitation in Fynbos Ecosystems. Information taken directly from Holmes et al. (2008)

Phase	Response
Initial clearance	For dense to closed woody alien stands it is best to fell and remove large-diameter wood (>250 mm) from the riparian zone. This wood may be sold to offset some of the clearance costs, or else should be burnt in stacks when the soil is wet to minimize soil and seed bank damage. Where there is no secondary industry market, large-diameter trees should be killed standing (ring-barked or frilled). For aliens under substantive biological control, consider phased removal; For light to medium-density stands, slash may be left to decompose in situ or burn in the next fire without negatively impacting the recovery potential of the site. However large-diameter trees should be killed standing to keep biomass off the soil surface.
Revegetation	If some indigenous vegetation is present prior to alien clearance, soil seed (and propagule) banks supplying indigenous herbaceous and shrub understorey species are likely to be present. If there was little evidence of indigenous vegetation pre-clearance, seed banks may still be present provided that there was no other habitat disturbance (such as ploughing) or long-term dense invasion (exceeding 2 fire-cycles). However, if a severe fire has gone through the area (with evidence of burnt soil organic matter or subsequent soil erosion) seed banks will have been severely depleted. Where indigenous seed banks have been depleted, the site requires active revegetation. To restore ecosystem functioning, the minimum requirement is bank stability and soil surface erosion control. Thus a mix of local pioneer, understorey (herb and shrub) species should be sown. Where seed of local indigenous species is not available or insufficient, commercial non-invasive grasses may be used in an area that is primarily agricultural or disturbed. In the Western Cape, potential species are annuals such as sterile Italian Rye Grass (*Lolium perenne*) and commercial oats (*Avena sativa*). In the Eastern Cape *Digitaria eriantha* may be used. In terms of restoring structure, if pockets of indigenous scrub persist along the river – within 200 m or upstream of the site – then these species will recolonize over time. If there are very few pockets of remaining scrub in the catchment, then active planting of scrub species is recommended, especially if the surrounding terrestrial vegetation is degraded and cannot supply pioneer shrub species. Riparian scrub species may be established from rooted cuttings or seedlings transplanted in the field, or for some Western Cape species (e.g. *B. stellatifolium*) directly from fruits placed on site. However, early results suggest that unrooted truncheons have limited success Sowing should be done directly onto bare ground, with the seed lightly raked into the soil or covered by light woodchip mulch. If done after initial clearance, the establishing vegetation has potential to partially suppress alien recruitment and reduce follow-up costs. Seed should be sown in autumn in the Western Cape, and either early autumn or early spring in the Eastern Cape. Planting is best done under similar conditions to the sowing treatment, although some scrub species may establish better in the presence of sheltering herbaceous species. In the Eastern Cape grasses are better planted in spring.
Follow-up control	Only methods that do not damage recovering indigenous species should be used: e.g. hand-pull, cut and stump treat. If foliar herbicide spraying has to be done, then it must be on a wind-free day with all indigenous species first covered in a protective cone or similar device. Special care should be taken to identify aggressive secondary invader species and control these timeously to allow time for indigenous vegetation recovery.
Monitor ecosystem recovery	Geomorphology: simple measures such as channel depth and width (using permanently marked locations) Soil erosion: e.g. hammer steel pins into bank and measure soil loss or gain Vegetation cover: fixed point photography, permanent plots to measure alien, indigenous and ground cover Vegetation structure: permanent plots to monitor growth form density; including kill rate

Phase	Response
	of aliens Vegetation composition: permanent plots to monitor species presence and cover.
Adaptive management	Assess monitoring results relative to ecosystem repair targets and where necessary revisit methods and adapt management.

Table 2.6: Guidelines for invasive alien plant removal and subsequent rehabilitation in Grassland and Savanna Ecosystems. Information taken directly from Holmes et al. (2008)

Phase	Response
Initial clearance	For dense to closed woody alien stands, fell and remove large-diameter wood (>250 mm) from the riparian zone. This wood may be sold to offset some of the clearance costs, or else stacked and left to decompose. Where there is no secondary industry market, large-diameter trees should be killed standing (ringbarked or frilled). For aliens under effective biological control, phased removal should be considered. For light to medium-density stands, slash may be left to decompose in situ. Woody species must be cut low enough to prevent resprouting. However large-diameter trees should be killed standing to keep biomass off the soil surface to lower the risk of damaging fires in regenerating riparian woodland.
Revegetation	If some indigenous vegetation is present prior to alien clearance, soil seed (and propagule) banks supplying indigenous herbaceous and shrub species are likely to be present. If there was little evidence of indigenous vegetation pre-clearance, seed banks may still be present provided that there was no other habitat disturbance (such as ploughing) or long-term dense invasion (e.g. wattle or *E. grandis*). Where indigenous seed banks have been depleted (e.g. after a 30 year dense aliens or following a severe fire) and the surrounding catchment is transformed, the site requires active revegetation. To restore ecosystem functioning, the minimum requirement is bank stability and soil surface erosion control. Thus grass or understorey (herb and shrub) species should be sown or planted. Campbell (2000) compiled guidelines for using grass to cover soil after alien plant control (including species and planting guidelines). Although aimed at terrestrial ecosystems, these techniques can be applied to highly-transformed riparian zones. Grasses broadcast sown or planted help to suppress recruitment of aliens (e.g. wattle) from the seed bank while providing cover to bare soil. Grasses sown in rows or terraces may assist in halting surface erosion on slopes. Where seed of local indigenous grass is not available or insufficient, commercial non-invasive grasses may be used in an area that is primarily agricultural or disturbed. In terms of restoring structure, if pockets of riparian woodland persist along the river – within 200 m or upstream of the site – then these species will recolonize over time. If there are very few pockets of remaining indigenous trees in the catchment, then active planting of tree species is recommended, particularly following dense wattle or Eucalyptus invasion. Planting of trees and shrubs should be done at the start of the wet season (November), from seeds (scarified or prepared in order to allow rapid germination) or using pre-grown transplanted seedlings (~200 mm tall) in forestry plugs. Sowing and/or planting should be done after a thorough initial clearing treatment

Phase	Response
	and the re-introduced plants tended (weeds removed around them) during follow-ups and during the first year until well established.
Follow-up control	Only methods that do not damage recovering indigenous species should be used: e.g. hand-pulling, cut and stump treat. If foliar herbicide spraying has to be done, then it must be on a wind-free day with all indigenous species first covered in a protective cone or similar device. Special care should be taken to identify aggressive secondary invader species and control these timeously (before seed-set) to allow time for indigenous vegetation recovery.
Monitor ecosystem recovery	Geomorphology: simple measures such as channel depth and width (using permanently marked locations) Soil erosion: e.g. hammer steel pins into bank and measure soil loss or gain Vegetation cover: fixed point photography, permanent plots to measure alien, indigenous and ground cover Vegetation structure: permanent plots to monitor growth form density; including kill rate of aliens Vegetation composition: permanent plots to monitor species presence and cover.
Adaptive management	Assess monitoring results relative to ecosystem repair targets and where necessary revisit methods and adapt management.

B General Guidelines for the control or removal of problem species

Appendix A2.1 provides brief summary information regarding the availability of different methods for the control of the most pervasive and problematic alien invasive plants affecting South African rivers. The list is based on riverine, wetland and floodplain associated plants as listed in the CARA and NEMBA listings, with biocontrol information supplemented with information from Hill et al. (2005). Although this list should be used as a guideline, it is important to note that in time additional alien plant species are likely to become invasive or problematic along South African rivers, and new methods for the removal of current and future invaders may well be developed. As a result, the table will need regular updating, to ensure that it remains relevant to alien clearing activities in South Africa.

Note also that in some cases a combination of approaches may be required for effective long-term control, depending on the type and density of a species, its life stage (e.g. seedling or mature adult). Decisions around the selection of clearing approach also need to take into account factors such as availability of labour, sensitivity of the site (e.g. the use of machinery may be too damaging in some areas), the available budget and the extent of clearing required.

2.2. Guidelines for managing invasive indigenous or cosmopolitan plants

Section 2.1 of this chapter dealt with invasion by alien plant species. This section deals with invasion of riverine habitats by indigenous or at least cosmopolitan species that over time come to dominate certain habitats / environments.

2.2.1. Setting management objectives

The objectives for removal of indigenous or cosmopolitan species must be clearly established prior to any plant removal programme being embarked upon, and the indirect effects of such activities should be clearly understood.

Where the objectives of plant removal are primarily to facilitate access, improve visibility, allow extension of agricultural areas, increase open water in areas that are considered largely natural, it is **strongly cautioned** that the following questions should be answered and carefully considered, before any plant removal takes place. That is:

- What functional role do the plants under consideration currently perform? For example, bank stabilisation, water quality improvement, sediment trapping? (refer to Volume 1 (Rehabilitation Guidelines) for a discussion of such effects).
- What will be the effect on bank stability, water velocity, bed stability, flood velocities, biodiversity without these plants in place?
- What other plants will dominate if the plants are removed?

Why do plants invade?

Plants (alien or indigenous) invade when:

- Disturbance allows them to take advantage of available space (e.g. removal of plant communities as a result of fires, erosion, ploughing) – invasive plants are usually fast-growing and reproduce rapidly, allowing them to become established over large areas before other slower-growing species can
- Local conditions change (e.g. becoming wetter, drier, more nutrient-enriched, more or less saline), negatively affecting the health of some plants and allowing plants with different or broader tolerance ranges to thrive
- Natural control factors (e.g. fire, floods, grazers) are removed as a result of human development / interventions, allowing some species to thrive in the absence of such controls, at the expense of others

Caution: If plant removal poses any threat at all to peat wetlands, the activity should not take place without a full assessment by an aquatic ecologist and hydrologist.

2.2.2. Control methods for particular invasive indigenous species

<u>Typha capensis (bulrush)</u>

Typha capensis is a common invader of shallow, perennially saturated freshwater conditions, with a stable hydroperiod, and the generally high availability of seed material in (particularly) urban areas, coupled with its fast growth rate and high rate of spread, means that this species rapidly establishes itself as a wetland dominant or monospecific stand in freshwater systems with the above conditions.

Typha capensis is usually absent where there is strong flow, steep banks, high salinity, water depth in excess of 1.2 m for most of the year (in practice, the plant usually occurs at much shallower depths) or where soil moisture is low, and Hall (1990) found that water supply and depth are the most important variables governing *T. capensis* distribution.

The most effective control measures for this species comprise:

- Drowning, by cutting shoots to ground level in situations where at least three months' subsequent flooding is likely thereafter, and when shoots can be cut at least monthly for the duration of the growing season if they do occur, noting that cutting is most effective if carried out in the flowering season (October to December);
- Hydraulic controls – by exposing *T. capensis* to extended summer drought (when heat stress affects plant resilience) or flooding (provided that gently sloping banks for upland invasion are not present);
- Chemical controls – using glyphosate (Roundup®) on shoots, if applied when male flowers (i.e. at the top of the flower head) mature;
- Burning – this measure is usually a short term measure only, as rapid resprouting usually occurs unless the reedbed is dry enough for root material to burn; it is however useful as a means of reducing leaf litter and thus improving habitat quality;
- Excavation – *Typha capensis* can be removed by uprooting it, taking care to remove the lateral rhizomes. This method is useful only for control of small patches of the plant, and it is usually likely to re-establish quickly from seed.

One of the primary reasons for removal of *Typha capensis* is the nuisance value of its seeds to local communities, who may be affected by seed allergies and asthma, or the inconvenience from seeds sticking to curtains and laundry, and being sucked into electric appliances including computers. Seeding can however be addressed by cutting plants off as close to their base as possible in their first or second year after sprouting, as this plant generally sets seed only in its second growth year (December to January).

One of the other negative effects of *Typha capensis* in channels is hydraulic occlusion (i.e. forming a barrier to flows, particularly as it senesces). An effective management approach to this issue is to cut lateral swathes across the channel, removing the plant as close to the substrate as possible, in wide swathes up to 10 m in width. Such swathes, separated by bands of intact reedbed, allow for the controlled spread of flows through a valley bottom wetland system, and phased reedbed regeneration, without the possible effects of channelisation associated with the more common approach of longitudinal excavation of a channel though a dense, senescent reedbed.

Phragmites australis

This reed (fluitjiesriet) grows on the lower banks or shallow margins of slow flowing rivers, and may grow across the whole channel where flows are very slow. It favours mildly brackish waters – possibly because these outcompete *Typha capensis*. It has a deep rhizome root system, and its removal through digging and hand pulling is ineffective, as a result of its extensive root system. Disturbing the soil mechanically may also contribute to rapid expansion of this reed and is not recommended. A similar approach to that used in the treatment of Spanish reed (*Arundo donax*) is however recommended by Reinecke et al. (2014), namely:

- Cut paths through dense stands of reed in order to gain access to the heart of the stand;
- Apply a foliar spray of herbicide Glycophosphate 360 or MAMBA in Autumn to reed leaves only, when the reeds begin to transfer nutrients from their leaves to the roots before growth ceases

in winter (you can tell this process is starting by split leaf-tips, which is followed by drying/browning of the leaves). Spray application should be by means of a low pressure, fine droplet spray (400 µm) from a narrow cone nozzle, and an appropriate dye should be used to indicate sprayed areas.

- The herbicide travels to the roots killing them and reduces the growth of new shoots;
- Note that cut access paths will resprout vigorously and must be sprayed the following year;
- Note also that the stems of sprayed plants must not be cut, as this stimulates the growth of new, taller and thicker stems and treated plants should rather be left to rot until dead and can be removed later.

Use of fire in reedbed control

Although burning reedbeds is used in many agricultural areas to promote new growth for grazing, as a control method it is not useful, as it stimulates growth rather than killing off the plant. Reedbed burning can however be an effective means of reducing wetland organic loading. It should be undertaken only with strict fire management controls (see Appendix A2-2) as reedbeds once lit can burn very fast, and get out of control.

Before clearing *Phragmites australis* from any river channels, answer the question: what effect will removal of the reed have on erosion? Is removal by herbicide going to be sustainable? And if not, rather simply cut the stems back, retaining root / soil function, and allow to regrow on an annual basis.

<u>*Palmiet (Prionium serratum)*</u>

This indigenous plant is endemic to South Africa and occurs in rivers from the Western and Eastern Capes, and southern KwaZulu-Natal, with a disjunct in that it does not occur between Port St John's and Howiesons Poort (near Grahamstown). The plant plays an important role in protecting river banks and beds from erosion, and when it is removed, streams may become choked by sediment and banks eroded by unchecked floodwater. In some rivers, particularly those subject to severe abstraction and regulation of flows, Palmiet may grow across the entire channel, blocking access to open water. Landowners often clear it for this reason.

Given the high value that Palmiet has in terms of stabilizing river banks and beds, coupled with the fact that the plant often grows in peatland wetlands, which are highly vulnerable to headcut erosion and subsequent severe, permanent degradation (see Volume 3: Tesselaarsdal Case Study), **it is strongly recommended that Palmiet should not be removed from rivers** and management guidelines for this activity are not provided here**.**

This recommendation is a potential issue from the perspective of many landowners, who routinely remove Palmiet from river channels, to prevent bank overtopping and to maintain areas of open water.

Where maintenance removal of Palmiet is required, this should only be undertaken with the support of a wetland ecologist, and with a clear understanding of natural wetland condition, extent and function, at an appropriate scale – that is, not just at the level of the site!

Salix mucronata

This indigenous willow has become invasive along many sandy rivers in the Western Cape, where it has established on what were naturally mobile sand banks that washed away in big floods before vegetation could establish on them. Today, the summer release of irrigation flows into many of these rivers means that the sandbars are wetter than under natural conditions in summer, and can sustain young seedlings, which once grown into saplings are able to withstand floods, and contribute to progressive narrowing of the river corridors and restrictions on the passage of floodwaters into the floodplains. Control of these plants is an important part of river maintenance, and should include:

- Hand pulling of seedlings while they are still small and establishing themselves along river beds and banks
- Uprooting (and removal) of well-established trees, to allow erosion of sedimented areas and allow the passage of sediment downstream.

Note that:

- Trees should be removed from both river banks, otherwise remaining trees may deflect floodwaters onto cleared banks, resulting in flood damage to that side only.
- Decisions as to the need to mobilise sediment in rivers (i.e. promote erosion) should be informed with reference to past river conditions, and by a geomorphologist, and it is stressed that in many riverine environments, *Salix mucronata* is a highly desirable riparian species.

Useful references

Hall, D. 1990. The biology and control of *Typha capensis*

Review of soil, water quality and other conditions of natural stands of Typha capensis and *Phragmites australis* in the Western Cape, with results of experimental manipulation of reed beds and recommendations for Typha capensis control.

CROSS REFERENCE

- Water quality has implications for invasive vegetation (and can in turn be affected by alien vegetation) – see Section 2 of Volume 1 and Section 2 of this Volume
- Water quality in downstream ecosystems is also a consideration in planning for the removal of dams and weirs – as already discussed in Section 7 of this volume
- Water quality can have an overwhelming effect on the rehabilitation potential of rivers – and must be considered in planning for biodiversity rehabilitation and in particular, rehabilitation of fish communities and/or habitat (Sections 10 and 11)

Environmental legislation

- The removal of plants from threatened ecosystems listed in terms of NEMBA requires a permit
- The use of machinery in a wetland (including valley bottom wetlands) or river may require authorisation in terms of NEMA and the NWA, as it is likely to result in movement of bed material and /or changes in the bed or banks of the river channel.

References

eThekwini Municipality's Environmental Planning and Climate Protection Department: 2014: http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/

APPENDICES TO SECTION 2

APPENDIX A2.1

Table A2.1.1: Background ecological and growth form information for all aquatic and river/wetland associated invasive alien plant species as listed in terms of NEMBA

Photo credits: Unless noted otherwise, images taken from Invasive Species South Africa – http://www.invasives.org.za

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Bailey's Wattle  Australia	*Acacia baileyana*		Seed Dispersal	Category 3	**Manual:** Hand pulling or hoeing of seedlings or saplings. Grubbing, hoeing and digging out of immature stage up to 2 m. Felling and cutting of stump to the ground for larger mature trees. **Bio Control:** Seed feeder (*Melanterius maculatus*).
Rooikrans  South-Western Australia	*Acacia cyclops*	Primarily coastal dunes; banks of watercourses, occasionally water edges; can colonise shallow water; Resprouter.		Category 1b	**Manual:** Hand pulling or hoeing of seedlings or saplings. Grubbing, hoeing and digging out of immature stage up to 2 m. Felling and cutting of stump to the ground for larger mature trees. **Bio-Control:** Indigenous field mice eat the seeds. Rooikrans seed weevil. Flower galler (*Dasineura dielsi* Rubsaamen). Seed feeder (*Melanterius servulus*).
Silver wattle	*Acacia dealbata*	Varied – including watercourses.	Seed dispersal	Category 2	**Manual:** Difficult to remove mechanically, as the tree coppices strongly. **Bio Control:** Seed feeder (*Bruchophagus acaciae*). Seed feeder (*Melanterius maculatus*).

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
 Australia					Chemical: Seedlings/ Garlon 4, Triclon EC Viroaxe EC Large/ mature : Kilo 500 Timbrel 360 SL (L4917) (Best Control Method: Combination)
Green wattle  Australia	*Acacia decurrens*	Varied – including watercourses.	Seed dispersal	Category 2	**Manual:** Difficult to remove mechanically, as the tree coppices strongly. **Bio Control:** Seed feeder *(Melanterius maculatus*). **(Best Control Method: Combination)**
Long leafed Wattle  South-eastern Australia and Tasmania	*Acacia longifolia*	Banks of watercourses, occasionally water edges. Resprouter.	Transformer: declared weed	Category 1b	**Manual:** Hand pulling of seedlings or saplings. Grubbing, hoeing and digging out of immature stage up to 2 m. Felling and stump cut to ground level of large mature trees. **Chemical:** Seedlings/ saplings – Garlon 4 / Viroaxe. Mature tree stumps – treatment not necessary. **Bio Control:** Bud galling wasp (*Trichilogaster acaiaelongifoliae*). Seed feeding weevil (*Melanterius ventralis*).

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Black Wattle  South and East Australia	*Acacia mearnsii*	Banks of watercourses, occasionally water edges; can colonise shallow water. Resprouter.	Transformer: invader	Category 2	**Manual:** Hand pulling of seedlings or saplings <40 cm. Grubbing. Hoeing. Digging of immature trees up to 2 m. Felling used for large mature trees. Ringing, ring of 10 cm width in large plants. **Chemical:** Seedlings – Mamba, Garlon 4, Viroaxe. Tree stumps – Timbrel 3A. **Bio Control:** Stump fungus *(Cylindrobasidium laeve)* applied to freshly cut stumps. Seed weevil (*Melanterius maculates*).
Blackwood  South and East Australia	*Acacia melanoxylon*	Banks of watercourses, occasionally water edges. Resprouter.		Category 2	**Manual:** Grubbing and hand pulling of seedlings (ensure most of the root material is removed). Felling used for large mature trees. **Chemical:** Seedlings – Starane. Immature stage up to 2 m tall – Garon 4/ Viroaxe, also apply to cut stumps. **Bio Control:** Seed feeder (*Melanterius acaciae*). Seed weevil (*Melanterius maculates*).
Golden Wattle  South and East Australia	*Acacia pycnantha*	Banks of watercourses, occasionally water edges. Resprouter.	Transformer: Declared weed	Category 1b	**Bio Control:** Wood rot fungus (*Cylindrobasidium laeve*). Seed feeder (*Melanterius maculatus*). Bud galler (*Trichilogaster signiventris*).

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Port Jackson  South-West Australia	*Acacia saligna*	Banks of watercourses, occasionally water edges; can grow in shallow water. Resprouter.	Transformer: Invader	Category 1b	**Manual:** Hand pulling of seedlings or saplings. Grubbing, hoeing or diggings out of immature stage up to 2 m. Felling and cutting of stump to the ground for large mature trees. **Chemical:** Seedlings/ saplings – Mamba/ Garlon 4/ Viroaxe/ Touchdown Immature stage – Garlon 4/ Viroaxe/ Touchdown Mature tree stumps – mixture of Garlon 4 and diesel. **Bio Control:** Gall rust fungus (*Uromycladium tepperianum*). Seed feeder (*Melanterius compactus*).
Burweed / haak-en-steek bossie  South-East Asia and Africa: https://en.wikipedia.org/wiki/Achyranthes_aspera	*Achyranthes aspera*	Along streams, shady conditions.	Seed dispersal	Not listed	**Manual removal.**

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Crofton Weed  Central America	*Ageratina adenophora*	Banks of watercourses.	Special effects weed: Declared weed	Category 1b	**Bio-Control:** Leaf rust pathogen (*Baeodromus eupatorii*). Shoot tip and stem borer (*Eugnosta medioxima*). Leaf feeder (*Lophoceramica* sp.). Leaf spot pathogen (*Passalora ageratinae* Crous & A.R. Wood (=*Phaeoramularia* sp. Mycosphaerellales: Mycosphaerellaceae)). Leaf miner (*Pentispa fairmairei*). Stem galler (*Procecidochares utilis* Stone).
Mistflower / Creeping Crofton weed  Central America’	*Ageratina riparia (formerly in Euraptorium)*	Invades stream banks, roadsides and plantations.		Category 1b	**Manual:** Hand pulling of seedlings or saplings. Grubbing, hoeing or digging out **Bio Control:** Leaf pathogen (*Entyloma ageratinae*).
Invading ageratum / bokkruid  South America	*Ageratum conyzoides*	Various including riverbanks.	Windblown seeds	Category 1b	**Manual:** Relatively easy to control by cultivation and pre-emergence herbicides. But once matured, difficult to control.

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Garden ageratum / tuinageratum / Todd's curse  South America	*Ageratum houstoniarium*	Various including riverbanks.	Windblown seeds	Category 1b	**Manual:** Relatively easy to control by cultivation and pre-emergence herbicides. But once matured, difficult to control.
Spanish reed  Mediterranean	*Arundo donax*	Banks of watercourses, occasionally water edges. Propagates from fragments.	Transformer: Declared weed	Category 1b	**Manual:** Repeated removal. Cutting of stalks. However, cut stalks can re-root and manual methods generally unsustainable. **Chemical:** [3]Apply MAMBA or Nexus GLYPHOSATE 360 Reg. NO L7113: Act /Wet no 36/ 1947. This is a broad spectrum herbicide so applicable in dense monospecific stands. Ideally use as foliar spray, just before winter (as this is the time that translocation in plant nutrients to the root-mass takes place in preparation for winter dormancy and toxin transfer to roots is most effective. If stands too dense for good foliar application, cut stems and then apply as foliar to resprouting material – but note that cut material may resprout and transfer to roots less effective as cutting stimulates stem growth. If mixed stands,

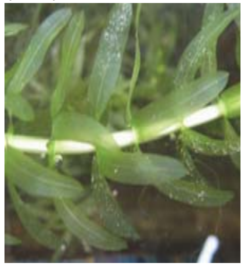
[3] Information courtesy Mossie Basson, 2013 Chairman; Rooiberg-Breederivier conservancy

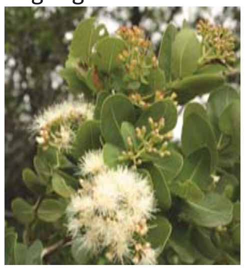
Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
					use GLYPHOSATE 360, on cut stems, but note less effective.
Red water fern (RWF)  Tropical South America	*Azolla filiculoides*	Standing water in wetlands or rivers; variable depth.	Floating, emergent, mat-forming. Fertile when mature; sexual reproduction (spores). Established Transformer; Declared weed.	Category 1b	**Bio Control:** Frond feeding weevil (*Stenopelmus rufinasus*). **(Best Control Method: Bio Control)**
Mauritius thorn / kraaldoring  India & Sri Lanka	*Caesalpinia decapetala*	Various, including watercourses and riverbanks.	Seed dispersal (especially transported by water) and vegetatively. Weed	Category 1b	**Manual:** Seedlings and saplings can be uprooted, remove rootstock to ensure no further coppicing. Bio Control: (*Sulcobruchus subsuturalis*).

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Canna  Tropical America and West Indies	*Canna indica*	Banks of watercourses, occasionally water edges; can grow in shallow water. Resprouter.	Potential transformer: Declared weed	Category 1b	**Manual:** Grubbing. Hoeing. Digging – remove the entire rhizome. **Chemical:** None Registered.
Beefwood  Australia	*Casuarina cunninghamina*	Varied – including watercourses.	Cones	Category 2	Manual: seedlings, saplings – handpulling, cutting; Mature, young felling using a hand saw or chainsaw
Rigid hornwort (RH)  Western United States and Canada: http://www.biodiversityexplorer.or	*Ceratophyllum demersum*	Standing water; wetlands or rivers; variable depth.	Floating, submerged, but may root to the substrate. Mostly spreads vegetative, but can reproduce sexually (seeds). Established.	Not listed	**Manual:** Hand removal using rakes, nets or an excavator for small scale infestations. Weed harvester for dense infestations. **(Best Control Method: Manual)**

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
g					
Inkberry  South America	*Cestrum laevigatum*	Banks and edges of watercourses.	Transformer: Invader	Category 1b	Manual: seedlings, saplings handpulling, young and mature, lopping, slashing
Wandering Jew (WJ)  Africa and Asia: http://www.biodiversityexplorer.org	*Commelina benghalensis*	Mostly terrestrial, but likes wet areas; water edges, standing water, wetlands or gently flowing rivers.	Rooted, creeping. Vegetative (Propagates from fragments) or sexually (seeds). Emerging.	Not listed	**(Best Control Method: Manual** for smaller invasions; No herbicide approved in SA**).**
Pampas grass	*Cortaderia selloana*	Banks of watercourses, occasionally water edges.	Potential transformer: Declared weed	Category 1b	**Manual:** Small plants – dig out. Large plants : Remove flowers early, before setting seeds; brush cut the plant, apply herbicides Kilo WSG

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
 South America					
Common dodder  North America	*Cuscuta campestris*	Varied, including river banks, and other moist sites.	Parasitic. Vegetative (Propagates from fragments) or sexually (seeds). Established.	Category 1b	**Manual:** Cut out and burn infected plants before they can produce seed.
Patterson's curse/ blou-echium  Europe and Asia	*Echium plantagineum*	Banks of watercourses.	Ruderal and Agrestal weeds: Declared weed	Category 1b	Manual: Digging out, Chemical: Roundup Brushcutting and chemical for larger plants

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Brazilian waterweed (BW)  South America	*Egeria densa*	Standing water; wetlands or rivers; variable depth.	Floating, submerged with emergent stems/flowers, forms dense masses. Vegetative. Established (Category 1b).	Category 1b	**(Best Control Method: Manual)**
Water hyacinth (WH)  Tropical South America	*Eichhornia crassipes*	Standing water; wetlands or rivers; variable depth. Vegetative or sexually (seeds); flowers when stressed. Established (Category 1b).	Mostly floating, emergent, mat-forming, may root in shallow waters. Vegetative or sexually (seeds); flowers when stressed. Established (Category 1b).	Category 1b	**Manual:** Hand removal of plants, ineffective for large scale infestations. Small dams can be drained. Large infestations use a floating weed harvester / cutter. Follow a catchment-scale approach, removing from upstream waterbodies **Chemical:** Glyphosate, Diquat, Terbutryn. Most effective herbicide is Roundup. Advisable to remove dying plants to avoid algal blooms. **Bio Control:** Two petiole-boring weevil species (*Neochetina bruchi* and *Neochetina eichhorniae*). Petiole-boring moth (*Niphograpta albiguttalis*). Leaf sucking mite (*Orthagalumna terebrantis*). Fungi (*Acremonium zonatum*, *Altemania eichhomiae*, *Cercospora piaropi*). Leaf pathogen (*Cercospera rodmanii* Conway). Leaf sucker (*Eccritotarsus catarinensis)*. **(Best Control Method: Bio Control as well as Chemical in combination with Manual control methods).**

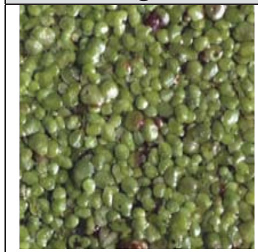
Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Canadian Water weed  North America	*Elodea Canadensis*	Still or slow moving water.	Submerged aquatic plant – stems up to 3 m long. Seeds or runners.	Category 1b	
Red River Gum  Australia	*Eucalyptus camaldulensis*	Banks of water courses. Resprouter.	Transformer: Declared invader	Category 1b	
Sugar gum  South Australia	*Eucalyptus cladocalyx*	Varied – including watercourses.	Tall evergreen tree. Seed dispersal.	Category 1b	Handpulling: seedlings Chemical: Foliar and Cut stump : Access; Chopper; Timbrel, Hatchet

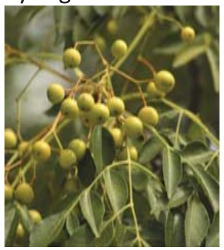
Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Karri  South-Western Australia	*Eucalyptus diversicolor*	Varied – including watercourses.	Seed dispersal.	Category 1b	Handpulling: seedlings Chemical: Foliar and Cut stump : Access; Chopper; Timbrel, Hatchet
Spider gum/ Spinnekopbloekom  South-Western Australia	*(Eucalyptus lehmannii – misapplied in S Arica) E. conferruminata*	Banks of watercourses. Resprouter.	Transformer: Invader	Category 1b	Handpulling: seedlings Chemical: Foliar and Cut stump : Access; Chopper; Timbrel, Hatchet
Grey ironbark  Australia: http://www.biodiversityexplorer.or g	*Eucalyptus paniculata*	Water courses in South Africa.		Not listed in NEMBA, Listed in CARA	Handpulling: seedlings Chemical: Foliar and Cut stump : Access; Chopper; Timbrel, Hatchet

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Honey locust  North America	*Gleditsia triacanthos*	Among others – can grow in watercourses.	Spreading tree. Seed dispersal.	Category 1b	**Bio Control:** Seed feeder (*Megabruchidius tonkineus* (Unknown).
Sweet Hakea  South-Western Australia	*Hakea drupacea*	Banks of watercourses. Reseeder.	Transformer: Declared weed	Category 1b	**Manual:** Hand pull small plants < 40 cm tall. Cut larger plants to the ground below the level of branches or leaves which can re-sprout.
Rock Hakea, Harigehakea  South-Eastern	*Hakea gibbosa*	Banks of watercourses. Reseeder.	Transformer: Declared weed	Category 1b	**Manual: Seedlings – handpulling** **Mature: Cut close to the ground using a lopper or handsaw** **Bio Control:** Green seed feeder (*Erytenna consputa* Pascoe).

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Australia					
Silky Hakea,  S-E Australia	*Hakea sericea*	Banks of watercourses Reseeder.	Transformer: Declared weed	Category 1b	**Manual: Seedlings – handpulling** **Mature: Cut close to the ground using a lopper or handsaw** **Bio Control:** The Hakea fruit weevil *(Erytenna consputa). Seed feeder (Carposina autologa Meyrick). Stem gummosis disease (Colletotrichum acutatum).*
Morning Glory  West Indies	*Ipomoea indica*	Banks of watercourses.	Transformer Declared weed	Category 1b	Manual: remove entire plant; Chemical: Kilo (non-target plants may be affected)
Morning Glory	*Ipomoea purpurea*	Banks of watercourses.	Special effect weed: Declared weed	Category 1b	Manual: remove entire plant; Chemical: Kilo (non-target plants may be affected)

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
 Tropical America					
Lantana  Central & S. America	*Lantana camara*	Banks of watercourses.	Transformer: Declared weed	Category 1b	**Manual:** Hand pulling of seedlings or saplings. Grubbing or hoeing of small patches. Cutting is ineffective as plant coppices use of herbicides needed. Large infestation should be crushed or rolled with brush cutters then stumps treated with herbicides. **Chemical:** Seedlings/ saplings – Mamba/Kilo Touchdown / Access. Mature tree stumps – Chopper / Access/ Timbrel 3A. **Bio Control:** Flower galler (Aceria *lantanae* Cook). Leaf miner (*Calycomyza lantanae*).Leaf sucker (Falconia intermedia). Leaf feeder (*Hypena laceratalis* Walker). Leaf miner (*Octotoma scabripennis* Guerin-Meneville). Leaf miner (*Ophiomyia camarae* Spencer). Seed miner (*Ophiomyia lantanae*). Leaf & flower sucker (*Teleonemia scrupulosa* Stal). Leaf miner (*Uroplata girardi* Pic).
Duckweed	*Lemna gibba*	Open water.		Cosmopolitan not listed	**Manual:** Remove plants by hand, using a net or rake. A floating or amphibious weed harvester can be used. Stack the removed plants above high water mark.

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
 Mediterranean					**Chemical:** Glyphosate – to be used a last resort.
Australian Myrtle  South-eastern Australia and Tasmania	*Leptospermum laevigatum*	Sandy soils.	Seed dispersal. Transformer: Declared weed	Category 1b	**Manual: saplings, seedlings handpulling Young and mature plants, cut close to ground. Can be successfully controlled without herbicides** **Chemical:** Several soil-applied herbicides have been registered for the control of this weed. Apply to base of plant. **Bio Control:** Leaf feeder (*Aristaea thalassias*). Bud galler (*Dasineura strobila*).
Willow herb (WHB)  Asia and South America: https://en.wikipedia.org/wiki/Ludwigia_adscendens	*Ludwigia adscendens*	Standing water, wetlands and river margins.	Floating or rooted, creeping; mixed with other species. Vegetative or sexually (seeds). Emerging	Not listed	**(Best Control Method: Manual)**

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Purple loose-strife  Eurasia	*Lythrum salicaria*	Standing or gently flowing water, wetlands and river margins. Mainly in the Liesbeek River.	Rooted; forms colonies from single root mass. Mostly sexual, but also vegetative. Established (Category 1a).	Category 1a	**(Best Control Method: Manual or Chemical *No registered in SA)**
Syringa  India to Australia	*Melia azedarach*	Commonly found along streams.		Category 1b or 3 in urban areas	**Manual:** Difficult to remove mechanically, as the tree coppices strongly. Trees to be cut well below the ground. **Chemical:** Confront Basal : Garlon Frill: Timbrel
New Zealand Christmas Tree  Australasia	*Metrosideros excelsa*	Invades coastal fynbos on moist peaty soils in Western Cape.	Seed dispersal.	Category 1a in the Overstrand District, not listed elsewhere Sterile cultivars or hybrids not listed	Manual: handpull, seedlings Cut or fell large trees using hand saw or chainsaw

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Parrot's feather (PF)  South America	*Myriophyllum aquaticum*	Standing water; wetlands or gently flowing rivers; variable depth.	Rooted, emergent. Vegetative; plants are female and sterile. Established (Category 1b).	Category 1b	**Manual:** Removal of plants using rakes or nets, care must be taken to remove all fragments. **Chemical:** Glyphosate as a last resort. **Bio Control:** Leaf feeding beetle (*Lysathia sp.).* **(Best Control Method: Bio Control or Manual *Effective only if in conjunction with Bio Control)**
Watercress (WC)  Europe and Asia	*Nasturtium officinale*	Standing water; wetlands or rivers; variable depth.	Rooted with floating and emergent stems. Vegetative or sexually (seeds). Established (Category 2).	Category 2	**Manual control, remove entire plant best to control before setting seeds**
Stinkbean  Western and South-Western Australia	*Paraserianthes (Albizia) lophantha*	Banks of watercourses.	Transformer: Declared weed	Category 1b	**Manual:** Hand pulling of seedlings. Grubbing, hoeing and digging out of saplings by the roots. Cutting down as close to ground as possible for immature – mature trees. **Chemical:** Cut stumps – Timbrel 3A. **Bio Control:** Seed weevil (*Melanterius servulus*).

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Kikuyu grass  Tropical and East and North-East Africa	*Pennisetum clandestinum*	Banks of water courses, but occasional on water's edge.	Potential transformer: Declared invader	Category 1b in Protected Areas and wetlands in which it does not already occur.	**Manual:** hand pull by roots; kikuyu often associated with raised fill / disturbed areas – removal will reduce invasion opportunities; Inclusion of hard paths on upland edge of river, buffer or wetland provides hard management edge from which to manage invasion and also reduces to some extent root spread **Chemical:** Spray with Roundup ® while grass is actively growing (not when dormant) and follow up spray any regrowth after 4 months.
Persicaria  Eurasia and Tropical and subtropical Africa	*Persicaria lapathifolia*	Standing water or gently flowing river margins.	Rooted. Sexually (seeds). Emerging.	Not listed	**Manual : handpul, remove entire plant**
Persicaria	*Persicaria senegalensis*	Edges of water courses, occasionally shallow water.	Potential transformer.	Not listed	**Manual : handpul, remove entire plant**

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
 Tropical and subtropical Africa: http://www.biodiversityexplorer.org					
Belhambra  South America	*Phytolacca diocia*		Seed dispersal.	Category 3	Manual: Hand pull seedlings and saplings Felling, cutting mature/young trees
Aleppo pine	*Pinus halepensis*	Occasional banks of watercourses.	Transformer: Declared invader	Category 3 in the Eastern Cape, Free State and Western Cape. Not listed elsewhere	**Manual:** Hand pull small tree <40 cm tall. Remove a ring of bark 30-40 cm wide on larger trees. Cut large trees to ground level.

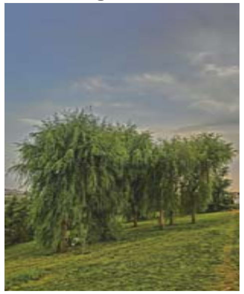
Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
 Mediterranean					
Cluster Pine  Mediterranean	*Pinus pinaster*	Occasional banks of water courses.	Transformer: Declared invader	Category 2 for plantations and wind-rows , 1b elsewhere. National heritage trees not listed	**Manual:** Hand pull small tree <40 cm tall. Remove a ring of bark 30-40 cm wide on larger trees. Cut large trees to ground level.
Stone Pine  Northern Mediterranean	*Pinus pinea*		Special effect weed.	Not listed	**Manual:** Hand pull small tree <40 cm tall. Remove a ring of bark 30-40 cm wide on larger trees. Cut large trees to ground level.

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Monterey Pine  South-Western North America	*Pinus radiata*		Transformer: Declared invader	Category 2 for plantations and wind-rows, 1b elsewhere. National heritage trees not listed. Urban Cape Town, Winelands, Overberg, areas>400 mm diameter , height of 1000 mm not listed except in riparian area – 1b	**Manual:** Hand pull small tree <40 cm tall. Remove a ring of bark 30-40 cm wide on larger trees. Cut large trees to ground level.
Water lettuce (WL)  South America	*Pistia stratiotes*	Standing water; wetlands or rivers; variable depth.	Usually floating, emergent, but may root in shallow waters. Vegetative or sexually (seeds). Established (Category 1b)	Category 1b	**Manual:** Remove plants using raking, nets or an excavator. A floating weed harvester can be used. **Chemical:** Herbicides used as a last resort. Terbutryn, Roundup, Glyphosate). **Bio Control:** Weevil (*Neohydronomus affinis*). **(Best Control Method: Bio Control; Manual;)**

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Australian Cheesewood/ Australiesekasuur  Eastern Australia	*Pittosporum undulatum*	Banks of watercourses.	Potential transformer: Declared weed	Category 1b	Manual: hand pull seedlings & saplings Felling, cutting: mature and young plants
Pickerel weed (PW)  North, South and Central America	*Pontederia cordata*	Standing water, wetlands and river margins Vegetative Established (Category 1b).	Rooted, emergent, forms dense clumps. Vegetative Established.	Category 1b	**(Manual: hand pull, cut Herbicide: Mamba, Roundup, Springbok**

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Grey Poplar  Europe and Asia: https://en.wikipedia.org/wiki/Populus_%C3%97_canescens	*Populus x canescens*		Transformer: Declared invader	Category 2	**Manual:** Hand pulling – seedlings. Saw off low down on truck of immature stage up to 2 m. Felling used for large mature trees. **Chemical:** Seedling / saplings / immature plants – Garlon 4, Viroaxe. Stumps – Chopper. Mature tree stumps – Chopper / Timbrel 3A.
Castor-oil Plant  Tropical East and North-East Africa	*Ricinus communis*	Banks of watercourses	Special effect weed; poisonous: Declared invader	Category 2	Manual: hand pull, Cut/slash young and mature plants Chemical: Confront
Black locust  North America	*Robinia pseudoacacia*	Riverbanks and roadsides.	Forms dense stands. Seed dispersal and suckering.	Category 1b	**Manual:** Physical removal requires care and persistence, as regrowth is vigorous. Felling, cutting: mature, young plants Chemical : Confront

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
(Watercress)  Europe: https://en.wikipedia.org/wiki/Watercress	*Rorippa nasturtium-aquaticum (Nasturtium aquaticum)*	Open water.	Special effect weed: Declared invader	Category 2	**Manual:** Removal of plants by hand using nets or excavator.
European Blackberry and probably other species/ hybrids  Europe and Mediterranean	*Rubus fruticosus*	Banks of watercourses.	Seed dispersal & vegetatively.	Category 2	**Chemical:** Mamba max – most effective in autumn when downward sap movement.

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Weeping willow/ Treurwilg  Asia: https://en.wikipedia.org/wiki/Salix_babylonica	*Salix babylonica*	Banks and edges of watercourses.	Transformer: Declared invader	Not listed	Manual: hand pull small trees Felling, cutting large & young trees
Crack or brittle willow  Europe and W. Asia: https://en.wikipedia.org/wiki/Salix_fragilis	*Salix fragilis*	Banks and edges of watercourses.		Not listed	Manual: hand pull small trees Felling, cutting large & young trees

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Kariba weed (KW)  South America	*Salvinia molesta*	Standing water; wetlands or gently flowing rivers; variable depth.	Floating, emergent, mat-forming. Vegetative. Established (Category 1b).	Category 1b	**Manual:** Remove plants using rakes and nets; take care to remove all the pieces. **Chemical:** Glyphosphate, Diquat and Igran to be used a last resort. **Bio Control:** Snout beetles. Leaf feeding beetles. Weevil (*Salvinia molesta*). Stem borer (*Cyrtobagous salviniae*). Frond feeder (*Paulinia acuminata*). **(Best Control Method: Bio Control or Chemical)**
Red Sesbania  South America	*Sesbania punicea*	Banks of watercourses.	Transformer: Declared weed	Category 1b	**Manual:** Cutting of plants to as close to ground level as possible and treat with chemicals. NOTE: Sesbania is poisonous so wash hands after handling. **Chemical:** Garlon 4, Viroaxe, Touchdown, Mamba, Chopper, Timbrel 3A. **Bio Control:** Sesbania flower bud weevil *(Trichapion lativentre)* Sesbania seed weevil *(Rhyssomatus marginatus)* Sesbania stem borer *(Neodiplogrammus quadrivittatus).* If two of the three control agents are present no other control measures are needed.
Bugweed/ Luisboom  South America	*Solanum mauritianum*	Banks of watercourses.	Transformer: Declared invader	Category 1b	Manual: hand pull small trees Felling, cutting large & young trees **Herbicides:** Confront, Roundup, Tumbleweed **Bio Control:** Leaf sucker (*Gargaphia decoris*).

Common Name Photo Origin	Scientific Name	Preferred Habitat and flow condition (where relevant)	Comment	NEMBA Category Invasive	Control Method - Manual: Chemical: Bio-control
Spanish Broom  Europe and Britain	*Spartium junceum*	Banks of watercourses.	Potential transformer: Declared weed	Category 1b in the Eastern and Western Cape or 3 in the Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga. North-West and Northern Cape	**Manual:** Recommended where possible. **Bio Control:** Stem galler (*Aceria spartii*).
Chinese Tamarisk  Eastern Europe to Asia	*Tamarix chinensis*	Various, including banks of watercourses.	Seed dispersal.	Category 1b	Manual: handpulling saplings, seedlings Felling, cutting : mature, young
Pink Tamarisk  E. Europe to Asia	*Tamarix ramosissima*	Various, including banks of watercourses.	Seed dispersal.	Category 1b	Manual: handpulling saplings, seedlings Felling, cutting : mature, young Chemical: lumberjack, Timbrel

Photo References:

Invasive Species South Africa. 2015. [Online]. Available: http://www.invasives.org.za/invasive-plants.html [2015, July 21].

Biodiversity Explorer: Weeds and Invaders. 2015. [Online]. Available: http://www.biodiversityexplorer.org/plants/weeds_and_invaders [2015, July 21].

Wikipedia – The Free Encyclopaedia. 2015. Available: https://en.wikipedia.org/wiki/Prosopis_velutina [2015, July 21].

Wikipedia – The Free Encyclopaedia. 2015. Available: https://en.wikipedia.org/wiki/Salix_fragilis [2015, July 29].

Wikipedia – The Free Encyclopaedia. 2015. Available: https://en.wikipedia.org/wiki/Salix_babylonica [2015, July 29].

Wikipedia – The Free Encyclopaedia. 2015. Available: https://en.wikipedia.org/wiki/Watercress [2015, July 29].

Wikipedia – The Free Encyclopaedia. 2015. Available: https://en.wikipedia.org/wiki/Populus_%C3%97_canescens [2015, July 29].

Wikipedia – The Free Encyclopaedia. 2015. Available: https://en.wikipedia.org/wiki/Ludwigia_adscendens [2015, July 29].

Wikipedia – The Free Encyclopaedia. 2015. Available: https://en.wikipedia.org/wiki/Achyranthes_aspera [2015, July 29].

APPENDIX A2.2

FIRE CONTROL MEASURES

This document provided by the Biodiversity Management Branch of the City of Cape Town

“Conserving our Future”

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ECOLOGICAL BURN GUIDELINES

COMPILED BY: City of Cape Town – Biodiversity Management Branch

Edited by Dalton Gibbs

Things to take into consideration when planning and executing a prescribed burn

> The more you sweat in preparation, the less you burn in the fire

PLANNING
Objective

1) Define your objective up front. Is this burn an ecological burn to renew the veld? Is it rather to reduce the fuel on a site and address the fire risk to infrastructure?
2) Is the fire to suppress alien grasses; does it need to be a hot fire?

The Site

1) What is the infrastructure on the site? How will this infrastructure behave if a fire got through your line and burnt it? Will it burn, explode or not be affected.
2) What is the infrastructure on surrounding the properties?
3) Determine what properties and who surrounds the site.
4) Are there power lines across or near the site that could arc?
5) Are there adjacent roads that will be affected or closed?
6) Locate the nearest fire hydrants and routes to them.
7) Determine the vegetation type on site, is it fire driven and how does it behave when burning?

8) Determine the age of the veld; what is the fuel load? How fast will it burn and how long will the follow up period be?
9) Determine if there are any species of concern on site (rare & endangered or locally rare species on site).
10) Is there alien vegetation, or a seed bank, on site? Will alien clearing be necessary after the burn?
11) Given different wind scenarios, where will the resultant smoke go?
12) Determine the total extent of the fire.
13) Are the adequate fire breaks in place; do new fire breaks have to be cut?
14) Determine suitable water re-filling sites for vehicles (hydrants, water tankers, etc.) and helicopters

Fire Parameters

1) Set the optimum weather parameters for the burn to take place; remember that local terrain features can increase wind speeds on site.
2) Have cut off points during the burn where the fire can stopped if for some reason the fire cannot be continued for some reason.
3) Have fall back lines if the fire crosses the burn perimeter; plan as if this is going to happen.
4) Plan a time table for the burn, with cut off points in order to achieve the objective by the end of the day.
5) Determine the resources available for the burn, both during the initial burn and for the next few days during the monitoring phase.
6) Determine the ideal fire conditions, season & weather. Determine outside parameters beyond which the fire will not go ahead.

Administration

1) Apply for a burning permit and advise the neighbours and local Fire Protection Association.
2) Inform the local councillor of the proposed dates.
3) Determine fire crews for the initial burn and roster of crews for ongoing shifts.
4) Determine catering arrangements for crews.
5) Catalogue all necessary phone numbers, radio easy numbers and contact details.
6) Designate a Fire Boss.
7) Designate Sector Bosses if necessary.
8) Designate a suitably qualified first aid person.
9) Designate a logistic person.
10) Designate an admin officer.
11) Do a pamphlet drop to neighbouring properties if necessary.
12) Determine where the closest fuel points for vehicles are.

Site Preparation

1) Walk the proposed site and check the radio communications that there are no dead zones of no reception.
2) Cut and clear fire breaks where necessary.
3) Cut open and repair access roads for vehicles where necessary.
4) If needed remove certain vegetation such as *Searsia* (Rhus) or alien species.
5) Select a site for the temporary command point or JOC (Joint Operation Command).
6) Walk the fire line with the fire boss, crew leaders and City Fire services representative.
7) Rehearse the steps of the burn according to the plan and time table.
8) Check that the nearest fire hydrant points work; these need to be checked two weeks before and immediately before the burn.
9) Check for any gate keys needed.
10) Loosen and open fences where necessary.

Burn Execution – Briefing Stage

> When in doubt rather over resource your fire; rather have crews standing idly by than standing idly by at home!

1) Have crews on standby to respond early if the fire goes ahead.
2) Check weather reports for at least 3 days. Use www.windfinder.com; www.windguru.com, www.weathersa.co.za and www.yr.no
3) Phone the weather office for their personal input.
4) Set up the JOC or base area.
5) Brief fire crews and crew bosses. Briefing to cover fire plan, escape routes, fall back plan, logistics and water sources.
6) Inform fire crews of role players (i.e. Fire boss, crew leaders, first aider, logistics person, etc.).
7) Allocate crew leaders their roles and objectives.
8) Allocate a radio channel for the burn.
9) Crew leaders to check crews Personal Protective Equipment (PPE).
10) List all crew leaders (with radio no.), crews and resources deployed at the JOC.
11) Start all motors of vehicles and pumps.
12) All motors to be fully fueled.
13) Have a map or aerial photo of the burn area.
14) Have non-permanent marker pens on hand.
15) Have a copy of the burn permit on hand.
16) Have all contact numbers on hand.

Burn Execution – Burn Stage

> If you are in doubt lighting the match; then don't!

> If you find yourself just managing to hold the fire line, you haven't done your planning properly!

1) Important: start the burn as early as possible.
2) Important: if the weather parameters are not within the predetermined limits DO NOT START the fire. When in doubt don't!
3) Get crews to check any structures or bushes in the burn area for vagrants.
4) Ensure that no hikers are in the area. Implement access control at all public entry points.
5) If the fire is to be a closed ring burn, crews to walk through to herd out any larger animals.
6) Determine all crews are in position and safe on the start line before ignition.
7) Inform City Fire Control of ignition.
8) Inform all crews on the radio channel of ignition.
9) Burn ignition.
10) Check the fire is meeting the time schedule.
11) Ensure burn lines are actively monitored as the fire line is burnt ahead.
12) Monitor wind strength and weather conditions.
13) Determine whether to continue the burn before teams reach the predetermined cut off lines.
14) Update the site map at the JOC (Joint Operation Command) with changing situation.

Burn Execution – Monitoring Stage

1) Crews coming off the line to brief crews going on.
2) Crews arriving or leaving to sign in/out at the JOC.
3) Update fire map and crew resource list at the JOC.
4) Scan the fire line where necessary with a Knox Scanner.

Post Burn

1) The immediate post burn period is a very good time to remove old rubbish and minor infrastructure that was hidden in the veld. Do this before rain and seed germination takes place.
2) Sort through equipment and tools to return the correct place/owners.
3) Update the site fire map.
4) Write a press release beforehand and post this release.

VEGETATION TYPES – BURNING CHARACTERISTICS

VEGETATION TYPE	FUEL LOAD	BURN CYCLE	BURNING CHARCTERISTICS
Afro-montane Forest	Heavy > 5 hour fuel load. High moisture content	>100 years; only burns under exceptional conditions	Edges burn, slow burn with lots of long term fuel – long follow up period
Fynbos	<1 hour fuel, fast burning, especially reseeding species	12-20 yrs mountain 10-12 yrs lowlands	Hot quick fires, prone to spot fires – short follow up; land scape "burns clean"
Strandveld	High > 1 hour fuel load.	>35 years	Reluctant to burn at first; burns when preheated and dried by oncoming fire front. Leaf litter smolders for a long time – long follow up period.
Renosterveld	Medium – 1 hour fuel	5-10 yrs	Reluctant to burn at first; burns late morning (10:00) and afternoon. Prone to spot fires – black smoke. Short follow up period.
Wetlands(Typha & Phragmites)	High < 1 hour fuels	6-10 yrs (depending on eutrophic factors of water body)	Quick hot fires; create heavy ash fall out. White smoke. Prone to spot fires.
Kikuyu Grasslands	Low < 1 hour fuels	5 yrs depending on growth 7 herbivory	Relatively slow moving, heavy white smoke. Easy to suppress, but in thick Kikuyu difficult to extinguish.

Appendix 1

POLICY REGARDING WILDLIFE AND CONTROLLED FIRES

As compiled by the

Fauna Management Committee

ERM DEPARTMENT

A controlled fire is meant to mimic a natural occurrence in a more urban setting so as to keep the natural processes going as far as possible. This entails not tampering with the natural selection that will take place in these events.

Having said that, the Fauna Management Committee also acknowledges that these situations are not that simplistic and that under certain conditions it is advisable to perform search and rescue missions before a planned fire intervention. These conditions are:

a) Whenever a circular burn is planned to keep the fire contained, a search and rescue mission will be performed by flushing the animals into an adjacent management block, because a circular fire does not mimic a natural fire and might not leave animals with enough of a chance of escaping, should they wish to do so.
b) When a more natural pattern of burning will be followed, we do not encourage rescue missions before such an event but will not prevent interest groups from flushing the area before a planned burn.
c) The FMC encourages members of the public and interest groups to conduct such a search and rescue mission before a planned burn, but it only allows animals to be flushed to a next management block that falls outside the perimeter of the planned burn to allow natural migration to occur.
d) No animal will be caught and kept in crates or containers to be released again.
e) Managers are advised to add this information to the press release before a controlled burn.

Chapter 3:

Reducing flooding risks by improving flood conveyance or flood attenuation

Author:

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Chris James (Wits University)

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Introduction

Floods are naturally occurring events which are important for scouring the river channel, redistributing sediment within the channel and along the reach, maintaining ecological processes in riparian zones, activating floodplains and recharging floodplain wetlands and lakes. The frequencies, flow velocities and heights of floods can however be incompatible with some landuse activities within or adjacent to floodplains, or become unnaturally high due to changes in the catchment (such as urbanization or changing storm characteristics associated with climate trends). That floods present problems is a consequence of humans' use of flood-prone locations rather than their natural occurrence. Reducing flood risk is therefore usually motivated more by people's needs than for river rehabilitation or restoration purposes. However, the ameliorative measures available may have different ecological impacts that should be considered in relation to rehabilitation issues.

Problems arising from unacceptable flood levels and frequencies can be addressed in three ways. Firstly, the problem can be avoided by **restricting types of landuse activities** in flood prone areas to those that are compatible with occasional flooding. This is the ecologically least disruptive approach and therefore the most desirable. Secondly, the water levels during a flood event can be lowered by **increasing the conveyance** or discharge capacity of the river reach in the vicinity of the problem site. Some approaches require in-channel modifications with potentially high ecological disruption. Flood discharges at the problem site can also be decreased through **attenuation** in the catchment by managing flood peaks or increasing attenuation on floodplains further upstream.

Practical measures for applying the above approaches at the site scale are listed in **Table 3.1**, grouped by objective type and, at the site scale, roughly in order of increasing potential ecological impact. These approaches to managing flooding risk are then described in more detail in the following sections of this chapter. The various options are furthermore compared in **Figure 3.1** in terms of their relative costs and expertise requirements, and their suitability in relation to the space available at the problem site.

Flood management approaches that rely on increasing the capacity of the river channel to convey floods do so by either reducing flow resistance (for example by channelizing – Section 3.6 – or removing natural roughness features, such as vegetation – Section 3.3) or by **increasing the cross sectional area of the channel** (making it wider – Section 3.4). Unnatural and excessive encroachment of vegetation within the channel and/or floodplain, by vegetation that is either alien and invasive, or indigenous and invading (see Volume 1: Guidelines, Section 3.2 on invasive plants), can be managed through vegetation control or removal. Removal of invasive vegetation, especially alien vegetation, is the best option.

Implications of managing floods at the site versus downstream

- Flood attenuation on a floodplain or within a channel necessarily causes elevation or expansion of flooding at that location, whereas
- Increasing channel conveyance will exacerbate flooding conditions further downstream. Increasing conveyance may also increase erosion and decrease habitat diversity.

Thus solving flood problems at one site will have implications for flooding risks at the site as well as downstream. The implications of any activities that affect flooding must therefore be clearly understood before embarking on such interventions. Where erosion is an expected outcome of implementation of flood control measures, the approaches and cautions regarding bank stabilization as outlined in Chapter 4 should be considered.

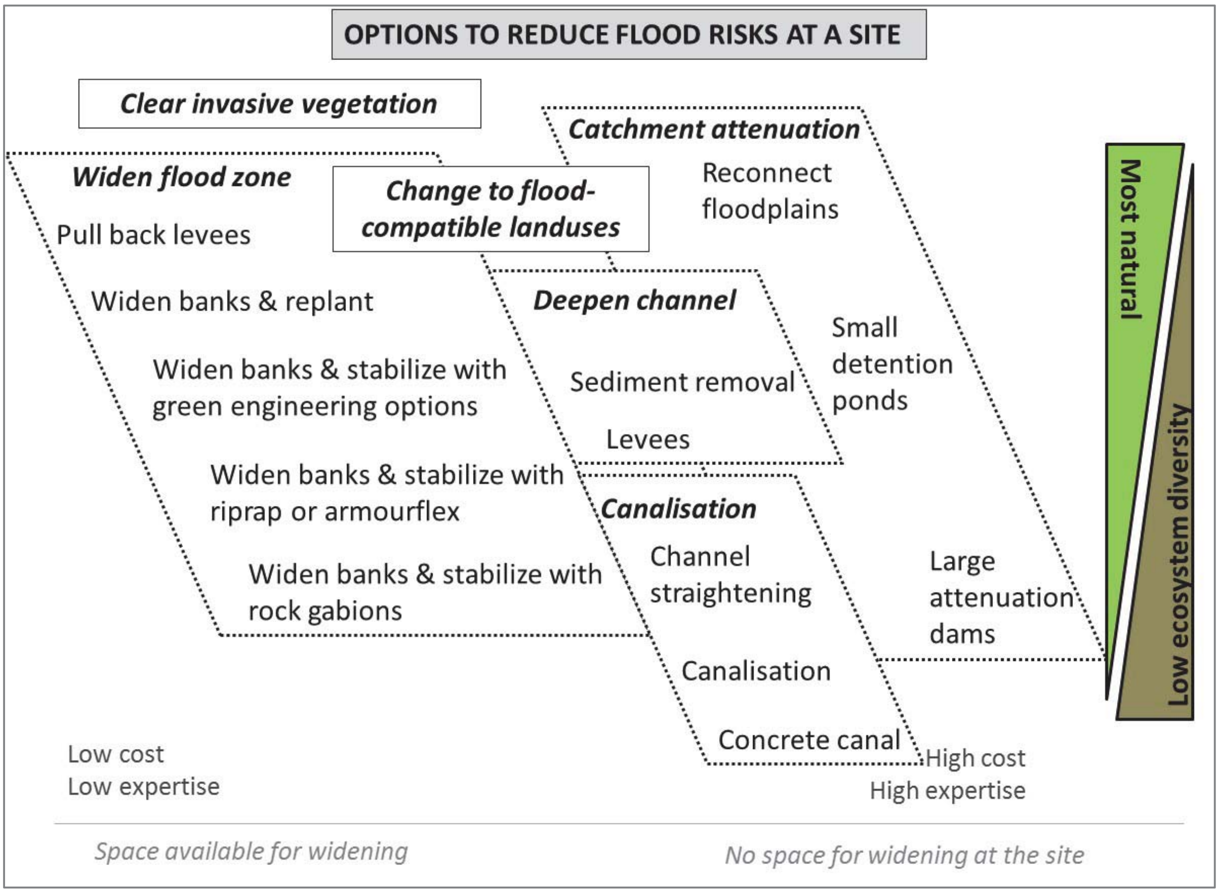


Figure 3.1: A summary of options available for reducing flooding risks.

Avoidance approaches include a "**do nothing**" approach (Section 3.1) or making **landuse changes** that to select landuse options which are less impacted by flooding thereby minimising flooding impacts (Section 3.2). There are many options to increase flood conveyance at the site scale, including **invasive vegetation removal** (Section 3.3), **channel widening** (Section 3.4), pulling back **levees** (Section 3.5) and **channelization** (Section 3.6). The last options for managing flooding look at **attenuating flood peaks upstream** of the site through (1) either reconnecting riparian areas and floodplains in the upstream catchment (Section 3.7) or (2) through stormwater management and attenuation in dams (Section 3.8). The latter option is applicable for sites where upstream catchment developments have increased flooding volumes and frequency – upstream attenuation of the increased runoff can restore flooding discharges and frequencies to a more natural pattern.

From an ecological perspective, removal of invasive vegetation is the best option. It is also the cheapest. Thereafter, channel widening is usually the preferred option over channelization. Channelisation is almost always ecologically damaging and is not supported, except in the case of unnaturally high sedimentation rates, where some sediment removal could create more natural conditions (see Chapter 6). Channel widening is however often constrained by the availability of land adjacent to the river for flood management purposes.

THINK GREEN

Main principles for managing flooding risks at the site

The guiding principles to managing flooding risks along a river should be:

1. to allow the river as much lateral space as possible to allow floodwater to spread and thereby reduce velocities and minimize erosion and safety hazard,
2. to restrict floodplain activities to those compatible with occasional flooding (such as for pastures or recreation), and
3. to keep rivers and riparian zones clear of invasive vegetation in order to preserve their conveyance function and reduce flood heights.

Table 3.1: Summary of the options to reduce flooding risks.
Options described in more detail in text – presented largely in order of most to least ecologically benign options – within groups of broad objectives (conveyance, attenuation, etc.).

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
Avoidance approaches						
No interventions	**Do nothing (Section 3.1)**	No intervention	0	None, but risk of further loss of ecosystem degradation may be high	None	Do not consider if rate of degradation is fast and/or risk of widespread impacts is high.
Minimise the impact of flooding	**Change landuses to flood-compatible activities (Section 3.2)**	Within flood- prone areas, employ landuse activities (e.g. sportsfields, flood tolerant crop, parklands) which are compatible with occasional flooding.	++	Some ecological benefit may occur where the new landuse activities allow for more natural vegetation and flooding processes to be reinstated.	NEMA, NEMBA and CARA authorization may be required for some instances of landuse change	The most fertile soils tend to be found on floodplains, and abandonment or relocation of existing agricultural landuses to other sites will not always be possible. Moreover, the cost of relocating fixed infrastructure (irrigation, dwellings, roads, bridges, etc.) will present an enormous cost to society and may preclude this option in many cases..
Conveyance approaches (aimed at increasing discharge through the site)						
Increase flow velocity	**Clear invasive vegetation (Section 3.3)**	Removal of invasive vegetation from river and banks	+ (R4k-R15k/ ha)	Can be beneficial if more natural conditions are being created – note that functions such as water quality improvement through sediment and nutrient trapping may be reduced and erosion may increase.	None unless species are protected	Some indigenous species are protected and clearing requires additional authorizations – Refer to Section 2 of this document. All debris should be removed from the channel and riparian area. Costs of clearing, based on 2014 SANBI data, range from R4000-R8000 per ha for Acacias and R10 000-R15 0000 per ha for large bluegums. In addition, follow up clearings (from R2000 to R4500/ha) must be budgeted for.

[4] Costing estimates kindly provided by Ms. Heidi Niewoudt (SANBI) are indicated primarily for comparative purposes. Site specific factors, such as access, available materials, environmental authorisations and method of construction will determine final costing. These costs based on 2014 data only.

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
Increase cross-sectional area of the channel	**Widen channel and stabilize new banks (Section 3.4)**	Widen the channel, reshape the banks and stabilise with either: • vegetation, • green engineering options, • Riprap, • Flexible armouring mats, • Rock retaining walls (gabions;	+ ++ (+++) +++ +++ +++++	**Revegetation** with a variety of indigenous species may improve habitat diversity and quality, as well as longitudinal and lateral connectivity, while reducing erosion; Important positive component is that it allows the low flow channel to be relatively natural, and unlined, supporting habitat quality, diversity and low flow water quality amelioration **Green engineering options** usually provide better habitat diversity over harder options. If design allows for establishment of plants other than grasses, and with vertical diversity, then could be ecologically improved **Riprap and flexible armouring mats** tend to offer poorer ecological condition of the banks (but riprap can be appropriate for boulder streams and can be adapted to support vegetation) **Gabions** offer even lower habitat diversity, but planting of lower wetted gabions may provide improved river bank habitat	NWA: Section 21 c and i; NEMA applies unless very small (<5 m^3) sediment volumes are moved.	**Revegetation**: Only applicable to low energy sites where vegetation will be sufficient to stabilise reshaped banks. Revegetation costs are estimated at R16-35 per m^2. **Green engineering options**: May only be applicable to moderate energy sites where green options adequate to stabilise reshaped banks – note that if used in high energy areas, may result in significant ecological and other risk and/or damage **Riprap and flexible armouring mats**: In boulder and cobble streams, riprap would be preferable over armourflexing. If armourflexing is used, the cells must be left open for vegetation establishment. **Gabion**: Engineer is required to design structures

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
Increase cross-sectional area of the floodplain/ riparian area	**Widen the flood zone by pulling back levees (Section 3.5)**	Pull back existing levees from the bank or water's edge.	++	Ecological impact reduced (but not avoided) by setting levees back as far from the top of the bank as possible – where levees set back to include high flow area, this allows for low flow habitat to be undisturbed and increases conveyance through the site.	NWA: Section 21 c and I (General Authorisation should apply); NEMA Activity 19 will apply unless very small (<5 m^3) sediment volumes are moved.	Pulling back existing levees should be encouraged wherever practicable.
Increase flow velocity	**Channelisation: excavation, levees and channel straightening (Section 3.6)**	**Channel straightening** (excavated, unlined) whereby a narrow, deep, straighter channel is created to speed up the rate of flow, especially in rivers with a highly meandering or braided pattern, where channel straightening allows for more effective, rapid flood conveyance	++	High in-channel disturbance, but in cases of aggradation (i.e. where sedimentation is raising the level of the river bed), this approach may be essential. If carried out infrequently, high levels of ecosystem recovery may be possible; disturbance and steepening of river banks often associated with dredging sediment	NWA: Section 21 c and I (GA may be applicable in some cases); NEMA applies unless very small (<5 m^3) sediment volumes are moved.	May be applicable for high sediment rivers where adjacent landuses are at unacceptable risk (***Refer to Chapter 6***). Engineer should design the channel straightening to planform to identify the minimum amount of channel straightening to achieve the required reduction in flood risk. Note that significant downstream impacts may result as a result of receipt of increased volumes of flow, potentially resulting in the need for extended canalization / channelization and its associated negative impacts
		Levees: where new levees are constructed on the channel banks to constrain flood flows	+++	***None in the case of new levees.*** New levees definitely not recommended from an ecological perspective	NEMA Activity 19, NWA: Section 21 c and i	Loss of floodplains and/or riparian areas as the floods become restricted by levees. Downstream flood peaks may increase.

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
		Canalisation (excavated, lined) whereby a narrow, deep, lined channel is created to speed up the rate of flow , especially floodwaters	+++++	Unless water quality is seriously impacted, benefits in terms of ecological function are very limited for lined (concrete or other) canals. <u>New canalisation definitely not recommended from an ecological perspective</u>	NEMA Activity 19, NWA: Section 21 c and i	Engineer should design the canal dimensions to meet the flood conveyance objectives. Unlined canals are cheaper than lined canals (concrete structures in the region of R7500/m^3) but require more regular maintenance actions. Once in place, channelized or canalised system are difficult to undo, and are often associated with socio-economic ills, such as littering, poor water quality, invasion by alien vegetation, poor habitat quality and reduced property values
Attenuation approaches: decrease flood peaks into downstream areas						
Reduce flood peaks from the catchment	**Reconnect upstream riparian areas and floodplains (Section 3.7)**	**Reconnection of riparian areas and floodplains** to maximize flood attenuation through the removal of berms, pulling back levees and/or through construction of weirs to raise water levels to floodplain height. Even in reaches without floodplains, pulling back existing levees to positions farthest from the river channel will widen flood zones in upstream areas, increase attenuation and decrease flood peaks in downstream areas.	+ (++)	Pulling back or reducing levee heights on existing levees to reconnect riparian areas and floodplains would aid in river rehabilitation by promoting a shallower and wider flow area, thus reducing flow velocities and the sediment transport capacity of the river) and creating riverine habitat subject to extreme disturbance on a less frequent basis. Upstream attenuation may create an opportunity for reconnection of floodplains,	NWA: Section 21 c and I (GA should apply); NEMA applies unless very small (<5 m^3) sediment volumes are moved.	Floodplains may be rendered un suitable for economic uses and therefore costs may be very high. Economic and social costs should be weighed against benefits. Practitioners should be aware of risks of erosion. Where structures are necessary (e.g. weirs to raise water levels in incised channels), an engineer is required to design structures.

Objective	*Intervention Option*	*Description of approaches*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*[4]
	Attenuate flows in upstream dams (Section 3.8)	**Attenuation of stormwater** within urban drainage network [i](numerous options including small attenuation ponds)	+++++	Where floods are unnaturally high (e.g. downstream of urban areas or where the catchment has changed its function as a result of loss of wetlands or climate change), reduced flood peaks may improve the likelihood of ecosystem recovery between flood disturbance events; small attenuation ponds may provide opportunities to create seasonal wetlands in urban areas – provided that water quality and socio-economic impacts do not over-ride these benefits.	NEMA, NWA: Section 21 b, c and i	The cost and expertise to retrofit attenuation options and structures within the existing urban environment could be challenging, and this is not a viable solution for an individual downstream landowner with site-specific flooding problems; It is however a viable option for "Friends of Rivers" groups or local authorities seeking to improve flood management without impacting on river ecosystems.
		Large (catchment-scale) flood attenuation dam/s	+++++++	Reduced flood peaks may reduce flooding downstream, but sediment starvation (causing enhanced erosion) and the barrier effect of the dam would possibly outweigh these benefits in some catchments.	NEMA, NWA (numerous)	Large dams would be needed to attenuate floods, and these dams would need to be designed or operated to maximize temporary storage of flood peaks. This would be a very expensive option and is ***not recommended as a river rehabilitation intervention*** , both from an environmental perspective of dam impacts and due to the prohibitive costs which make this unviable for individual landowners

3.1. Do nothing

"Do nothing" is an option that should always be considered with every proposed river intervention. In terms of flood management, doing nothing may have little risk associated with it if:

- the risk from flooding at the site is very low;
- the risk of further degradation at the site is low (the habitats are already severely degraded and there is no risk for nearby infrastructure);
- the risk to up- and downstream environments is minimal (e.g. no risk of habitats being threatened by headcut erosion or concentration of flows).

Alternatively, where interventions at a particular site carry with them high risks of triggering downstream erosion or have implications for upstream or downstream flooding as a result of altered attenuation requirements that cannot be accommodated (cost or space) or have significant negative ecological consequence, then the "do nothing" / "no intervention" approach may be the least damaging approach, and lead rather to consideration of other sites where flood control measures may be better achieved.

In many cases, doing nothing would however result in severe economic and social costs, while not alleviating ecological conditions, as in the case where agricultural lands are increasingly flooded due to sedimentation and/or invasive alien plant infestations along and within watercourses. The progressively reducing flow capacity of the river channel would cause increasing depths and extents of flooding of nearby lands, with consequent risks for adjacent landuses such as residential safety or, in agricultural areas, sustainable food production and job creation. In addition, further ecological degradation may also occur should there be no intervention. This is particularly true in cases where the natural catchment or river channel characteristics have altered as a result of past impacts (e.g. largescale erosion, catchment hardening, loss of wetlands or climate change), resulting in larger, more frequent flood events.

3.2. Change to flood-compatible landuses

The option for replacing landuse activities located within flood prone areas that are incompatible with flooding, with those that are compatible with occasional flooding could be considered as an alternative option for managing flood risk. Recreational areas (public parks, sports fields) and pastures may be options for flood-prone areas in some cases, allowing for occasional flooding without negating the landuse or placing the long term use of the site at risk. Some orchard types (e.g. mangos, macadamia nuts) may also be potentially viable within infrequently flooded areas, where flooding is likely to extend over a few hours or days only, on an infrequent basis.

A change in landuse activity is however costly and any potential benefit would need to be considered against the costs arising from the loss of productive agricultural land and/or costs of relocating existing infrastructure.

Ecological benefits could include:

- Improved opportunities for habitat restoration, as a result of reduced levels of flood disturbance, and hence the possibility that riparian and marginal river vegetation could be established;
- Reduced rates on in-channel disturbance (e.g. sediment and plant scour)

- Improved opportunities for the creation of backwater habitats and secondary flood channels – all important in terms of provision of habitat to indigenous riverine fauna and flora, and often critically limiting in terms of provision of breeding and nursery habitat for indigenous fish.

3.3. Clear invasive vegetation

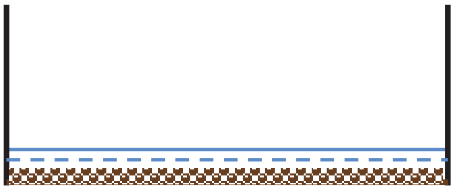
Increased vegetation on bars, in the channel and on the banks of a river will increase the roughness (resistance to flood flows) of the river and therefore slow down average flow velocities. This will decrease the potential of the river itself to convey large floods, raising flood levels when vegetation becomes dense and increasing erosion in some areas, as a result of concentration of flows through reaches constricted mainly by invasive vegetation (indigenous river vegetation tends to lie flat during floods).

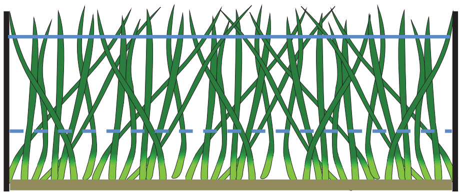
Unnatural levels of invasion of river beds, banks and floodplains by indigenous vegetation can be associated with:

- Reduced floods (as below large dams, where the size and frequency of floods are reduced and vegetation scouring events are more infrequent, allowing for increased vegetation growth which often thrives in the disturbed conditions created downstream of dams);
- Stabilised flow conditions (which promote vegetation growth, especially on the lower banks);
- Increased sediment storage (where, usually reeds, increase in response to recently deposited sediment); and/or
- Increased nutrient loads, where the elevated nutrients allow for more vigorous vegetation growth;
- Decreased levels of disturbance by large herbivores (e.g. hippo, antelope);
- Decreased fire frequency, especially in urban areas.

Text Box 3.1

The effect of vegetation on flow depths and flood heights





The relationship between the depth (or height) of flow and flow volume (discharge) for each channel were estimated for vegetated an unvegetated channels. The diagrams above show two 5.0 m wide channels with 0.0010 (1:1000) river slopes. The bed of left channel has 10 cm diameter riprap, while the channel on the right is covered with emergent vegetation stems with diameters of 0.5 cm, spaced at 5 cm apart, such as would be found in a typical reed bed.

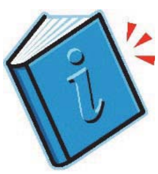
The results* show that ***water levels in the vegetated channel increase very fast, even at small flows, whereas the riprap channel can convey large flood volumes within the same width and depth of channel***. Two water levels are shown in the top diagrams for discharges of 0.10 m^3/s (dashed line) and 0.30 m^3/s (solid line) in each of the channels. These results show that the effect of vegetation in the channel is to greatly increase high flow (flood) heights in the river channel as a result of vegetation: from 0.60 m compared with 0.11 m for the lower discharge and 1.63 m compared with 0.21 m for the higher discharge. However, the increased flow depths are compensated by a low risk of bank and bed erosion, since in this case study, velocity would remain constant at about 0.033 m/s in the vegetated channel, compared with velocities of 0.18 m/s to 0.29 m/s in the riprap channel.

**Calculations for the riprap channel were done using the Darcy-Weisbach equation with the friction factor as recommended by Bray and Davar (1987). Calculations for the vegetated channel were according to the method of Jordanova et al. (2006).*

References:

Bray, D.L. and K.S. Davar (1987).Resistance to flow in gravel-bed rivers. Canadian Journal of Civil Engineering, 14(1): p77-86.

Jordanova AA, James CS and Birkhead AL (2006) Practical resistance estimation for flow through emergent vegetation. Proc. Inst. Civ. Eng. Water Manage. 159 (WM3) p173-181.



CROSS REFERENCE

See Volume 1: Section 3.2 for further information on the effect and reasons for invasion by indigenous plants.

See Chapter 2 of this document on Invasive Vegetation.

In addition to the above factors that can result in invasion affect patterns of indigenous vegetation growth in rivers, particularly under managed flow conditions, invasive alien vegetation (most commonly invasive Australian *Acacia* species) has rapidly invaded in many southern Africa rivers in recent decades (see Volume 1 (Rehabilitation Guidelines): Section 3.2). In many areas, particularly where water quality is impacted (e.g. nutrients are enriched) or flow regulation occurs, exotic vegetation has greatly increased the density of vegetation in the channel and riparian zones. Additionally, many invasive species are not natural riparian plants and thus lack the flexible branch and stem structures of most indigenous riparian trees. The invasive species thus offer a higher resistance to floodwaters than do indigenous species, further increasing flooding heights. The increased flood heights, and secondary damage caused by woody debris to downstream culverts and bridges, greatly increases flooding risks.

Removing alien versus indigenous vegetation from rivers

The removal of problematic invasive vegetation is considered one of the more desirable and ecologically benign approaches to decreasing flood impacts at a site, but removal of indigenous vegetation that is not invasive is considered ecologically undesirable.

It is important to note that some indigenous vegetation types are protected and environmental authorisation for the removal of large stands of these protected vegetation types is required. Refer to the Guidelines (Appendix 1) for more information.

Wherever there is excessive vegetation growth within the channel or on the banks, flood flows will occur at higher elevations (i.e. flood risks will increase) due to reduced velocities resulting from the increased channel resistance (roughness).

The removal of excess or invasive vegetation can increase flood conveyance potential in the river reach. Note that where natural conveyance levels are achieved (e.g. by removal of alien vegetation), this would class as **rehabilitation**; where vegetation is removed and flood conveyance increases beyond natural levels, the intervention would no longer be considered as rehabilitation but would be to achieve other social or economic objectives.

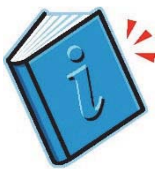
3.3.1. General recommendations for invasive vegetation clearing

The approach for the removal of vegetation from the river channel and banks is discussed in detail in Chapter 2 of this Technical Manual. Note that removal methods are often dependent on the type of vegetation, its location, and the species, and that environmental authorization may be required for the removal of indigenous species. In addition to the guidelines for vegetation removal provided in Chapter 2, some general points particularly relevant for flood conveyance should also be considered:

- The removal of invasive alien (exotic), or excessive encroaching indigenous vegetation from the river channel, marginal zones and upper riparian zones may result in increased flood conveyance and reduce over-bank flooding risks;
- All woody debris from the clearing of exotic species should be removed from the riparian (flood) zone to prevent floods washing the debris downstream as this could otherwise cause damage

to downstream properties and infrastructure (see Volume 3: Case Study 19) for which the upstream landowner could be liable – make sure that alien vegetation is removed from both sides of the channel, to prevent erosion occurring on the cleared side only. This may require liaison between different landowners;

- In general, below-ground material (stumps and roots) should remain in the ground to continue to provide for bank stability (and inhibit erosion) while indigenous vegetation is re-establishing; (see Chapter 2);
- Efforts should be made to organise communities to co-operate with the clearing of alien vegetation along both banks of rivers simultaneously, to prevent erosion of cleared banks as a result of increased flow resistance by invaded floodplain areas. A secondary benefit of removing invasive alien vegetation for flood conveyance is that the indigenous riparian vegetation can re-establish, resulting in an overall improvement in ecological condition of the river reach (see Chapter 2 and Chapter 11 of this document);
- Follow-up maintenance (follow up clearing of saplings and resprouting vegetation) is essential to prevent densely resprouting vegetation from creating worse conditions.



CROSS REFERENCE

The approach for the removal of vegetation from the river channel and banks is discussed in detail in Chapter 2 of this Technical Manual.

Erosion risks after vegetation clearing

Alien clearing activities must not result in erosion, and should ensure that adequate replanting and associated temporary stabilisation takes place in cleared areas. See Chapter 12 for planting guidelines

Environmental legislation

- Some indigenous vegetation types are protected and removal of large stands of indigenous vegetation may require authorisation from the Dept. of Environmental Affairs.
- If during the course of the removal of vegetation more than 5 m^3 of soil (any river sediments, including cobbles and gravels) is moved or removed, then NEMA authorisation is required unless the activity forms part of an approved river Maintenance and Management Plan.
- Alteration to the shape of any river or stream bed or banks, irrespective of the volumes which will be moved, requires authorisation in terms of the National Water Act.
- Refer to Section 10 of the Guidelines: "*Legal authorisations necessary for river rehabilitation*"

3.3.2. Case studies

Refer to Volume 3: Case study 14 (Alien vegetation removal and management of degraded channels in agricultural areas – the Vier-en-twintig Riviere system). Also refer to Case Study 19 (Addressing bank erosion using riprap: Berg River bank stabilisation project) for the impacts of vegetation debris on road crossings.

3.4. Widen channel and stabilize banks

Widening of confined river channels allows for a greater flow area and reduced flow depths and velocities to be created. This can increase flood conveyance in a reach. Bank widening involves widening the river channel, possibly creating stepped river channels within these banks, and generally re-sloping river banks to gentler slopes.

Due to the bank disturbance involved in these activities, methods for bank stabilisation (to prevent erosion) would be necessary. These could range from bank stabilization with appropriate planting (see Chapter 12) to the inclusion of green engineering approaches and harder engineering approaches such as riprap or even gabions in very high velocity or high risk environments. ***The reader MUST refer to Chapter 4*** of this document for options to stabilize the banks once the river channel has been widened.

Ecological importance of maintaining natural aquatic habitat / allowing vegetation in the lowflow channel

From an ecological perspective, flood control measures that rely on increased channel conveyance should as a minimum include in their design measures that will allow for the establishment of plants in the channel, and the creation of low flow habitats that (assuming not prevented by water quality impacts) could support at least a moderate level of aquatic macroinvertebrate diversity.

The low flow channel in an impacted river is often the area in which or along which plant growth is easiest to achieve (because of access to water). Water quality improvement by plant uptake or filtration is also often most readily achievable in low flow rather than flood flow conditions.

3.4.1. Description of the concept

The purpose of this suite of interventions is to increase the flood capacity of the river channel to prevent overtopping and thus reduce flood risks by lowering flood water levels. Channel banks should be widened to provide an increased flow width. The widened banks must then be reshaped and stabilised with vegetation, coir roles, geofabric, flexible erosion control mats, riprap or gabions.

The banks and effective flood area can be widened, and banks stabilized, through:

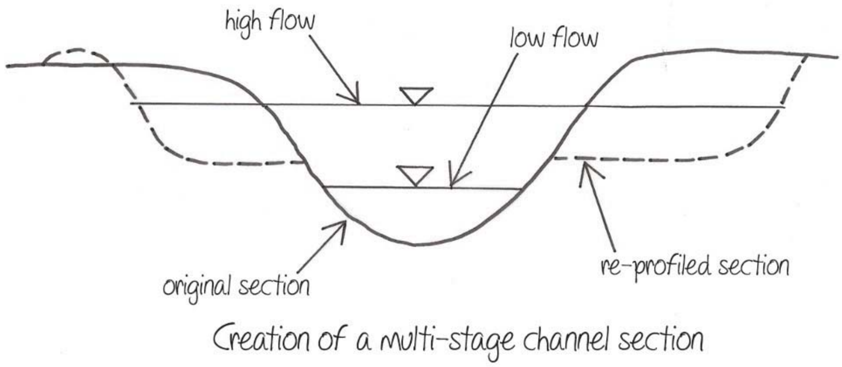
- Widen the channel, reshape the banks and stabilise with vegetation,
- Widen the channel, reshape the banks and stabilise with green engineering options,
- Widen the channel, reshape the banks and stabilise with riprap,
- Widen the channel, reshape the banks and stabilise with flexible armouring mats,
- Widen the channel, reshape the banks and stabilise with rock retaining walls (gabions.

The ***purpose of this suite of interventions is to maximize the width of flood flows*** through one or more of these options. Banks should be widened as much as possible. The increased flood zone allows for flood flows to spread out over a larger area, thus reducing flood heights and velocities. A larger riparian corridor is also created in the process.

THINK GREEN

Use multi-stage channels to improve instream and riparian habitat diversity

Multi-stage channels entails the stepping or terracing of a river bank or wider flood zone. Between the active (low flow) channel and the upper bank, one or two steps or terraces are included. Provided they are designed to allow for the establishment of vegetation, these would potentially create a seasonally (wet season) flooded zone on the channel margins and an upper riparian zone, which would be flooded during larger, less frequent flood events.



Creation of a multi-stage channel section

A compound, or multi-stage, channel comprises a main channel that is able to convey normal flows and a "floodplain" or upper riparian zone that is encroached on during floods. The flood conveyance of a simple channel can therefore be increased by excavating a berm into the riverbank, or landscaping an embankment on one or both sides. Normal flows are then conveyed by the lower part of the original channel, but the conveyance is increased considerably by allowing overbank, but confined, flow when discharges are high.

Multi-stage banks which provide marginal habitat (along the wetted edge of the low flow channel) and a lower riparian zone (the height flooded a few times per year in the wet season) would mimic natural river bank structures better than a uniformly sloped bank.

3.4.2. Site suitability – where the method can be applied and cautions/considerations

The methods are suitable for small to medium-sized streams, especially in urban environments, but should only be applied:

1) where the river channel has been historically narrowed or confined, AND

2) where there is sufficient land available for widening of the river channel and creating gentler slopes for the river banks,

OR

3) where the floods from the catchment have increased (such as in an urbanising catchment) and the river channel is eroding (widening) in response to the increased flood flows. Widening the channel and stabilizing the banks would aid in improved flood flow conveyance.

3.4.3. Pros and cons

Widening of the river channel and creation of gently sloping banks can reduce flood flow depths and velocities, potentially reducing flood peaks downstream, reduce erosion risks at the site, and create a wider migration corridor for biota along the river and riparian zone. These benefits must be considered against possible loss of productive agricultural or urban lands which may need to be sacrificed to achieve a wider river channel and gentler bank slopes.

Widening of the channel may have limited effect where the existing gradient is very flat, and excessive additional width is required to achieve attenuation. Upstream attenuation may be more effective in such cases.

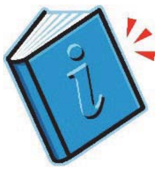
A major advantage of creating a compound section is that the main channel portion can be left in its natural state – low-flow habitats and high flow refuges can therefore be left fairly undisturbed, but the upper banks would be heavily disturbed. Berms can be landscaped to fit in with the surrounding environment or to enhance amenity value in urban areas by creating walking or cycling space. A disadvantage in tightly constrained situations is that the total width required might be slightly greater than for simple widening or channelizing of a single stage watercourse.

3.4.4. Cost

Aside from the cost of the land, reworking of the banks by hand or with mechanical equipment would be a standard cost for bank reshaping, but thereafter, the choice of bank protection selected to stabilise the reworked bank would dictate costs. Available materials (such as cobbles or boulders for riprap, indigenous plants for revegetation), flow energies at the site and anticipated maintenance commitments should be considered in the selection of the bank protection option. Refer to Chapter 4 of this report for a full suite of bank protection options.

3.4.5. Technical guidelines

Banks should be sloped as gently as possible, to not more than a 1 in 3 slope, but preferably 1:4 or less steep, as gentler slopes allow for more effective revegetation and generally simulate natural bank structure. The lower (toe) banks should have some protection against erosion from small floods, with sandy banks requiring greater protection measures than cobble or cohesive (clay-rich) banks. The toes of the banks can be protected with riprap, coir rolls or geofabric. ***Detailed recommendations for the various bank protection measures can be found in Chapter 4*** of this report.



CROSS REFERENCE

Refer to Chapter 4 for methods for bank stabilization and Chapter 12 for methods on revegetation of river banks.

Some considerations specific to bank widening for increased flood conveyance are:

- Reshaped banks should be stabilized (see Chapter 4);
- Where possible, multi-stepped channels should be created to improve instream and riparian habitat diversity; and
- Any levees present should also be pulled back as far up the bank, or across the flood zone, as is practicable.

3.4.6. Technical expertise needed for input to design and implementation

There is no formal requirement for any additional expertise. Landowners could undertake these activities on their own or with the aid of a contractor. Input from a local botanist regarding revegetation of the banks would help to achieve an appropriate mix of locally indigenous riparian species.

3.4.7. Maintenance requirements

Softer options for bank protection, such as revegetation and/or coir rolls or geofabric, would generally require more continuous maintenance activities than riprap. Irrigation of planted banks would accelerate vegetation establishment and thus reduce the need for maintenance. After large floods these reshaped banks may need to be repaired (where there is scour activity) to prevent bank destabilisation.

3.4.8. Legal considerations

Both NEMA and NWA authorizations would generally be required, although if the movement of material at the site is less than 5 m^3 (i.e. the reshaping of the bank would need to be over a very small area), and the banks are being reshaped to a more ecologically sensitive shape, and replanting is with locally indigenous species, then it is possible that the activities could be exempt from a full, detailed authorisation process. The landowner should contact their regional Water Affairs and Sanitation and Environmental Affairs departments to determine applicability of exemptions.

Environmental legislation

- The movement or removal of more than 5 m^3 of soil (any river sediments, including cobbles and gravels) requires environmental authorisation in terms of the NEMA regulations.
- Alteration to the shape of any river or stream bed or banks, irrespective of the volumes which will be moved, requires authorisation in terms of the National Water Act.
- Refer to Section 10 of the Guidelines: "*Legal authorisations necessary for river rehabilitation*"

3.4.9. Case studies

Refer to the following case studies which have aspects of bank widening to accommodate floods:

- Case study 2: Flood attenuation in urban rivers – improving river habitat quality and social amenity in low income areas
- Case study 10: Restoration and realignment of a valley bottom wetland – Pagasvlei Stream, High Constantia Development
- Case study 12: Dam removal and channel re-establishment – Bruma Lake rehabilitation.

3.5. Widen the flood zone by pulling back levees

In many rivers the river channel has been isolated from its riparian areas, floodplains and secondary channels due to the creation of levees or berms along the channel, which serve to constrain most floods within the levees. Constraining the flows within an unnaturally narrow, deep channel reduces flood attenuation in the reach and also raises flood water levels to higher water levels than if they were allowed to flow out across the entire flood zone. The reduction or removal of these flow constraints can improve the ecological condition and functions (ecological services) of the river reach through increased area of habitat, lower flow velocities and increased flood attenuation which reduces flooding risks for downstream reaches

3.5.1. Description of the concept

The ***purpose of this suite of interventions is to maximize the width of flood flows*** through increasing the width between levees and the distance between the channel and the levees. The increased flood zone allows for flood flows to spread out over a larger area (Fig 3.2), thus reducing flood heights and velocities. A larger riparian corridor is also created in the process.

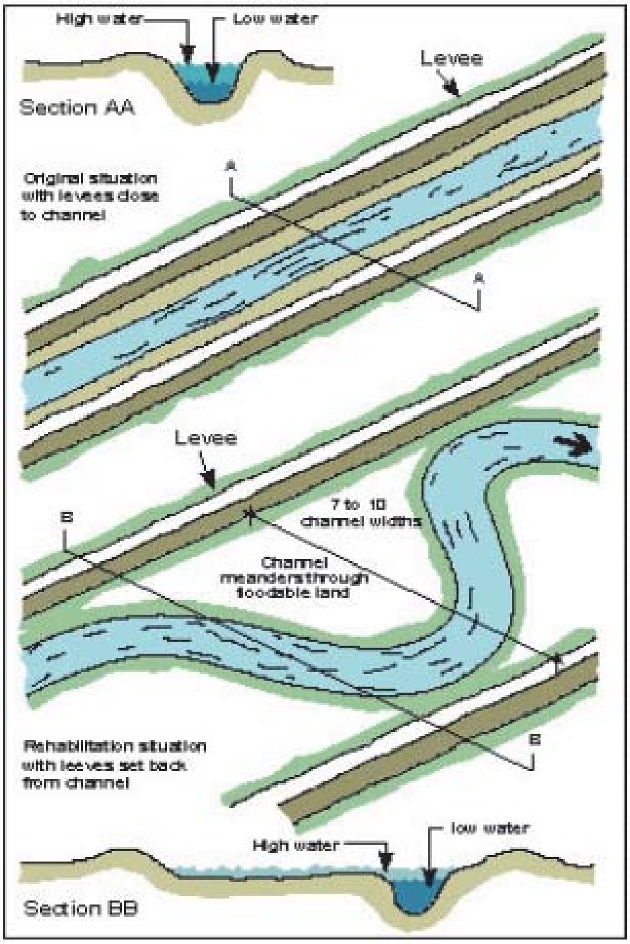


Figure 3.2: Levees pulled back from the edge of the river channel

3.5.2. Site suitability – where the method can be applied and cautions/considerations

This option involves pulling back existing levees to widen the effective flood zone of the river. This option is only suitable for sites:

1) where there is an existing artificial levee or berm alongside the river channel, ***and***

2) where there is sufficient land available for moving this berm to the outer edge of the riparian zone or floodplain (i.e. where there is scope to widen the flood zone).

If the river banks are natural and no artificial berms or levees are present, this option must not be considered.

Widen existing levees wherever possible

Widening of confined river channels allows for a greater flow area and reduced flow depths and velocities to be created. An easy way to lower the risk of flooding in areas where there are levees (berms) is to ensure that the levees are pulled back away from the channel as far as is possible. In agricultural areas, levees should be pulled back to the outermost edge of crop lands or roads adjacent to the watercourse, and indigenous riparian vegetation allowed to establish in the area between the low flow river channel and the levees.

Widening of the area between the river channel and the levee allows for a greater width of flow during flood periods, and this will result in a lower flood flow depth.

3.5.3. Pros and cons

Widening of the levees and creation of a wider flooding zone would reduce flood flow depths and velocities, potentially reducing flood peaks downstream, reduce erosion risks at the site, and create a wider migration corridor for biota along the river and riparian zone. These benefits must be considered against possible loss of productive agricultural lands which may need to be sacrificed to achieve a wider river corridor. The long-term reduced risk of ongoing flood damage (e.g. loss of fruit trees, vines), and potential reduced economic activity on agricultural land that is exposed to floods when levees are reduced or removed needs to be considered against the potential ecological benefits for the site and downstream.

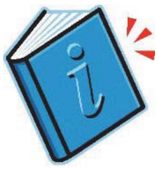
The larger flood zones may create a perpetual additional maintenance cost, in terms of an increased area in which invasive vegetation must be managed, for the landowner. The river channel, banks and all area between the levees (including the flood zone and levee banks) should be kept clear of invasive vegetation to enhance the flood conveyance function of the flood zone.

3.5.4. Cost

The original level material must be removed from within the river channel and moved out to be reused in the creation of the new, further apart, levees. Reworking of the levee material with mechanical equipment would be a standard cost for levee repositioning, but thereafter, the choice of bank protection (if any) selected to stabilise the reworked levee would dictate costs. These earth or cobble structures could be stabilized with vegetation – refer to Chapter 12 for revegetation guidelines. Available materials (such as cobbles or boulders for riprap, indigenous plants for revegetation), flow energies at the site and anticipated maintenance commitments should be considered in the selection of the levee protection option. Refer to Chapter 4 of this report for a full suite of bank protection options.

3.5.5. Technical guidelines

Levees should be of as low an elevation as possible, with gently sloped banks to facilitate revegetation. Ideally the levee side slopes should not be steeper than a 1 in 3 slope, as gentler slopes allow for more effective revegetation and generally simulate natural bank structure. If flow velocities, flood frequencies and local bank material are such that erosion of the levee is a risk, revegetation of the banks; geofabric or coir rolls to protect the recently disturbed (resloped) bed and banks; and riprap (local cobble material) could be used to stabilise the levees. Detail of these measures can be found in Chapter 4 of this report.



CROSS REFERENCE

Refer to Chapter 4 for methods for bank stabilization and Chapter 12 for methods on revegetation of river banks.

3.5.6. Technical expertise needed for input to design and implementation

There is no formal requirement for any additional expertise. Landowners could undertake these activities on their own or with the aid of a contractor. However, ***the repositioned levees should not exceed the height of the original levees, and no new levees should be introduced***.

3.5.7. Maintenance requirements

Levees that are moved further back from the channel may need occasional repairs, especially in the first few years following modification as the constituent sediments may not yet me vegetated and/or stabilized.

Short term irrigation of planted levees would accelerate vegetation establishment and, through accelerated stabilization, reduce the need for maintenance. After large floods, levees may need to be repaired (where there is scour activity) to prevent failure. The flood zone should be kept clear of invasive vegetation to ensure efficient flood conveyance.

3.5.8. Legal considerations

Both NEMA and NWA authorizations would generally be required, although

- if the movement of material at the site is less than 5 m^3 (i.e. the levee volume to be moved is relatively small), then the activity would be exempt from NEMA authorization.
- If the levees are being pulled back, the flood zone is being expanded and the levee is to be constructed of local *in situ* soil (derived from the original levee), then it is possible that the activity may be generally authorized in terms of the National Water Act.

The landowner should contact their regional Water Affairs and Sanitation (or Catchment Management Agency) and provincial Environmental Affairs departments to determine applicability of exemptions.

Environmental legislation

- The movement or removal of more than 5 m^3 of soil (any river sediments, including cobbles and gravels) requires environmental authorisation in terms of the NEMA regulations.
- Alteration to the shape of any river or stream bed or banks, irrespective of the volumes which will be moved, requires authorisation in terms of the National Water Act. However, in the case of levees being moved away from the river channel, a General Authorisation for the activity may be possible.
- Refer to Section 10 of the Guidelines: "*Legal authorisations necessary for river rehabilitation*"

3.5.9. Case studies

Refer to the following case studies which have aspects of bank widening to accommodate floods:

- Case Study 16 – Canal and floodplain rehabilitation: Langevlei Canal

3.6. Channelisation: excavation, levees and canalization

Channelisation options refer to any options for flood control which aim to straighten the river channel and in the process constrain the extent of flood flows through earth works that facilitate the deepening and/or straightening the river channel. Specifically, this option includes:

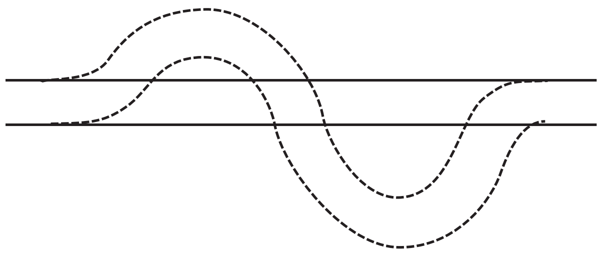
- **Channel straightening** – where, especially rivers with a highly meandering or braided pattern, channel straightening is used to "train" a river along a straighter path to reduce the roughness of the river reach and allow for more effective, rapid flood conveyance
- **Levees** – the creation of levees to deepen the floods through restricting them within the levees, but the river still flows along an unlined, relatively naturally meandering river channel,
- **Canalisation** – excavation and deepening of the river channel (canalisation) to create a canal (usually with concrete) which is deeper and straighter than the original river channel.

Canalisation and straightening of rivers is undertaken to reduce stream roughness and increase flow conveyance. This usually involves deepening and/or straightening of the river channel, usually with a loss of lateral flow space and reduction or abandonment of floodplains. ***Canalisation, new levee formation and channel straightening should not be considered river rehabilitation initiatives***, but are included in this manual to highlight their impacts as these are commonly undertaken initiatives, especially within urban areas.

3.6.1. Description of the concept

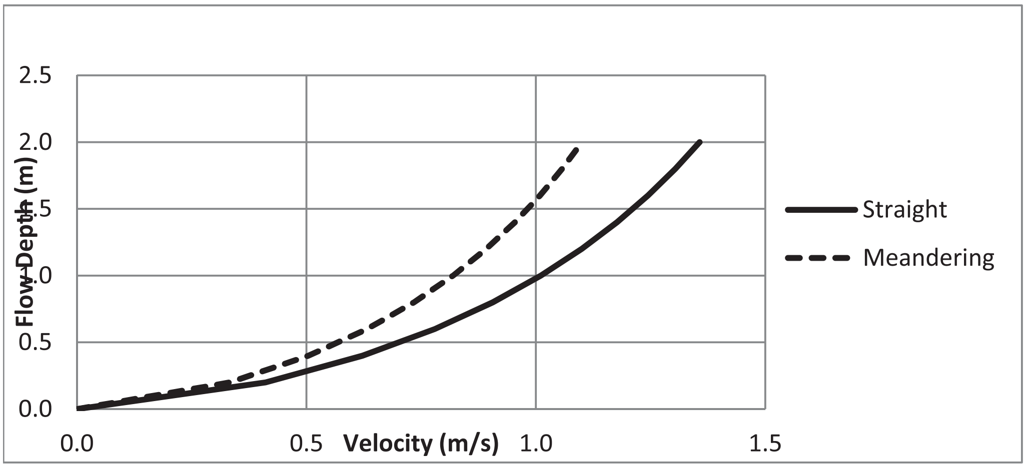
Sediment is usually removed from the bed of the river channel to increase flow depths and flood conveyance through levee creation (on the banks) or deepening and/or straightening of the river channel itself. Vegetation on the river bed and banks is often also reduced or removed during these activities.

The Effect of channel straightening on flood heights



Channel straightening is not considered rehabilitation as it generally degrades, or alters the river further from its natural condition. However, it is one option (albeit not recommended from an ecological perspective) which in the past was commonly used in urban areas to reduce flooding risks and increase developable area).

The figure above represents a straight, 5 m wide channel on a slope of 0.0010 which is realigned to create the meandering form shown. The effect on the relationship between flow depth and velocity is shown below*. Floods in straight channels flow at far lower flow depths than meandering channels.



*Calculations were done using the Manning equation, with the effect of meandering accounted for using James's (1994) linearization of the United States Soil Conservation Service (1963) recommendation.

Levees (also known as berms, dykes or embankments) are walls constructed parallel to, or on top of riverbanks (Figure 3.3) with the objective of preventing water spreading from the river channel into the floodplain during high flow situations. ***Levee construction should not be considered as river rehabilitation***. It is rather the reduction or removal of levees which should be promoted, where feasible, from a river rehabilitation perspective (see section 3.5 of this report).

LEVEES

Earth levees are among the most commonly sought solution by farmers and other land users for riverbank erosion and other flooding related problems, primarily because they intuitively see that they need something to divide their land or infrastructure and the river which is seen to be causing damage. Unfortunately it often happens that the effect of increased flow depth on the flow velocity and erosive power of the river is not understood, and levees make the problem worse locally and elsewhere.

Even the US Army Corps of Engineers cautions that if levees are not set far enough back from the river channel, the river becomes destabilized, from increased flood peak flows, to channel widening and alteration of meander dimensions. There are several considerations where new levees are being proposed:

- First attempt to cope with the flooding without interfering with the river or building any levees. Consider crops or landuse options which are compatible with occasional flooding, such as pastures (as recommended in Section 3.2 of this chapter), as well as upstream attenuation;
- Alternatively, use levees "outside the meander belt" before considering placing them within the meander belt (or within the lower riparian area or on the active channel bank – see section 3.4 of this report). In South Africa the experience tends to be to use levees within the meander belt as a first option;
- If levees along the river bank are being proposed, it is recommended that the flow velocity in the river channel and floodplain during a design flood situation be determined and compare the derived flow velocities with the known stable flow velocities for the river-bed material to ensure that the design will not destabilise the river reach. Should the flow velocities be such that the soil will erode, the levees must be set back further so that the flow depth and flow velocity decrease, until a satisfactory solution is found.

In the designs of levees, four main types of earth bank levee failure have been identified (Figure 3.5). It is important to be aware of these because the successful design of levees would have to reduce the possibility of this occurring. The US Army Corps of Engineers manual details suitability tests for the soil to be used, the design of seepage control measures, the safe levee section design, and the construction of levees.

Levee construction is not supported in this manual as a means for river rehabilitation, or for the control of floods. NEMA authorization and a full Water Use Licence application would be required to undertake the necessary earthworks for levee construction.

Figure 3.3: The sediment laden Jan du Toits River flowing within a levee.

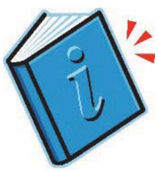
3.6.2. Site suitability

Straightening and canalization can be undertaken most easily on alluvial meandering river reaches, but ***channel straightening and canalization should not be considered as rehabilitation options and do not form part of the suite of flood control options espoused by this manual***.

3.6.3. Pros and cons

The extensive disturbance of the beds and banks of the river will impacts upon the biota and reduce habitat diversity and meandering river processes, including sediment trapping functions of the reach. Straightening channels will however result in a lower flood water level ***at the site*** due to faster flow velocities and reduced resistance, but can be expected to increase flow velocities (potentially increasing erosion at the site), and, downstream, may increase flood peaks.

Canalised or otherwise lined channels show significantly reduced biodiversity. The lack of instream habitat (e.g. cobbles, vegetation, boulders) means that there are often no areas in which fauna can take shelter, particularly in high flows. During low flows, water quality is often problematic, as canals do not support the ecological systems that provide services such as nutrient cycling an aeration.



CROSS REFERENCE

Refer to Chapter 3 in the Rehabilitation Guidelines (Volume 1) for a discussion of the problems associated with canals and canalisation and to Chapter 10 of this manual for input into measures that improve riverine habitat quality and diversity.

During the construction phase, the removal of sediment disturbs the river bed and banks, degrading habitat condition, especially where the sediment is being removed from the active channel and marginal zone. In addition to the onsite impacts, downstream and upstream impacts can result from poorly managed sediment extraction areas:

- Where large volumes of sediment are removed from the channel, the downstream reaches can become starved of sediment (similar to the impacts below a dam), initiating erosion (incision) of the channel;

- Where the removal of sediment creates a deeper, narrower channel with a bed and/or banks of erodible sediments, the reach can be destabilised through lateral and vertical erosion, resulting in upstream headcut migration and downstream sediment deposition; and

- Elevated fine sediment loads can degrade the downstream instream habitat quality.

- The small in-channel sediment deposits and lower riparian vegetation slow down flood velocities and serve to reduce flow speeds, increasing flood attenuation and sediment deposition. These physical environments and their associated ecosystem services are reduced or lost during channelization, reducing important habitats for fish, invertebrates and other fauna.

Levees and impacts on rivers

Berms or levees are earth artificial banks constructed to contain floods in the river channel, so that the adjacent flood plain is less frequently inundated and the land becomes available for development. Small scale levee construction, for containing inter- and larger intra-annual floods, has historically occurred in the Western Cape, KZN and other areas of the country where floodplains are more common to enable agricultural utilisation of these lands. Flood protection levees cut off access to the flood plain and cause higher peak flows, river stages and velocities, and increased sediment and woody debris transport rates in the main channel, often resulting in erosion along the channel bottom and a coarsening of sediment sizes on the bed (USDIBR, 2006). Similarly, river reaches with multiple channels (braided river reaches) often have many or all of these secondary channels isolated from the main channel through the construction of levees/berms across the confluences. This has enabled landuse activities to further encroach in to the floodplain. These activities mean that floodwaters are prevented from spreading out, and flood attenuation is reduced. However the levees not only cause loss of flood attenuation within their own reach and increased flood peaks downstream, but can also, due to elevated flood stages and a constricted channel, cause backup and deposition in the reach immediately upstream (Bountry *et al.* 2002).

Levees thus prevent floodwater entering lands (in the floodplain or riparian zone) and these lands then become more suitable for development, but the impacts may be transferred up and downstream to adjacent reaches. The creation or artificial raising of earth berms/levees along the top of the banks serves to increase the flood conveyance of river channels results in condensing of braided rivers into single channels, excavation of the river bed and disturbance to the banks all contribute to the situation where many rivers flow in artificially deep and narrow channels with the coupled unnatural increase in flow velocity and sediment transport capacity. The increase in sediment transport in some areas leads to an increase in deposition and meandering of the river in downstream reaches.

The reduction in flooding frequency on floodplains where levees are installed can also promote encroachment of settlements in these flood prone areas. However when large floods which breach these levees occur, such as those which occurred in New Orleans in 2005 during the floods associated with Hurricane Katrina, widespread devastation can result. Similar such processes are underway outside Worcester in the Western Cape, where urban areas are increasingly encroaching across the floodplains of the Breede and Hex River floodplains.

3.6.4. Minimizing impacts – recommendations

Channelisation (channel straightening) new levee formation and construction of canals is NOT endorsed by this manual as rehabilitation

Erosion and deposition of sediment on the channel bed occurs naturally during floods, but the mechanical excavation of river channels introduces a very high level of disturbance to the river channel environment. This disturbance should be minimized through:

- Using existing access routes. If there are none, create one route through the most degraded area avoiding stands of indigenous vegetation. This will limit the spatial extent of the disturbance footprint;
- Undertaking sediment removal during the dry season;
- Keeping potential pollutants away from the river – Where machinery is used, ensure that there are no oil leaks, and refuel outside of the riparian area, where accidental spillages of fuel or lubricants will pose no threat of pollution.
- Do not block the river flow or the passage of aquatic and riparian biota;
- Do not create new berms (but existing berms should be moved outwards from the river channel as far as possible);
- Do not deepen the river beyond the original (historical) thalweg (point of lowest elevation in the channel), and to the extent possible, do not disturb the area immediately adjacent to the thalweg. It is important from an ecological perspective that the natural low-flow channel remain as undisturbed as possible (see Figure 3.4).

Figure 3.4: The red arrow illustrates the thalweg (lowest point of the channel)

3.6.5. Technical expertise needed for input to design and implementation

Landowners should not undertake channel straightening or lining activities without first seeking professional advice. The resultant increased flow velocities may increase erosion rates within the reach and subsequent channel incision would make the impacts largely irreversible.

3.6.6. Maintenance requirements

Some maintenance or follow up work is likely to be necessary after major flood events, as these are likely to result in further sediment deposition.

3.6.7. Legal considerations / required authorisations

Both NEMA and NWA authorizations would generally be required, although if the movement of material at the site is less than 5 m^3, the activity would be exempt from NEMA authorization but not from the National Water Act authorisation.

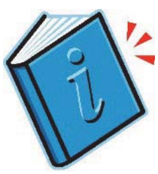
3.6.8. Case studies

The river channel is excavated and usually straightened. The purpose of the intervention is to improve flow and, often, achieve a reduction or alteration of the position of the watercourse in order to increase developable areas on a property (see, for example, case study 10 – Use of gabion structures to halt erosion and improve natural wetland hydrology).

3.7. Catchment attenuation: reconnecting floodplains

Most of the approaches discussed in this chapter relate to engineering or altering the conditions of the site or reach to increase flood conveyance and lower flood water levels. Additional options are however available to reduce flooding risks at the site (see Section 3.2). Attenuation of flood flows upstream of the problem site would serve to reduce flood peaks and thus flood water levels.

Flood attenuation is possible through the activation of upstream floodplain wetlands or riparian areas. Reconnection of the river channel and flows to the floodplain or riparian area can be achieved through reconnecting the river channel and the old floodplain area or riparian zone, by breaking through levees or other reinforced banks, such as concrete canals. In some cases however, channelisation and deepening or erosion of the main channel may mean that flows now cannot naturally overtop the river channel and spread out across the floodplain. Where over-deepened river channels exist, either bank reshaping (with some infilling) or weir structures would be required to increase the height of flood water levels to allow flood flows to reach the floodplain. For these situations, refer to Chapter 4 of this report for bank reshaping and Chapter 5 for information on rock, gabion and concrete weir construction options.



CROSS REFERENCE

See Chapter 4 of this report for bank reshaping and Chapter 5 for information on rock, gabion and concrete weir construction options that can be used to raise water levels to connect incised rive channels to their old floodplains.

3.7.1. Description of the concept

Levee removal or breeching allows flood flows from a river to reconnect with adjacent floodplains, wetlands or riparian areas where rivers have been confined by levees and the removal of the levees may allow for the recreation of meandering or braided floodplain areas and associated secondary flow channels. This would increase habitat diversity and flood attenuation within the rehabilitated reach, and reduce flood peaks to downstream reaches. Widespread removal of levees and bank armouring would allow the channel to migrate naturally and recover its former sinuosity, but the relative extent of such rehabilitation actions is often limited by land constraints. In most cases projects would involve only partial levee removal or the setting back of levees further away from the channel, along sections of the river where land is available for floodplain or riparian area restoration. This then has only a limited impact on flood attenuation.

3.7.2. Site suitability – where the method can be applied and cautions/considerations

This option can only be implemented in river reaches where

- there is land available;
- where the landuse activities on the floodplain enable its use for infrequent flood inundation;
- where the risks of erosion of water moving out of the channel in to the floodplain and most importantly, back from the floodplain in to the river channel, can be controlled (short sections or small areas of floodplain restoration – i.e. pockets of floodplain reconnection – can mitigate this erosion risk);
- where the slope is such that adequate attenuation can be achieved relative to the amount of space required.

3.7.3. Pros and cons

Reconnection of the floodplains has ecological benefits, such as increased habitat diversity and area, increased flood attenuation, restoration of nutrient flows between the river channel and floodplain, but these must be considered against possible loss of productive agricultural lands as the frequency and extent of flooding is increased through restoration actions. Maintenance requirements for re-opened wetland areas must also be considered – these are likely to require periodic flushing by large flows or alternative maintenance activities to prevent long-term sedimentation and loss of attenuation function (see Langvlei Canal Case Study).

3.7.4. Cost

The cost of levee breaching or removal is minor, but the opportunity costs for increasing inundation depths/frequencies of reconnected floodplains, and removal of spoils if needed, could be high.

3.7.5. Technical guidelines

Material removed from the levees must be taken to the outer edge of the flood zone or riparian area, unless this is river sediment and it is required for bank protection measures or reshaping of banks within the reach.

3.7.6. Technical expertise needed for input to design and implementation

Where flows are being directed out of the channel on to the floodplain and then redirected back in the channel further downstream, some technical evaluation of the risk of erosion at the flow reentry point is required. If there is a risk of erosion, the flow re-entry point could be armoured (with riprap) or a more permanent structure such as a gabion or concrete weir could be considered.

3.7.7. Maintenance requirements

Maintenance requirements would be minimal, but careful monitoring for any potential erosion knickpoints at the flow reentry point/s should be undertaken and immediate steps to remedy potential erosion should be in place.

3.7.8. Legal considerations

Both NEMA and NWA authorizations would be required. The landowner should contact their regional Water Affairs and Sanitation (or Catchment Management Agency) and provincial Environmental Affairs departments to determine applicability of exemptions that can potentially be applied in rehabilitation activities.

3.7.9. Case studies

Refer to case study 15: Canal and floodplain rehabilitation: Langevlei Canal.

3.8. Catchment attenuation: detention ponds and attenuation dams

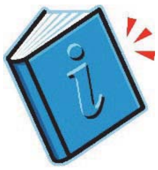
A major cause of flooding problems, especially in urban areas, arises from the hydrological consequences of upstream development or changes in land use. An increase in the impervious surface in the catchment reduces infiltration, thereby increasing runoff volumes. This results in higher flood peaks for similar rainfall events, and an increase in the frequency of bank overtopping downstream.

In river reaches that are downstream of such urban areas, unprecedented flooding problems thus result from the increased urban stormwater runoff and increased peak flows. Downstream landowners would thus incur the problems of insufficient stormwater attenuation in the urban areas, resulting in an increased frequency of flooding and flooding of areas which were previously not within the floodzone.

Recent research (Armitage et al. 2013) has highlighted the need for improved stormwater management in South Africa, with a strong focus on attenuation of flows from urban areas. Small detention ponds throughout urban areas, together with alternative technologies (e.g. SUDS approaches – see Chapter 8 and Armitage et al. 2013), can be used to reduce peak runoff from cities. Alternatively, a more centralized approach of creating large attenuation dams for flood management can be considered. In South Africa, very few large dams have been built for regional flood control, and their prohibitive costs and scale of implementation would preclude these options for individual landowners.

Moreover, ***much caution should be used when considering dams as river rehabilitation options***. Whilst reduction of enhanced flood peaks and frequencies in rivers downstream of urban areas would help to reduce downstream erosion impacts, the sediment trapping of the dam and resultant downstream sediment starvation may offset the potential positive impacts arising from flow management.

For technical details related to the options and construction of weirs and dams in rivers that could be used for flood control, please refer to Chapter 5 of this document.



CROSS REFERENCE

See Chapter 5 of this report for structures to address river incision. These weir structures can be used for stormwater attenuation, but specialist hydrological and hydraulic experts would be needed to effectively size the weirs and outlets to mimic more natural outflow rates and flood peak sizes in order to protect downstream landowners and environments from excessively high flood peaks.

3.9. REFERENCES

Ackers, P (1993) Stage-discharge functions for two-stage channels: The impact of new research, Journal of the Institution of Water and Environmental Management 7(1): 52-61.

Armitage N; Vice M; Fisher-Jeffes L; Winter K; Spiegel A. 2013. The South African Guidelines for Sustainable Drainage Systems. Water Research Commission Report No. TT 558/12 (ISBN No: 978-1-4312-0413-7). Water Research Commission, Pretoria, South Africa.

James, C S (1995) Compound channel design : An environmentally acceptable option for river engineering, Journal of the South African Institution of Civil Engineers, 37(4): 25-27.

James, C S and Wark, J B (1992) Conveyance estimation for meandering channels, Report SR 329, HR Wallingford, December, 242 pp.

Knight, D W, McGahey, C, Lamb, R and Samuels, P G (2010) Practical Channel Hydraulics – Roughness, Conveyance and Afflux, CRC Press, London.

Shiono, K and Knight, D W (1991) Turbulent open channel flows with variable depth across the channel, Journal of Fluid Mechanics 222: 617-646.

Wark, J B, James, C S and Ackers, P (1994) Design of straight and meandering compound channels, Interim guidelines on hand calculation methodology, R & D Report 13, National Rivers Authority, Bristol, UK, 86 pp.

Chapter 4:

Managing eroding banks (lateral erosion)

Author:

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4.1. Introduction

River bank- or bed erosion can be naturally occurring or as a result of human disturbance of the river. The erosion as a result of human disturbance can often be natural in nature, but the accelerated rate at which it happens is far from natural (for example the meandering of a river can be accelerated should the flow of sediment in the river be accelerated un-naturally).

Options for the management of river erosion sites fall into two broad categories. The first category is managing **eroding banks**, which is where usually only one bank, or a short section of the river banks, are eroding. The second category of erosion involved managing sites and reaches which are **down-cutting or incising**, which is when the river bed is eroding in to itself and resulting in donga or gulley formations and steep, vertical banks for extensive lengths along both banks of the river.

This chapter deals with the management of eroding river banks whilst Chapter 5 examines the management options for addressing down-cutting and river incision of river beds and gullies.

A variety of rehabilitation options to manage river bank erosion (structural and other) are discussed in this chapter whether they are recommended or not. Many options are discussed only because the reader may discover them in literature or on the internet, and it has been seen as necessary to discuss the relative merits of these options in a South African context.

The rehabilitation options are divided into three broad groups being **non-invasive techniques** such as doing nothing or just removing alien vegetation, and the two other groups which require construction of some sort being **indirect techniques** for addressing erosion where the intervention is slightly remote from the site of the problem, and **direct techniques** where the problem is addressed directly (i.e. something covers the soil to prevent it from eroding). To assist the reader with considering options, within each group the more environmentally friendly options are given first. The alternatives presented are:-

NON-INVASIVE TECHNIQUES

1. Do nothing option
2. Invasive vegetation removal

INDIRECT TECHNIQUES

3. Removal of sediment bars
4. Bank stabilization with groyne structures (permeable, solid, micro-groynes, Iowa vanes)

DIRECT TECHNIQUES

5. Bank reshaping (landscaping)and re-vegetation
6. Bank shaping and armoring with coir or geo-filter rolls
7. Bank shaping and armoring with flexible concrete block mats
8. Bank stabilization with riprap (rock)
9. Bank stabilization with longitudinal river training structures (logs and tree stumps, green gabions, rock gabions, concrete block retaining walls, used-tyre retaining walls, reinforced concrete retaining walls)

CANALIZATION

10. Partial-canalization between retaining walls (i.e. like Lourens River)
11. Concrete canalization

IMPORTANT POINTS FROM THE GUIDELINE (Volume 1)

- Understanding erosion mechanisms (section 3.4 "*Erosion*").
- An interdisciplinary approach is needed to understand the drivers of river instability causing the bank to erode, and what to do about it (section 2.1 "*The need for an inter-disciplinary approach*").
- Thought must be given to what extent rehabilitation is required (sections 1.1 "*Philosophy and aims*" or 2.4"*Sediment processes*"? 4 "*What is rehabilitation?*"). This should include considering the option for doing nothing.
- The reader must be aware of typical problems in rivers (section 3 "*Problems in rivers*") to help the correct identification of the source of the problem.
- The reader must be aware of appropriate scales of remediation.
- The reader must be aware of different options for river bank stabilization, and the relative advantages and disadvantages of these (section 8.1 "*Overview of options*" and 8.4.1 "*Managing eroding banks*") so that an appropriate choice can be motivated.
- The reader must be aware of technical competencies required to undertake certain design tasks.
- The reader must be aware of legislative requirements for working in water courses (section 10 "*Legal authorisations necessary for river rehabilitation*").

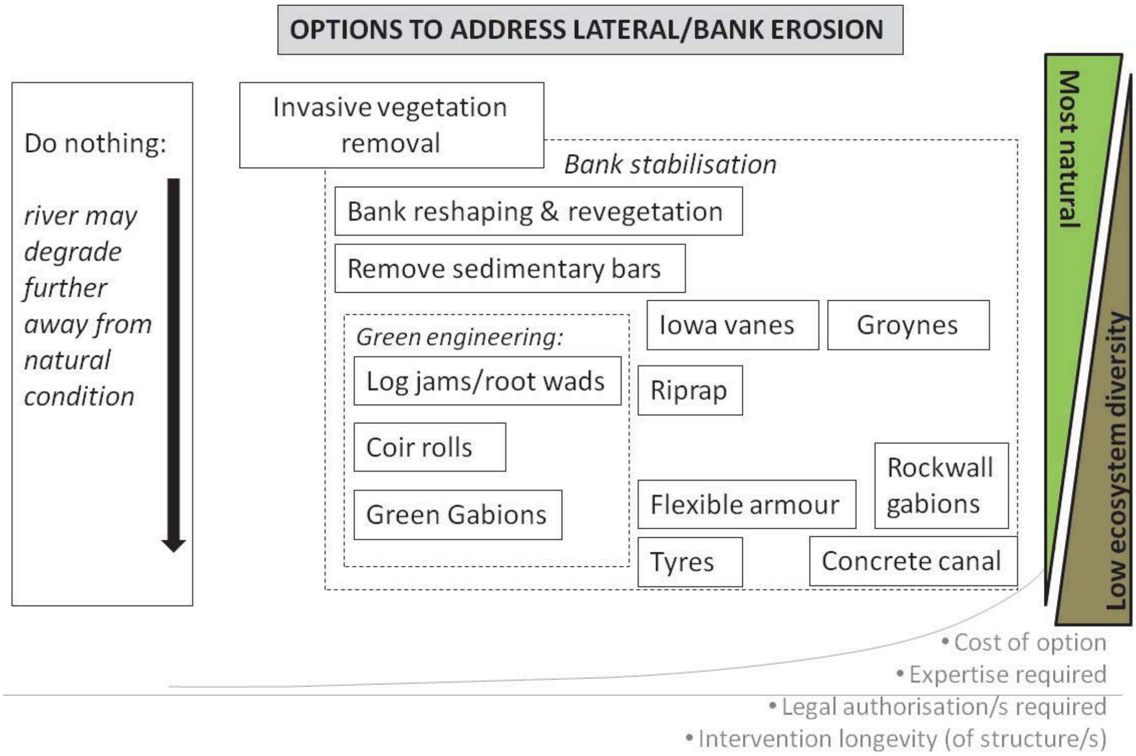


Figure 4.1: Options for addressing lateral or bank erosion in rivers.

Figure 4.2: Natural erosion on the outer bend of a meandering highveld river (photo: M. Rountree). Note the left bank's gently sloping, sediment accumulating point bar on the inner bend.

Table 4.1: Summary of options considered in this chapter for addressing eroding banks

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
Non-invasive intervention	Do nothing	0	None, but risk of further loss of ecosystem degradation may be high	None	Do not consider if rate of degradation is fast and/or risk of widespread impacts is high.
	Removal of invasive vegetation	+ (R4k-R15k/ ha)	Allows endemic vegetation to re-establish	None (notify authorities)	All debris should be removed from the channel and riparian area. Costs of clearing, based on 2014 SANBI data, range from R4000-R8000 per ha for Acacias and R10 000-R15 0000 per ha for large bluegums. In addition, follow up clearings (from R2000 to R4500/ha) must be budgeted for.
Indirect intervention for bank stabilization	Removal of sedimentary bars from the channel	**	Temporarily increases flow channel capacity and reduces flood heights Facilitates movement of water straight down river without being directed into the bank	NEMA DWS	Should not be considered unless source of sedimentary bar addressed (otherwise bar will form again).
	Permeable groynes	*	Structures can retard the flow velocity along a bank, promote the deposition of sediment, create a zone where revegetation of the river can take place Structures usually made of natural materials (timber poles and branches)	NEMA DWS	Should structures be washed out the poles and branches could cause a blockage in the river or at a bridge pier, and cause infrastructural damage. The layout of the structures should be planned / checked by a suitably qualified person to ensure that the structures will not direct the flow of the river into the opposite bank.

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Solid groynes	+++	Structures can retard the flow velocity along a bank, promote the deposition of sediment, create a zone where revegetation of the river can take place Structures usually made of natural materials (timber poles and branches)	NEMA DWS	The layout of the structures should be planned / checked by a suitably qualified person to ensure that the structures will not direct the flow of the river into the opposite bank.
	Iowa vanes and micro-groynes	+++	Structures reverse the helical flow of water around bends, which reduces the tendency for the band to erode faster than the rest of the canal.	NEMA DWS	The structures are experimental and untried in South Africa
Direct interventions for bank stabilization	Bank reshaping and re-vegetation	+	By reducing the soil slope and increasing the hydraulic roughness with vegetation it is possible to stabilize some river banks	NEMA DWS	Only applicable in slow flowing rivers
	Bank reshaping and erosion control mats	++	By reducing the soil slope and increasing resistance to erosion by means of a mat it is possible to stabilize some river banks	NEMA DWS	
	Bank reshaping with concrete grass-blocks	++	By reducing the soil slope and increasing resistance to erosion by means of a concrete blocks and vegetation it is possible to stabilize some river banks	NEMA DWS	

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Bank stabilization with flexible bank armouring	+++	By reducing the soil slope and increasing resistance to erosion by means of a flexible bank armouring it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with riprap	+++	By reducing the soil slope and increasing resistance to erosion by means of a heavy rock layer it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 1/7: Root wads	+	By increasing resistance to erosion by means of a stack of tree trunks it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 2/7: Green gabions (TerraMesh)	+++	By increasing resistance to erosion by means of a soil filled gabion mesh structure (Green Terramesh) it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 3/7: Interlocking concrete blocks (Loffelstein)	+++	By increasing resistance to erosion by means of interlocking concrete blocks (Loffelstein) it is possible to stabilize some river banks	NEMA DWS	

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Bank stabilization with retaining walls 4/7: Pre-cast concrete blocks	+++	By increasing resistance to erosion by means of dry stacked precast concrete blocks it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 5/7: Rock filled gabions	+++	By increasing resistance to erosion by means of rock filled gabions it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 6/7: Concrete walls	+++	By increasing resistance to erosion by means of a reinforced concrete wall it is possible to stabilize some river banks	NEMA DWS	
	Bank stabilization with retaining walls 7/7: Used car tyres	+	By increasing resistance to erosion by means of used car tyres it is possible to stabilize some river banks	NEMA DWS	This intervention is not recommended because of the tendency for the structures to fall apart and block culverts and bridges during floods.
Canalization	Semi-canalization: Hardened base of canal	+++	Vertical erosion in a confined channel may be controlled by hardening the base of the canal. This in turn limits the height of the banks, and the tendency of the banks to erode.	NEMA DWS	

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Semi-canalization: Hardened river bank	+++	Horizontal erosion (meandering) in a confined channel may be controlled by hardening the banks of the channel.	NEMA DWS	
	Full canalization	++++	All erosion is controlled by full canalization as long as the canal section is large enough to contain any given flood. Full canalization increases the flow velocity and discharges more water through a confined space.	NEMA DWS	Sediment should not be allowed to wash into the canal. The flow capacity of the canal must be large enough to contain a reasonably expected flood. Very careful control of the slope of the canal must be exercised during construction.

4.2. Do nothing option

"Do nothing" is an option which should always be considered with every proposed rehabilitation intervention. Doing nothing may have little risk associated with it if:

- the erosion is a natural phenomenon (such as erosion of a meandering river across a floodplain after a flood, and not meandering accelerated by erosion resulting from upstream disturbances in the river)
- the rate of erosion of the banks is year on year, including in response to large floods, very low
- the ecological condition of the banks being eroded is already poor – habitats are already severely degraded
- there is no risk of damage to nearby infrastructure, or curtailment of economic activities, if the erosion continues
- the risk to up- and downstream environments is minimal (i.e. the sediment entering the river from the site is not going to cause further erosion downstream)

Consideration of a hands-off approach is important to determine the importance or level of urgency of rehabilitation interventions and is an important consideration to compare and prioritise a series of sites and, through understanding the risks, identify appropriate rehabilitation options for the highest risk sites.

Doing nothing may however result in:

- further ecological degradation at the site
- smothering of downstream instream habitats with fine sediment eroded from the river banks
- increased bank erosion downstream as material eroded from the site in question creates islands that deflect the flow of the river into the bank
- economic and social costs where the eroded banks prevent access to economic activities (such as the erosion of road/drift approaches and the prevention of access to agricultural lands)
- direct damage to roads, fields, housing and infrastructure as the banks which they are located on are washed away
- increased flooding risks downstream as the eroded sediment is deposited in slower river reaches, causing channel infilling and a loss of channel competency

These potential risks should be weighed up against the costs of intervention and the risk of non-intervention.

4.3. Removal of invasive vegetation

In Chapter 2 the impacts of invasive vegetation on river ecosystems is discussed in detail. With regard to its specific impact on river banks, invasive woody alien vegetation such as Black Wattle has a serious destabilizing effect on rivers in the following ways:

- It quickly colonizes deposited sediment and, once taller and established, reduces channel competency of the river. The presence of stands of alien vegetation effectively transforms the cross section of the river and causes the water to flow deeper and faster. Where the alien vegetation grows on the inside of river bends, it directs the flow of water to the outside of the bend, accelerating the meandering process and destabilizing formerly stable river banks.
- The alien vegetation is woody and does not lie flat during floods, so it collects debris and creates blockages in the river, and, in addition to increasing the frequency of overbank flooding, the debris similarly diverts fast flood waters on to the banks, initiating erosion.
- The alien vegetation grows fast and often recruits in dense mono-species stands. The vegetation quickly shades out and eventually out-competes indigenous vegetation. Invasive alien vegetation tends to not have the same thick, deep root system as indigenous plants such as Phragmites, Palmiet and Besembos, and so although the vegetation is often denser than indigenous vegetation, the ability to bind the soil and prevent erosion across the whole channel is reduced.

Figure 4.3: Alien vegetation (Black wattle) displacing flow channel and causing erosion of opposite bank

The removal of invasive vegetation from all rivers but in particular, eroding river reaches is critical to effective river restoration and should be seen as a priority for all proposed interventions. Often the invasive vegetation plays a key, if not determinant, role in the problems being experienced within a river reach.

Ironically alien vegetation often first establishes itself in areas that have already been disturbed. Places where indigenous vegetation and sand bars have been bulldozed out of a river, river banks cleared by bush-fires, and rivers with disturbed runoff patterns because of water abstraction are all places where alien vegetation flourishes. It is thus important that the disturbance footprints at rehabilitation sites be kept as small as possible, and that follow-up clearing of any invasive vegetation after the rehabilitation activity has been completed, is undertaken until the re-growth of alien vegetation ceases.

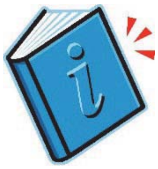
In the same way as invasive alien vegetation can divert flows in to the banks, so too can excessively dense stands of indigenous vegetation. Indigenous vegetation may increase unnaturally due to elevated nutrients (for example downstream of sewage plant outfalls), in response to excess sediments (from upstream erosion sites) and/or due to reduced floods or stabilized baseflows. The latter impacts have been observed below many large dams in South Africa, where the reduced frequency and size of scouring flood events has allowed for dense riparian vegetation to encroach upon the channel. When large floods do occur, the impact of encroaching vegetation and associated loss of channel competency leads to unexpected results, such as the debris blockage at bridge at Laingsburg during the 1981 flood which lead to many fatalities and widespread damage.

Controlling the un-naturally dense invasive vegetation through removal and follow-up control measures will alleviate the flooding risks, reduce the diversion of floodwaters to opposite banks and overall increase flood conveyance through the channel. Note however that clearing activities should include stabilization by planting with alternative indigenous vegetation, to prevent erosion of disturbed, bare banks.

Environmental legislation

- The removal of alien vegetation does not trigger the need for environmental authorisation in terms of the NEMA regulations providing that not more than 5 m^3 of soil or rock is disturbed in the process.
- The Conservation of Agricultural Resources Act (CARA) would be contravened if a landowner leaves or allows an obstruction in the river which could lead to soil loss (i.e. if alien trees are felled and left in the river in the path of floods).
- Refer to Volume 1: Section 10 "*Legal authorisations necessary for river rehabilitation*"
- Clearing of alien vegetation is a legal requirement in terms of NEM:BA for many alien species – see Chapter 2 for details

Figure 4.4: Alien vegetation has colonized sediment on the inside of the bend during the dry period, and in the rainy season pushed the river into the opposite bank



CROSS REFERENCE

Various methods for removal of alien vegetation are described in Chapter 2 of this publication

4.4. Planning the location of interventions in a river rehabilitation project for any interventions other than vegetation modification

TECH TIP – the desirability of minimalist interventions / scale of interventions

It is desirable to keep all constructed river rehabilitation interventions (earthworks, soft structures, hard structures) to a minimum, not only for reasons of economy, but for avoiding interfering with natural processes as far as possible.
The converse is also true, that one does not want half-hearted interventions that fail unnecessarily during floods and the river has to be disturbed by construction once more when the intervention is reconstructed.

CASES WHERE THE RIVER IS VERY WIDE IN RELATION TO THE SCALE OF INTERVENTION

With large and very wide rivers (such as the Amazon, Rhine and Congo), relatively small erosion protection structures on one bank will not influence the stability of the opposite bank, irrespective of the position or alignment. For these wide rivers, the erosion protection must be positioned and aligned such as to perform the task intended.

Figure 4.5: Erosion control groyne on bank of Upper Amazon at Campanilla, Peru.
The river is too wide for the structure to influence the opposite bank

CASES WHERE THE RIVER IS NOT WIDE IN RELATION TO THE SCALE OF INTERVENTION

Especially for rivers which have limited flow width, when rehabilitating a bank using one or another form of construction, the question should arise as to where the rehabilitated bank must be positioned? The eroded position of the bank can be used, or a pre-erosion position could be more suitable but would have an extra cost implication assuming that a lot of earth fill will be required. Although it is important to control the cost of the rehabilitation work, it is also important that the bank does not get stabilized in a position and orientation that it directs the flow of water into the opposite bank and cause erosion there. For this reason it is strongly recommended that projects where this option is used and the catchment being drained is in excess of 500 ha, the magnitude of expected floods, the flood height, flow directions and velocities, and the appropriateness of the design be checked by a suitably qualified professional.

Figure 4.6: A typical river where rehabilitation work on one bank can influence the stability of the opposite bank

With rivers of limited main channel capacity, it is often useful to determine the natural discharge capacity of the main channel nearby where the proposed rehabilitation is to take place. The main channel where the rehabilitation is taking place can be designed to accommodate at least this flow so that the rehabilitated section does not constrict the channel and cause water to exit the channel to the floodplain unnaturally. As a general rule, in agricultural areas the main channel should accommodate at least the flood expected once in ten years and in urban areas once in fifty years.

The plan view layout of the rehabilitated channel must be comprised of a collection of straight sections and tangential bends along which the river could flow. This planned channel should fit within what is known as the river channel, either the existing or that which existed prior to flood damage. Historical aerial photography is very useful for motivating the position of the rehabilitated channel. The choice radius of rehabilitated channel bends requires experience of a given river and catchment's behavior. For European rivers (Przedwojski B, Blazejewski R, Pilarczyk KW, 1995) a bend radius of twice the river width could be suitable, but these are wide and generally slow flowing rivers. In the Western Cape (King, 2014) a radius of around four times the river width is used. Figure 4.7 shows the development of the rehabilitated channel geometry for a river.

The constructed bank erosion protection (groynes, retaining wall, riprap, etc.) would then be employed especially on tight bends to assist the rehabilitated river channel to remain on this alignment. It must be understood that because of the dynamic nature of rivers and the movement of sediment that the river will not always follow this planned path, but with the assistance of properly planned bank stabilization interventions, it is likely that the main channel will tend the rehabilitated channel.

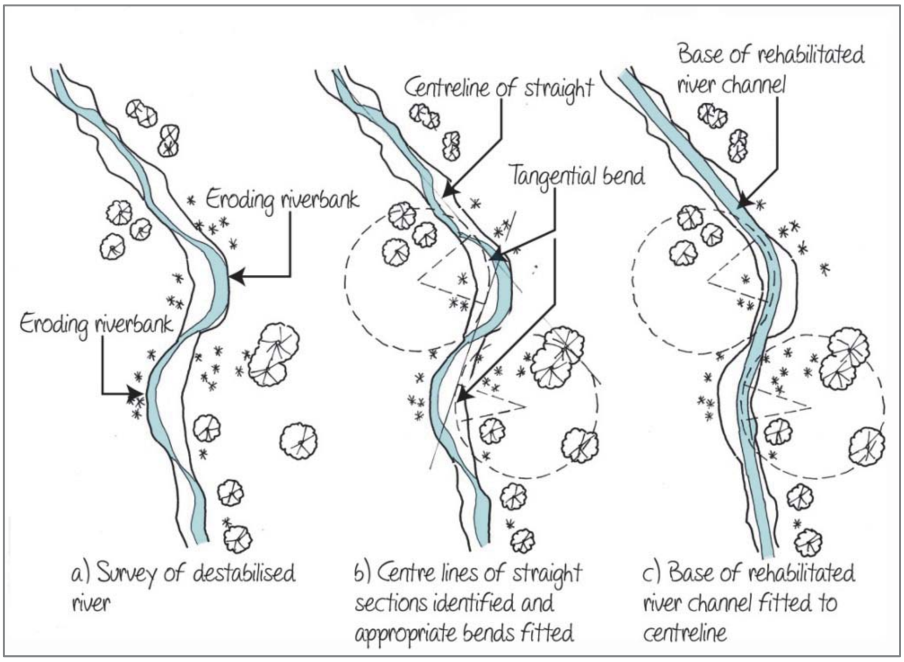


Figure 4.7: Development of rehabilitated river channel geometric layout

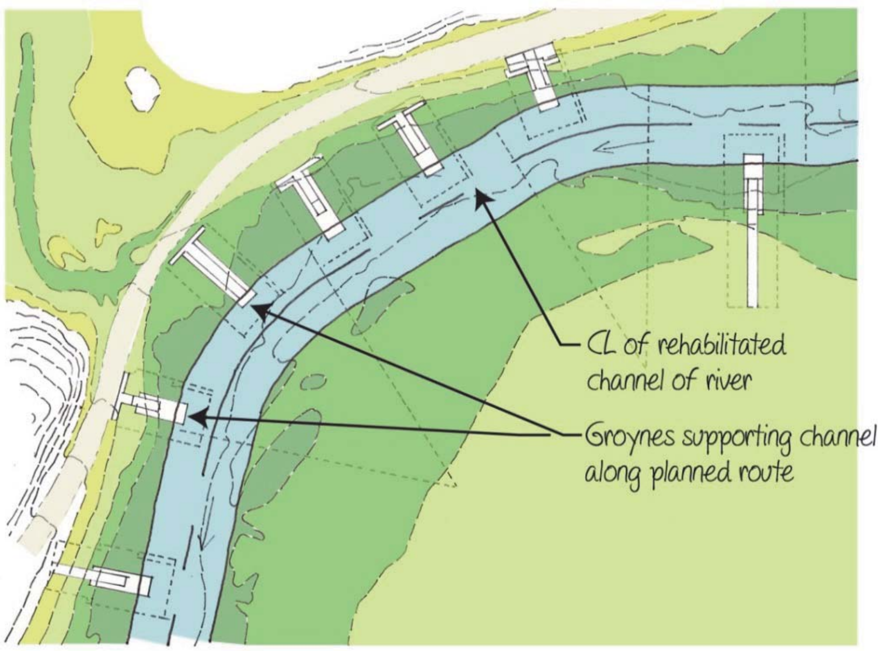


Figure 4.8: Typical layout of a surveyed river, the planned rehabilitated channel, and structures stabilizing the river banks

Experience in managing Western Cape Rivers in Agricultural Areas

The Department of Agriculture in the Western Cape takes the following approach to management of highly disturbed agricultural rivers:

- The rivers are commonly highly disturbed, narrow channels and severely constrained flood plains. Indigenous vegetation has in many places been replaced with black wattles. Farmers have attempted to bring order to rivers by bulldozing them, and in the process have only made the rivers more unstable.
- It is not possible to return the rivers to the pre-development state, as the best agricultural soil is found immediately adjacent to the rivers. It is necessary to find a means of stabilizing rivers while largely accepting the constrained river space.
- Because of the space limitation, careful consideration is given to the position and orientation of erosion protection structures.
- A minimum discharge channel is planned to safely accommodate at least the 1:20 year flood so that it does not exit the defined river channel, or cause erosion on the bank opposite the structure – the streamlined geometric layout of the project in this case is essential.
- Structures are kept largely inside the space that used to be occupied by the river bank prior to its washing away, i.e. the structures are kept within the footprint as well as the level to which the bank existed, so as to not present more of a resistance to flow than what the previous bank did.

4.5. Indirect interventions for bank stabilization

4.5.1. Removal of sedimentary bars from the channel

As with the dense stands of invasive vegetation causing flow diversions and bank erosion described above, deposits of sediment within the channel can similarly lead to flows being directed towards the outer edges of the channel and causing erosion of the river banks. The removal of in-channel features can reduce bank erosion through preventing secondary (deflected) currents from causing erosion of the banks of the river (although it may be not justifiable from an environmental point of view).

Caution

REMOVAL OF SAND BARS

The removal of sand bars has been included in this document because it is often seen as an attractive rehabilitation option.

The mechanical removal of sand bars is not recommended if the circumstances which gave rise to the sand bar have not changed, because the sand bar will only form again. In addition to this, the mechanical removal of sand bars creates bare patches which get colonized by alien vegetation, which in turn creates a new set of problems in the river (narrowing, etc.).

The removal of sand bars would typically be a once-off operation as part of an overall rehabilitation intervention if correctly motivated.

Should the removal of sand bars be recommended for rehabilitation, due care must be taken so that it is not done in a way that it initiates river bed incision, or it creates flow conditions which direct the river into a river bank and causing erosion. Part of the solution to the negative impacts of sand bar removal is to provide a geometric layout and minimum discharge capacity through the excavated section of river (see Section 4.4 of the Technical Manual)

The removal of sediment (small sedimentary bars, deposits and bed and bank material), vegetation and (natural woody) debris can reduce in-channel and riparian habitat diversity. If carried out too frequently, so that the rate of disturbance is greater than the rate of recovery of riverine fauna and flora from disturbance, sediment removal as a maintenance measure may have long-term biodiversity implications. See Chapter 10 for more information. The promotion of a straight, single channel river also reduces habitat diversity. Often the backwaters and secondary channels provide important habitats for instream biota, whilst the small bars and lower riparian vegetation also slow down flood velocities and serve to reduce flow speeds and increase flood attenuation and sediment deposition. These physical environments and their associated ecosystem services are reduced or lost during channel straightening and vegetation/bar/debris removal.

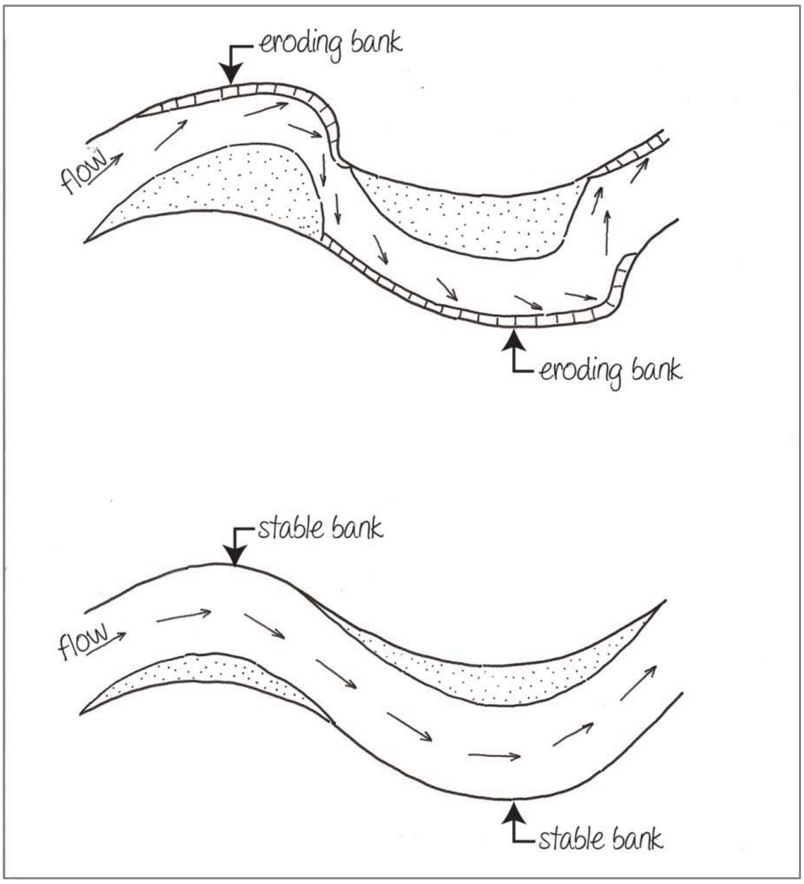


Figure 4.9: Channel bars causing diversion of flows in to the banks, resulting in erosion

Due to the unsustainability of this option, the advantage of using sediment removal from the river as a rehabilitation option in relation to other options is very poor.

Environmental legislation

- The removal or in-filling of more than 5 m^3 of material does trigger the need for environmental authorisation in terms of the NEMA regulations placed in the river, or more than 5 m^3 soil moved.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.5.2. The protection of banks using structures the redirect water flow

Groynes are finger-like structures projecting from a river bank into the river which deflect the flow of water away from the bank, or to retard the flow of water along the bank, to protect it from erosion. These groyne structures can be permeable or impermeable.

4.5.2.1. Permeable groynes

Permeable groynes are groyne structures that are designed to reduce flow velocities along the bank where erosion is taking place. They are constructed usually with hardwood timber which gets replaced from time to time, but there are also records of them being constructed with concrete poles. Although this is a low-tech option, the positioning of the structures should still be planned to support a rehabilitated river channel as considered in Section 4.4 of the Technical Manual.

A significant feature of these structures is that they do not necessarily form a continuous structure but can be just a collection of poles driven vertically into a river bed. It is likely that these structures are more intended for slower flowing lowland rivers such as the Yellow River and Mekong River. It appears that they have been used mostly in Asian and Eastern countries. To date there has not been a noticeable use of these in South Africa, possibly because of the cost of the timber and the flow velocities of the rivers.

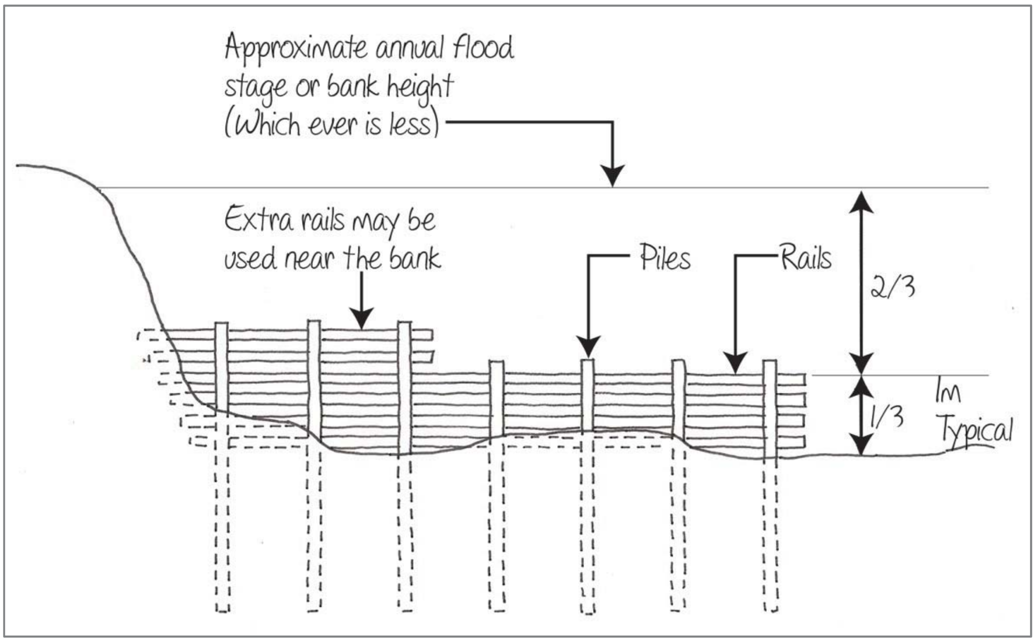


Figure 4.10: Permeable groyne

The effectiveness of permeable groynes cannot be determined analytically but use must be made of physical model testing or previous experience under similar conditions.

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of permeable groynes are:-

- They cost less than formal permanent structures.
- They have less of a visual impact on a river, especially when they are permanently submerged.

The disadvantages of permeable groynes are:-

- If they are made from timber, they need to be replaced at an interval which implies that the river and vegetation gets disturbed repeatedly.
- Their stability when a river carries a heavy load of floating flood debris is uncertain.
- Should the structures be washed out during a flood, the poles will add to the flotsam in the river which often blocks bridge openings.

Environmental legislation

- The use of permeable groynes triggers the need for environmental authorisation in terms of the NEMA regulations if more than 5 cubic metres of material (in this case timber) is deposited in the river, as well as a total structure footprint exceeding 100 m^2 is common.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.5.2.2. Solid groynes

Solid groynes offer a more permanent solution to permeable groynes. They require far less maintenance than do permeable groynes, and are more suited to protecting areas of bank from erosion while vegetation is being established. Figure 4.11 shows typical solid groyne components, notably the tip, shank, root, and scour protection. The image is of a rock filled gabions groyne, but groynes may be constructed with other materials such as concrete as well.

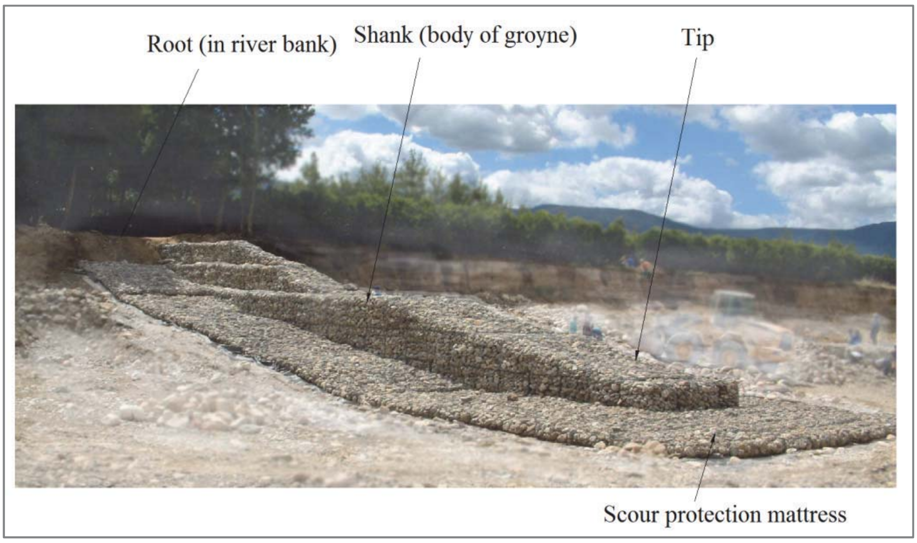


Figure 4.11: Typical groyne components

Groynes are normally constructed in groups called "fields" where the objective is to encourage fast flowing water to negotiate a bend without eroding the bank. Figure 4.12 shows a typical field of groynes.

Figure 4.12: Typical field of groynes

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of groynes are:-

- Groynes displace the faster flowing main channel away from the bank so to reduce the risk of erosion by undercutting.
- Groynes can promote a wider and shallower flow channel, which slows down flow velocities and implies lower levels of sediment transport
- Groynes provide a space along the bank where indigenous vegetation may be re-established. This would not only enhance the biodiversity in the river, provide a connection between the aquatic and terrestrial habitats, but if groynes are constructed with gabions, by the time the wires of the baskets degrade the re-established vegetation will stabilize the watercourse.
- If properly managed, groynes can disappear to a large extent under the canopy of re-established vegetation

The dis-advantages of groynes are:-

- Any bank erosion structure that is in-appropriately designed has the potential to cause fresh erosion (for instance by directing the flow of water into the opposite bank).
- The scour holes at groyne tips can be problematic if not catered for in the design of the groynes (tip of groyne needs to be sloping, foundation level of groyne needs careful consideration).
- Groynes are not suitable for stabilizing river channels which have a discharge capacity that is less than the flood flow which is frequently expected. This is because to function, a groyne has to project into a river’s flow area, and under these circumstances if a groyne is to achieve the objective of protecting a bank from erosion, it will increase flood levels in the adjacent flood plain.
- Groynes, like many other interventions have to de planned by specialists.

Environmental legislation

- The use of groynes triggers the need for environmental authorisation in terms of the NEMA regulations because usually more than 5 cubic metres of material is moved, as well as a total structure footprint exceeding 100 m^2 is common.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.5.2.3. Iowa vanes and Micro-groynes

Most bank erosion techniques attempt to adapt the river channel to increase resistance to erosion (such as riprap or longitudinal river training walls) but these techniques are very expensive and don't allow for good contact between the aquatic and terrestrial habitats. Iowa vanes as well as micro groynes, although still largely experimental, have a fundamentally different approach to stabilizing the river bank and are thus very significant. The basis of the approach is to alter the currents in the river which cause the erosion of the outer bank of a bend in such a way that a state of stability is facilitated.

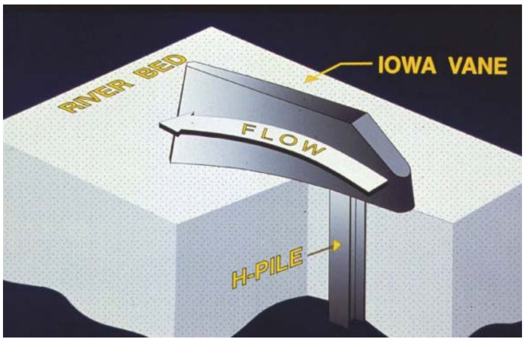


Figure 4.13: Iowa Vane

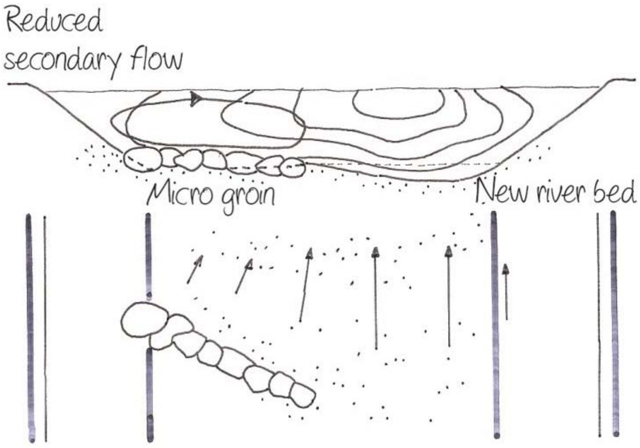


Figure 4.14: Micro groin on outside of bend – the section through the river (at top) shows the secondary current set up by the micro-groin the counter-acts that which causes the bank on the outside of a bend to erode

Under normal conditions, water flowing around a bend tends to follow a helical flow pattern. Water flowing at the surface of the channel experiences more centrifugal force than water flowing along the river bed, so water flowing at the surface moves towards the outer bank as well as downstream, and water flowing along the river bed moves towards the inner bank as well as downstream (see Figure 4.15). Iowa vanes and micro-groynes are planned in such a way that they tend to induce a spiral current in the opposite direction (in other words directing the flow of water towards the outer bank of the river), cancelling the spiral flow of water and reducing the potential for erosion to the outer bank.

Iowa vanes are vertical fin-like structures embedded into a river on a bend to deflect the current along the bed of the river towards the outside bank. This process was pioneered in the USA (Odgaard, 2014) in the USA during the 1980's. The vanes were originally conceived as steel plate structures welded on top of heavy steel girders hammered into the river bed. Although very effective for river management, the presence of the steel pile and fin is hardly likely to be acceptable from an environmental point of view in South Africa. It is important to note that the process of reversing the spiral current around a bend can actually influence the river's meandering process.

Design information for Iowa vanes is limited to a few rules of thumb, so experience with the use of these structures is essential. The projection of the vanes from the river bed is in the order of 10 to 40 % of the design flood depth. The length of the vanes (in the direction of flow) is about three times the projection from the sediment. The spacing between vanes in a row is 3-4 times the vane projection. Rows of vanes are spaced 10-30 times the vane projection. The vanes are oriented 10-20 degrees in the direction of the outer bank.

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of Iowa vanes are:-

- From the case studies reported, Iowa vanes can be quite effective in reducing river bank erosion.

The dis-advantages of Iowa vanes are:-

- Although the intention is that the vanes remain submerged for most of the time, in many South African rivers which virtually dry up in the dry season, they will emerge and be quite unsightly.
- There must be safety issues with Iowa vanes for river users (such as sportsmen in rivers).
- Flotsam in rivers during floods will also get caught on the fins and cause an obstruction.
- The design procedure for Iowa vanes is uncertain although the reported case studies are impressive.

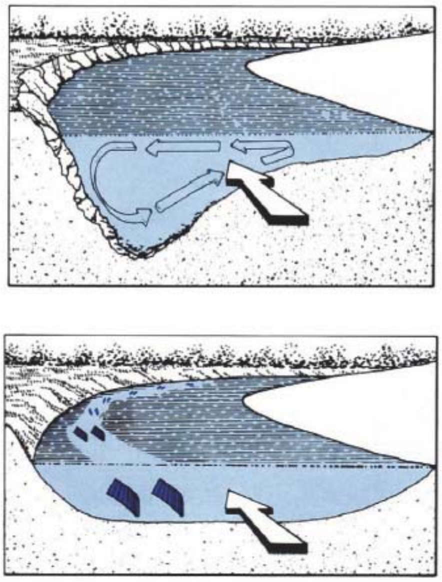


Figure 4.15: Submerged vanes for mitigating bank erosion on bends. Naturally-occurring secondary current (top), net current after adding vanes (bottom). Odgaard USA

Micro-groins are similar to Iowa Vanes but constructed with very heavy boulders set into the river bed (see Figure 4.14). The boulders are arranged in rows projecting into the stream from the outer bank of a bend, and oriented in a slightly downstream direction. In the same way as Iowa Vanes, micro groynes induce a current which interrupts the corkscrew current formed by water flowing around a bend, and reduces the tendency for the outer bank to wash away. Micro-groins have been constructed in Switzerland on an experimental basis (Werdenberg N, Mende M & Sindelaar C, 2014).

Little information on the planning of micro-groins is available because of the still experimental nature of the approach. Most certainly the boulders have to be sized that they do not get moved by high velocity flows during floods, and one way of doing this would be to establish the expected flow velocity and determine a minimum boulder size using the tractive force theory as described in the SANRAL Drainage Manual (SANRAL Drainage Manual, 1981). One stated aspect of the structures are that in spite of the large boulder size, only 10 to 20 cm of the boulder projects above river bed level, the rest is buried. Trials have been done with different groin orientation with respect to the stream flow direction, but no conclusive recommendation has been published yet.

Micro-groins are reported to have the following advantages:-

- They can reduce the erosion of the outer bank of a river on a bend
- They do not alter a river's flow depth (because their projection from the river bed is very small)
- The large boulders used could increase in-stream habitat diversity

The dis-advantages of micro-groins are:-

- Very large rocks are required (those used by Werdenberg et al. were 1,5 t), these have to be specially sourced and are expensive
- It is uncertain to what extent the technology developed could be used in South African rivers

Figure 4.16: Construction of micro-groyne (photo C Sindelar, Austria)

Environmental legislation

- The use of Iowa Vanes and micro groynes would probably trigger the need for environmental authorisation in terms of the NEMA regulations should more than 5 m^3 soil be moved while producing foundations for the structures.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- An activity could constitute an offence in terms of the CARA Act if it is shown that an action could lead to excessive agricultural soil loss. If the fins of an Iowa Vane trapped floating vegetation during a flood, which in turn caused an obstruction and soil erosion in a watercourse, this would be the case.
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.6. Direct interventions for bank stabilization

4.6.1. Bank reshaping and re-vegetation

Unless streams have extremely slow velocities during floods (<1,5 m/s depending on the soil type) even during floods, the simple landscaping (sloping) and revegetating of river banks will yield very unpredictable results.

The design of the system is very dependent on the erosion resistance of the vegetation employed (and information on this is hard to get). The information provided for some grass species is for short term flow tests and does not represent the situation of inundation for several days.

Localized stream velocity accelerating effects around obstructions such as tree stumps or rocks can cause localized failure of the rehabilitated bank, which in turn can progressively lead to a general failure of an extended stretch of bank.

RELATIVE SIGNIFICANCE OF THIS OPTION

Where possible the simple landscaping and re-vegetation of banks is the most desirable form of bank rehabilitation and the viability of this option must be considered first.

If flow velocities along the landscaped bank are making it unstable, one can combine a landscaped and vegetated bank with other options to achieve a suitable result. One option is to consider combining landscaping with structures which create a more stable lower flow velocity condition along the bank such as those in Section 4.5 (groynes, micro-groins, etc.). Another option is to consider combining landscaping with other interventions that increase the river bank's ability to withstand high flow velocities in Section 4.6 (erosion control blankets, gabion mattresses, riprap, retaining walls, etc.).

ADVANTAGE / DISADVANTAGE OF THIS OPTION

Bank shaping and re-vegetation has the following advantages:-

- Landscaping and vegetating banks, although it involves disturbing the soil, does not involve introducing foreign material to the river environment, and this makes it attractive;

- The indigenous vegetation used for revegetating (if appropriately chosen) is adapted to thriving in the environment and will eventually spread down the river, enhancing the stability of the river;
- The indigenous vegetation used for revegetating (if appropriately chosen) will support other life forms that belong in the habitat and enhance the biodiversity status of the environment.

The disadvantages are the following:-

- There is a lot of difficulty associated with quantifying the engineering properties of vegetation in order to produce a professionally reliable design;
- The engineering properties of vegetation are not constant, but depend on the age of the vegetation, the presence of burrowing animals like moles, the current status of the vegetation such as recent rainfall, bush fires, etc., the presence of animals grazing and trampling the vegetation.

DESIGN CONSIDERATIONS

With reference to Section 4.4, it is necessary to consider in which position and orientation the bank is to be landscaped. Providing that this option is appropriate for the prevailing conditions, flow velocities during floods will be relatively low and the implication of choices made regarding the position and orientation of the bank should not be extreme. Nonetheless the rehabilitator of the site does not want to be accused of causing some other problem upstream or downstream (i.e. fresh erosion of the banks or a blockage of the river), and caution is urged.

TECH TIP

In cases where the discharge capacity of the river channel is low and the frequent overbank flooding is causing the erosion of the bank, it should be considered to allow the river more width and withdraw the position of the bank accordingly, alternatively providing a wide margin of land adjacent to the river channel where flooding may be accommodated safely.

The stability of an un-vegetated earth slope when inundated by flowing water is related primarily to soil particle properties, the slope of the soil surface and the flow velocity of the water. An engineer should verify that the proposed bank slope is stable before the planning of the project is finalized.

Allowable flow velocities for various soils and grasses are given in the Table 5.6 below (SANRAL Drainage Manual, 1981). Please note that these have been determined for small channel applications alongside roads, and are not necessarily suitable for extended duration flows that can be found in rivers – but are typical of the data that is available. No such table is available for indigenous river and wetland vegetation such as *Cyperus textilis* (papyrus), *Prionium serratum* (palmiet) or *Typha* (bulrush).

Mean annual rainfall (mm)	< 600			600 – 700			> 700		
Type of grass	% Clay content in the soil								
	> 15	6 - 15	< 6	> 15	6 - 15	< 6	> 15	6 - 15	< 6
Kikuyu	No data			1,8	1,5	0,8	2,5	2,0	1,2
NK 37				2,0	1,5	0,8	2,0	1,5	1,0
K11				1,5	0,8	0,6	2,0	1,5	1,0
Rhodes				1,2	0,8	0,6	1,5	1,0	0,8
*E Curvula	1,0	0,8	0,8	1,2	0,8	0,6	1,5	1,0	0,8
Blue Buffalo	1,0	0,8	0,8	1,2	0,8	0,6	No data		
Paspalum didatum	No data			1,2	0,8	0,6	2,0	1,5	1,0

Figure 4.17: Permissable maximum flow velocities (m/s) for grass covers. Valid for flow depth of up to 0,3 m and slopes less than 3%

TECH TIP – research related to allowable flow velocities over vegetated banks

Threshold values have been established for some of these mortality conditions (mainly for purposes of vegetation control).

Samani and Kouwen (2002), for example, reviewed different approaches for assessing the resistance to erosion of grass covers, and provided a method for predicting the rate of soil removal from within a cover. This enables the conditions to be determined at which no erosion would occur, and at which the grass would be uprooted.

Duan et al. (2006) modelled the velocity required for breaking stems of an emergent plant. Friedman and Auble (1999) established thresholds of erosive flows and periods of inundation required to prevent streamward encroachment of a tree species.

These and other results show that useful threshold conditions can be established but are mainly limited to particular species and would need revision for South African applications.

The reader is however referred to the "Think Green" guideline boxes in Section 7.4 of Volume 1 (Rehabilitation Guidelines) for further discussion of situations promoting or preventing the effective use of plants in bank stabilisation projects.

A commonly expressed concern with the introduction of vegetation into a river channel is the effect it might have on flood levels. The impact on flooding is unlikely to be great if vegetation is used only on the banks and the channel is relatively wide, as most resistance then arises from the bed substrate. (See the section on flow resistance in Technical Manual Section 3 for further discussion of flow resistance.)

SELECTING VEGETATION FOR BANK STABILIZATION

TECH TIP – research shows that the type of bank erosion is related to its location in catchment

Successful bank stabilization using vegetation requires matching effective vegetation characteristics to the likely mode of bank retreat. For example, Abernethy and Rutherfurd (1998) found the modes to be distinctly related to location within the catchment for an Australian river, with subaerial preparation dominating in the upper reach, fluvial erosion in the mid reach and mass failure in the lower reach. Guidelines for assessing bank stability conditions are presented by Thorne et al. (1996) and Abernethy and Rutherfurd (1999).

See also the Guideline Section 3.4 and Section 7 regarding mass failure rates.

Different bank conditions and failure modes clearly require different vegetation treatment: subaerial preparation (weathering processes like freeze thaw, exfoliation, chemical weathering) and erosion are best controlled by grasses and shrubs with their effective surface shear reduction capabilities and root mass soil strengthening properties, while mass failure potential requires deep root reinforcement provided by trees. Abernethy and Rutherfurd (1999) provide a procedure for determining the width of riparian forest required for effective mass failure protection.

TECH TIP – understanding the engineering properties of plants

When implementing a vegetative stabilizing project, it is useful to have knowledge of the relevant characteristics of the species to be used, including its root architecture and tensile strength. This information is not commonly available, but it is anticipated that over time it will be.

Javernick (2013) listed the following causes of vegetation mortality for which threshold conditions could be determined:

Sediment movement

- erosion (lateral and surface), leading to uprooting
- deposition, leading to burial
- transport (suspended and bed load), leading to trauma by abrasion

Water movement

- drag, leading to uprooting
- Inundation, leading to drowning of plants.

The “Think Green” guideline boxes in Section 7.4 of Volume 1 (Rehabilitation Guidelines) also provide some discussion as to plant traits (or characteristics) that lend themselves to the control of erosion in certain conditions, and which should be considered in selecting appropriate plants.

Crucial to the success of vegetative bank stabilization is the resilience of the vegetation itself to environmental threats, including extreme flow events. Failure of the vegetation could result in exposure of the unprotected banks to conditions well in excess of their unprotected failure thresholds. It is therefore essential to know the strength characteristics of the species used and their vulnerability to damaging conditions. Reeds, for example, provide effective protection to surface erosion under high flows, but some species are vulnerable to uprooting through lateral erosion by prolonged moderate flows.

Environmental legislation

- The movement of more than 5 m^3 of soil or rock in a river triggers the need for environmental authorisation in terms of the NEMA regulations.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 “*Legal authorisations necessary for river rehabilitation*”

CROSS REFERENCE

Refer to Volume 1: Section 7.4.3 for guidelines for the selection of plants for erosion control on the basis of root traits, and for general guidelines for specific conditions lending themselves to stabilization by plants rather than with structural interventions.

4.6.2. Bank reshaping and erosion control mats

4.6.2.1. Coir fiber mats

Products like this are very useful for re-vegetating slopes where a micro-climate needs to be created until small plants appear with leaves shading the soil, creating a habitat where other plants can thrive.

On river banks this could be the same situation, but it is foolish to believe that large mats can be used to stabilize soil under fast flowing water. Do not be misled by attractive looking sketches until you are sure that the product will work in the proposed situation.

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of erosion control mats are:-

- The coir creates a micro-climate where hydro-seeded grasses may take root.
- Although not indigenous, they are natural fibres, and decay over a short period of time, leaving the vegetation to hold the soil together.

The dis-advantages of erosion control mats are:-

- They do not offer significant strength to the structure
- The mat only lasts for between one and two years once in the sun, and if the seeding of the slope is not successful, it may be difficult to finish off a project.
- Unless additional support is given to the coir (such as placing it in Maccaferri Terramesh units, or similar, it cannot be used to wrap soil in flowing water unless the flow velocity is very slow (< 1 m/s).
- Coir mats can be expensive.

Figure 4.18: Typical non-woven coir mat

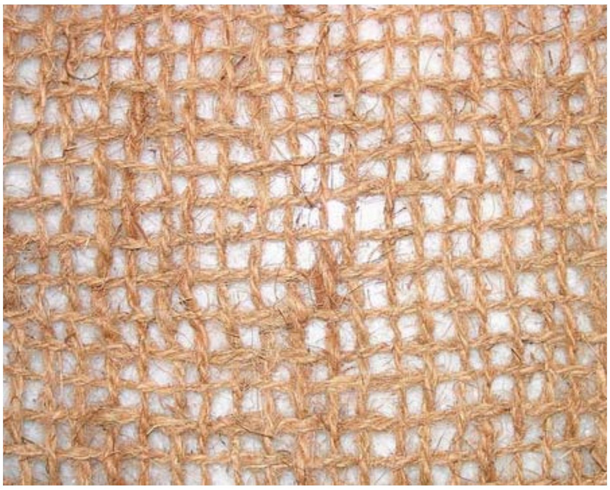


Figure 4.19:Typical woven coir mat

Coir mats are available from several suppliers and in different forms. One type is a general non-woven mat, and another is netting woven from thin coir rope. It is possible that the woven mat works better with a hydro-seeded surface as many of the seeds can pass through the opening to the soil, but the non-woven mat may create retain more moisture and be more appropriate for use when planting cuttings or small plants directly into the soil (through slits cut in the coir).

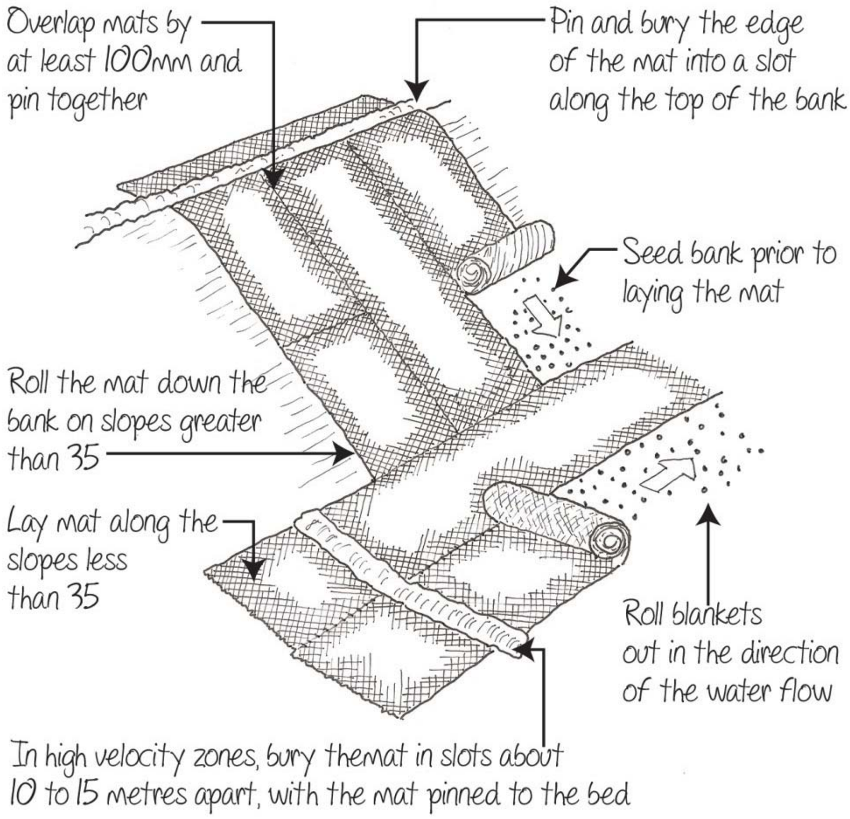


Figure 4.20: A suggested coir mat use in conjunction with bank reshaping to stabilize the banks, limit erosion and promote faster vegetation re-establishment (Torre, 2001)

Please note that this is viewed as generally un-practical. The detail of placing coir under water is un-acceptable as the coir will get snagged by floating debris and dislodged.

Environmental legislation

- The movement of more than 5 m^3 of soil or rock in a river triggers the need for environmental authorisation in terms of the NEMA regulations. If more than 5 m^3 of coir fibre is deposited in the river, authorisation is required. In addition to this if the area covered by erosion control matting exceeds 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.6.2.2. Geotextiles

Products like this are very useful for re-vegetating slopes where a micro-climate needs to be created until small plants appear with leaves shading the soil, creating a habitat where other plants can thrive.

On river banks this could be the same situation, but it is foolish to believe that large mats can be used to stabilize soil under fast flowing water. Do not be misled by attractive looking sketches until you are sure that the product will work in the proposed situation.

Figure 4.21: A range of geotextiles
(Wikipedia https://en.wikipedia.org/wiki/Geotextile#/media/File:Geotextile-GSI.JPG)

Geotextiles are mats of artificial fibre, with the intention amongst other things that they be used to reinforce soil and/or provide an economical filter layer (i.e. an alternative to granular filters). For this reason in the early days of the development of geofabrics, they were often referred to as filter fabrics.

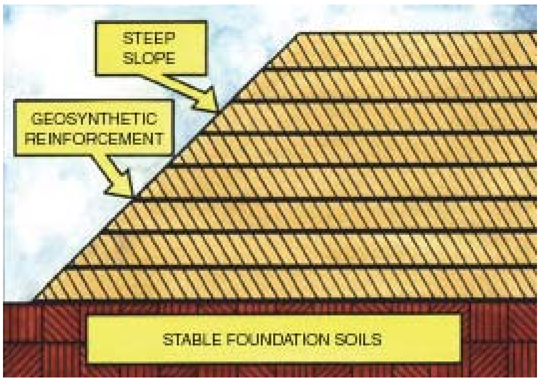


Figure 4.22: Soil reinforcement with geotextile
Geotextile is placed under a soil layer and then folded back over the top before the next soil layer is placed

Figure 4.23: Large sand filled geobags used to construct groynes in the sea at Langebaan

The most well-known form of geotextile is the needle punched monofilament mats which come in a variety of thicknesses with different strength and permeability properties. Although generally used for separating the soil from structures (like riprap, drainage pipes, roads, etc.), they can be used in river rehabilitation projects in several ways. One way is to stabilise slopes (i.e. the higher part of river banks) by means of "soil reinforcement" – this has enables the construction of a much steeper fill than what could be achieved without the geotextile reinforcement (see Figure 4.22). Another use of geofabrics is the construction of "geobags", i.e. sand bags on a large scale. Figure 4.23 shows geobags (made with specially produced thick mat) for use in the sea. These bags have been made successfully to be filled with between 1 and 25 tons of sand depending on the application and the placement technique. The advantage of these bags is that in areas where stone is not available for construction, it turns the locally available sand into a building material.

More recent developments of geotextiles have produced "geomats" (higher strength polymer grids for soil reinforcement) and "geocells" (a honeycomb like polymer grid which contains soil or other fill material in an array of small cells which can greatly reduce surface erosion – see Figure 4.24).

Figure 4.24: Geo-cell used to stabilise slope
This can be very effective for slope stabilization, but not in the presence of fast flowing water.

Figure 4.25: Geo-cell prior to soil fill used to reinforce channel.
This can be a good solution if the cells are filled with cementitious material and the flow velocities are not too high. It is however more appropriate for addressing surface drainage than river stabilisation.

All of these products have the disadvantage that they cannot withstand UV-radiation for long and if provision is not made to protect them, they are likely to degrade over 10 years. This problem can be mitigated by ensuring that sustainable vegetative cover will be achieved before the product degrades completely.

ADVANTAGES / DISADVANTAGES OF THIS OPTION

Advantages

- Fairly simple construction
- More eco-friendly than concrete
- Blends in with environment
- Economy

Disadvantages

- Limited strength, limited capacity for flow velocity
- Susceptible to uv-degradation

Environmental legislation

- The removal or in-filling of more than 5 cubic metres of material in a watercourse definitely triggers the need for environmental authorisation in terms of the NEMA regulations. In addition to this “infrastructure or structures with a footprint exceeding 100 m^2” requires authorisation – it is possible that a landscaped bank covered with coir mat triggers this.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 “*Legal authorisations necessary for river rehabilitation*”

4.6.3. Bank stabilization with concrete grass-blocks

Concrete grass blocks are most useful for lining ditches on the sides of roads, where water is flowing or places where the soil is often saturated, trafficked areas, and where a grass or vegetative cover is desirable. They are available from many manufacturers in different forms.

Figure 4.26: A typical grass block (Cape Concrete)

Grass blocks provide stability because of their weight, but have holes through them to allow the growth of vegetation through them. Grass blocks also have raised knobs on them so that vegetation will not necessarily be damages should vehicles drive over the block. The blocks are not linked together in any way but are simply lain against one another. Although intended for open drains, these could be placed on a landscaped river bank, or across the bed of a river should it be needed and the flow and soil conditions allow it. They have been seen to be used in conjunction with retaining wall blocks to form permeable channelized streams in urban areas.

Figure 4.27: Grass block waterway on a farm

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of using grass blocks are:-

- Vegetation can be established in an environment where factors such as vehicular traffic or water flow velocity would have otherwise prevented it from flourishing.
- Grass blocks do not require major foundation construction and offer an intervention with a lower level of impact on the environment during construction
- Should there be a failure of the grass block lining, it is a simple matter to reshape the foundation and re-lay the grass blocks.
- The laying of grass does not require sophisticated technology and can be done by a contractor with limited training.
- Grass blocks do not always support the most desirable plant species because of the size of the holes. Ecologically, grass blocks are more useful if you want to replicate non-ecological functions such as infiltration, or to serve as low-impact maintenance guides in short sections in a channel (e.g. in artificial vegetated channels that will need periodic dredging, and one doesn't want that process to result in deepening wetland)

The disadvantages of grass blocks are:-

- There are limiting flow velocities when the grass blocks will fail (by being lifted), as well as flow velocities when the soil in the grass block will be washed out – but these have not been determined in a laboratory yet.
- Grass blocks can be costly, especially if they are being used far from the point where they get manufactured.
- It could be in many cases that grass blocks only support weedy vegetation or grass. The main issue ecologically is that the gaps for roots are too small. Most indigenous plants need a rooting space of diameter at least 10 cm and usually are better with wider spaces. Also, the blocks get hot if out of water and drain too fast, so small plants don't last either.

DESIGN CONSIDERATIONS

Design considerations for grass blocks are:-

- The capacity and alignment of the channel formed by landscaping should be determined with due regard to the flow rate of expected floods and local topographic conditions (see section 4.4).
- The actual flow velocity in the channel under design conditions must be checked against a safe flow velocity for the block (this must be determined experimentally, or by approximating the block as a spherical rock and using something like a tractive force method to determine a stable flow velocity).
- If the soil below the block is very fine it may be desirable to place a geotextile below the block.
- If only a portion of the river cross-section is being armoured, then care must be taken to stabilize the edge of the armoured section.

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this case grass blocks) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by grass blocks has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

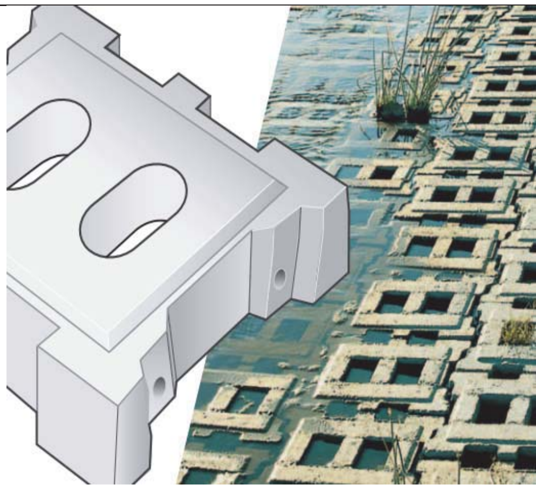
4.6.4. Bank stabilization with flexible bank armouring

Caution

Some manufacturers of flexible bank armoring claim that their product can withstand unrealistically high flow velocities. There is no excuse for common sense and experience when planning projects using these and deciding on an acceptable maximum flow velocity.

Flexible bank armouring can be gabion mattresses, or a network of concrete blocks which are held together by cables running through them to form a mat (such as "Armorflex" and similar products). Flexible artificial armoring provides a means of protecting an earth bank from the erosive power of flowing water, such that it can be stable during a design flood. As a solution it can offer financial as well as aesthetic and even environmental benefits over other options such as rip-rap and concrete retaining walls. Usually the flexible armoring is that it must be laid on a specially prepared slope.

Figure 4.28: Gabion mattress protection stabilizing a river bend (Lourens River)

 **Figure 4.29: Channel protected with flexible block armoring**	 **Figure 4.30: Armorflex® by Technicrete**

ADVANTAGE / DISADVANTAGE OF THIS OPTION

Advantages

- Both gabion mattresses and concrete block mats are reasonably flexible and deflect with the foundation soil should there be settlement or minor scour, and still offer the intended protection. Should there be large settlement or scour, the protection can be unpacked and re-instated locally.
- Both gabion mattresses and concrete block mats have many joints and cavities which can be used for covering the armouring with vegetation.
- Gabion mattresses can offer significant cost advantages when suitable stone for filling them is available locally.
- The packing of gabion mattresses and the installation of concrete block mats is relatively quick.
- The packing of gabion mattresses is labour-intensive and suitable for use with job-creation programs.

Disadvantages

- The edges of flexible armouring layers are subject to undermining by flowing water if not properly provided for. The implication is that the flexible armouring must be extended up a bank to a point where the flow velocity during high flow conditions is low enough that the earth embankment is not in danger of eroding. In addition great care must be taken to anchor the upstream edge of flexible armouring that water does not flow behind it. This is done partly by placing the upstream edge of the layer at a point where the flow velocity is not severe, as well as folding it into the embankment or attaching it to something like gabions buried in the embankment.
- The space requirement for the slopes on which the flexible armouring is constructed may be too much in some situation (especially urban situations).
- The wires of gabion mattresses are subject to abrasion in the lower parts of the river cross section, and may need an abrasion protection layer (especially in cobble bed rivers).
- The cost of concrete block mats is very much dependant on the distance from the point of supply. It is heavy and transport costs are high, a lifting crane is required for placing if the blocks are not placed by hand and wired together in-situ, and this needs to be transported to site as well.

DESIGN CONSIDERATIONS

The design considerations for flexible artificial armoring are:-

- The capacity and alignment of the channel formed by landscaping should be determined with due regard to the flow rate of expected floods and local topographic conditions (see section 4.4).
- The slope on which the armouring is laid must be of suitable material, and must conform to the minimum slope specified for the armouring type (for example gabion mattresses must not be on a slope steeper than 1:1,5 v:h)
- The flow velocity of water in the channel formed must not exceed the safe flow velocity for the armouring used.
- Appropriate provision must be made to prevent the edges of the armouring layer (in particular the toe) from being excessively undermined by flowing water, or being lifted by passing tree trunks during floods.
- The location of the bank being protected must be such that the channel formed is large enough to discharge a reasonable flood without creating excessive flow velocities, the alignment of the channel must be reasonably streamlined and the armouring layer must not direct the flow of water into the opposite river bank.

GREEN OPTIONS

- Gabion mattresses and concrete block mats can provide environments which are suitable for planting appropriate indigenous river plants. These plants not only enhance the biodiversity of the environment but also offer protection to the armor layer against rolling rocks during floods
- See Chapter 10 for a discussion on ways of improving ecological function of these linings through planting and stepping back

Figure 4.31: *Cyperus textilus* cuttings planted in gabion mattress 2010

Figure 4.32: The same site 2014 – The Loffelstein wall behind the mattress in which vegetation was planted cannot be seen.

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this case flexible bank armouring) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by flexible bank armouring has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.6.5. Bank stabilization with riprap

"Riprap" is a layer (or collection of layers) of large rock placed on a riverbank to provide protection against the erosion of the bank by flowing water. The rock can be natural or quarried rock. The rock is usually large, and it's size is designed so that it is heavy enough to not be dislodged by floods (i.e. the design flood flow velocity has to be determined). The size of rip-rap is the average minimum dimension of the rock used, and can vary from 300 mm for light protection up to 2 m for very heavy protection. The thickness of a riprap layer usually gets designed, often specified as twice the rock average minimum dimension. The protection layer is founded in the bed of the stream and generally extends up the portion of the bank threatened by erosion. This technique provides localized protection only and does not address river wide processes.

Figure 4.33: Riprap erosion protection on a river bank

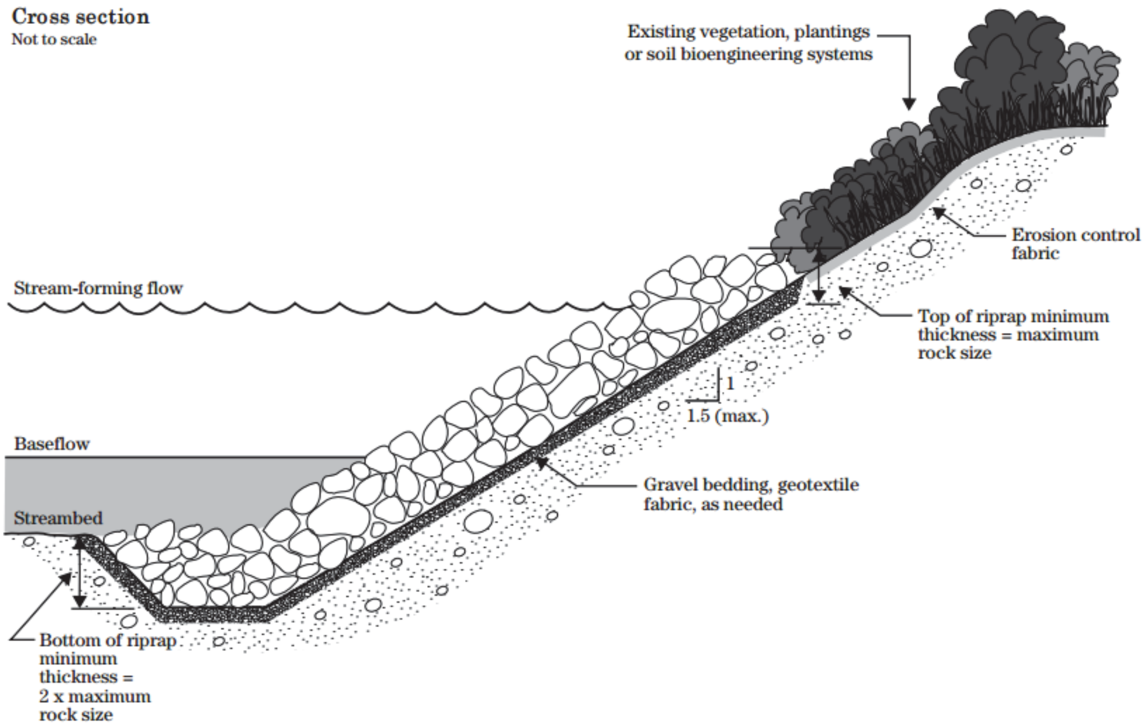


Figure 4.34: Typical riverbank riprap protection detail (from USDA NRCS Field Engineering Handbook Chapter 16)

Figure 4.35: Rip-rap protecting river banks from scour at culvert outlet (Genadendal)

Figure 4.36: Many river channels in Spain are protected with a large stone facing which is very similar to rip-rap in principle

There are various formulae that can be used to determine the size of riprap, usually based on the flow velocity of the water, the slope of the bed on which the rock is placed, the amount of turbulence in the water, etc.

TECH TIP – further information for the design of riprap

A commonly used approach is the one proposed by Pilarczyk (Fundamentals of river engineering).He compared the shear stress exerted by the moving water on the river bed mainly by virtue of its velocity, to the shear resistance of the river bed based on particle size, shape, bed slope, etc. At the point where the shear stress and the shear resistance of the layer (stabilizing force) are equal, it is referred to as the point of incipient motion. The design of rip-rap involves making sure that the shear resistance of the river bed material is greater than the activating shear force exerted by the flowing water by placing a layer of appropriately large enough rocks on the river bed.

CROSS REFERENCE

A good references for the design of riprap include

- SANRAL Drainage Manual (SANRAL Drainage Manual, 1981)
- River training techniques (Przedwojski B, Blazejewski R, Pilarczyk KW, 1995)
- (USACE, Hydraulic design of flood control channels EM1110-2-1601, 1991)

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of using riprap are:-

- Riprap layers can be placed underwater, and may provide increased habitat diversity in some circumstances under water – see Chapter 10.
- Riprap protection is flexible and can adjust to river bank settlement and other local damage without necessarily failing.
- The behaviour of a wide range of rock sizes more easily quantifiable under a wide range of conditions, making it attractive as an engineering alternative.
- Rip-rap may be longer lasting than other methods of bank stabilization (as it does not suffer from rusting or uv-degradation).

The dis-advantages of rip rap are:-

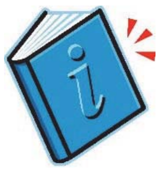
- It is very costly because the rock has to be specially produced at a quarry, and transport costs to site can be a significant extra expense if the site is far from the quarry.

The ecological and aesthetic value of a layer of rocks on a river bank can be quite low if the rocks do not occur naturally in the river. This can be offset if appropriate indigenous vegetation can be established in the riprap – See Chapter 10 for input on improving riprap function from an ecological perspective by encouraging the growth of plants, and Volume 3: Case Study 19 for an illustration of riprap that has however produced a substantially better quality of riverine habitat.

DESIGN CONSIDERATIONS

Design considerations for riprap are:-

- The capacity and alignment of the channel formed by landscaping should be determined with due regard to the flow rate of expected floods and local topographic conditions (see section 4.4).
- The rock must be large enough to not be moved by the flow of water during the design flood.
- The velocity of water flowing through voids between the rocks must not be sufficient to disturb the foundation material. To prevent this, it may be desirable to place a geotextile or granular filter layer below the riprap.
- If only a portion of the river cross-section is being armoured, then care must be taken to stabilize the edge of the armoured section (this is normally done by providing extra or sacrificial riprap material at the edge so that it may fall into a scour hole that develops and allow the rest of the riprap layer to remain undisturbed).
- Many specifications for riprap give grading limits to which the mix of stone sizes must conform. What is important to note is that riprap layers without large voids between the rocks are more stable than those with large voids. The reason for this is that the greater the voids, the greater the drag exerted by the moving water on individual rocks.
- The most stable rock shape for riprap is angular as opposed to round, because these rocks tend to form an interlocking layer. Cubical rocks are ideal, but thin platy rocks should be avoided.



CROSS REFERENCE

- The case study 19 “Berg River Case study” Illustrates the use of riprap in a South African river.
- See Chapter 10 for input on improving riprap function from an ecological perspective by encouraging the growth of plants

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this case riprap) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by riprap has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 “*Legal authorisations necessary for river rehabilitation*”

4.6.6. Bank stabilization with retaining walls

Figure 4.37: A retaining wall being constructed as a river training wall

River training walls are retaining walls constructed parallel to the direction of flow, with the objective of protecting a river bank from erosion, and controlling the flow direction of a river. Retaining walls are expensive, and generally can only be afforded when rehabilitating a river at a location where adequate space for the natural functioning of a river is not available, such as in urban areas. The main advantage of retaining walls is that they can be almost vertical and take a minimum of space as seen on plan.

There are many ways of constructing retaining walls – ranging from reinforced concrete, a variety of pre-cast concrete blocks, rock filled gabions, tree stumps and used motor vehicle tyres (the last two are generally not good options). The choice of retaining wall system is governed by cost, foundation conditions, river flow conditions, the availability of a given system, and the availability of persons to plan and oversee the construction of the structure.

Figure shows different types of retaining walls based on the way that they function. Of these, for most river rehabilitation structures the gravity wall is most common. The reinforced soil retaining walls are effectively anchored walls.

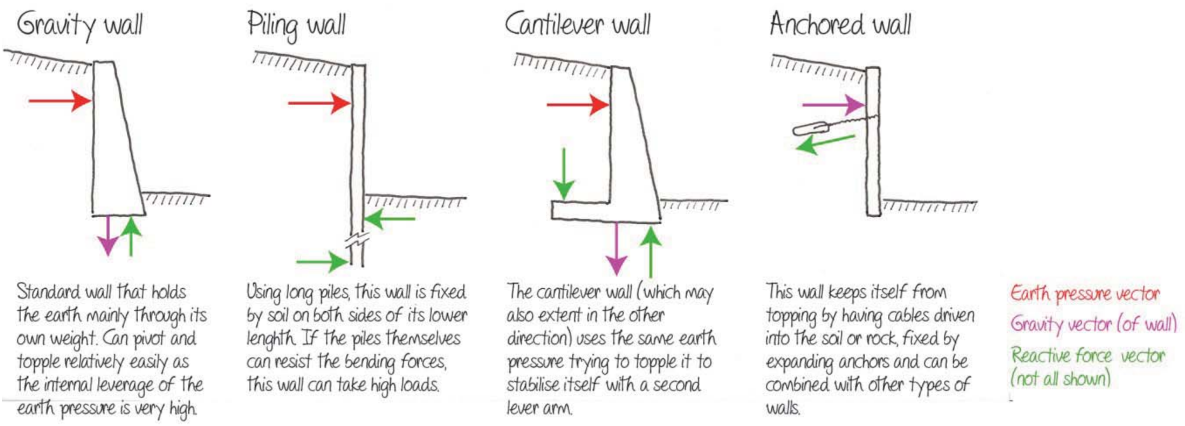
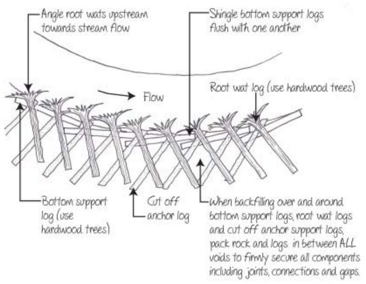
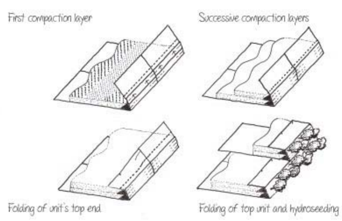
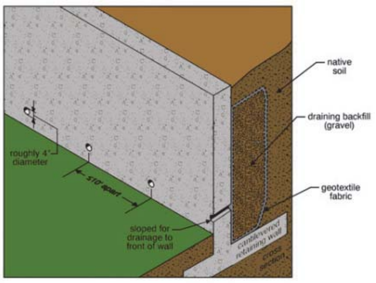


Figure 4.38: Different types of retaining walls based on structural type

The following table describes some of the different retaining wall systems available, as well as relative advantages:-

1) Tree stumps (root wads)  	Advantage: • Employs material that would otherwise be seen as waste • Using a natural material has the attraction of being eco-friendly Disadvantage: • It is extremely difficult to anchor the tree stumps while catering for large floods • The durability of this option is very limited because when the stumps rot, they collapse and de-stabilize the bank
2) Green gabions (Green Terramesh)  	Advantage: • These gabions do not require rocks, but are filled with soil Disadvantage: • They are only intended as retaining walls, and cannot be used as hydraulic structures. Should a conventional structure have to be higher than the expected flood level, these gabions can be used in the dry zone.
3) Loffelstein blocks (Interlocking pre-cast concrete blocks) 	Advantage: • Walls made with the Loffelstein blocks are more stable than other concrete block walls because of the mechanical interlock of the blocks. They can be used in higher flow velocity zones and possibly on higher walls than other blocks. • Loffelstein blocks have a pocket in the front which can be filled with soil in which plants can be grown. Disadvantage: • These blocks are a lot more expensive than other blocks. • The volume of the planting pocket is small however and the

<table>
<tr>
<td></td>
<td>concrete makes the environment alkaline. It is seldom possible to establish vegetation that provides habitat quality, or functions other than aesthetic covering over of blocks</td>
</tr>
<tr>
<td>4) Hollow concrete blocks
(Non-interlocking concrete blocks)
</td>
<td>Advantage:
• These blocks have a cost advantage over the more sophisticated blocks, and can offer a competitive alternative where lower wall heights and flow velocities have to be catered for.
• If the block voids are filled with suitable soil, the wall face may be vegetated.
• It is seldom possible to establish vegetation that provides habitat quality, or functions other than aesthetic covering over of blocks.
Disadvantage:
• These blocks offer less structural stability than larger blocks.</td>
</tr>
<tr>
<td>5) Rock filled gabion
</td>
<td>Advantage:
• The wire gabion baskets are filled with locally available materials
• The structure is flexible and easy to repair should a small failure be experienced
• Gabions can be constructed over relatively poor foundations
• It is possible to create soil pockets in the structure to vegetate the wall face – see Chapter 10.
Disadvantage:
• The wires will not last forever, and it is critical to vegetate the structure for longer term functionality</td>
</tr>
<tr>
<td>6) Reinforced concrete

</td>
<td>Advantage:
• Concrete retaining walls can be designed withstand higher imposed loads (such as vehicular traffic)than most of the other systems
Disadvantage:
• Reinforced concrete walls offer the most resistance to biological connectivity between the river and bank.
• Reinforced concrete walls offer little opportunity to vegetate the bank.</td>
</tr>
<tr>
<td>7) Reused waste tyres
</td>
<td>Advantage:
• Employs material that would otherwise been used as landfill
Disadvantage:
• The tyres will most likely wash downstream and create blockages

These structures are not recommended – See section “Reused tyres”</td>
</tr>
</table>

When considering the use of any hydraulic structure including retaining walls it is important to be aware of typical modes of failure, so that reasonable provision can be made to prevent them. Figure 4. shows the classic failure mechanisms for retaining walls. Part of the design process is to ensure that these do not take place under normal design conditions.

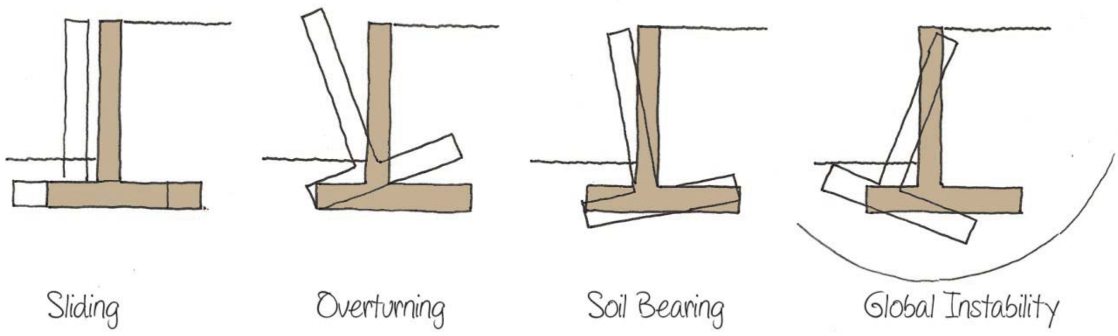


Figure 4.39: Classical retaining wall failure mechanisms

Additional training wall failure mechanisms that have to be considered are foundation scour failure and outflanking failure .

The advantages of retaining walls are:-

- The structure has probably the smallest foot print, and facilitates the creation of a wider flow channel when in a very confined environment.
- Some of the structure construction materials enable the greening of the structure face with vegetation.

The disadvantages of retaining walls are:-

- Retaining walls all constitute a large scale and undesirable engineered alteration of a river environment;
- Retaining walls (or river training walls), because they have close to vertical faces, encourage a greater zone of high velocity flow in the river channel, as opposed to the slower marginal flow that would be present in the zone where the river would naturally have become gradually shallower. This impacts on the habitat found in the river;
- Cost;
- Impact on biodiversity – not as bad as full channelization as the toe scour protection should be lower than the river bed level, and it does not have a channel floor, but in spite of potential greening it does limit the possibilities for creating a natural environment appropriate for the geographic location.

The retaining wall options are presented below in more detail.

4.6.6.1. Retaining walls for bank stabilization with logs and tree stumps (root wads)

The use of logs, root wadding and stumps needs to be carefully considered in a South African rehabilitation context.
While according to literature this seems to be a popular approach in the Europe and the USA, in South Africa such methods may trigger significant environmental damage through erosion associated with debris dams in flood conditions. The differences in situations must be understood so that the approach can be seen in the right context.

- The difference between normal flow and flood flow particularly in Europe, but also the USA are nothing like arid South Africa. In South Africa tree stumps on river banks will be submerged during floods and are likely to float out of the constructed position.
- Trees available in South Africa are generally soft-wood which will rot easily and leave unacceptable cavities in the river bank within a short period of time.

The use of tree stumps as a river erosion protection material is popular because they are often available where land has been cleared close to rivers, or they have floated down the river during a flood. The concept is usually to pack tree stumps along the bank forming a barrier against the moving water, in essence this forms a retaining wall – see Figure 4.40. Experience has shown that farmers typically use heavy fencing wire to link the tree stumps together, or to some other object on the bank to anchor the tree trunks. Unfortunately people using this cannot compare the strength of the wire, the force needed to loosen the anchor, and the force exerted by flowing water on the tree trunks, and frequently the tree trunks get washed away during a flood. Once the tree trunks become dislodged, they float downstream where they block bridge openings or cause river banks to be eroded.

Figure 4.40: Tree stump erosion protection
(Alberta Fish Habitat Manual)

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of using tree stumps for bank erosion protection are:-

- The material is readily available and the only cost involved is transporting the tree stump and excavating a hole for it.
- The protection can be constructed rapidly.
- Tree trunks are a natural material.
- Lower construction cost (short term advantage as maintenance or re-construction is expected to be frequent)

The disadvantages of using tree stumps are:-

- The chance that they float during a flood, or rot and leave a cavity in the river bank is great, so they do not present a sustainable solution.
- There is a great possibility that the tree stumps cause river erosion problems elsewhere should they float free.
- It is extremely difficult to quantify the loads involved on an individual tree trunk, should a stability calculation be attempted because of the unknown mass, shape and volume of the tree, and the drag force that the water exerts on it. This leads to haphazard and unacceptable results.

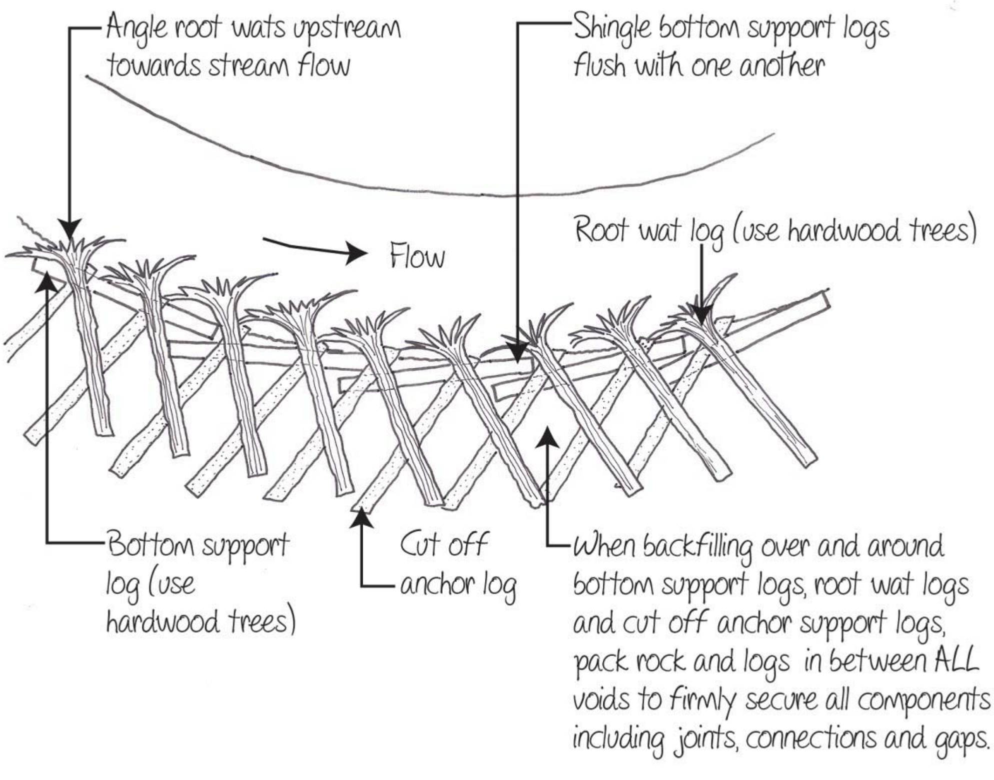


Figure 4.41: Root Wad Construction (after Bowers 1992)

DESIGN CONSIDERATIONS

- There is no generally accepted way of using tree stumps for protecting river banks from erosion.
- The capacity and alignment of the channel formed by constructing a root wad retaining wall should be determined with due regard to the flow rate of expected floods and local topographic conditions (see section 4.4).
- Somehow it must be ensured that the tree stumps will not be washed away during flooding, simply binding the tree stumps together with heavy gauge wire would not be adequate.
- Somehow it must be ensured that the tree stumps used will not rot and leave cavities in the river bank making it prone to erosion and necessitating the reconstruction of the protection.

Figure 4.42: A bad example of watercourse management.
The haphazard dumping of material in to watercourse does not constitute "green options" for rehabilitation, but merely the further degradation of the watercourse.

Environmental legislation

- The deposition of more than 5 m^3 of any material into a river triggers the need for environmental authorisation in terms of the NEMA regulations. Should the footprint of the intervention be greater than 100 m^2, or more than 5 m^3 of earth be moved, these will also trigger the need for authorisation.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- The Conservation of Agricultural Resources Act (CARA) would be contravened if a landowner leaves or allows an obstruction in the river which could lead to soil loss (i.e. if tree stumps are placed in a river where they may break free during floods).
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.6.6.2. Retaining walls for bank stabilization with green gabions

Green gabions can mean various things. It can be conventional gabions that have a horizontal sheet of geotextile within the rock fill, which gets used to support soil which is washed in after the gabion has been closed, so that vegetation may be planted in the soil. An alternative is the use of the Maccaferri product "Green Terramesh" or similar. This is a "reinforced earth" product for constructing retaining walls, with a vegetated exposed face. A steep slope can be achieved with this system (70 degrees off the horizontal), but it is not intended for constructing spillways or retaining walls within river channels. It could well be used above the medium to high flood level (where it would stand on top of other bank protection stabilizing the channel itself).

Figure 4.43: A "Green Terramesh" retaining wall
(ex http://cms.esi.info/Media/productImages/Maccaferri_Terramesh_reinforced_soil_system_10.jpg)

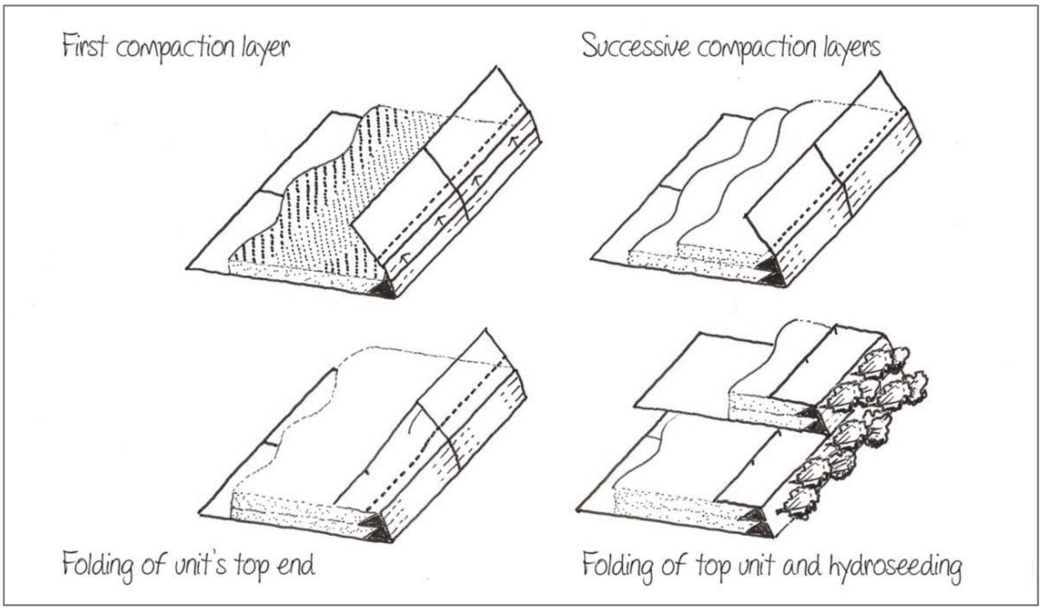


Figure 4.44: Green Terramesh construction sequence

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of this option are:-

- This product enables the construction of a stable steep slope, which is vegetated and has the potential for contributing to the biodiversity of the rehabilitated site.
- The use of this product has a greater potential for using locally sourced material (soil) than gabions as the rocks often have to be imported at great cost.

The dis-advantages of the option are:-

- The Green Terramesh units are not in-expensive.
- Systems like this have to be designed and specified by persons with specialist knowledge of these systems.
- The construction process has to be carefully controlled to make sure the design conditions are achieved. This includes ensuring that the units are placed on the correct levels and correctly fastened together, the correct fill material is used, the correct fill layer thicknesses and densities are achieved.

DESIGN CONSIDERATIONS

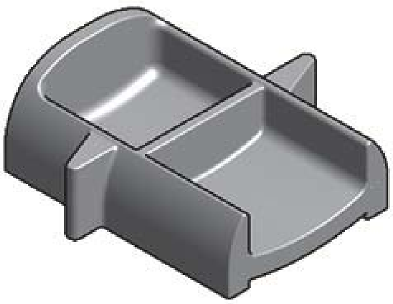
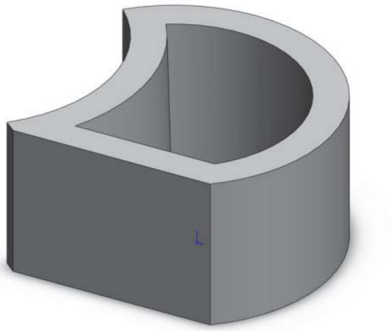
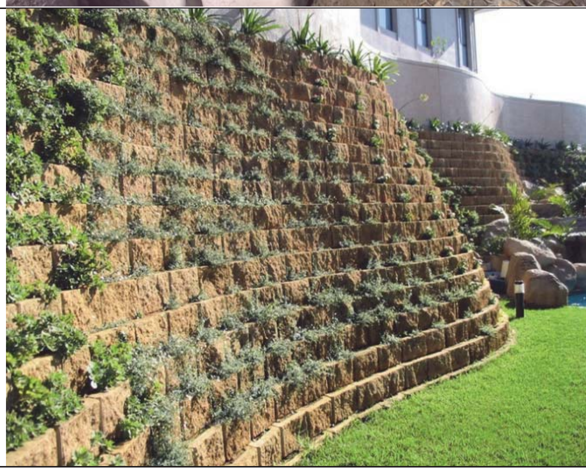
- The capacity and alignment of the channel formed by constructing green gabion retaining walls should be determined with due regard to the flow rate of expected floods and local topographic conditions (see section 4.4).
- Reinforced earth requires specialist design
- Facing material requires special consideration – can be jute or coir which decays in a few years and by then vegetation must be ready to replace it

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this case green gabions) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by a retaining wall has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.6.6.1. Retaining walls for bank stabilization with pre-cast concrete blocks

Many different types of dry-stacked concrete blocks are available on the market for constructing retaining walls. The table below shows a selection of what is available and examples of retaining walls constructed with the block.

 Loffelstein – Waterloffel	
 Terraforce	

Aveng RidgeBlok

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of dry stacked concrete block retaining walls are as follows:-

- The construction time is very short.
- The pre-cast concrete blocks usually have some sort of provision for placing soil within the block so that vegetation may be established on the face of the structure.
- The precast blocks can be packed in curves around obstructions, and this softens their visual appearance.

The disadvantages of dry stacked concrete block retaining walls are:-

- If not vegetated, the presence of such a large concrete structure in a river could detract from the aesthetic value of the environment.
- The pockets in which soil gets placed are small and not all plants are suited to this environment.
- Some of the block systems are suitable for use in the river zone where the water flows (such as the WaterLoffel), but many others not. Little research has been done to determine under what flow conditions the various blocks are suitable.

DESIGN CONSIDERATIONS

- The capacity and alignment of the channel formed by the construction of blockwork retaining walls should be determined with due regard to the flow rate of expected floods and local topographic conditions (see Section 4.4).
- Blockwork walls higher than 1,2 m require engineered designs. Blockwork retaining walls are only stable for wall heights of about 0,5 m to 3,0 m depending on:-
  - the properties of the block
  - the type of soil being retained (cohesive or cohesion-less)
  - the slope of the front face of the wall (from 60 to 90 degrees off the horizontal)

– and the surcharge placed on top of the soil retained

These allowable heights can be greatly improved by reinforcing the fill material behind the wall (with geogrids or other soil reinforcement) providing that the block can accommodate this, and also by reinforcing the wall itself by thickening it's base and adding steel reinforcing bars providing that the block can accommodate this.

- There are limitations as to how high concrete block retaining walls may be stacked before the weight of the wall becomes too much for the lower blocks to bear – this must be checked by the designer.
- The stability of the proposed wall must be checked by a person qualified to do so.
- The footing of the wall requires special attention to ensure that it will not be undermined by the river, and that it will not be unstable as a result of the weight of the wall.

TECH TIP

Some of the concrete block manufacturers have invested in the production of design guidelines. See:-

- Terraforce design manual http://www.terraforce.com/downloads/
- CMA http://www.cma.org.za/Publications/RetainingWalls/tabid/111/Default.aspx

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this concrete blocks) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by a retaining wall has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.6.6.2. Retaining walls for bank stabilization with rock filled gabions

Gabions are wire baskets that are usually filled with rock and attached to other gabions to form structures. The SABS specification for gabions describes the wire thickness, the thickness of the galvanizing coating, and for some baskets the type and thickness of PVC coating as well, to ensure a reasonable gabion life span.

 Figure 4.45: 2 m long gabion basket	 Figure 4.46: Gabion retaining wall (https://theriverfinn.files.wordpress.com/2014/04/20140428_170047_1.jpg)

ADVANTAGES AND DISADVANTAGES OF THIS OPTION

Rock filled gabions are a popular means for constructing erosion control structures in rivers, for a variety of reasons. The advantages of gabions structures are as follows:-

- They often utilize naturally occurring rock and in a sense blend into the environment more easily than concrete structures.
- They are flexible and deform in sympathy with changes to the structure foundation (i.e. should the foundation settle or be scoured by water, a gabion structure has a great chance of settling with the soil, but a concrete structure will not).
- Gabion construction lends itself to job-creation schemes, and gabion structures can be assembled by relatively inexperienced workers.
- Gabions can be “greened” by planting in them (see below).

The disadvantages of gabions are:-

- The wires of the baskets decay with time, although structures around 100 years old have been seen (these have been well vegetated and are not subject to abrasion any more).
- Gabion structures are mass gravity structures, and in some conditions reinforced concrete structures could be cheaper.
- Gabion structures can be damaged by floating trees and rolling rocks during floods. It is useful to take this into account when designing gabion structures to reduce the impact.

DESIGN CONSIDERATIONS

The following should be considered when designing gabion retaining walls in rivers:-

- The capacity and alignment of the channel formed by constructing gabion retaining walls should be determined with due regard to the flow rate of expected floods and local topographic conditions (see section 4.4).

- The potential depth of scour in front of the structure must be ascertained and provided for in the design – either by deepening the structure foundation to below the level of scour, or the provision of flexible mattresses, or both.
- The need for abrasion protection must be determined and provided for if necessary.

GREEN OPTIONS

- Gabion mattresses and concrete block mats provide environments which are suitable for planting appropriate indigenous river plants. These plants not only enhance the biodiversity of the environment but also offer protection to the armor layer against rolling rocks during floods

Figure 4.47: Cyperus textilus cuttings planted in gabion mattress 2010

Figure 4.48: The same site 2014 – The Loffelstein wall behind the mattress in which vegetation was planted cannot be seen.

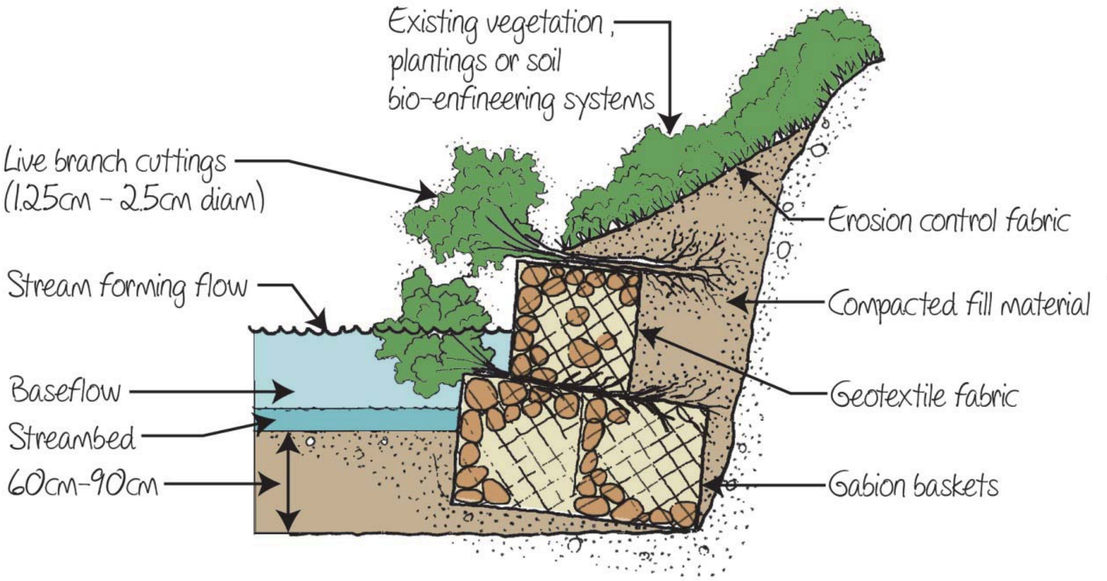


Figure 4.49: Typical cross section for gabion retaining wall with shrubs planted through it – this type of detail is seldom used in South Africa

TECH TIP

Some of the gabion manufacturers have invested in the production of design aids. See:-

- Maccaferri South Africa http://www.maccaferri.com/za/documents/
- Maccaferri Bioengineering manual
  http://www.maccaferri.com/ca/download/brochure-ca-soilbioengineering/

Environmental legislation

- The construction of gabion retaining walls does trigger the need for environmental authorisation in terms of the NEMA regulations should more than 5 m^3 of material be placed in the river or more than 5 m^3 rock or soil moved, or the footprint of the structure exceed 100 m^2.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.6.6.3. Retaining walls for bank stabilization with concrete walls

Concrete retaining walls are possibly the most common retaining walls in South Africa, especially along road fills and in urban areas. Gabion and concrete block retaining walls have lately grown in popularity, possibly because of their perceived more environmental acceptability. There are many kinds of concrete retaining walls and they can be classified according to structural function (gravity-, counterfort-, cantilevered-, tied-back, etc.), and they can be classified according to fabrication method (cast in-situ, precast).

Cast in-situ concrete retaining walls are not commonly used for river training because of the high cost involved, unless it is protecting a high-value investment like a bridge or national road.

Figure 4.50: Reinforced earth retaining wall protecting a road from river

ADVANTAGES AND DISADVANTAGES OF THIS OPTION

The advantages of concrete river training walls are:-

- Concrete as a material can be hard and very durable, and if used correctly the structure could stand a long time with little maintenance.
- Concrete structures could be more economical than other types (especially for high structures) considering that they can be slender and use less material.
- Concrete is a well-researched and understood construction material.

The dis-advantages of concrete river training walls are:-

- Concrete structures are rigid and cannot accommodate foundation movement. Either the foundations would have to be specified at a very deep level where they won't be influenced by scour, or an alternative flexible scour protection must be used in conjunction with the concrete structure.
- Concrete structures inhibit biological connectivity between the riverbed and the bank – this can be acceptable for short lengths of river such as bridge abutments, but a poor alternative for long lengths of river.
- Large flat concrete surfaces are aesthetically unpleasant to many.

4.6.6.4. Retaining walls for bank stabilization with reused tyres

The construction of erosion control structures with used car and truck tyres is a popular thought because of the perceived suitability as a building material and low construction cost. In addition it offers the prospect of recycling waste material. Unfortunately these projects are embarked on without a full awareness of the ability of tires to almost float when submerged (the relative density of rubber is in the order of 1.5, whereas stone is commonly in the order of 2.5). By the nature of their shape, submerged tires are not streamlined and are easily dragged by flowing water. If structures made with tires are not extremely well tied together, and securely anchored to the ground, and provision made to prevent the foundation soil from being scoured out by flowing water, they will wash away during floods and cause obstructions and fresh erosion wherever they are deposited.

Figure 4.51: Retaining wall made with used tires

Good advice for planning the use of tyres for river bank erosion protection is hard to find, mainly because there is no recognized way to use tyres for this purpose. The type of issues that would have to be addressed by a successful planning process are the stability of the structure with respect to falling over, the stability of the foundation with respect to scour, and the stability of the structure with regard to individual tyres being dislodged from the structure by flowing water.

Too often people tip tires into gulleys thinking that erosion will be reduced because the flow velocity is reduced. While this approach may yield beneficial results in the short term, eventually a larger flow will be experienced that will cause the gulley to widen and flow outside of the tyres. For this reason this practice is not recommended.

Tyres should only be considered for stabilization works when the thickness of the tyre is greater than the depth of water flowing over or past it during high flow situations.

Much information is available on the internet regarding the use of waste tyres for erosion control. This is often driven by persons meaning well but not understanding the implication of using tyres in rivers, or persons profiting from the sale of tyre related products. The University of Oklahoma (Robert Nairn, Mark Winter, 2003) did an extensive study into the use of tyres for erosion control and found that because the tyres by far outlast the cables that hold them in place, the tyres will inevitably wash down the river and become somebody else's problem, and the practice must be avoided. The Australian EPA categorizes the use of tyres for erosion control in rivers as an "Undesirable practice for the reuse of waste tyres" and places severe limitations on erosion protection projects using waste tyres (Australian EPA, 2010).

Figure 4.52: A poor attempt to control erosion in a gulley

Figure 4.53: The remains of a typical failed tyre structure

The use of tyres for erosion control structures is not recommended because of the unpredictable nature of tyres in flowing water, their anchorage, and the implication of their breaking loose and washing downstream.

Environmental legislation

- The use of tyre structures quite likely will trigger the need for environmental authorisation in terms of the NEMA regulations. The disposal of tyres is governed under Act 59/2008. Depositing more than 5 m^3 of any material in a watercourse triggers the need for authorization in terms of the 2015 regulations. Similarly does the development of any structure in a watercourse with a footprint exceeding 100 m^2.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- An activity could constitute an offence in terms of the CARA Act if it is shown that an action could lead to excessive agricultural soil loss. In other words if tyres got washed out of the structure and created an obstruction that caused soil erosion in a watercourse, this would be the case.
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

4.7. Canalization

In the past the canalization of rivers took was used to create more space for urban development when the negative impacts of canals were not fully understood. Today the canalization of rivers takes place in urban areas as a last resort when it is found that not enough space has been left in urban planning for a river to function naturally. Alternatively rivers which were in the past of adequate size, have become inadequate because large scale urbanization and the corresponding hardening of the catchment area and increase in run-off rates, and now need greater discharge capacity and are limited by the space available.

Under these circumstances, although it is generally undesirable, there are several ways to canalize a river, with varying degrees of ecological awareness and acceptability. Each of these techniques has its own advantages and disadvantages as explained under each section. As a rule, hard canalization of natural channels should be avoided outright, and other approaches to manage flows sought, including upstream attenuation and measures to address catchment hardening.

TECH TIP / BRIGHT IDEA – terminology
"Channelization" – is a term that refers to the artificial straightening and deepening of a water course (say the condensing of a braided river into a single channel river
"Canalization" – refers to the provision of a hard lining to a watercourse to prevent erosion.
"Semi-canalization" – refers to the provision of only a hard base or hard sides to a watercourse

Note also that canalization / channelization are not rehabilitation approaches, but management approaches, and true river rehabilitation would seek to undo the negative effects implicit in channelization – see Chapter 10, for a discussion on approaches to remove or soften existing hardened channels.

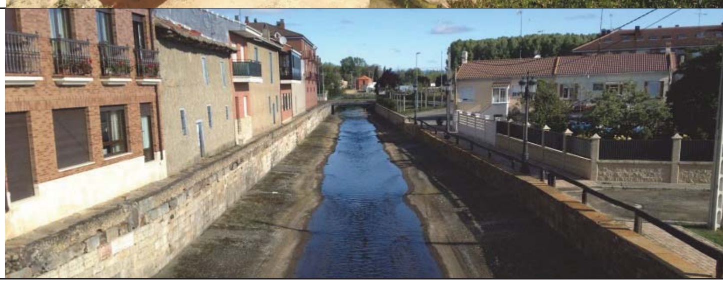
Semi hardening of river bed only (Bed incision prevented by porous blocks, banks stabilized by vegetation) http://www.nguniprecast.co.za/wp-content/uploads/2014/06/Terrafix-100-120-150.pdf	
Semi hardening of river banks only (Gabion mattresses left, Loffelstein blocks right, cobble bed)	
Semi hardening of whole channel (porous blocks over most of floor, and walls)	
Full hardening of whole channel (Concrete walls and floor)	

Figure 4.54: Table illustrating various ways in which rivers have been canalized

GREEN OPTIONS – REDUCE NEED FOR CANALIZATION BY INCORPORATING STORMWATER DETENTION PONDS IN PLANNING (refer also to Technical manual Chapter 3)

- Storm water detention ponds are ponds with a permanently open outlet which is of a controlled size, so that when large flood flows are experienced, only a portion of the flood is discharged immediately and a portion gets stored until the flood peak flow has past.
- Storm water detention ponds offset the increase in flood peak discharges produced by a catchment, by temporarily storing water until the peak flow has past, and then releasing it automatically into the channel. In this way storm water detention ponds can reduce the size of canal required to discharge a given size flood from a catchment.
- Although storm water detention ponds can require a large surface area (depending on the size of a catchment), in urban areas this can double up as sports fields or other recreational facilities.

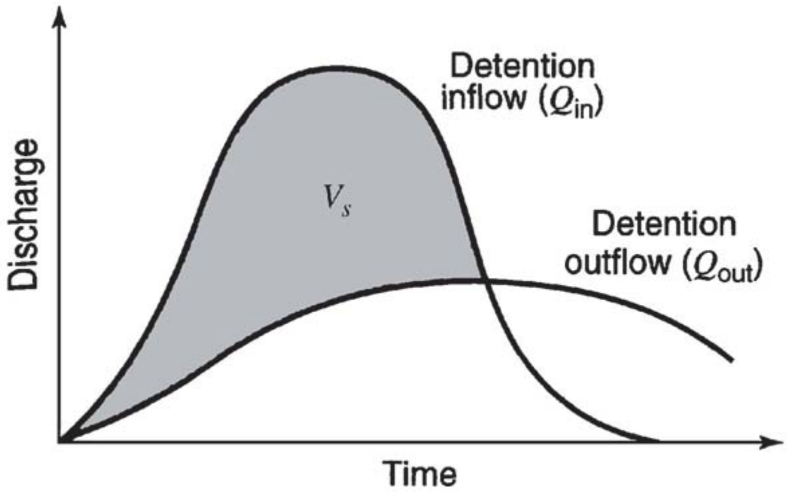


Figure 4.55: An idealized chart of inflow and outflow rates of an storm water detention pond – the shaded area represents the volume of water in the detention pond
(ex http://hydroviz.win.louisiana.edu/drycanyon/images/image034.png)

Figure 4.56: Small urban storm water detention pond

The photographs below show one of the eight large storm water detention ponds in Sao Paulo, Brazil. These were constructed in 2010 when the massive sprawl of this city (20 million inhabitants) caused runoff rates to increase dramatically, and the Rio Pirajussara to frequently burst its banks and flood low lying parts of the city. The detention pond is more than 8 m deep and 3 hectares large. A battery of pumps pump the water back into the river once the flood peak has passed.

Figure 4.57: Piscinao Sharp storm water detention pond Sao Paulo (Google Earth)

Figure 4.58: 8 m deep storm water detention pond Sao Paulo

Figure 4.59: Rio Pirajussara just downstream of detention pond

GREEN OPTIONS – WHY IS CANALIZATION ECOLOGICALLY PROBLEMATIC?

It creates a homogeneous environment (i.e. no diversity) , offering

- No protection from floods
- No habitat diversity
- Frequent and extreme effective "disturbance"
- Loss of aquatic organisms deprives the river of the "self-cleansing" function
- Loss of connectivity between the river and the floodplain

On a canal surface hardened with grass blocks or other pre-cast blocks, only a poor variety of plants can survive due to the hole sizes as well as the reduced hydraulic diversity and niche protection.

4.7.1. SEMI-CANALIZATION

Semi-canalization entails the partial canalization of a river for one or other reason. It is most likely to be used when full canalization is actually required, but for economic or environmental reasons a partially natural channel is more acceptable, such as if only the river bed or bank is hardened.

ADVANTAGES/DISADVANTAGES OF SEMI-CANALIZATION

The advantages of semi-canalization are:-

- Semi-canalization is environmentally far more preferable to full canalization, and this is seen as a huge advantage, especially if interventions that allow revegetation of the river bed and bank can be accommodated and thus make provision for habitat diversity.
- The construction cost can be lower than full-canalization

The disadvantages of semi-canalization are:-

- There will be a higher maintenance cost than with full canalization.
- Depending on the type of intervention, the quality of habitat provided and the river to floodplain connectivity may be significant and maybe not.

4.7.1.1. (SEMI-) HARDENED LOW-FLOW AREA

This option is useful when a transformed river bed is erodible, vertical erosion is the problem, and the vegetation on the river bed that can be sustained is patchy but a healthy cover can be sustained on the banks. Concrete blocks, gabion mattresses, and possibly geo-cells can be used to protect the bed from erosion, while still allowing vegetation to grow. An example of this is shown in Figure 4.60. A sample of the types of concrete blocks available for this are shown in Figure 4.61.

This option also is a vital element of the proposed multi-stage river channel.

Figure 4.60: Channel with concrete block base to prevent erosion but still to allow growth of plants

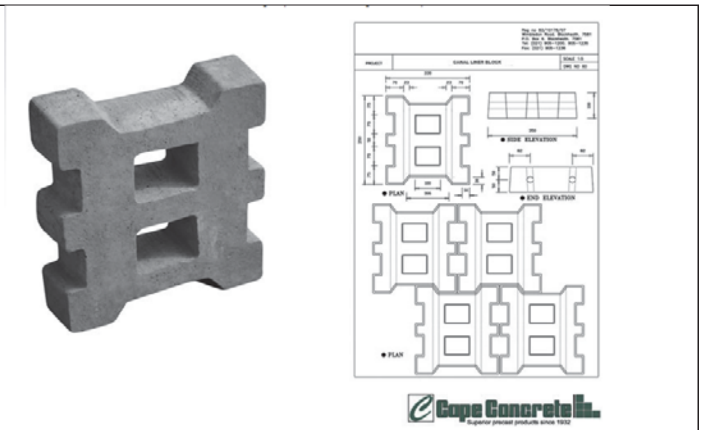
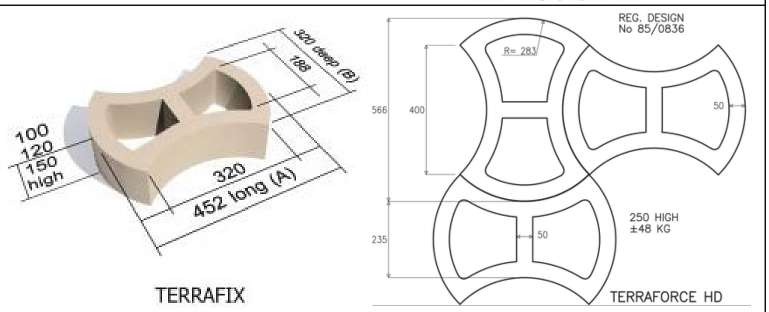
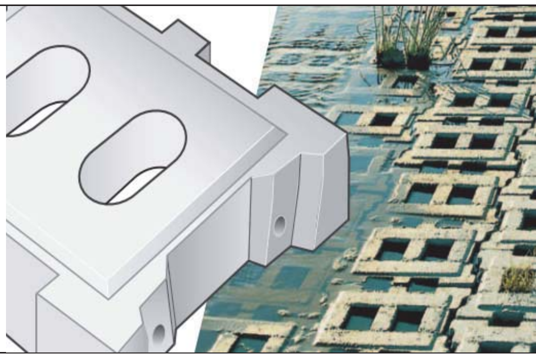
Cape Concrete – Canal Liner Block	
TerraForce – Terrafix	
Technicrete – ArmorFlex	

Figure 4.61: A selection of permeable blocks for channel floors

4.7.1.2. (SEMI-) HARDENED BANKS ONLY

This option is useful when a transformed river bed is stable, but it is critical to harden the banks to prevent the meandering of the river beyond given limits. Flexible armoring, riprap and retaining walls can be used to protect the river bank from erosion. An example of this is shown in Figure 4.62**.**

Figure 4.62: A river channel with gabion mattresses on the one bank and Loffelstein blocks on the other. The river is on a bend and more aggressive flow was expected along the outer bend, hence the use of concrete blocks.

Environmental legislation

- The semi-canalisation of rivers triggers the need for environmental authorisation in terms of the NEMA regulations in a variety of ways. Inevitably more than 5 m^3 of material will be placed or moved while constructing a canal, and more than 5 m^3 of rock or soil will be moved in the river. In addition should the footprint of the structure exceed 100 m^2 or its length 1 km, the need for authorisation will be triggered as well.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 “*Legal authorisations necessary for river rehabilitation*”

4.7.2. FULL CONCRETE CANALIZATION

Figure 4.63: Concrete canal in urban area

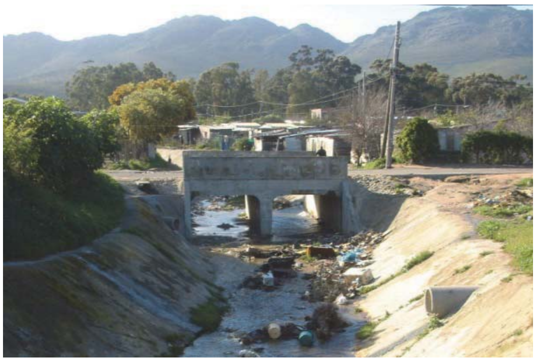


Figure 4.64: Concrete canal in informal area

ADVANTAGE / DISADVANTAGE OF THIS OPTION

The advantages of the full canalization rivers are:-

- A flood discharge facility, for large volumes relative to the space that the canal occupies, can be reliably designed.
- Canalizing a river can protect an urban area from the negative effects of flooding, and maximize the area of land available for urban development.

The disadvantages of canalizing rivers are:-

- Canals are of the most environmentally un-friendly means of managing a river. Canalized rivers do not have diversified habitat where there are significant zones of different flow velocity or depth, generally concrete lined canals do not have in stream vegetation, and canals do not allow for any normal aquatic biodiversity. This lack of biodiversity impacts negatively on a wide variety of plant and animal species that would normally exist in the environment around a river.
- Concrete lined canals can reduce the in-stream storage of a river system, and flood peaks move quicker downstream than they would have without the canal. This implies that the downstream end of canals can experience larger flood peak flows than prior to the construction of the canal.
- Canals also have the disadvantage of encouraging people to believe that the risk of flooding has been removed from the floodplain entirely and that development (urban or agricultural) may take place right up to the edge of the canal.

DESIGN CONSIDERATIONS

Concrete lined canals are extremely expensive and because they are normally in densely populated urban areas, the cost of failure can be a lot more than just repairing the structure. As a result of this the design of concrete lined canals has to conform to acceptable professional standards and requires that many factors be taken into account.

A hydrological study is required to determine the magnitude of flood flow that is intended to be safely accommodated by the canal. The behavior of water (flow depth, flow velocity, and other properties), flowing in the proposed canal must be clearly analyzed and understood. The canal has to be designed not only to accommodate the design discharge, but also to be structurally stable during floods and afterwards.

Figure 4.65: The full canalization of the LA River, Los Angeles, USA – an extreme example

CROSS REFERENCE

- The SANRAL Drainage Manual (SANRAL Drainage Manual, 1981) Section 5.4 gives useful suggestions for the design of concrete lined channels in South Africa.
- The USACE (USACE, STRUCTURAL DESIGN OF CONCRETE LINED FLOOD CONTROL CHANNELS EM1110-2-2007, 1995) provides a detailed design manual for concrete lined canals

GREEN OPTIONS – MULTISTAGE CHANNELS

River canalization has been promoted as an option when the development of an area has left too little space for any level of natural river function. From an environmental point of view, it is a last option. **It should only be considered when urban development has encroached so deep into a floodplain that it has become impossible to provide the space required to allow a river to function naturally.**

Concrete lined canals may be made less environmentally unacceptable by considering a multi-stage channel and only lining the most essential components with concrete such as the "low flow" or "trickle channel" where the lined portion accommodates around 5% of the design discharge – see Figure 4.66, or if conditions require a hardened channel that maybe accommodate a more significant flow such as the 2-year flood – see Figure 4.67.

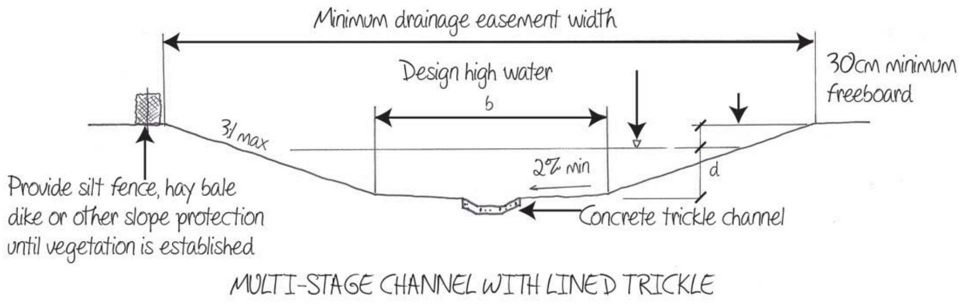


Figure 4.66: Multi-stage channel with lined trickle channel (could be solid concrete or perforated concrete blocks for a greener option)

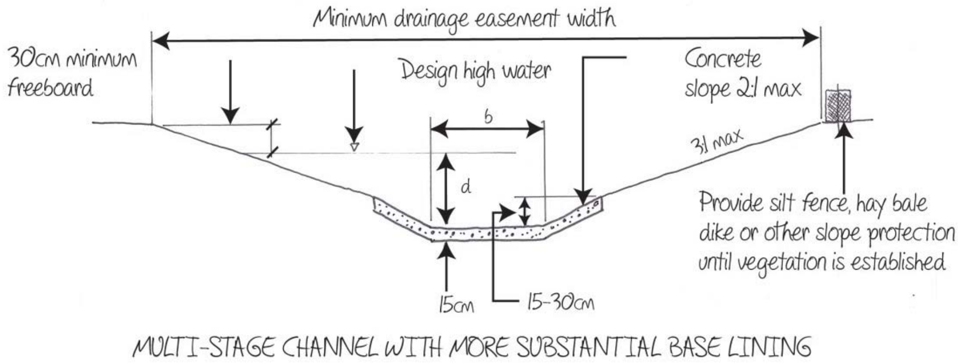


Figure 4.67: Multi stage channel with more substantial base lining

Environmental legislation

- The full canalization of rivers triggers the need for environmental authorisation in terms of the NEMA regulations in a variety of ways. Inevitably more than 5 m^3 of material will be placed or moved while constructing a canal, and more than 5 m^3 of rock or soil will be moved in the river. In addition should the footprint of the structure exceed 100 m^2 or its length 1 km, the need for authorisation will be triggered as well.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- CARA does not regulate the construction of canals.
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

References

Australian EPA. (2010). *EPA Guideline: Waste tyres.* Retrieved August 10, 2015, from www.epa.sa.gov.au/files/4771416_guide_tyres.pdf

David S. Biedenharn, Charles M. Elliott and Chester C. Watson. (1997). *The WES Stream Investigation and Streambank Stabilization Handbook.* Vicksburg, Mississippi: ASACE.

Rutherford, I.; Jerie, K. and Marsh, N. (2000). *A rehabilitation manual for Australian streams.* Canberra: Land and Water Resources Research and Development Corporation.

King, H. E. (2014). River stabilization with groynes in the Western Cape, South Africa. *RiverFlow 2014* (pp. 2145-2150). Lausanne: CRC Press.

Odgaard, A. J. (2014). River management with submerged vanes. *RiverFlow 2014* (pp. 2127-2133). CRC Press.

Przedwojski B, Blazejewski R, Pilarczyk KW. (1995). *River training techniques: Fundamentals, design and applications.* Rotterdam: AA BAlkema.

R W Hemphill, M. E. (1989). *CIRIA Water Engineering Report: Protection of River and Canal Banks.* London: Butterworths.

Robert Nairn, Mark Winter. (2003). *Tire mattress effectiveness on Oklahoma streambank restoration and stabilization.* Norman, Oklahoma: Centre for Restoration of Ecosystems and Wetlands, University of Oklahoma.

SANRAL Drainage Manual. (1981). Pretoria: The South African National Roads Agency Ltd.

Torre, A. (2001). *River restoration : Stream stabilization : Report RR10.* East Perth: Water and Rivers Commission.

USACE. (1991). *Hydraulic design of flood control channels EM1110-2-1601.* Washington: US Army Corps of Engineers.

USACE. (1995). *STRUCTURAL DESIGN OF CONCRETE LINED FLOOD CONTROL CHANNELS EM1110-2-2007.* Washington: U.S. Army Corps of Engineers.

Werdenberg N, Mende M & Sindelaar C. (2014). Instream river training: Fundamentals and practical example. *RiverFlow 2014* (pp. 1571-1577). Lausanne: CTC Press.

Chapter 5:

Managing river downcutting (incision) and gulleys

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Hans King (Dept. of Agriculture in the Western Cape)

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Introduction

River incision, as with bank erosion can be a natural process as highlighted by the Grand Canyon in the United States and the Fish River Canyon in Namibia. These examples have taken many years to develop and because they have occurred naturally there is no desire to interfere with them. When human development has caused the incision of rivers it is a different matter and for the sake of looking after the environment some action should be taken.

Figure 5.1: Natural river incision – Fish River Namibia (photo Namibia.org)

Figure 5.2: Un-natural river incision caused by the concentration of runoff and probable disturbance of the stream bed – Durbanville

Figure 5.3: Un-natural river incision in wetland caused by the stripping of indigenous wetland vegetation – Heidelberg

Figure 5.4: Incision of a river in the Karoo, temporarily halted by hard soil layer

The natural incision of rivers is often as a result of tectonic movements of the earth's crust which alter the slope of a river, causing higher flow velocities and vertical erosion.

The artificial incision of rivers also involves increasing flow velocities but by a different mechanism. When rivers are forced to flow in artificially narrow and deep channels, the flow velocity increases and so the erosive power of the water and the ability of the water to transport sediment also increases. The pre-existing balance between sediment brought down the river and that leaving the site alters, and the river bed drops in response to this. The condensing of multichannel braided streams into narrow and deep single channels is one example of this. The presence of woody alien vegetation on river banks effectively also reduces a river's flow width and causes the river to incise.

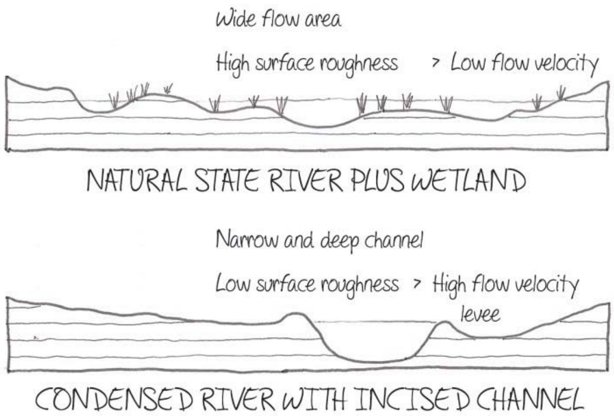


Figure 5.5: Sketch illustrating the impact of condensing braided streams into single channel streams

As mentioned in the Guideline, with the rehabilitation of rivers, it is seldom practical to return a river completely to its pre-incised state because of development along the banks, and because the river bed material that washed away with the incision has altered the topography that there is now a deep channel in it – downstream of a weir this influences the behaviour of water flowing in the floodplain.

The physical structure of rivers is usually determined by a network of inter-related factors including the frequency and magnitude of floods, the slope and cross section of the river, the type of sediment, the type of vegetation in and along the river, the presence of hard geological outcrops in the river, etc. When any of these factors are disturbed, the river adjusts until a new state of balance can be achieved.

For instance in the example shown in Figure 5.3 where the long existing state of balance in the river was disturbed by the farmer stripping the indigenous palmiet from the wetland, the river incised within 20 years, and if the river is not rehabilitated it will incise further until it reaches a hard geological layer where the erosion can no longer take place vertically. At that stage the vertical erosion will change to horizontal erosion, the river banks will be undercut during floods and collapse into the channel and the loose disturbed material will be washed away. Stability will probably only be achieved when a similar flood plain is developed at some level below the pre-disturbed flood plain, and providing the original vegetation returns. With several thousand years the flood plain and river will aggrade back to its pre-disturbed position. The alternative to allowing this natural response to the disturbance of the river is to attempt to halt the incision of the river by introducing an appropriate selection of engineered erosion control structures and the re-introduction of indigenous river vegetation that can hold back the disturbed sediment while at the same time providing for the safe passage of floods.

Table 5.1: Summary of options considered in this chapter for addressing river downcutting / channel incision

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
Non-invasive intervention	Do nothing	0 - +++++	None, but risk of further loss of ecosystem degradation may be high	None	Do not consider if rate of degradation is fast and/or risk of widespread impacts is high.
	Removal of invasive vegetation	+ (R4k-R15k/ ha)	Allows endemic vegetation to re-establish	None (notify authorities)	All debris should be removed from the channel and riparian area. Costs of clearing, based on 2014 SANBI data, range from R4000-R8000 per ha for Acacias and R10 000-R15 0000 per ha for large bluegums. In addition, follow up clearings (from R2000 to R4500/ha) must be budgeted for.
Indirect intervention for bank stabilization	Log weirs	+	Log weirs could possibly slow flow velocity in the river and retard incision. A more significant use is for creating fish habitat.	NEMA DWS	These structures are not sustainable, and are likely to fail during floods. They are very likely to cause more harm to the ecosystem than good.
	Rock weirs and chutes	++	Rock weirs could possibly slow the flow velocity in a river and retard incision.	NEMA DWS	These structures are not sustainable, and are likely to fail during floods. If there is not proper provision for the protection of the banks adjoining the structure during floods, the bank will wash away and the structure will be outflanked. If the structure rock size is not adequate they will wash away during floods. These structures are very likely to cause more harm to the ecosystem than good.
	Rock gabion weirs	+++	Rock gabion weirs can be used as slope control weirs in rivers to stop incision. Being flexible structures they can best accommodate the foundation settlement often experienced in alluvial soils.	NEMA DWS	The wires of gabion weirs need special consideration to protect them from abrasion and corrosion. The structures are ‘gravity’ structures and require a lot of rock to be stable. All weirs have the problem that they are barriers to the migration of biota up and down the river.

Rehabilitation objective	*Description of options*	*Cost*	*Ecological benefits*	*Legal authorizations*	*Technical limitations and cautions*
	Concrete weirs	++++	Concrete weirs can be used as slope control weirs in rivers to stop incision. Being concrete they have the potential to be the longest lasting of construction materials.	NEMA DWS	Concrete weirs can be constructed on 'floating foundations' – i.e. they may be constructed on soft sediments if need be, but rock foundations are much more desirable. All weirs have the problem that they are barriers to the migration of biota up and down the river.
Direct interventions for bank stabilization	Bank and bed reshaping and re-vegetation	+		NEMA DWS	
	Block ramps	+++	Block ramps can be used as slope control structures in rivers to stop incision	NEMA DWS	The design of rock size and distribution to achieve a specific level change objective is in a developmental stage. The erosion protection of the river banks adjacent to the block ramp requires consideration.
	Concrete blocks	+++	Concrete blocks (with or without cables stringing them together) can be placed on a river bed to prevent the incision of the channel.	NEMA DWS	Hardening the river bed will interfere with sediment movement and then impact negatively on instream habitat diversity. The erosion protection of the river banks adjacent to the lined bed requires consideration.

Rehabilitation objective	***Description of options***	***Cost***	***Ecological benefits***	***Legal authorizations***	***Technical limitations and cautions***
	Full canalization	++++	All erosion is controlled by full canalization as long as the canal section is large enough to contain any given flood. Full canalization increases the flow velocity and discharges more water through a confined space.	NEMA DWS	Sediment should not be allowed to wash into the canal. The flow capacity of the canal must be large enough to contain a reasonably expected flood. Very careful control of the slope of the canal must be exercised during construction.

Special considerations common to many techniques

Many of the techniques described require at least some insight into technical considerations. This manual is not intended to give detailed engineering design data and procedures, but it is important that the reader be aware of certain provisos and principles to ensure that decisions made are based on accepted sound scientific practice. This chapter is not only about the use of weirs, but weirs offer the most practical solution for most incision problems providing that environmental issues are addressed adequately. The section introduces the reader to the following:-

- Hydrology
- Hydraulics
- An introduction to weirs
- Weir construction materials
- Weir stability
- The sizing and positioning of weir spillways
- The placing of hydraulic structures in a landscape
- Fish ladders

Hydrology

Hydrology is the study of rainfall and run-off on the earth. Part of the study of hydrology is gathering and analyzing rainfall records from a catchment area in question. Another part of hydrology is gathering information about factors which determine how run-off from a catchment responds to a rainfall event (such a slopes, soil permeability, vegetative cover, etc.).

In South Africa there are a variety of techniques for performing a hydrological study of a catchment area, and each of these methods has its own advantage and dis-advantage. Two hydrologists will seldom assess exactly the same run-off from a catchment because of differences in interpretation of the data. To have faith in a hydrological study is clear is that there is no replacement for experience in evaluating catchment hydrological responses and knowledge of local catchment conditions.

Describing the science of hydrology is outside of the scope of this book.

Hydraulics

Hydraulics is the study of the behavior of flowing water and the forces which it and standing water exert on structures and soil particles. Knowledge of hydraulics is essential to predict the path that water will take through a wetland or a river channel, how deep it will flow over a structure like a weir and what force will be exerted on the structure.

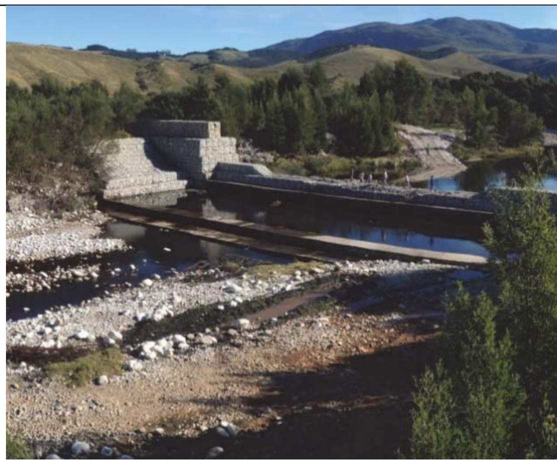
Describing the science of hydraulics is outside of the scope of this book.

An introduction to weirs

Weirs are barriers (usually walls) placed across rivers or channels to control the flow of water for a variety of reasons. From a river rehabilitation point of view, weirs are constructed to flatten the slope of watercourses to enable a slower flow velocity and then have less erosion and sediment transport – these weirs are also referred to as “check dams”. In the drier parts of the country they are constructed to retard the rate of runoff from land that has been historically mismanaged and there is little or no vegetative cover to the soil, retarding the rate of runoff increases the amount of infiltration and assists the revegetation of the land. Many weirs have been constructed to extract water from rivers for irrigation and often it is necessary to understand how the structure functions to enable successful rehabilitation of the river in the vicinity of the structure.

Weirs can be classified according to the structural elements used to provide stability to the structure such as "gravity wall", "buttress weir", "arch weir", "sloping weir". These all have their relative advantages.

Weirs are sometimes used to provide a stable minimum water level to feed water into a take-off canal for irrigation or urban extraction. (Buttress weir)	 Water extraction weir discharging low flow into irrigation canal (masonry)
Weirs are used to reduce the flow velocity of a stretch of river by creating an artificially flatter bed-slope, and thus reducing the potential for scour and sediment transport in the affected stretch. (Sloping weir)	 Stepped bed erosion control weir (gabion and concrete) – Italy

Weirs are also used to prevent the incision of a disturbed river channel into the topography by providing a fixed point below which further incision is not possible. In rivers this assists stabilizing a disturbed river by reducing the sediment load carried by the river, as well as limiting the upstream overall riverbank height needed to be stabilized by other means (such as riprap, landscaping or groynes). (Gravity wall)	 River bed erosion control weir Heidelberg
In the drier parts of the country (like the Karoo) weirs are used to slow down the departure of rainfall runoff, so as to improve infiltration and restore vegetation growth. (Arch weir)	 Karoo erosion control weir (concrete)
Elsewhere in the world weirs are also used to produce navigable river channels, create hydraulic head on water bodies for the generation of hydro-power, etc. (Arch dam)	 **Gariep Dam on Orange River**

Weir construction materials

Weirs can be constructed out of a variety of materials including rock filled gabions, reinforced concrete, mass concrete, concrete plus blockwork and so on. Different material weirs are illustrated briefly here and then again in detail in each of the different intervention types.

Natural materials (Timber crib weir with clay fill)	 Hubert CHANSON (h.chanson@uq.edu.au)	Advantages • Low initial cost • Uses natural materials Disadvantages • Short life span due to wood rotting • Short life span due to structural failure • Medium term high cost due to regular maintenance and repair
Grouted stone (Buttress weir)		Advantages • Uses natural materials • Uses significant labor to construct • If properly designed and constructed can be durable Disadvantages • The construction cost is moderately high
Rock filled gabions		Advantages • Uses natural materials • Uses significant labor to construct • If properly designed and constructed can be durable Disadvantages • The construction cost is moderately high
Blockwork / masonry		Advantages • If properly designed and constructed can be durable • It provides a solution where stone for construction is not available Disadvantages • The construction cost is moderately high

Mass concrete		Advantages • If properly designed and constructed can be durable • It can be a cheaper alternative to gabions for spillways higher than 2-3 metres, especially if gabion stone is scarce Disadvantages • The construction cost is very high • Not for use for weirs much higher than 4 to 6 metres
Reinforced concrete		Advantages • If properly designed and constructed can be durable • It can be used for extremely high spillways. Disadvantages • The construction cost is very high
Other artificial materials		

Weir stability considerations

A weir has a wall that is designed to with stand the force of upstream soil plus water acting on it during the design flood condition. Water falling over the weir has to fall on a specially prepared portion of channel which is designed to deal with the local increase in kinetic energy and turbulence, i.e. a stilling basin.

Weirs like retaining walls (see Chapter 4) are designed to withstand the force of the upstream soil plus water acting on it. The analysis of the weir stability is outside of the scope of this document, but the reader must be aware of it and ensure that it is addressed by a competent and qualified person.

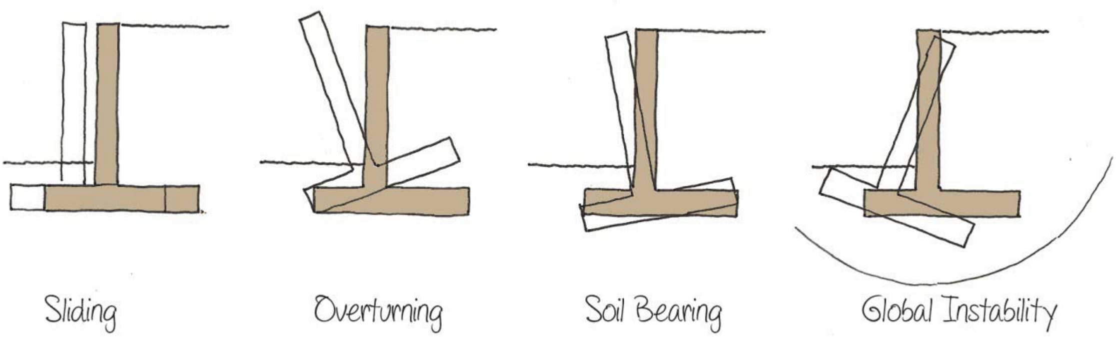


Figure 5.6: The classic modes of retaining wall failure also apply to weirs

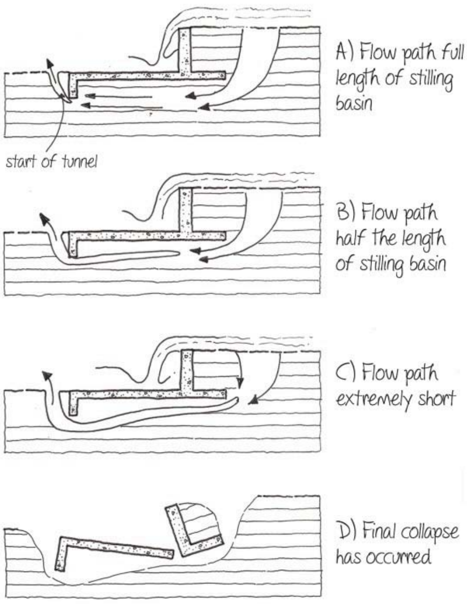


Figure 5.7: Development of piping failure

In addition to the classic modes of retaining wall failure, weirs can also suffer piping failure and this must be taken into account when a structure is designed. Piping failure is a progressive failure which occurs when seepage underneath or on the side of a weir is strong enough to dislodge soil particles at the downstream end of the structure foundation. As the particles get removed, the flow path for the seepage becomes ever shorter, so the flow rate increases and particles get removed quicker. The methods for preventing piping failure involve either increasing the flow path length (by placing a hyper-liner upstream of the structure), or by increasing the resistance to seepage of the foundation (for instance by stabilizing the foundation below the structure with cement).

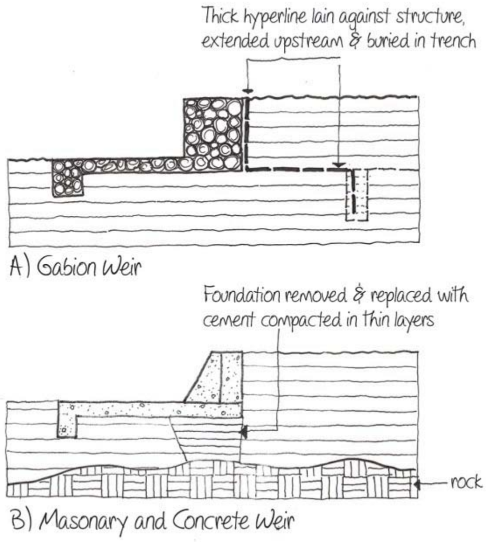


Figure 5.8: Methods for counter-acting piping under a weir

The sizing of weir spillways

Primary and secondary spillways

When the designed discharge capacity of a spillway opening is smaller than the magnitude of a flood peak that is passing, water will dam up behind the structure and unexpected outcomes such as the overtopping of side walls or overstressing of the weir structure can occur if there is no emergency spillway provided at a slightly higher level to cope with large floods.

It is quite likely that at some stage in the lifetime of a weir is will suffer a flood flow in excess of that for which it has been designed. The question is what will happen? When no provision has been made for this excess flow, the design can be seen as poor. The main concern is that water flowing over or around the earth banks adjoining the weir will return to the watercourse downstream of the weir, in such a way that it causes erosion of the watercourse and the weir gets outflanked by the gulley that forms.

A more carefully considered design would include an earth bank leading the surplus water some distance away from the structure to an emergency spillway, which does not have to be an expensive structure, rather just a facility to discharge the surplus water away from the expensive weir structure. It is thus vital that the behavior of floodwater at different stages must be understood and catered for. For this reason, erosion control weirs are often designed with two spillways, a primary and a secondary (emergency) spillway. The overall objective of this arrangement is that when large floods are experienced by the primary spillway, the secondary spillway becomes activated. Should a flood be so large that a failure of the structure must occur, the failure must be at the secondary spillway which is at a distance from the expensive primary spillway and the damage is relatively cheap to repair.

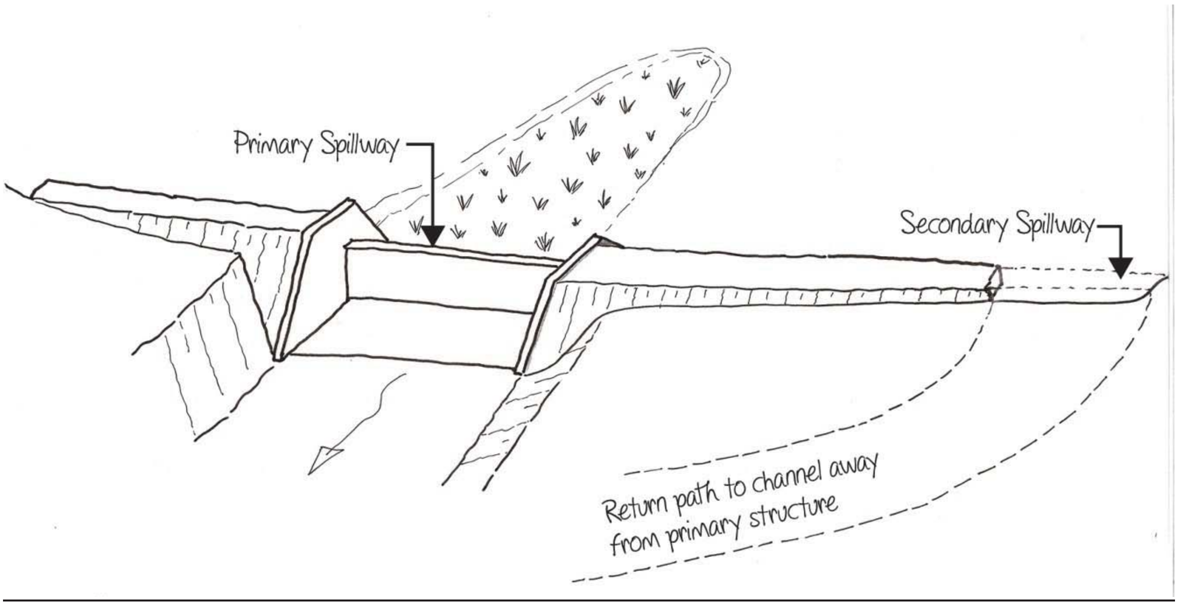


Figure 5.9: Sketch of incision control weir with primary and secondary spillways

Choice of design discharge for primary spillway and secondary spillways

The significance of the structure and the implication of a limited failure can determine the magnitude of flood chosen for design purposes. Normally the primary spillway of a weir is designed at least for a medium sized flood (at least a 1:20 year flood if not a 1:50 year flood) plus freeboard. The decision as to the split of water between the primary and secondary spillways is guided by :-

- Public safety should a failure of the secondary spillway occur (for example the proximity of a public road close downstream of the structure would indicate that more cost should be provided for constructing a larger stable primary spillway)
- The estimated cost of the primary spillway
- The economic and environmental impact of the failure of the secondary spillway during a flood

The dimensions of the secondary spillway is designed so that it may discharge the balance of what the primary spillway discharges, and the design flood for the whole structure, plus freeboard.

The freeboard mentioned is a measure of height of the spillway through-flow area where water is not intended to flow, but is provided on top of a design flood surface to accommodate waves on the water plus the possible settlement or weathering of the earth banks connecting the weir to the landscape.

The design of the primary spillway

The design of a spillway needs special consideration. It is critical that a spillway is designed by engineering staff that have competent training for the task. With many small dams, the construction of the spillway is half of the cost of the dam, and if the spillway is not properly designed the whole structure can be destroyed by a flood. There are many elements to the design of a spillway and these include:-

- The design of the spillway opening such that it can safely allow the design flood to pass

- The structural design of the spillway so that it is safe from failure by sliding, toppling, foundation bearing failure or foundation tunnel failure.
- The design of the downstream stilling basin to convert the fast turbulent flow of the falling water, into deeper slower flow, so that the weir's downstream foundation is not undermined or unnecessary erosion caused in the downstream river.

To design a spillway one must have a clear understanding of the flow of water in the vicinity of the structure, the forces acting on the structure (hydraulic, soil pressure, self-weight), the distribution of internal stresses in the structure and how to design for them, and the behavior of the foundation material under the structure (bearing capacity and the formation of drainage cavities).

Although a simple formula (the spillway discharge formula relating flow depth, flow width and spillway shape) is used to compute the flow rate through a weir opening, it takes insight and experience to produce a satisfactory design where construction cost, structural stability and desired effects on the flow of water are achieved. For instance when choosing a spillway opening dimensions, a very wide shallow flowing spillway may be desirable to limit flood level build up, but this would increase the cost of the spillway and stilling basin by virtue of its relatively long length. Alternatively a narrow and very deep flowing spillway may be seen as desirable, but because of the increase in hydraulic load on the spillway, measures required to achieve structural stability may be unacceptably expensive.

The placing of erosion control structures in a landscape

The correct placing of erosion control structures for river rehabilitation purposes in a landscape has a great influence on the success of the proposed work. Thought has to be given as to where the structure(s) must be within the length of the watercourse, as well as in the width of the watercourse and/or floodplain, and the level to which structures are constructed. Sometimes these choices are clear and easy to make, other times not. The incorrect positioning of structures can be the cause of the structure not functioning as intended because it fails structurally, or the water it is intended to control follows an unexpected path and bypasses the structure.

For these reasons it is very important to have a reliable estimation of peak flows for a range of floods, as well as an accurate and detailed topographic survey of the intended terrain and surrounding area, so that the flow of water during floods may be analyzed with and without the presence of the structure(s). It is also important to be aware of rock outcrops that may offer stable foundations for structures, as well as areas of soil particularly unsuitable for foundations (such as sodic or dispersive soils) (see Box 5.1).

Box 5.1
Problem soils for rehabilitation

Some soil types require additional caution and consideration when undertaking rehabilitation interventions. This is the case when the soils are particularly erodible (such as sodic and other dispersive soils) or where the properties of the soil structure require more careful consideration of structure designs (such as in peat soils).

- **Dispersive soils** are those soils with a high concentration of sodium in the clays. These soils can effectively be dissolved by water due to the charged clay particles. Because these layers of clay can occur below the surface (i.e. at depth), the effects of soil erosion may not be immediately visible as gulleys, but could manifest through tunnel erosion and small sinkholes. Dispersive soils have soil clods which appear to dissolve or go in to solution in water, and tend to have high turbidity runoff water.
- **Sodic soils** are where there is a *very* high excess of sodium salts relative to calcium and magnesium and the upper soil becomes highly dispersive. Lower down in the soil profile, the smaller sodium ions change the clay structures within soil, causing them to inhibit infiltration and prevent root growth through soil. Low vegetation cover and typically high grazing pressure (due to the high salt content of the vegetation) further promotes erosion.
    - Sodic and dispersive soils are highly erodible and need special care, especially when considering the construction of structures within such soils as the failure risks will be higher.
    - Depending on the pH, it is possible to mitigate the effects of sodicity or dispersive soils through the application of gypsum or lime, as this helps to correct the calcium imbalance within the soil.
- **Peat** is a highly organic rich soil which forms slowly over centuries in very wet environments through the accumulation of organic material. In Southern Africa, peats are typically associated with wetland environments. Hard, compacted peats can be impermeable, but are highly susceptible to desiccation and, if allowed to be drained or dry out, to fire which can burn off metres of the soil surface. Special care in peat environments must be undertaken to ensure that the peats are maintained wetted, and that no fire is permitted to encroach.

The positioning of structures along the length of a river

<u>Direct methods of incision stabilization (Landscaping and re-vegetation, block ramps, canalization)</u>

The positioning of the upstream end of structures for direct methods of incision stabilization is to a large extent directed by where the erosion is taking place. The positioning of the downstream end is not so simple because at the point where the protection ends there will have to be a transition zone from the stabilized channel to the non-stabilized channel. This transition point cannot be an arbitrary point such as a farm boundary, but rather a place where the bed slope has flattened to such an extent that the flow velocity has reduced to the point where incision protection is no longer required, or a rock outcrop, or a slope stabilizing weir.

<u>Indirect methods of incision stabilization (Log weirs, rock chutes, gabion and concrete weirs)</u>

Indirect methods of controlling river incision involve the provision of structures that effectively flatten the slope of a river and hence it's flow velocity and erosive power. Along with these methods it is preferable to also include a wider flow space to further reduce flow velocities.

The sketch in Figure 5.10 shows a long section down a river channel before and after the introduction of a series of weirs that flatten the river bed slope. Note that the slope upstream of each weir is not horizontal but rises slightly upstream – this is called the "silt slope". A relationship between the long term silt slope and the catchment area has been determined by the Department of Agriculture , and is important because it influences the spacing of structures and the cost of a river incision stabilization project.

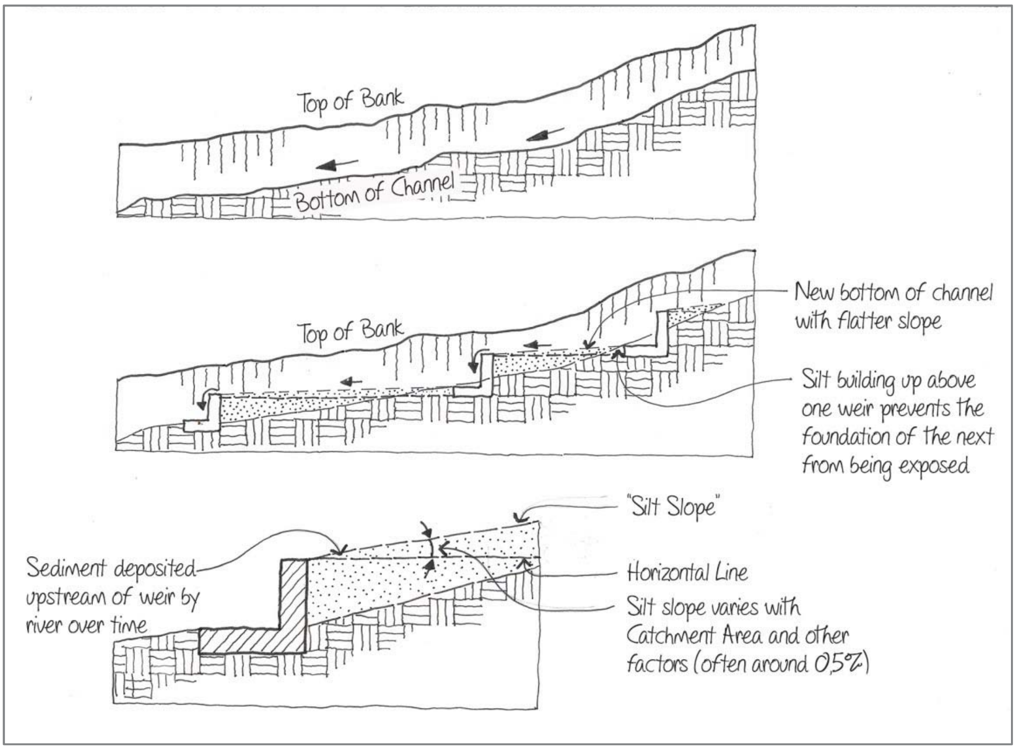


Figure 5.10: Indirect river incision control by means of a series of weirs which flatten a channel's slope

The positioning of structures laterally in a flood plain

When positioning an erosion control structure in a watercourse, it must be remembered that water will tend to flow where nature dictates, and it is useful to try and position the structure accordingly. For example it is often attractive to position a weir at a position away from where the water normally flows (say on a rock outcrop to the side of a valley where foundation conditions allow for a cheaper spillway structure) and guide the water to the weir with a compacted earth bank. Great care must be exercised when doing this because if the measures deflecting the flow of water to the weir are not substantial enough (i.e. the earth bank), the earth bank could be breached and the water will return to its old course, bypassing the weir.

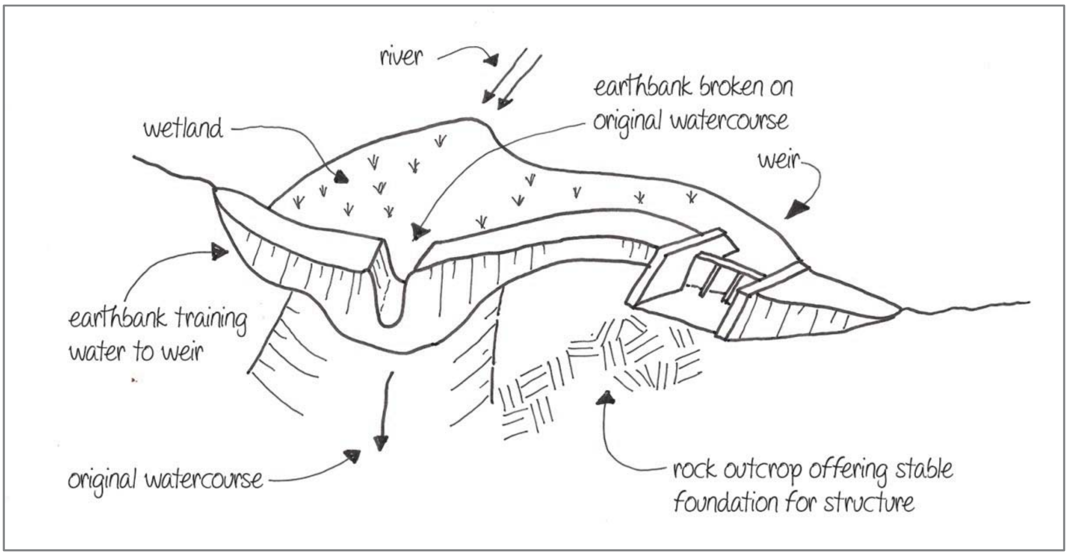


Figure 5.11: Positioning a weir in the landscape

Figure 5.12: Typical river incision arrest structure in the Karoo with long earth banks to collect water that would otherwise have bypassed the structure in other gulleys

Figure 5.13: Incising river with adjacent badlands – should a weir be constructed in the river at the left of this picture, the possibility of water bypassing the spillway into the badlands and finally outflanking the structure must be investigated and dealt with

It often happens that the incision of a river and its floodplain must be halted, but there are a number of gullies and the question arises as to whether there should be one large spillway to which all the water is channeled, or should there be several smaller structures each on its independent flow path? Should the former be chosen, the challenge is to ensure that the training walls are sustainably substantial enough to bring the water to the spillway. Should the latter be chosen, the first challenge is deciding how much water must be managed by each of the spillways. In this case it is considered good practice to expect that the division of flow will not be as planned and the discharge capacity of each of the spillways must to some extent be overdesigned to accommodate this problem.

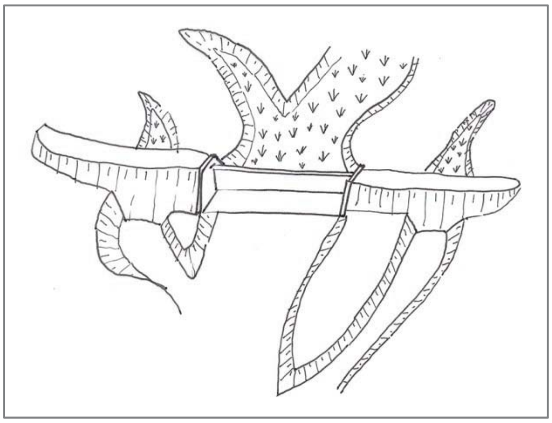


Figure 5.14: One large weir with earth banks controlling the slope of three streams

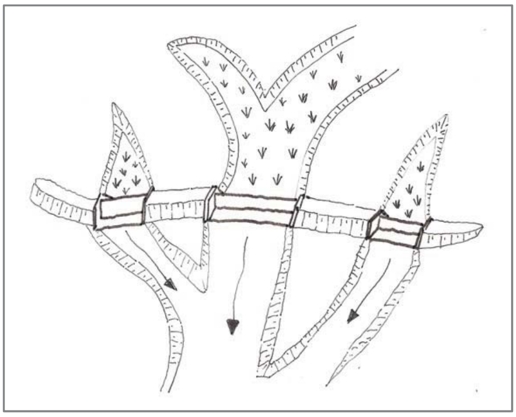


Figure 5.15: The same 3 streams each with its own weir to control the slope

The positioning of the level of structure spillways

Incorrectly planned spillway levels result in either the structure not being as effective in controlling the slope of the channel as it could have (if the spillway is set too low), or creates a delta in the channel upstream of the weir that deflects the water away from the weir and into the earth banks , causing the floodwater to outflank the structure (if the spillway is too high).

When planning structures such as weirs or anything else that lifts the level of water in a stream, extreme caution must be used as flowing water is very unforgiving, and will quickly show flaws in the planning process of hydraulic structures. The following are general rules for the placing of spillways in a landscape:-

- Keep the flow of water as close to where it would be naturally (if something goes wrong with a planned structure this is invariably where the water tends to return to).
- Reduce the energy of water flowing over a spillway by reducing the maximum overflow depth and if possible the height through which it falls. The old norm for soil conservation weirs is that spillways should not be higher than 4 metres and that the maximum overflow depth should not be more than 1,2 metres. The implication of this is that a range of flood peak flows must be computed, and the length of the spillway must be designed to take the chosen design flood without rising more than 1,2 metres above the spillway.
- Take into account that the moist environment just upstream of a spillway encourages the lush growth of vegetation and that this will partially obstruct flow to the spillway.
- For wetland rehabilitation weirs the level of the spillway should be referenced to the original Thalweg position (lowest point in topography prior to disturbance). The spillway must not be higher than the Thalweg otherwise the weir will cause the wetland to sediment up to an unnaturally new level as described above. In such cases it is advisable to take the vegetation into account by keeping spillways in the order of 300 mm to 500 mm below the Thalweg level, or more if experience shows that local vegetation requires it.

Figure 5.16: Typical vegetation growth upstream of a spillway reducing its discharge capacity (this must be taken into account in the design phase)

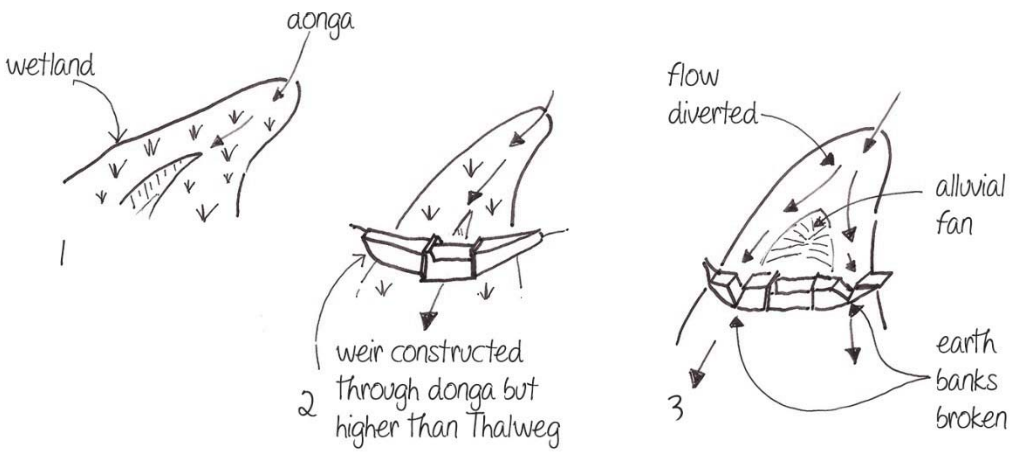


Figure 5.17: The relevance of the level of a spillway relative to the surrounding landscape

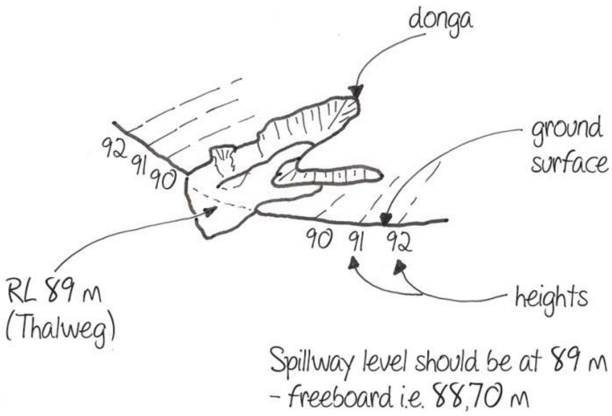


Figure 5.18: Relating spillway level to Thalweg level

- The spillway levels of a series of weirs <u>used for river incision control</u> where an artificially flat slope is being imposed on the river to slow the flow velocity, should also not be higher than the Thalweg level, and the implication is that the flat slope created between the spillways will be below Thalweg level.

Weirs can definitely impact on flood levels in a watercourse and this must be investigated and taken into consideration. Flood levels post the construction of a weir should be compared with flood levels that would have existed prior to the recent erosion of a wetland or river, and if necessary the design of the weir must be changed to reduce any negative impacts identified.

Caution

It is essential to check the expected flood levels and flow paths without- and with the planned intervention in place to ensure that water is not being diverted somewhere unexpectedly and is going to create a new source of river instability or any other problem, even with the spillway below the Thalweg level.

What would happen if a spillway in a wetland was constructed at the original surface level?

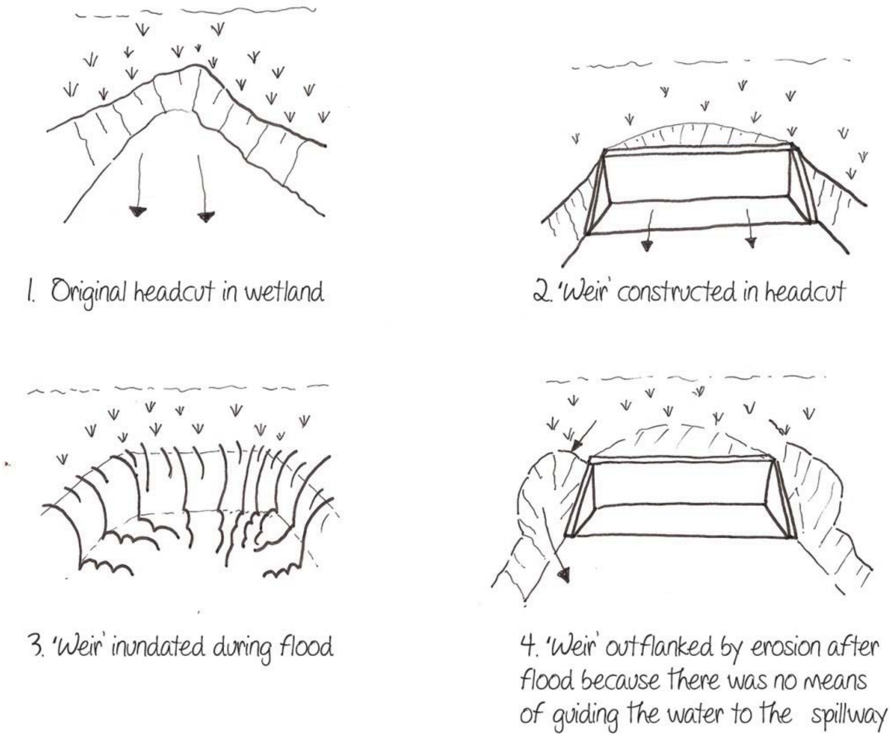


Figure 5.19: The consequence of constructing a spillway at ground level

As shown in the sketch above, if gravity does not draw the whole flood over a spillway, some will pass around the sides of the spillway and return to the gulley. This water passing around the ends of the structure accelerates as it falls into the gulley, initiating erosion and fresh gulleys going around the ends of the structure outflanking it and rendering it useless.

Refer to case study 10 where a low weir was damaged because of inadequate provision to prevent outflanking.

Other components of weirs

Usually weir structures are more than just spillways, they have shoulder walls, cut-off walls, stilling basins and maybe fish ladders as well.

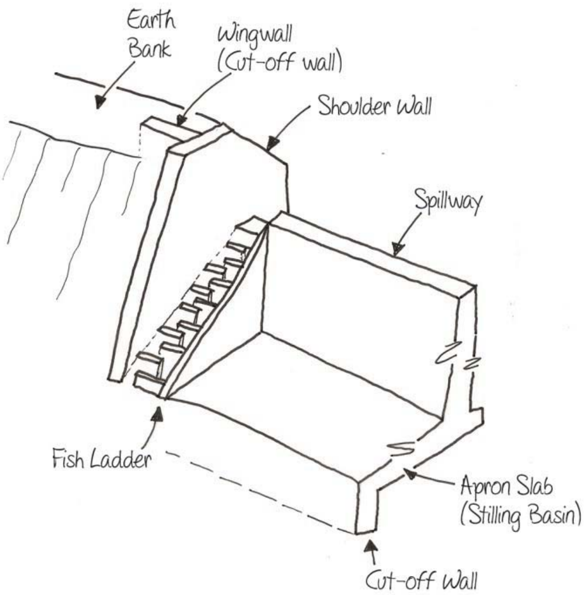


Figure 5.20: Cut-away view of a typical weir showing the structural elements

Shoulder walls: The shoulder walls contain the flow over water over the weir (they protect the earth bank from being eroded by the falling water). There is one at each end of the spillway unless the spillway ends on a rock outcrop.

Cut-off walls: Cut-off walls are features that retard or prevent the seepage of water under the foundation or the adjoining earth fill, and so reduce or prevent the risk of "piping failure" (the formation of tunnels under or on the side of the structure).

Apron slab: The apron slab is an element of the structure on which the water falls. It is hardened (such as with concrete) so that the falling water does not erode the foundation of the structure and then initiate a failure of the structure. Sometimes an "upstand wall" is placed along the downstream edge of the apron slab, and this traps a pool of water on the apron slab – the objective of this pool of water is to help dissipate the energy of the falling water so that it does not cause erosion downstream, and thus the apron slab becomes known as a "stilling basin".

Fish ladder: Weirs have a very negative impact on the ecology of a stream when they prevent the migration of biota up and down the river. This can be mitigated by including a "fish ladder", a channel carrying the low flow with a lot of baffle plates to slow down the velocity of the water that biota can still migrate over the weir. Fish ladders are discussed further in section 0 .

Fish Ladders

Serious consideration must be given to the provision of fish ladders whenever a step is formalized in a river by means of a weir, especially if there are known biota migrating up and down the river. Unfortunately the range of many aquatic species is not fixed with time but may move in response to changes in habitat such as the river bank vegetation having burned, or abnormally wet or dry seasons, so it is not right to determine at one point in time that there are no migrating species at a location and a fish ladder is not required.

The basic requirements for a fish ladder are, from a technical perspective:

- The fish ladder must carry at least a portion of the low flow of the river during the dry season – this implies that the notch in the spillway feeding the fish ladder must be located at a point where it will always have water and not be blocked by sediment deposits.
- The fish ladder must discharge to the uppermost part of the pool below the weir because fish will look for a path over the “obstruction” (i.e. weir) there.
- It is preferable that the fish ladder be fitted next to one of the shoulder walls for structural stability (often during floods the most severe structural loading can be from tree stumps or large boulders being washed over the spillway and not so much the water itself).
- A fish ladder must be positioned in such a way that it does not obstruct the flow of flood water, and constructed in such a way that it is least likely that flood debris will get stuck on the fish ladder.

Figure 5.21: Fish ladder constructed with masonry and concrete (Piketberg). In order to discharge at the point where the weir’s water falls back into the stream, this fish ladder turns back on itself.

CROSS REFERENCE

A more detailed section on the planning of fish ladders is provided in Chapter 11.

Overview of interventions

The current most popular practice for addressing river incision is to construct weirs, but these structures have ecological drawbacks, so this section attempts to present presents alternatives to weirs as well as weirs. This chapter looks at various options to address river incision problems and they are:-

NON-INVASIVE TECHNIQUES

1. “Do nothing” option
2. Invasive vegetation removal

DIRECT TECHNIQUES

3. Landscape river cross section and revegetate
4. Canalization

INDIRECT TECHNIQUES

5. Log weirs
6. Rock weirs and chutes
7. Block ramps
8. Green gabion weirs (Terramesh)
9. Rock gabion weirs
10. Concrete weirs

IMPORTANT POINTS FROM THE GUIDELINE

- Understanding erosion mechanisms (section 3.4 “*Erosion*”).
- An interdisciplinary approach is needed to understand the drivers of river instability causing the river bed to erode, and what to do about it (section 2.1 “*The need for an inter-disciplinary approach*”).
- Thought must be given to what extent rehabilitation is required (sections 1.1 “*Philosophy and aims*” or 2.4”*Sediment processes*”? 4 “*What is rehabilitation?*”). This should include considering the option for doing nothing.
- The reader must be aware of typical problems in rivers (section 3 “*Problems in rivers*”) to help the correct identification of the source of the problem.

- The reader must be aware of an appropriate scale of remediation.
- The reader must be aware of different options for river bank stabilization, and the relative advantages and disadvantages of these (section 8.1 "*Overview of options*" and 8.4.1 "*Managing eroding banks*") so that an appropriate choice can be motivated.
- The reader must be aware of technical competencies required to undertake certain design tasks.
- The reader must be aware of legislative requirements for working in water courses (section 10 "*Legal authorisations necessary for river rehabilitation*").

TECH TIP – the desirability of minimalist interventions / scale of interventions

It is usually desirable to keep all constructed river rehabilitation interventions (earthworks, soft structures, hard structures) to a minimum, not only for reasons of economy, but for avoiding interfering with natural processes as far as possible.

The converse is also true, that one does not want half-hearted interventions that fail unnecessarily during floods and the river has to be disturbed by construction once more when the intervention is reconstructed. *(… for example weir in a few gulleys in floodplain without considering medium flood)*

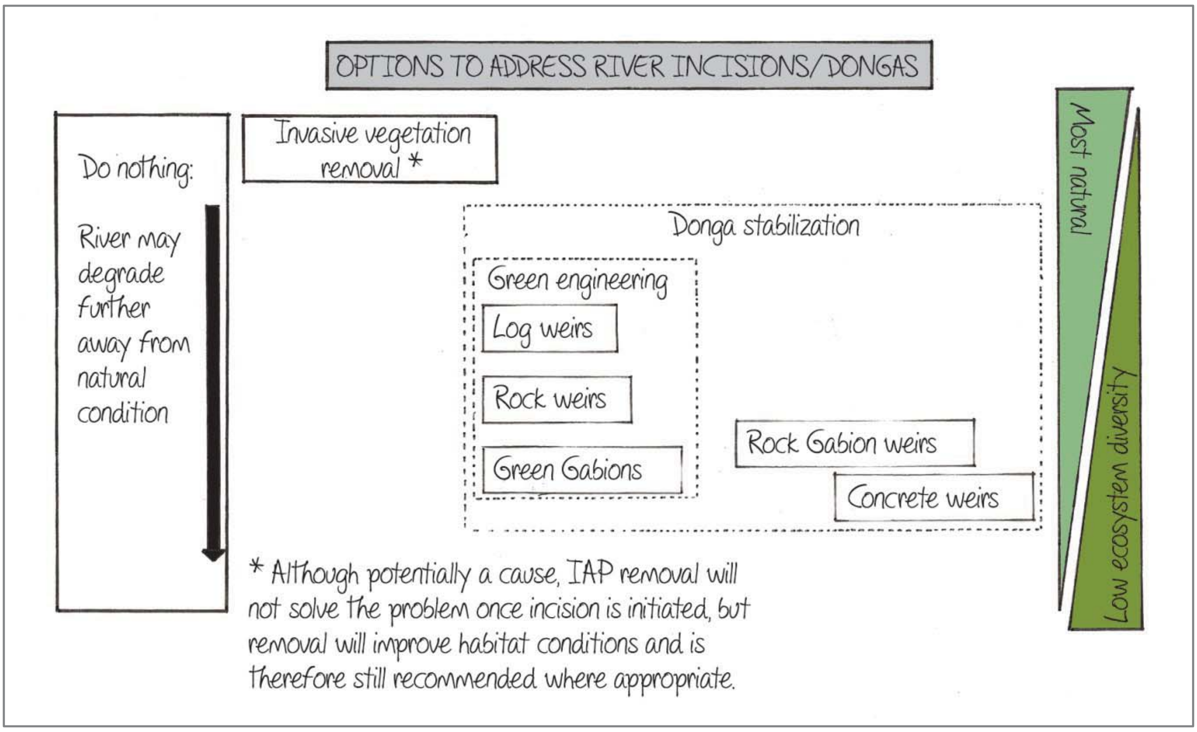


Figure 5.22: Options for addressing river incision problems

5.1. Non-invasive techniques

5.1.1. Do nothing

"Do nothing" is an option which should always be considered with every proposed rehabilitation intervention. Doing nothing may have little risk associated with it if:

- a hard geological layer is exposed that limits the depth of incision
- the erosion is a natural phenomenon (such as localised incision of a river in a wide floodplain after a flood, and not incision accelerated by the artificial narrowing and deepening of the river)
- the rate of incision is year on year, including in response to large floods, very low
- the ecological condition of the river channel being eroded is already poor – habitats are already severely degraded
- there is no risk of damage to nearby infrastructure, or curtailment of economic activities, if the erosion continues
- the risk to up- and downstream environments is minimal (i.e. the sediment entering the river from the site is not going to cause further erosion downstream)

Consideration of a hands-off approach is important to determine the importance or level of urgency of rehabilitation interventions and is an important consideration to compare and prioritize a series of sites and, through understanding the risks, identify appropriate rehabilitation options for the highest risk sites.

Doing nothing may however result in:

- the river bed could incise more, or the banks may start to erode as they become unstable and slump into the now deeper channel
- further ecological degradation at the site
- smothering of downstream instream habitats with fine sediment eroded from the river bed
- increased incision downstream as material eroded from the site in question creates islands that further alter the river channel into a narrow deep channel with high flow velocity
- economic and social costs where the incision of the river prevents access to economic activities (such as the erosion of road/drift approaches and the prevention of access to agricultural lands)
- direct damage to roads, fields, housing and infrastructure as the banks which they are located on are washed away when the banks collapse into the deeper channel
- increased flooding risks downstream as the eroded sediment is deposited in slower river reaches, causing channel infilling and a loss of channel competency

These potential risks should be weighed up against the costs of intervention and the risk of non-intervention.

5.1.2. Removal of invasive alien veg

Removal of invasive vegetation is often one of the most effective ways of preventing downcutting, as it allows the spread of flood flows into the floodplain, preventing constrictyion of flows and associated downcutting. See Chapter 2 for details regarding plant clearing interventions and cautions, particularly with regard to the clearing of indigenous vegetation.

Environmental legislation

- The removal of alien vegetation does not trigger the need for environmental authorisation in terms of the NEMA regulations providing that not more than 5 m^3 of soil or rock is disturbed in the process.
- The Conservation of Agricultural Resources Act (CARA) would be contravened if a landowner leaves or allows an obstruction in the river which could lead to soil loss (i.e. if alien trees are felled and left in the river in the path of floods).
- Refer to Volume 1: Section 10 "*Legal authorisations necessary for river rehabilitation*"
- Clearing of alien vegetation is a legal requirement in terms of NEM:BA for many alien species – see Chapter 2 for details

5.2. Direct techniques

5.2.1. Landscape the river cross-section and vegetate

Providing that the river flow velocities during floods are low enough to not cause new erosion, an adequate solution may be achieved by backfilling and compacting the incised channel with imported material, or with material landscaped from adjacent to the channel to create a flood plain all of similar level, and then to establish suitable indigenous wetland vegetation. Naturally it is also a proviso is that conditions in the river must be conducive to establishing suitable indigenous vegetation across the entire channel.

It is essential before embarking on this to understand why the erosion occurred in the first place (for instance the channelization of the flow between levees or woody alien vegetation) and to make sure that it does not happen again.

The advantage of this is that it is a more natural solution free of engineered structures. The danger with this is that the cause of the initial erosion has not been adequately addressed and that it happens again. This intervention, although desirable, is in practice often not feasible.

Environmental legislation

- The movement of more than 5 m^3 of soil or rock in a river triggers the need for environmental authorisation in terms of the NEMA regulations.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

5.2.2. Block ramps

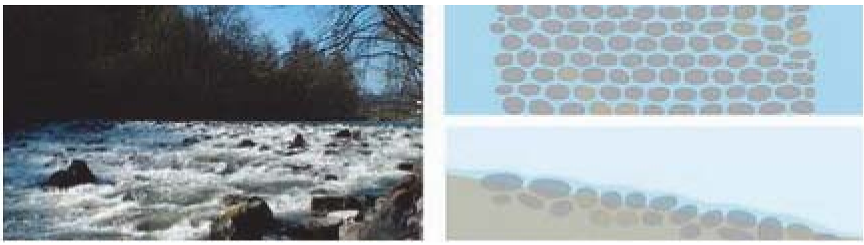
In many European and other countries, rivers have been confined to narrow channels for many years and as a result have started incising. Historically to counteract the incision of the rivers, small drop structures (weirs) have been constructed, but it has been found that these inhibit the migration and survival of many fish species.

In Switzerland experiments have been done to replace the drop structure weirs with bands of very large rock dumped in the river (with water flowing between them) such that the rocks offer resistance to flow and cause a gradual step in the water surface.

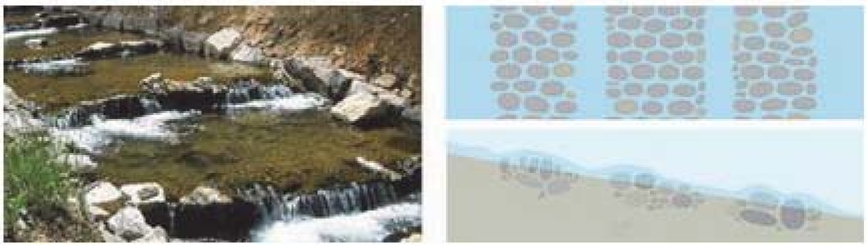
This is a noteworthy development, but the following should be carefully considered before proceeding to plan these structures:-

- The stability of the banks needs to be confirmed, so that the structures are not outflanked (refer to Section 0).
- The stability of the rock size for the flow velocities and turbulence expected during floods.
- The likelihood of these rocks trapping large quantities of washed out alien vegetation during floods, and the impact thereof on the stability of the rocks as well as the river.
- The ecological suitability of large rocks in a river where possibly there aren't any rocks at all.

Block ramps could be seen as a "Direct technique" or an "Indirect technique" depending on how its applied – if it is applied for a short stretch only to achieve a gradual step in the river slope, it would be an "Indirect method", otherwise it would be "Direct".



Classical block ramp (Photo: Thomas Berchtold)



Structured dispersed block ramp. (Photo Denise Weibel)

Unstructured dispersed block ramp. (Photo Armin Peter)

Figure 5.23: Different block ramp designs
Armin Peter, EAWAG, Switzerland

The advantages of block ramps are:-

- They create an artificial step in a river when required for rehabilitation purposes, while still allowing a large degree of connectivity between the river reaches for fish.
- It could provide a more aesthetically acceptable solution than a formal weir structure.

The disadvantages of block ramps are:-

- The rocks used have to be large enough so that they are not dislodged during floods, and for many rivers this could mean very large rocks and extremely high costs.
- When the step height required is large, the area covered by rocks will also become large and may be impractical.
- Bank erosion protection will be required if the river bed is lifted by means of blocks to prevent the river from meandering around the rocks.
- The aesthetic value of rocks in some rivers could be questionable.

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this case large boulders) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by riprap has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

5.2.3. Hardening the river bed with concrete blocks

Especially in urban areas where rivers may have been historically constricted and flowing at abnormally high velocities during floods, if it is not acceptable to reduce flow velocities by means of a series of low weirs it may be useful to harden the bed of the river to prevent incision. Using concrete blocks with openings where vegetation may be established is more environmentally acceptable than a solid concrete slab. Figure 5.24 and Figure 5.25 show typical blocks which could be used in such an application.

Figure 5.24: “Terraforce blocks"
(photo Nguniprecast.co.za)

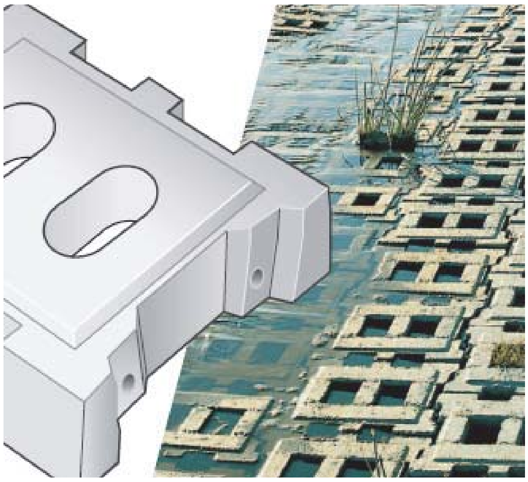


Figure 5.25: "Armorflex"
(photo technicrete.co.za)

The advantages of this are:-

- Vertical erosion may be halted
- There is still a connection with the river bed for flora and fauna
- Providing that only the river bed is hardened, the river banks are maintained with natural vegetation and a fairly high level of biodiversity may be sustained.

The disadvantage of this are:-

- The concrete is unnatural and detracts from the aesthetic value of a stream
- Should the river deposit sediment in this stretch and it needs to be cleared, it is difficult to do it without damaging the concrete blocks.

When hardening the base of channels, thought must be given to the discharge capacity of the canal and the magnitude of flood to be discharged so that the size of the channel and protected area are appropriate. The flow velocities expected during the design situation must be checked against that which is safe for blocks selected must be checked, in addition flow velocities must be such that the channel does not sediment closed in low flow conditions. Consideration must be given to the use of a geotextile below the structure to prevent leaching of subsoil by flowing water, and on steep slopes and poor soils cut-off walls should be provided below the lining to prevent the flow of water there.

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this case concrete blocks) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by grass blocks has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 “*Legal authorisations necessary for river rehabilitation*”

5.2.4. Canalization

Canalization implies containing the flow of water within a hardened canal, i.e. a floor as well as side-walls are provided. When the constriction of a river is severe (as happens in urban settings) and the resulting erosion and instability (vertical as well as horizontal erosion) is too much for just hardening the bed of the channel, it may be that the only alternative is to fully canalize the river.

Depending on circumstances, this can be done in a variety of ways which would provide a more or less ecologically acceptable solution, in other words the structure does not necessarily have to be solid concrete. Solid concrete canals have the advantage of much less maintenance, although the initial capital cost is much higher. Solid concrete canals have a major disadvantage that they do not enhance or even maintain the biodiversity status of the river.

Figure 5.26: Steel reinforced concrete lined canal

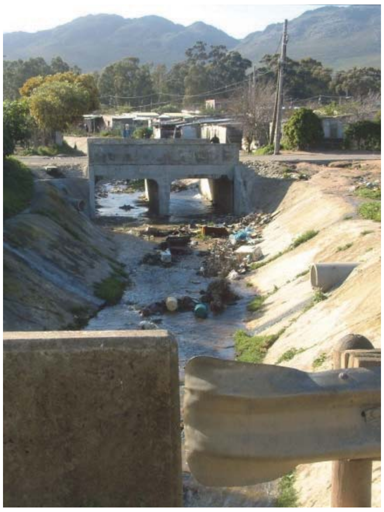


Figure 5.27: Concrete canal in informal settlement

Figure 5.28: Stone paved channel through town in Switzerland

Environmental legislation

- The full canalization of rivers triggers the need for environmental authorisation in terms of the NEMA regulations in a variety of ways. Inevitably more than 5 m^3 of material will be placed or moved while constructing a canal, and more than 5 m^3 of rock or soil will be moved in the river. In addition should the footprint of the structure exceed 100 m^2 or its length 1 km, the need for authorisation will be triggered as well.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- CARA does not regulate the construction of canals.
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

5.3. Indirect techniques

5.3.1. Log weirs

Log weirs would be constructed primarily to create diversity of habitat (i.e. the habitat that comes with a plunge pool) and not so much to arrest the incision of a river (it is unlikely that they can function as grade control weirs unless the flow velocity during floods is low and the thickness of the tree trunk is similar to the average flow depth during a flood).

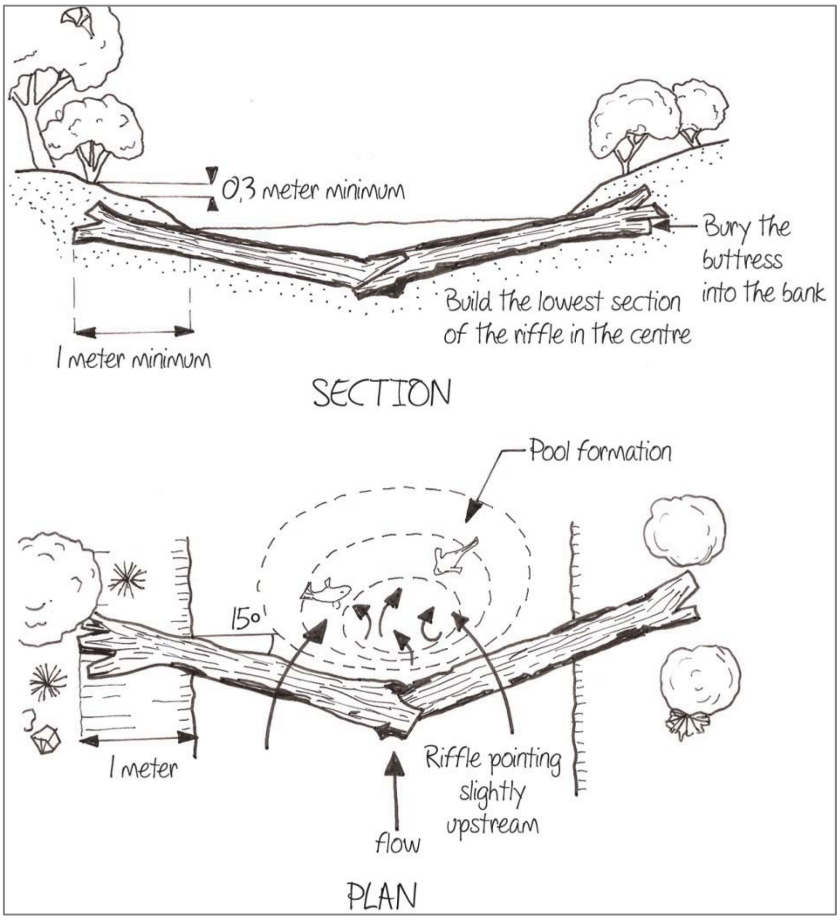


Figure 5.29: Conceptual layout of log weir
Water and Rivers Commission 2000, Stream Stabilisation Water and Rivers Commission (Government of Western Australia), River Restoration Report No. RR 10.

They are popular in the literature from some countries (e.g. Australia). Log weirs have been reported to be used with success in parts of the world such as Canada and Australia, but there is no record of success in South Africa yet. The concept is attractive because of its low cost and uses commonly available material, and so it is included in the publication because the reader may find references to it elsewhere.

The conceptual diagrams representing the idea always show stable scour holes creating habitat for fish, but problems are expected with forcing water to flow over the logs, as well as preventing the logs from washing away during floods. As with any such informally planned structures, unexpected outcomes would not be surprising (for instance the flow of the river being directed into a bank, or the formation of a larger than intended scour hole destabilizing the river).

In South Africa where flood peak discharges are often hundreds or thousands times larger than the dry season flow, the chances that structures of this type get outflanked during floods is great, and this would definitely lead to the tree trunks being washed out.

The implication of the failure of these structures could be very serious, especially should the tree trunks be washed out of the river bed during a flood and block a downstream road culvert or bridge. It would be also very serious should the tree trunks wash out and be deposited elsewhere in the river, causing an obstruction which would in turn lead to the erosion of the river bank.

For these reasons the use of this sort of technique is not recommended by this manual.

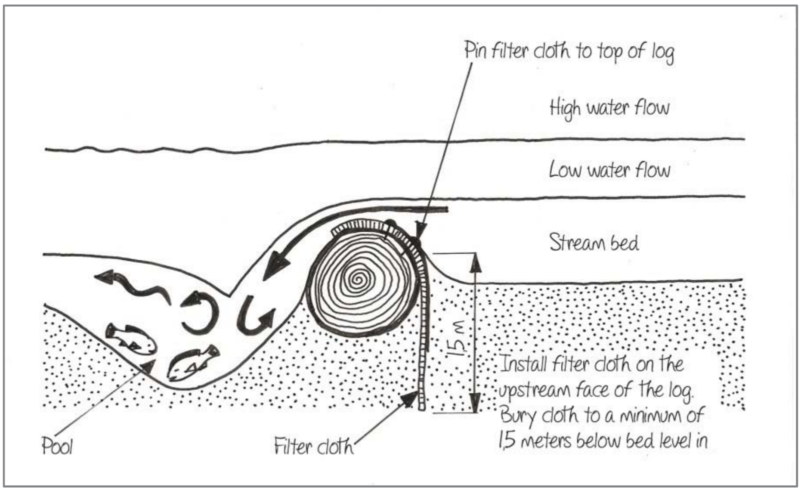


Figure 5.30: Reported detail of log with filter cloth
Water and Rivers Commission 2000, Stream *Stabilisation* Water and Rivers Commission (Government of Western Australia), River Restoration Report No. RR 10.

The only circumstances where such a practice could conceivably work is where:

- The diameter of the tree trunk is at least equal to the flow depth of the river when in flood
- The tree has to extend significantly beyond the zone inundated when the river is in flood (probably 30 % to 50% of the tree would have to be buried in the river bank)
- The slope of the river is relatively flat, implying that the energy level of the river is low.

In other words the tree would have to be extremely large in relation to the river channel size.

Environmental legislation

- The deposition of more than 5 m^3 of any material into a river triggers the need for environmental authorisation in terms of the NEMA regulations. Should the footprint of the intervention be greater than 100 m^2, or more than 5 m^3 of earth be moved, these will also trigger the need for authorisation.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- The Conservation of Agricultural Resources Act (CARA) would be contravened if a landowner leaves or allows an obstruction in the river which could lead to soil loss (i.e. if tree stumps are placed in a river where they may break free during floods).
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

5.3.2. Rock weirs and chutes

Rock weirs and chutes are also known as “rock riffles” and “rock ramps” (not to be confused with “block ramps”). They generally involve the excavation of a trench through the bed and banks of a stream, and the placement of quarried rock on the bed or banks on a slope that is steeper than the natural stream to create a graded weir. Rock chutes are largely constructed to control the gradient of stream beds, however they are also reported to be used to address other stream management issues such as the provision of fish passage, diversion weirs, sediment stabilization and the creation of riffle and pool habitat. They have not been used widely in South Africa but are reported on in Australian literature.

As with comments on “log weirs”, extreme caution should be used when considering this for use in anything but very slow flowing rivers. Strictly speaking the flow velocity of water flowing down the downstream face of the structure should be computed so that the size of stone selected may be large enough to be stable. In addition the size of the opening between the sloped-up sides of the spillway should be constructed to accommodate a reasonably expected flood. Difficulties will be encountered when gulleys are narrow and deeply incised, because it will be difficult to produce a spillway with sloped-up sides that can contain the reasonably expected flood. Generally this kind of approach should only be used for very small catchment areas (less than 100 ha) unless the structure is designed specifically to safely manage the design flood. A sketch of this structure is shown in Figure 5.32 – please note that it specifies the downstream face slope as between 1:10 to 1:20 which are both extremely flat.

Figure 5.31: A typical rock weir in a gulley

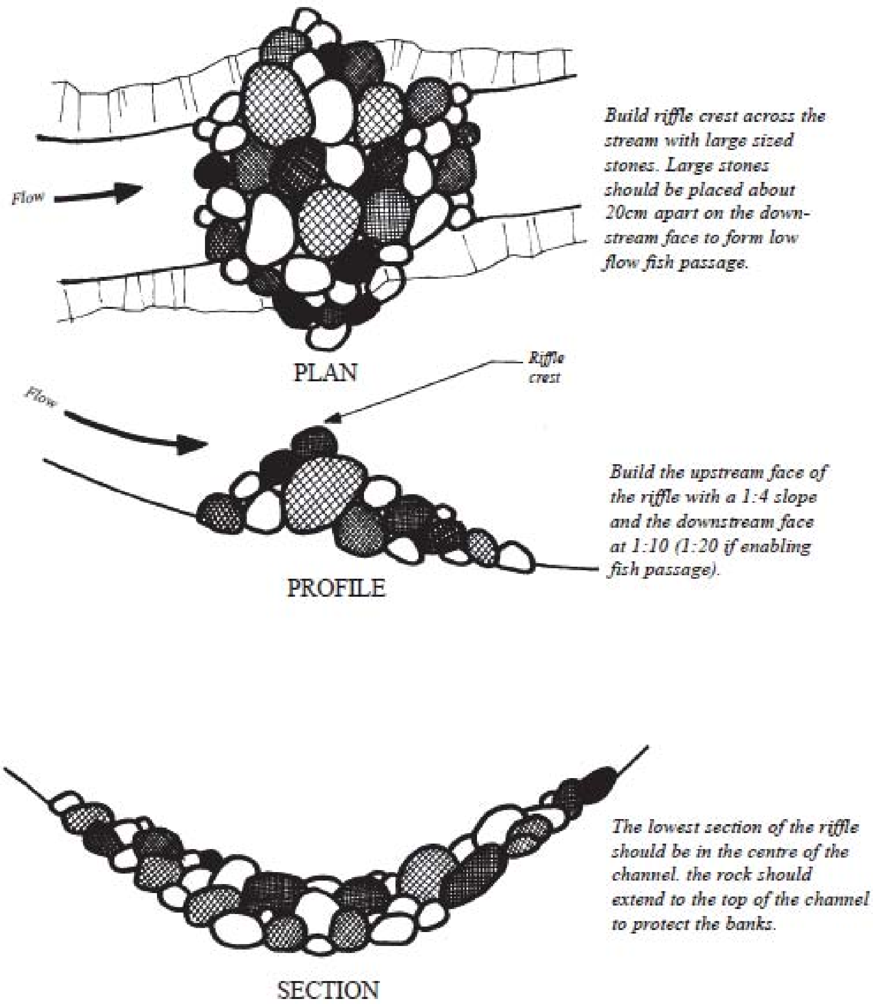


Figure 5.32: Typical rock weir detail

Apart from the difficulty in producing a structure than can safely accommodate a reasonably expected flood, there is a concern that during low flow water will flow through the structure and not over it, preventing the migration of biota in the dry season. This must be addressed when planning such a structure.

Environmental legislation

- The in-filling or depositing of more than 5 cubic metres of material (in this case riprap) in a watercourse triggers the need for environmental authorisation in terms of the NEMA regulations, as does the movement of more than 5 m^3 of soil or rock in a river. In addition to this if the footprint of the area covered by riprap has a footprint exceeding 100 m^2 authorisation is required.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

5.3.3. Rock gabion weirs and concrete weirs

Rock and gabion weirs have been used in South Africa to combat the incision of rivers since the 1950's. The reason for the frequent use of these structures is that technically they are well described and understood, and they utilize conventional construction methods.

Figure 5.33: Incision control weir near 3 Sisters, Karoo

The major difference between the two methods is in the construction – gabions are wire baskets which are linked together and packed with stone before the baskets are closed. Concrete structures are constructed by erecting formwork and then casting concrete inside the formwork (possibly with reinforcing steel depending on the design). The relative advantages and disadvantages of these structures are shown in the table below.

	Rock filled gabion structure	Concrete structure
Flexibility to cope with foundation settlement	Gabion structures can accommodate a high level of foundation instability without failing.	Concrete structures are rigid and do not accommodate foundation settlement at all.
Durability	Gabion structures are not as long lasting as concrete structures potentially are, although gabion structures close on 100 years old have been inspected and found still to be functional. It is important to use gabions with SABS approved galvanizing and if necessary PVC coating as well. Where subject to abrasion gabion structures require concrete pads or other coating for protection.	Concrete structures when properly constructed can be extremely durable. Care must be taken to ensure that the concrete mix is appropriate, correctly mixed, placed and cured.

	Rock filled gabion structure	Concrete structure
Suitability for job creation projects	Gabion structures can be constructed by relatively un-skilled labour with nominal training and supervision. The use of gabions is well suited to job creation programs.	Concrete construction requires the presence of highly skilled supervision and expensive equipment to be on site (concrete mixers, formwork, concrete transport equipment, poker vibrators). Small concrete structures can be suitable for job creation programs, but not large structures.
Cost	The cost of gabion structures is relatively high, especially if stone has to be transported over a large distance to the site.	The cost of concrete structures is very high – especially if the contractor is obliged to mix good quality concrete and cure it properly to get good strength.
Ease of repair	Gabion structures are easy to repair should a severe foundation failure be experienced. Either new baskets can be wired on to the existing structure, or the existing structure can be un-packed, corrected and repacked.	Failed concrete structures do not repair easily. Generally they have to be partially or completely demolished and re-constructed.

Weirs can be beneficial to a river rehabilitation project providing that the needs and functioning of the river are appropriately understood and that the structures have been properly designed. Weirs require high capital inputs and it is not worth constructing them in a haphazard manner. It is essential then that the design of weirs must be preceded by a proper hydrological study, a topographical survey. In addition, a study of the foundation material at several potential sites must be done before a decision can be taken as to how many weirs are required, what drop height they will have and where they will be placed. The sizing of the weir spillway, its position laterally within the landscape and the level of the spillway relative to the landscape are described in detail in Section 0 .

Figure 5.34: A weir on the Duiwenhoks River during construction (left) and during 1:5 year flood right. Although it is only a small flood, the energy of the water is high because it is falling more than 2 metres – imagine what a 1:50 year flood would look like. For this reason consider that it is a simple matter to detail a structure on a plan, but to ensure that a structure is designed to be stable under severe conditions can be very challenging and should only be undertaken by persons with appropriate qualification and experience.

GREEN OPTIONS

- Gabion mattresses and concrete block mats provide environments which are suitable for planting appropriate indigenous river plants. With weir structures this is more difficult because of the high energy of the falling water. Unless the fall on a weir is one metre or less, it is unlikely that vegetating the apron mattresses will protect the gabion wires from abrasion and concrete pads are necessary.
- Wetland plant like Palmiet Priounium Serratum has successfully been attached to the edges of gabion structures (with cable ties).
- "Green gabions" i.e. Maccaferri Terramesh and similar, have not been proven for the construction of weirs (it is very suitable for retaining walls where the saturation of the fill behind the structure is limited by the provision of sub-surface drainage). This is unfortunately a problem common to all "reinforced earth" construction techniques. Hopefully this will be resolved one day.

Sediment starvation downstream of weirs

Until such time that the basin upstream of a weir has filled with sediment, and sediment is passing over a weir during floods, the river bed immediately downstream of the weir can be subject to "sediment starvation". In other words the normal balance of sediment in a river has been (temporarily) disturbed, and although sediment is being washed away from below the weir at a normal rate (or an accelerated rate due to turbulence downstream of the structure), it is not being replaced, and the river bed level drops. This can temporarily threaten to expose the foundation of the structure, and this should be taken into account during the design of the structure.

Environmental legislation

- The construction of gabion or concrete weirs does trigger the need for environmental authorisation in terms of the NEMA regulations should more than 5 m^3 of material be placed in the river or more than 5 m^3 rock or soil moved, or the footprint of the structure exceed 100 m^2.
- Earthworks within the watercourse triggers the need for authorisation in terms of the Water Act (bed and bank modification are listed uses under the National Water Act)
- Refer to Volume 1 Guidelines: Section 8 "*Legal authorisations necessary for river rehabilitation*"

References

Peter, A. *Do block ramps improve river connectivity for fish?* [Internet] s.l. : eawag , eawag (aquatic research), 2013. 01/08.07.2013.

Water and Rivers Commission. 2000. *Stream stabilisation – River restoration report No. RR10.* s.l. : Government of Western Australia.

Maccaferri. 1981. *Flexible structures in river and stream training works: Section one Weirs for river training and water supply.* Bologna : s.n.

Przedwojski B, Blazejewski R, Pilarczyk KW. 1995. *River training techniques: Fundamentals, design and applications.* Rotterdam : AA BAlkema

van Coller AT, King HE, Koch EU. *National soil conservation structure manual series.* (unpublished).

Chapter 6:

Managing sediment

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TABLE OF CONTENTS

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Introduction

Sediment erosion, transport and deposition are important processes that create habitat diversity in rivers. In general, the more natural and varied a river or channel, the higher the ecological value. However, sediment deposits also act to increase the chance of flooding through their influence on channel roughness and channel depth. Increased sediment deposition reduces conveyance and increases flooding risks.

Excess sediment is thus sometimes perceived as a problem in some river reaches. The removal of sediment from rivers is sometimes considered for river management purposes, specifically where:

1. At sites where there has been excess sediment deposition related to reduced conveyance – such Mid-channel sedimentary bars cause high flows to be deflected to the banks, causing erosion of the banks and, where infrastructure is close to the banks, places infrastructure at risk;
2. Excess sediment deposition on the river bed causes the river bed to be raised. The impacts of excessive sediment deposition are:
    - smothering the underlying habitats by the newly deposited sediment,
    - promotion of vegetation establishment on the newly deposited sediment, and
    - the higher sediment (river bed) level, and in some cases vegetation in top of this, raises flooding risks due to the reduced channel depths and reduced flood conveyance.
3. Where there is a demand for sediment for building or construction purposes, river environments are often targeted as they offer a clean and often well-sorted source of sediments for construction purposes.
4. In special cases, contaminated bed sediments may be a critical management issue. In some Gauteng and Northwest catchments where gold mining has occurred, heavy metal and even radioactive elements are present in the sediments of rivers and wetlands. The removal of such sediments can mobilise these pollutants and present risks for the site and downstream environments and biota. Due to the high risks and varying responses of different heavy metal elements, very site specific, specialist assessments are required in these activities and they are not addressed further in this chapter.

The following situations represent scenarios where sediment removal could be considered as part of true rehabilitation or restoration actions for a river system:

- In reaches where there is excess sediment erosion upstream (such as of the catchment, or of a large upstream wetland or of extensive lengths of the river banks) and this has resulted in a perceptible higher river bed level within the river reach in question.
- as upstream of a bridge where culverts are insufficient to convey floods, resulting in a backup of floodwaters, reduction of velocity and increased sediment deposition upstream of the constriction.

- At sites or reaches where there has been excess sediment deposition related to increased flow resistance – such as where a reach has been invaded by invasive vegetation, causing a reduction of flood velocities and increased sediment deposition due to the reduced water speeds.
- Reaches downstream of areas which have recently been cleared of invasive vegetation may also experience enhanced sediment deposition. This is because sediment previously trapped in the invasive alien vegetation stands upstream becomes mobilised following clearing activities.

Assessing whether sediment removal is appropriate:

1) In general, removal of sediment from a watercourse is not a good idea due to risks of initiating instability (incision and bank erosion) at the site and to the downstream reaches. However, this is not a hard and fast rule, because
2) In some river reaches, effective management of the watercourse and mitigation of risk for adjacent landuses is not possible without some sediment management actions. Each case must therefore be considered based on the reach-specific evidence and understanding of sediment processes for that site or reach.
3) For cases where the removal of sediment is found to be justified, best practice must be used to carry out the necessary work to minimise adverse effects on the environment. (Environment Agency 2004).

There are however, other situations where the removal of sediment may be considered by a landowner or river manager due to the risks to infrastructure, or additional erosion, which sediment deposits present. ***Removal of sedimentary bars*** (in-channel sediment deposits) is often undertaken to reduce flooding risks and prevent secondary (deflected) currents from causing erosion of the banks of the river.

The ***removal of sediment from the channel*** is usually undertaken to reduce the risk of overbank flooding through increasing channel depth and therefore competency. The demand for sediment in construction activities can also lead to large reaches of rivers being used for ***sediment mining***.

Often mechanical interventions must be used to manage sediment loads in the rivers as the cost and physical impracticality of hand-excavation or reworking is not feasible. The bulldozing of riverbeds and banks is generally very harmful to river stability and should be avoided or mitigated as much as possible. The most negative effects of the bulldozing of rivers are the stripping of indigenous vegetation and the promotion of un-natural and unstable river geometries.

- In the Western Cape as well as the Eastern Cape, the alteration of rivers by excavation and the construction of levees is common;
- Bulldozing disturbs the composition of the river bed locally, increasing the risk of erosion. The segregation of river sediment into windrows of fine and coarse material facilitates the erosion of both (the most stable river bed material is a mixture of fine and coarse particles);
- In parts of the Western Cape, Eastern Cape and Kwa-Zulu Natal, mechanically disturbed riverbeds are an ideal place for fast growing alien vegetation such as Black Wattle and Silver Wattle to get established;
- River habitat diversity is reduced when the rivers are "trained" in to straight, single channels;
- The removal of sediment disturbs the river bed and banks, degrading habitat condition, especially where the sediment is being removed from the active channel and marginal zone.

In addition to these onsite impacts, downstream and upstream impacts can result from the large-scale removal of sediments in that:

- Where sediment is being removed at a greater rate than sediment is flowing in to the reach, the downstream reaches can become started of sediment (similar to the impacts below a dam);
- Where the removal of sediment creates a deeper, narrower channel with a bed and/or banks of erodible sediments, the reach can be destabilised through lateral and vertical erosion, resulting in upstream headcut migration and downstream sediment deposition; and
- Elevated fine sediment loads can degrade the downstream instream habitat quality.

TECH TIP

Try to identify the cause and source of sediment that is deposited

An eroding upstream wetland or eroding river banks would increase the sediment load of the river, increasing deposition. Extensive invasive vegetation, or downstream bridges and weirs, can cause upstream water velocities to slow down during floods and this will increase sediment deposition. Addressing the cause of sediment deposition rather than symptom (the bar itself) will yield a more sustainable solution to the problem of excess sediment deposition.

In such cases the proponent should weigh up the risks of the continued sediment deposition and potential risks for erosion and/or increased flooding that this may present, against the ecological risks, ongoing maintenance costs and risks of erosion posed by sediment removal from the channel.

In this chapter, five options for managing sediment are presented. These are:

1) Do nothing
2) Remove invasive vegetation
3) Remove mid-channel bars
4) Excavation of the river bed (widespread removal of sediment), and
5) Using weirs to trap sediment.

CROSS-REFERENCE TO THE RIVER REHABILITATION GUIDELINE

IMPORTANT POINTS FROM THE GUIDELINE

- Thought must be given to what extent rehabilitation is required. Refer to the Guidelines document for "*Philosophy and aims*" (Section 1.1), "*River Dynamics*" (Section 2.4) and "*What is rehabilitation?*" (Section 4).
- An interdisciplinary approach is needed to understand the drivers of river instability causing the bank to erode, and what to do about it (section 2.1 "*The need for an inter-disciplinary approach*").
- Understand the erosion mechanisms (section 3.4 "*Erosion*") and consider typical problems in rivers (section 3 "*Problems in rivers*") to help correctly identify the source of the problem.
- The reader must be aware of an appropriate scale of remediation. Think about the scale of the problem versus the site where problems are being seen – refer to "*River Dynamics*" (Section 2.4).
- The reader must be aware of legislative requirements for working in water courses (section 10 "*Legal authorisations necessary for river rehabilitation*").

6.1. Do nothing option

"Do nothing" is an option which should always be considered with every proposed intervention. Doing nothing may have little risk associated with it if:

- the amount and location of sediment deposition is within the natural range and location (such as bars in a naturally braided river reach, or river bed aggradation in a natural depositional river reach)
- the rate of deposition of the bars or on the bed is low year on year, and thus impact on floods is marginal
- there is no risk of damage to nearby infrastructure, or curtailment of economic activities, if the deposition continues

Consideration of a hands-off approach and development of a scenario of what would happen if no intervention is undertaken is important to determine the level of urgency of rehabilitation intervention. This is a key consideration when comparing and prioritising a series of sites and, through understanding the risks, identify appropriate rehabilitation options for the highest risk sites.

Doing nothing may however result in:

- further ecological degradation at the site if the sediment deposition is smothering habitat or causing river bank erosion
- sediment starvation to downstream reaches if sediment is being trapped in a reach due to excess vegetation growth
- increased flooding risks for the site
- direct damage to roads, fields, housing and other infrastructure located along the riparian zone or within the floodplain if excess flooding or bank erosion occurs
- economic and social costs where the flooding damages infrastructure or prevents economic activities

These potential risks should be weighed up against the costs of intervention and the risk of non-intervention.

6.2. Removal of invasive vegetation

Invasive vegetation plays an important role in sites where sediment is perceived to be a problem. Invasive vegetation in the channel and in the riparian/flood zone causes increased flow resistance and this causes:

- Raised flood water levels directly in river channels (the increased resistance of vegetation causes the flood waters to flow slower and go higher up the banks);
- Through the decreased velocity of flows, more sediment is deposited (when water slows down, sediment is deposited) and patches of invasive vegetation thus trap and cause deposition of sediment within the vegetated patches as well as downstream in the lee areas of the vegetation patches. The increased sediment reduces conveyance and raises flood levels;
- Patches of invasive vegetation also divert flood waters away from themselves and towards the opposite bank. This can initiate new areas of erosion, and the eroded sediment becomes deposited downstream.

Environmental legislation

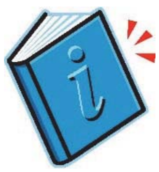
- The removal of alien vegetation does not trigger the need for environmental authorisation in terms of the NEMA regulations, providing that not more than 5 m^3 of soil or rock is disturbed in the process
- The Water Act does not require any authorisation for the removal of invasive alien vegetation. In fact, alien invasive vegetation reduces water availability in catchments (alien vegetation is generally much “thirstier” than indigenous vegetation), so its removal increases flow in rivers and should be encouraged wherever possible.
- The Conservation of Agricultural Resources Act (CARA) would be contravened if a landowner leaves or allows an obstruction in the river which could lead to soil loss (i.e. if alien trees are felled and left in the river in the path of floods).
- Refer to Section 10 of the Guidelines: “*Legal authorisations necessary for river rehabilitation*”

Simple removal of invasive vegetation, especially alien invasive trees, from river channels and the entire flood (riparian) zone will increase river conveyance, increase flood velocities and thus increase the ability of the river to transport the sediment through the reach. Often the invasive vegetation plays a key, if not determinant, role in the problems being experienced within a river reach. Refer to chapter 2 of this document for detailed methods on invasive vegetation removal techniques.

TECH TIP

Manage sites cleared of invasive vegetation

A river site that has recently been cleared of vegetation will be more susceptible to erosion until indigenous vegetation has had a chance to re-establish. Mitigation is possible through actively planting locally indigenous vegetation appropriate to the cleared river zones (see Section 12); in some cases, leaving the roots of cleared plants in the soil (provided that this does not prevent rehabilitation measures such as reshaping of banks); planting an annual, sterile, cover crop, and irrigation of cleared areas to speed up regrowth of planted indigenous species.



CROSS REFERENCE

Various methods for the removal of alien vegetation are described in detail in Section 2 of this publication.

6.2.1. Case studies

Case Study Number 15 (“*Alien vegetation removal and management of degraded channels in agricultural areas the Vier-en-twintig Riviere system*”) describes a reach-wide invasive alien vegetation clearing project.

6.3. Removal of mid-channel bars (individual site scale)

Sedimentary deposits in the centre of the river channel are often linked to erosion of the river banks. These bars can divert flows from the centre of the river channel to the outer edges and banks of the river, sometimes initiating erosion. This is more pronounced when the mid-channel bars become infested with dense vegetation, especially if the vegetation is dense invasive trees. In addition to their larger stature, trees also tend to trap debris during floods, strongly enhancing the flow resistance and diversion of flood waters to the banks. However these risks should be weighed against the ecological benefits of instream bars.

THINK GREEN

Bars and secondary channels are important ecological habitats

Often the backwaters and secondary channels provide important habitats for instream biota – secondary channels are important for juvenile fish and bars provide protected resting and nesting areas from predators. The small bars and riparian vegetation slow down flood velocities, increasing flood attenuation and sediment deposition. These physical environments and their associated ecosystem services are reduced or lost during the removal of mid-channel bars and the straightening and deepening of river channels. Unless the risks are absolutely unacceptable, bars and the secondary channels which they create should as far as possible be left to remain in river systems for the benefit of instream ecology (especially fish habitats).

6.3.1. Advantages/disadvantages of this option

Where instream bars are present and present a problem in terms of flood management or erosion on the banks, ***the first step should always be to control or remove the invasive vegetation, but wherever possible, leave the lowlying bars in place.*** Invasive alien vegetation within a channel always presents a higher risk for flood conveyance than the sediment upon which the vegetation is establishing. Moreover,

1) Allowing the bars to remain in place but removing only the invasive vegetation is beneficial for the instream ecology, and
2) Allowing the bars to remain in place but removing only the invasive vegetation is cheaper (and much faster!) in terms of environmental authorisations. Removal of invasive alien vegetation does not, on its own, trigger the requirement for NEMA or NWA authorisations. However, as soon as sediment removal is contemplated, expensive and lengthy authorisations from the Depts. of Environmental Affairs and Water and Sanitation will be required.

When it is essential that the sediment is also removed from the channel, lengthy environmental authorisations will be required from the Dept. of Water and Sanitation, and, if more than 5 m^3 of material is to be moved, then also (and separately) from the relevant provincial Dept. of Environmental Affairs.

Environmental legislation

- The movement or removal of more than 5 m^3 of soil (any river sediments, including cobbles and gravels) requires environmental authorisation in terms of the NEMA regulations.
- Alteration to the shape of any river or stream bed or banks, irrespective of the volumes which will be moved, requires authorisation in terms of the National Water Act.
- Refer to Section 10 of the Guidelines: "*Legal authorisations necessary for river rehabilitation*"
- **NOTE:** Any ***sale*** of sediment extracted from a river or stream will be considered as a mining activity, and a mining permit is required for such an activity. Refer to Appendix 1 of the Guidelines document for more information.

6.3.2. When is this appropriate?

In aggrading river reaches, or where large in-channel sedimentary deposits are forcing floodwaters to the outer edges of the channel and causing bank erosion and placing infrastructure at risk, effective management of the river reach may not be possible without some removal or reworking of mid-channel bars.

In such cases, some mitigation is possible through:

- Minimizing the disturbance footprint to as *small* and *short* (longitudinal distance downstream) an area as possible;
- Relocating the removed mid-channel bar sediments to other nearby locations within the reach through the creating small, low elevation alternating lateral bars attached the banks. These must be less than 0.5 m from the low flow water level in order to prevent impacts for flood conveyance, and these bars must be kept free of invasive alien vegetation. Also, if there are eroded banks nearby, the material could be used to repair these on a like-for-like basis. Reusing the removed sediment within the flood zone ensures that the sediment volume is still available during flood periods and the reach does not become starved of sediment during high flow periods; whilst maintaining low elevation bars prevents loss of flood conveyance functions.
- Only work on (at most) half the total channel width, or only one of the channels if the mid-channel bar creates two low flow channels. This will ensure a continuous and undisturbed section of river habitat remains in place for biota.

6.3.3. Case studies

Case Study Number 15 ("*Alien vegetation removal and management of degraded channels in agricultural areas the Vier-en-twintig Riviere system*") describes a reach-wide invasive alien vegetation clearing project.

6.4. Excavation of the river bed (widespread removal of bed sediments)

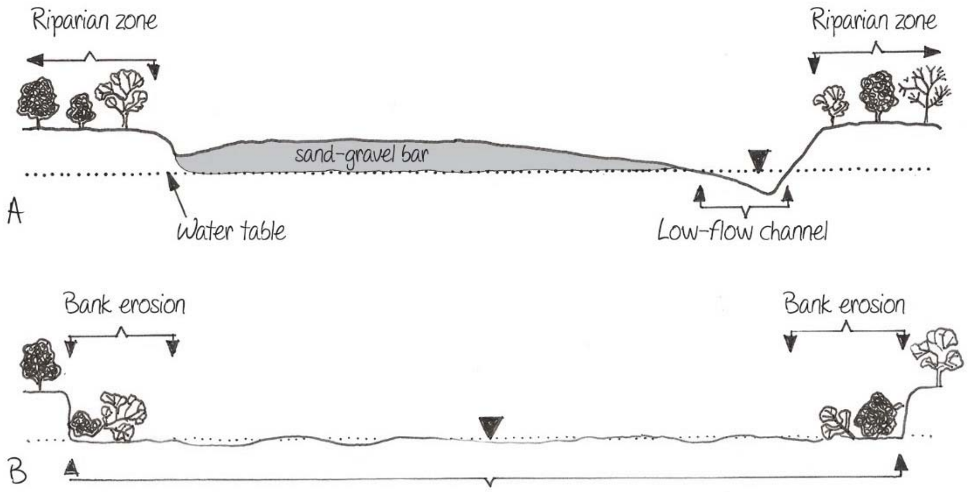
This option for sediment management describes the approaches of mechanical removal or reworking of large volumes of sediment from long (hundreds of metres or more) river reaches. Such activities are occasionally necessary in aggrading river reaches. Open cast, in channel or riparian sand mining operations could also be included in this category of river management options.

6.4.1. Advantages/disadvantages of this option

The disturbance to the river bed and banks is high during the sediment removal process, and the effects at the site can result in prolonged destabilization of the site, but this can be mitigated to some extent by keeping the thalweg unimpacted. Smaller areas of impacts will also be able to recover faster.

THINK GREEN

Minimise impacts and maintain the low flow channel



Wherever possible, when removing accumulated sand or gravel on the river bed, leave the thalweg (the deepest part of the low flow channel) untouched (top image). If the entire bed of the river is reduced to a uniform flat, wide channel (bottom image) the flows are spread too thinly and this causes sedimentation, shallow water and higher water temperatures which all reduce the habitat quality for fish and invertebrates. A defined low flow channel also allows vegetation to establish along its edges, and this stabilizes the low flow channel and helps to maintain and improve habitat quality.
(image: Adapted from Environment Agency, 2004)

Where very extensive sediment removal is being considered, impacts at a larger scale than just the site of impact can be affected. If the nickpoint (lowered bed level) migrates upstream and/or the sediment starvation (due to reduced sediment availability) zone migrates downstream (Figure 6.1), a far wider length of the river can be affected. The disturbance of the bed and erosion risks should be considered against improved flood conveyance and protection and maintenance of existing infrastructure and economic activities within the flooding zone.

Authorisations for large scale sediment extraction from rivers is costly, as are the necessary supporting specialist studies which the authorities are likely request. If any of the sediment extracted is to be sold, then additional authorisations from the Dept. of Minerals and Energy will be required as the selling of sediment is regarded as a mining activity.

Environmental legislation

- The movement or removal of more than 5 m^3 of soil (any river sediments, including cobbles and gravels) requires environmental authorisation in terms of the NEMA regulations.
- Alteration to the shape of any river or stream bed or banks, irrespective of the volumes which will be moved, requires authorisation in terms of the National Water Act.
- Refer to Section 10 of the Guidelines: "*Legal authorisations necessary for river rehabilitation*"
- **NOTE!!!:** Any ***sale*** of sediment extracted from a river or stream will be considered as a mining activity, and a mining permit is required for such an activity. Refer to Appendix 1 of the Guidelines document for more information.

Some of the impacts of sediment removal can be mitigated through reducing the footprint of the activity, and leaving the channel thalweg untouched (see text box below).

TECH TIP

Keep disturbance footprints to a minimum

It is essential to keep disturbed areas within the river and riparian (flood zone) area as small as possible, and to keep the frequency of disturbance as low as possible. This avoids the destruction of large areas of vegetation and minimizes the disturbance of river and riparian habitats. Smaller disturbance areas will rehabilitate/recover much faster.

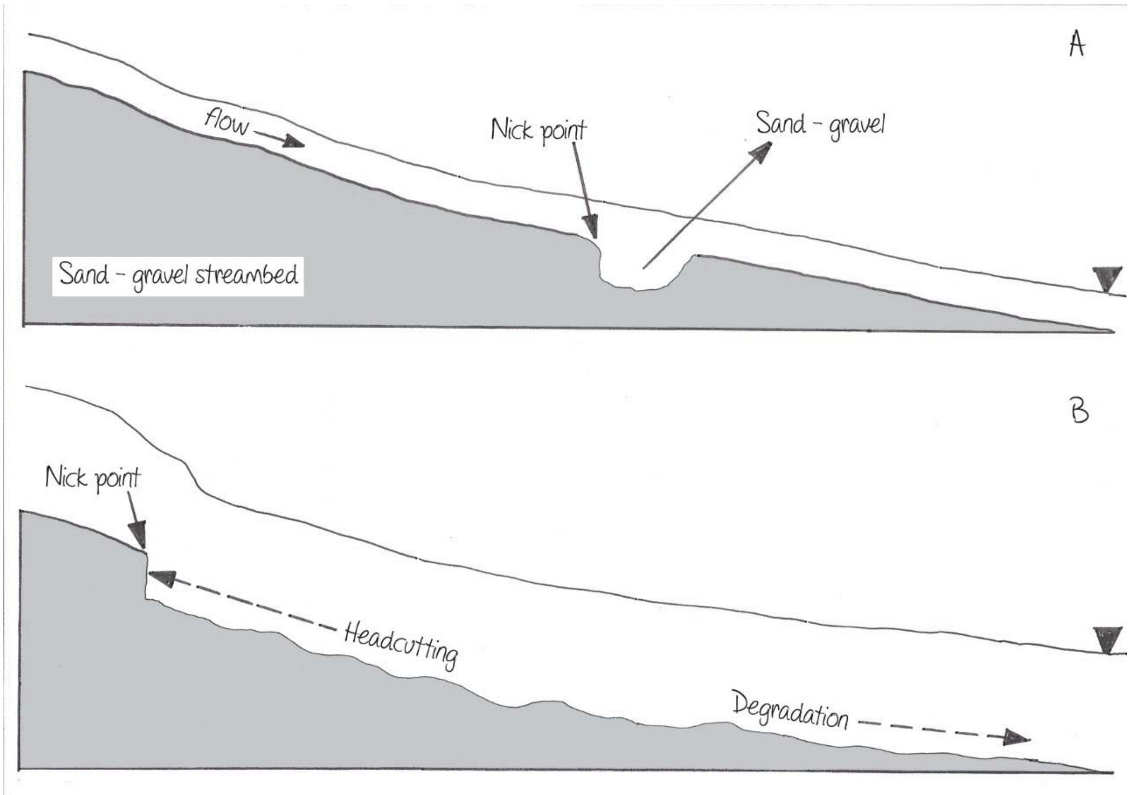


Figure 6.1: Excessive sediment removal from a section of river (as in A, top) can over time cause headcutting as a lowered river bed level migrates upstream, and cause a zone of limited sediment availability to migrate downstream, degrading the river condition, as demonstrated in B (adapted from Environment Agency, 2004).

6.4.2. When is this appropriate?

The consideration of this activity as a "rehabilitation" option for a river reach is not automatic and in fact ***large scale sediment removal should not generally be supported from an ecological perspective.*** Only in exceptional, specific circumstances could such activities be considered as a legitimate rehabilitation option, such as where:

1) Bed sedimentation is occurring over a prolonged period at an unnaturally rapid (possibly accelerated by high levels of upstream erosion in the catchment or upstream wetlands), smothering natural instream habitat types; ***and***

2) The ecological and/or socio-economic risks for adjacent landuse or infrastructure of the resultant reduced channel competency of this reach are unacceptably high.

These situations typically occur

- in urban areas, where high sediment runoff from developing catchments is deposited in to small remaining watercourses;
- in river reaches downstream of large eroding wetlands, and
- in agricultural areas where sediment deposition areas (the floodplains) have been cut off from the river and the only remaining place for the deposition of sediment is within the remaining narrow channels.

Sediment removal in urban watercourses

Sediment removal from rivers, streams and canals within urban areas is necessary to maintain the flood conveyance of these watercourses and thus reduce the risk of flooding and associated damage to human wellbeing and infrastructure.

(photo: M Rountree).

6.4.3. Case studies

Case Study Number 12 ("*Incising and aggrading river reaches: problems with agricultural development on an alluvial fan*") describes problems of river management in an aggrading river reach.

6.5. Weirs to trap high sediment loads

An alternative to the removal of sediment across long reaches in rivers where there is unnatural sediment loads and deposition is to build a dedicated sediment trap structure within the river channel. The construction of a dam or weir for the trapping of elevated sediment loads is a highly specialized undertaking.

6.5.1. Advantages/disadvantages of this option

The benefit of a dedicated structure for the trapping of excessive sediment deposition is that the disturbance footprint is minimized. Over time, the downstream reach will incise due to the reduced sediment loads, and excess sediment trapped in the weir would need to be removed occasionally.

The disadvantages of this approach are that:

- Weirs are costly, as are the necessary environmental approvals and associated specialist studies to obtain authorization;
- Weirs that trap sediment can result in excessive downstream erosion, and may thus end up initiating a larger and more costly problem than was initially being addressed (see text box below); and
- Weirs interrupt not only the movement of sediment, but also the movement of biota.

Environmental legislation

- The movement or removal of more than 5 m^3 of soil (any river sediments, including cobbles and gravels) requires environmental authorisation in terms of the NEMA regulations.
- It is likely that a full Water Use Licence Application (WULA) would need to be submitted to the Dept. of Water and Sanitation for the wire. Additionally, any alteration to the shape of any river or stream bed or banks, irrespective of the volumes which will be moved, requires authorisation in terms of the National Water Act.
- Refer to Section 10 of the Guidelines: "*Legal authorisations necessary for river rehabilitation*"
- <u>**NOTE:**</u> Any ***sale*** of sediment extracted from a river or stream will be considered as a mining activity, and a mining permit is required for such an activity. Refer to Appendix 1 of the Guidelines document for more information.

6.5.2. When is this appropriate?

Large weirs or dams for the trapping and ultimate removal of sediment from river reaches should in general not generally be supported from an ecological perspective. Only in exceptional, specific circumstances could a weir be considered as a legitimate remediation (but not rehabilitation) option, such as where:

1) Bed sedimentation is occurring over a prolonged period at an unnaturally rapid (possibly accelerated by high levels of upstream erosion in the catchment or upstream wetlands), smothering natural instream habitat types; ***and***
2) The ecological and/or socio-economic risks for adjacent landuse or infrastructure of the resultant reduced channel competency of this reach are unacceptably high.

6.5.3. Case studies

Case Study Number 12 ("*Incising and aggrading river reaches: problems with agricultural development on an alluvial fan*") describes a situation where the author of that case study recommended a large sediment trap be utilized to aid in the management of sediment.

Erosion downstream of sediment trapping weirs

A series of sediment-trapping weirs in the Princesskasteel watercourse in the Tokai Forest in Cape Town is thought to have contributed to the number and size of erosion headcuts in the downstream reach. These headcuts are likely to be associated with reduced sediment supply in the stream; which is at least partly attributable to the trapping of sediment in the weirs.

(photo: M Rountree).

References

Environment Agency (2004) Environment Agency Policy – The Removal of Gravel from Rivers, Policy Number 359_04. http://www.intertidalmanagement.co.uk/contents/management_processes/pdfs/risks%20benefits/359_04.PDF

Chapter 7:

Removal of weirs

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Introduction

In the southern African environment, numerous weirs have been constructed in rivers and wetlands to arrest erosion head cuts, limit the incision of the river bed, or as water extraction facilities for municipalities and farmers. Where such structures are incorrectly designed or placed, the structures may not only fail, but can also contribute to the instability of the river through enhanced downstream erosion. In addition, the areas impounded by weirs (as in the case of dams) alter the aquatic riverine habitat, creating lake-like conditions in formerly wetland or riverine habitats, and sometimes severing or at least interfering with migration routes for instream biota.

> **Weirs and indigenous fish**
>
> Ironically, the location of weirs on some rivers in the south western Cape has actually resulted in the protection of endemic fish species in upstream reaches, by preventing the passage of alien fish upstream. See Chapter 11.

As a result of the above issues, there is ecological motivation in some situations for the removal of weirs. The removal of weirs can also be motivated on economic grounds, with some weirs associated with high maintenance costs / efforts to remove sediment and the alien vegetation that invades such sediment (see Volume 1: Section 3.2 and Chapter 2 (this volume)), as well as the costs of repairing weirs, the function of which is no longer required (see Chapter 10.6 for discussion of the removal of weirs on the Goshen River, United Kingdom).

Review of information regarding the effectiveness of weir and dam removal

Because weir and dam removal is a relatively new technique, there is not extensive published literature on its effectiveness, though many of the benefits are inherently obvious (e.g. fish access and passage – but again, see caution regarding alien fish passage). Below we summarize the results of studies that have examined the effects of dam and weir removal on connectivity, processes, habitat and biota below the dam, and processes, physical habitat, and biota immediately above the dam.

The restoration of upstream-downstream connectivity and fish access is one of the most clearly demonstrated effects of weir and dam removal. Hart et al. (2002) summarized the results of several dam removal projects in the United States and reported more than 10 cases of dam removal that resulted in rapid colonization of former impoundment sites and upstream areas by both migratory and resident fishes in both warm and coolwater rivers. For example, dam removal on the Clearwater River, Idaho (USA) in 1963 reconnected the main stem, increasing both habitat quality and Chinook salmon runs (Shuman 1995). Similarly, removal of the 150-year-old Edwards Dam on the Kennebec River in Maine (USA) resulted in large numbers of American eel (Anguilla rostrata), alewife (Alosa pseudharengus), and Atlantic and shortnose sturgeon (Acipenser spp.) moving upstream within the first year, as well as juvenile downstream migrants in subsequent years (Hart et al. 2002). Smith et al. (2000) reported improved fish passage following removal of a 3 m high dam on a stream in Oregon (USA), but continued water withdrawal and other factors upstream of the dam prevented full recovery of both physical and biological conditions. Kanehl et al. (1997) also examined the effects of removal of a low head dam in the Wisconsin (USA) and found improvement in habitat quality, biotic integrity, and smallmouth bass (*Micropterus dolomieu*) abundance and biomass five years after dam removal. Clearly dam removal has a number of benefits for migratory and lotic fishes.

Downstream of dams and weirs that are removed, several major changes occur, the most obvious being a change in sediment and channel form due to a change in sediment flux. Several studies have demonstrated changes in sediment transport and fine sediment, but the changes in sediment depend upon the composition and levels of fine sediment trapped behind the former structure. For example, Doyle et al. (2003) examined low-head dam (<3 m high) removal in two Wisconsin rivers and erosion of fine sediment deposited in the former reservoir and increased deposition of fine sediment downstream. Hart et al. (2002) reviewed 20 dam removals in the US, 14 of which documented increased sediment transport, but few studies were long enough to document changes in the channel downstream of the dam. Other changes include a return to a more natural temperature regime, plant colonization, and a greater exchange of nutrients and organic matter with upstream portions of a watershed (Hart et al. 2002). Downstream effects from dam removal on ecological attributes ultimately depend on how reservoir-derived deposits move into and through downstream reaches (Stanley and Doyle 2003). Changes in downstream water temperatures also typically occur following dam removal as do shifts in the macroinvertebrate community (Hart et al. 2002). Whether temperature increases or decreases following dam removal depends on several factors including the previous operations and structure of the dam and reservoir.

Chisholm (1999) reported anecdotal evidence on the positive effects of 25 dam removals in the United States. However, he also provided information on one dam removal (Fort Edward Dam on the Hudson River in New York State) that is considered a failure because it released heavy metals and pollutants trapped in reservoir sediments, which continue to have negative consequences on aquatic resources downstream from the former dam site. In addition, increase in turbidity and sediment immediately following and shortly after dam removal are not uncommon.

Former impoundments are affected by dam removal because they are returned to river, riparian, and floodplain habitats (Stanley and Doyle 2003). This physical change reduces the residence time of water in a former reservoir reach, and subsequently reduces the amount of sediment and other materials stored within a reach. This in turn shifts the biota from a standing water (lentic) to a flowing water (lotic) system (Hart and Poff 2002). For example, fish and macroinvertebrates adapted to a high sediment supply reservoir environment gave way to riverine fish and macroinvertebrates within a year of two separate dam removal projects in Wisconsin (Stanley et al. 2002; Stanley and Doyle 2003). In a related study on the Baraboo River, Wisconsin, Stanley et al. (2002) found that within one year, macroinvertebrate assemblages in formerly impounded stream reaches were similar to those in upstream and downstream reaches. Clearly weir / dam removal will also result in changes in algae and other aquatic vegetation as well as riparian vegetation in the former reservoir sites (Hart et al. 2002; Shafroth et al. 2002). These studies demonstrate the dramatic changes in physical habitat and riparian and aquatic flora and fauna that follow weir /dam removal. They also suggest that there are some negative consequences of dam removal such as short-term channel instability or colonization of newly exposed riparian areas by invasive riparian species.

Cautions regarding weir removal

Despite the negative impacts of many weirs, their removal, as in the removal or decommissioning of dams, is a potentially major exercise and should not be undertaken lightly.

Potential negative consequences of injudicious weir removal include:

- Smothering of downstream habitats through the pulsed release (and increased overall) sediment loads as accumulated sediment from the dam basin is flushed downstream;
- Increased downstream flooding due to increased bed levels (aggradation from sediment influx) and (in the case of large weirs or small rivers) due to reduced flood attenuation functions;
- Release of contaminated sediments downstream (in the cases where sediment may be trapping pollutants, such as mine tailings); and
- Flush of nutrients and anoxic conditions associated with the mobilisation of accumulated sediments in the impounded area;
- The free passage of undesirable species (e.g. alien fish s) into river reaches into which they have not had previous access.

Recommendations for weir removal

The serious consequences for life, property and ecosystem function associated with removal of weirs mean that there are no circumstances where their removal can be recommended without a detailed structural, hydraulic , hydrological, geomorphological (sediment transport) and ecological assessment. Moreover, in South Africa, weir removal has not been carried out to any level that can inform this document regarding particular concerns and considerations that apply to the South African context. As a result, this document has taken a highly conservative approach to this aspect of river rehabilitation, concluding that:

Due to the high risks and specialist insight required, qualified environmental practitioners and engineers should be consulted prior to considering the potential for the removal of any weirs.

Environmental legislation

- Removal of a weir would trigger the need for authorisation in terms of the NEMA regulations, as it would include *inter alia* the movement or removal of more than 5 m^3 of soil (any river sediments, including cobbles and gravels);
- It is likely that a full Water Use Licence Application (WULA) would need to be submitted to the Dept. of Water and Sanitation for the activity in terms of the National Water Act.

Chapter 8:

Water quality improvement

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Introduction

Water quality can be a significant constraint in achieving effective rehabilitation of riverine ecosystems. While physical structures may stabilise erosion and prevent sedimentation, for example, if water quality is poor, the river is likely to support only the most pollution tolerant fauna and flora – often pest or nuisance species (see photo in **Figure 8-1**).

Unfortunately, water quality is often an aspect over which small landowners have little control. It is however important at least to be aware of the kind of water quality flowing through your site, and the degree to which it is likely to limit rehabilitation outcomes. Section 3.6 and Section 7.7 of the guidelines should be consulted for this kind of information.

This said, this section nevertheless provides a number of approaches that may be possible to implement, depending on the circumstances of the site, its position in the catchment, and the source and nature of pollution.

Figure 8.1: Bleached vegetation on a stream in KwaZulu-Natal following severe sewage pollution and assumed ammonia bleaching

Considerations when selecting rehabilitation approaches

This section of the manual outlines different approaches for improving river water quality – the degree to which each would be practicable in any particular rehabilitation project should be carefully considered, taking into account:

- The **type of pollution** – heavy metals, sediment, turbidity, salinity, freshness, nutrient enrichment, etc.;
- The degree of river water quality impairment (how polluted is the river?);
- The **source of pollution** – is it mainly a single source, or is the river affected by inflows from multiple sources of pollution?
- The **way in which pollution enters** the river – is it via point source inflows, or diffuse seepage or runoff, or both, or neither (for example, pollution is in the form of abstraction of fresh water inflows and resultant instream concentration of flows);
- The **position** of the site / reach in the catchment and the size of the catchment – is it high up in the catchment, where landuse controls might be exercised, or is it low down in a large catchment, where controls are unlikely to be achievable;
- The **extent** of the catchment under the **control** of the rehabilitating body – this indicates the potential to bring about change;

- The **effects** of impairment – does water quality threaten existing river function (e.g. is the survival or functioning of existing ecologically desirable plants or animals threatened by water quality; are undesirable plants or animals encouraged by existing water quality (e.g. alien aquatic plants); are future rehabilitation objectives unlikely to be met as a result of poor water quality?);
- The **feasibility / costs** of achieving **measurable** water quality improvement;
- The **likelihood** that **river condition would be improved / realistically improvable** if water quality was improved – that is, is water quality a limiting factor on measurably improving river condition, or are other impacts too permanent and too significant (e.g. canalised system with no space for canal removal);
- Would **downstream systems**, for which rehabilitation is desirable, improve measurably if water quality was addressed?
- Would water quality improvement remove existing threats to downstream systems of conservation or rehabilitation importance?`
- What is the **scale** of the problem? Is it achievable at the level of the site, or is it an issue that must be taken up at a catchment level, or in terms of policy and legislation?

Catchment activism …
In urban areas, most of our rivers are polluted by treated effluent, which alters their flow patterns and water quality irrevocably. At the same time, many of our large rural rivers have been abstracted from, to supply urban and agricultural areas, and so generate the problematic effluent. Re-use of effluent should be a matter of course in South African cities … and yet it is something that with a few exceptions, we largely shy away from. Did you know that re-use occurs in Windhoek, London and many more major cities?

Decision-making around the need for / approach to water quality rehabilitation

The following steps should be taken in any rehabilitation project, before deciding on the need to embark on a water quality amelioration project, or the risks / costs of not doing so:

1. Characterise the river's water quality, drawing on information provided in the Guidelines (Section 3.6) as well as **Table 8.3** in this section, as to likely indicators of particularly problematic variables (e.g. excessive algal growth, blanketing sediments, unnatural salt crusting, organic sediments);
2. Identify (if possible) the source(s) of variables of concern – useful approaches could include:
   a. using GOOGLE Maps imagery to identify changes in landuse that might be linked to changes in water quality;
   b. walk upstream along the river banks, and look for pipe inlets or visible signs of changes in water quality (plumes of discoloured water, erosion, seepage from irrigated lands, leaking pipes or overflowing manholes);
3. If this somewhat subjective process suggests particular water quality problems, or you have other reasons to suspect poor water quality (e.g. smells, discoloured water, dead fish or bleached plants, vigorous plant growth, presence of black, foul-smelling muds / organic sediments and in extreme circumstances, the presence of deformed aquatic organisms (e.g. frogs and tadpoles) then consider any of the following:
   a. if visibly or potentially polluted point source inflows are apparent, request assistance from local DEA/DWS officials in their analysis and policing ;

b. investigate whether there are diffuse/catchment wide sources of pollution, what these are likely to be, and whether water quality has degraded significantly over time (speak to longtime residents, DEA, DWS or nature conservation officials);

c. Ideally, obtain one or a series of water quality samples using the sample collection guidelines presented in the information boxes below, and have these analyzed at an approved laboratory to determine the water quality conditions of the river. Although expensive, these results will show the current condition of the water quality and can be used to highlight problems.

4. Consider the water quality that the river of concern would be expected to display in its natural (or "reference") condition, remembering to consider seasonal variability in water quality too, usually as a result of wet season dilution or temperature differences – ask an aquatic specialist for assistance, or consult River Health Programme documents or personnel for assistance / information;
5. Compare water quality data obtained from laboratory analyses with expected reference conditions, and highlight areas of concern
6. Assess the degree to which water quality amelioration is realistically achievable, and consider the importance of doing so – consultation with local Dept. of Water and Sanitation representatives may be useful;

Consider the options in Table 8.1 (this section), with regard to the site / river reach in question.

Collecting water samples for analysis at a laboratory

If water samples are collected from ill-chosen sites, not collected properly, stored or transported incorrectly (or over too long a period) or not analysed at a competent laboratory, results may be meaningless and waste of money and time will result.

Use the following basic steps to guide you in sample collection and analysis:

- Consult a selected, reliable (preferably accredited) laboratory before you collect your sample, and find out what volume is required, particular precautions to take when sampling for certain variables (e.g. chlorophyll-a samples must be stored in a blacked-out jar away from light) and whether the laboratory has capacity to analyse the sample before its storage time expires – in the case of *Escherichia coli* bacteria, for example, samples should ideally be analysed within 6 hours of collection., and no later than 24 hours after collection;
- Source sterile bottles for sample collection – new plastic bottles, capped in-store to prevent contamination, are a good option. To ensure sufficient sample, collect in at least 1 L bottles, and if sample is important or sourced from a distance, collect a spare sample as well;
- Select the sampling point with care – as a general rule, river water samples should only be collected from sites where there is at least trickle flow – that is, the water should not be stagnant (look for signs of slow flow, such as slowly moving leaves, twigs or sediments);
- Ensure that you consider point- and diffuse-source inflows when deciding on the sample point – you may wish to include or exclude their influence, depending on the reason for sampling;
- Label the bottle carefully, using a permanent marker;
- As a protocol, rinse the inside of the bottle and its lid three times in the water to be sampled before collecting the actual sample. As a precaution, use gloves or a sampling pole if you suspect the water is contaminated, and keep antibacterial waterless handwash in your sample kit, to use after sampling;
- Fill the bottle to three fingers from the top, especially if it is to be frozen, to prevent the bottle cracking. While filling the bottle, stand downstream of the bottle, and ensure that you do not stir up sediments that will be entrained into the sample;
- Seal the bottle, and place in an iced cool box;

- Transport to the laboratory as soon as possible, or store as directed by the laboratory;
- Consult a river ecologist or water quality specialist for help in interpreting the results received.

What variables should be included in analysis?

Water quality analysis can be costly, and the concentrations of variables should only be determined if the data will add value / information to the investigation. Unless specific concerns prompt the need for a more detailed suite of variables, the following variables usually provide adequate information to understand the main water quality issues at a site (at that moment!):

- Total phosphorus
- Soluble reactive phosphorus
- Total ammonia and “free”or unionized ammonia, at a particular pH and temperature;
- Total inorganic nitrogen (TIN) OR nitrate and nitrite nitrogen, which can be added to nitrogen in total ammonia to estimate TIN
- Total suspended solids (TSS)
- pH – best measured in the river with a portable field pH metre
- Electrical conductivity (EC)
- *Escherichia coli* bacteria – note that rapid transport to the laboratory time is required for this variable, and some laboratories do not take in *E. coli* samples on Fridays or even Thursdays, as there is no time to process them before the weekend.

Approaches / activities included in this section

This section provides conceptual approaches to addressing water quality impacts from various perspectives, as follows:

- Approaches applicable to addressing specific water quality variables of concern;
- Addressing pollution at source; Managing point source pollution problems;
- Managing diffuse sources of pollution;
- Instream approaches to addressing water quality pollution.

These approaches are outlined in the following sections. Where relevant, case studies that illustrate particular aspects alluded to in the text have been flagged – these are presented in Volume 3 of the River Rehabilitation Manual.

Environmental legislation

- Water quality improvement *per se* should not trigger environmental authorisation in terms of the NEMA regulations, and is specifically promoted in terms of the National Water Act
- However, where water quality improvement measures would result in disturbance to the bed or banks of the river, or to a natural wetland, or to the diversion of flows from a water course, the above legislation could be triggered.

Identifying and addressing specific water quality issues

Once the landowner / rehabilitation body has identified the water quality constituents that are of main concern (see later), there are a number of approaches that can be taken to addressing these concerns. A selection of these are outlined in **Table 8-2**, for common variables only – but it is emphasised that this table should be read in conjunction with information provided in subsequent sections in this chapter, which are based on measures to address sometimes generic poor water quality. In some cases, it may be sensible to draw on approaches from several of these sections.

Table 8.1: Descriptions of interventions and approaches used to improve habitat quality and biodiversity (note: cost estimates are relative only and likely to vary widely on a scale- and site-specific basis).

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
1. Do nothing option	No gains – may waste opportunities	None	None – unless wasted funding opportunity	Consider this option if ecological gains from interventions minor compared to costs / effort
2. Increasing habitat diversity in unlined, but channelised rivers				
2.1 Removal of alien vegetation	Positive if carried out properly	None – notify authorities	+ (R4k-R15k/ ha)	Long-term maintenance usually required; Stabilisation of cleared areas necessary
2.2 Management of invasive indigenous vegetation	Management often symptomatic and usually needs to be ongoing – ensure that natural function is not being destroyed by process	NEMBA; NEMA, NWA	+	Make sure that implications of removal are clearly understood
2.3 Reshaping and planting of banks with guidelines around the selection of plants for these purposes	Good ecological option	NEMA (if > 5 m^3) NWA (21c and i)	+ - ++	Check that infrastructure not threatened
2.4 Creating riffle/pool sequences	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i)	+ - +++	May have low real ecological impact and will probably require ongoing replacement; check water quality impacts do not negate habitat diversity impacts
2.5 Other interventions				
Creating pools	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i)	+	
Creating instream rock and boulder habitat			+=++	
Rehabilitating or recreating meanders	Usually good ecological option		+-++++	Needs land and high levels of

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
				technical input
2.6 Creating artificial valley bottom wetlands	May provide useful ecosystem function and amenity value n otherwise sterile usually urban landscape		+-+++	Needs land and high levels of technical input
3. Increasing habitat diversity in lined canals				
3.1 Adding hydraulic diversity and providing instream cover	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+-++	Hydraulic implications must be checked
3.2 Creation of planting ledges in canals				
Retro-fitting canals with planted gabions	Adds habitat diversity to highly degraded usually urban systems	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	++	Hydraulic implications must be checked
Retrofitting canals with ledges stabilised with airblock, brick or retaining block walls			+-++	
Use of bagwork and pilings			++	
Use of floating vegetated islands	Not recommended for rivers		+	
3.3 Canal removal and/or daylighting of piped river flows				
Partial canal removal – Diversion of canalized low flows	Recommended where possible; full or partial canal removal preferred	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+++	Hydraulic implications must be checked
Partial canal removal – removal of canal base and / or walls and the establishment of plants and rock substrate	Excellent approach where technically feasible and where water quality not major issue		+++	Hydraulic implications must be checked; Water quality issues may over-ride benefits of habitat creation; Should be reconsidered when through area with poor servicing and high levels of poverty

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
4. Improving floodplain and off-channel habitat function and diversity				
4.1 Retain existing floodplain areas	Best approach	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+ (but lost development costs)	
4.2 Breaching levees	May provide limited opportunities for habitat creation and (importantly) prevents the need for erosion control structures in alternative confined channel		+	Hydraulic implications must be checked
4.3 Channel excavation to reconnect existing relict floodplains	Better option than 4.2 in terms of habitat improvement as provides active habitat reconnection		+++	Hydraulic implications must be checked; May provide useful urban stormwater attenuation and filtration options
4.4 Creating off-channel wetlands	Localised ecological value – may be important nodes in highly urbanized area		++	Hydraulic implications must be checked; Desirability of receipt of river flood water to be checked (in terms of quality and quantity / timing)
5. Improving habitat quality in existing erosion control structures				
Facilitating plant establishment	Best option in case where use of stabilising structures unavoidable	No additional, if approvals for structures already in place	+	Need for structures to be carefully motivated by engineers; Allowance for planting essential, unless size of structure small in relation to area rehabilitated (e.g. there is no need to plant a stabilizing weir)
6. Removal of weirs to rehabilitate aquatic habitat				

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
	May provide opportunities to redress past impacts of impoundment, sediment trapping and erosion – but should be carefully motivated and real ecosystem benefits should not be exaggerated	NEMA (if > 5 m^3) NWA (21c and i)	++-++++	Hydraulic and geomorphological implications must be checked; Effects on indigenous fish populations to be checked
7. Design and management of riparian buffer areas				
	Critically important aspect of river management and ensuring rehabilitation outcomes are sustainable	NEMA if excavations within 32 m of river bank outside of urban areas	+-++ (land costs)	Must be implemented and managed in the long term
8. Managing alien fish species				
8.1 Preventing alien fish introductions	Preferred ecological approach	Required in terms of NEMBA	+	Requires long-term education and consistent management / auditing / control effort
Managing aquaculture facilities	Important to prevent introductions where catchment not invaded already			
Protecting barriers to movement	Important where indigenous fish populations remain			
Education and Policing	Important and should be ongoing			
8.2 Alien fish eradication			+++	
Piscicides	Effective – but targets all gill-breathing fauna; highly specialist application	NEMBA; NWA; notify authorities	+-+++	Full ecological assessment and motivation required with input from multiple stakeholders

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
Manual clearing	Less effective but reduced indirect effects		+-+	including anglers, conservation authorities and river ecologists
9. Managing other alien fauna				
	Prevention is referred approach Conservative attitude required	Required in terms of NEMBA	+-++++	Requires long-term education and consistent management / auditing / control effort

Table 8.2: Symptoms of particular water quality problems and how to address them. This table to be read in conjunction with information in subsequent sections. (information adapted from Rutherford et al. 2000). See Section 3.6 in Volume 1 (Rehabilitation Guidelines) for discussion of why these variables can be problematic.

Water quality constituent	Problem Signs	Rehabilitation approaches
Nutrients – phosphorus and nitrogen	Excessive growths of algae in the channel, adhering to stones and even sediment in shallow water; Establishment of alien aquatic weeds (e.g. water hyacinth) in slow flowing deeper open water areas; Rapid rate of growth of reeds and other plants in shallow marginal areas; Algal blooms in slow flowing / standing water – the water will appear turbid or green with algal scums in extreme cases; Smells and/or accumulation of black organic scums on the river bed; In extreme cases of ammonia toxicity there may be visible fish deaths – usually though, fish death are attributable to low oxygen; Sustained extremely high levels of nitrites and (less commonly) nitrates can lead to deformities in frogs / tadpoles and affect fish and aquatic invertebrates ;	- Focus on nutrient removal at source; - Trap sediments entering the river (see section below) – phosphorus often binds to inorganic sediments (e.g. fine sands and clays) and can be removed with sediment; - Remove enriched sediments from in-channel weirs in dire circumstances (see Chapter 6) - Establish vegetated filter strips along seepage or runoff zones into the channel to improve water quality; - Harvest plant material to remove nutrients bound in plants – noting that most of the nutrients are usually in root / soil / microbe zones rather than in the stems and leaves, except in the case of floating (non-rooted) plants (usually aliens). (See Chapter 2 – alien control).

	Remember: ❖ There may still be nutrient enrichment downstream even if there are no signs of it at your site – particularly if it is a deep, fast flowing channel. ❖ Certain algal species occur to some degree even in low nutrient water	
Salinity  *Sarcocornia* spp. (above) are typical salt-tolerant plants.	- Very clear water, as high salts cause clay particles to drop out of the water column; - Presence of salt-tolerant species – e.g. *Phragmites australis* is more tolerant of brack conditions than *Typha capensis* - Visible salt crusts on the edges of channels, particularly ones with high seasonal variation in stream flow - Changes in water palatability and / or poor crop and/or livestock condition.	- Very difficult to address at a site scale - Usually requires catchment-level interventions that look at landuse practice and salt sources; - Preferential abstraction of freshwater inflows / tributaries may make naturally saline streams much more saline and this issue could be pursued with local authorities.
Toxicants	These may include heavy metals, un-ionised ammonia (NH_3), oils (hydrocarbons), herbicides and pesticides	- Heavy metals may be bound to sediments (but not all forms) and thus river beds, reedbeds and river sediments in contaminated watercourses should be handled with care as disturbance of the beds, banks, wetlands and sediment sorted in weirs can potentially remobilise otherwise stable contaminants; - Hydrocarbons should be separated out at source, using bunding and oil/ grease traps where possible; - Aeration may be effective where ammonia concentrations are elevated – this is most likely where pH > 8 (DWAF 1996) as the proportion of potentially toxic NH_3 : non-toxic NH_4^+ increases significantly as pH increases above 8.
Turbidity and fine sediments	Most river systems have some fine material (silt, mud) included in their habitats.	- Addressing sources of turbidity / fine sediment (usually erosion) – this usually requires

	However, if silts or muds blanket the stream bed, completely fill in the spaces between cobbles and gravels, or smother plants it is likely that turbidity and/or fine sediments are a problem in the river reach. Suspended sediments can also be visually recognized to some degree, as a cloudy or murky layer, although depth does influence perception and such assessments are not accurate. - Remember that the volume of suspended sediments can vary enormously, depending on flow velocity and volume. Also – too little sediment can be as bad as too much, leading to channel. - You need to be able to distinguish between high-flow and low-flow sources of turbidity .	catchment level interventions and is beyond the scope of this manual, but in small catchments, or high up in the catchment, this may be more feasible. A survey of the river in conditions of high flow and low flow may be useful to identify sources of sediment, using water turbidity as a guide, and noting that at times, single road crossings or runoff from un-contoured agricultural areas may be the main cause of turbidity. In such cases, remedial action would include provision of vegetated buffer strips (see Section 10.7); - Sediment trapping upslope of the river / stream, using devices such as buffer strips and sediment traps (see Section 10.7 and Chapter 3), noting that sediment traps are less effective for fine sediments (especially clays) and other approaches (e.g. dams, detention ponds and vegetated buffer strips) may be more useful for addressing suspended clays; - Sediment trapping within the stream – such approaches may include vegetation of eroded channels; widening of artificially narrowed channels to accommodate shallower flows at lower velocities conducive to sedimentation; encouraging the growth of reeds in channels to trap fine sediment, construction of sediment dams or traps. Of these, the latter would not usually be recommended instream, but would be useful in addressing sediment in inflows.
Low dissolved oxygen	- In severe cases, fish gulping at the water surface or fish deaths may occur; Signs of nutrient enrichment (see above) particularly black muds in shallow, warm water; Inflows of known nutrient enrichment in warm conditions – e.g. downstream of waste water inflows;	- Ideally, address at source; - Create instream structures (e.g. low weirs) to aerate water (see Liesbeek Canal case study); - Plant the riparian zone to create shaded, cooler areas; - Design inflows of polluted water for maximum aeration – e.g. channel over rock-lined open channel, rather than piping).
Temperature	High temperatures: -Shallow, unshaded waters in areas with high air temperatures may be prone to overheating at times. - Effluent inflows may have high temperatures. Low temperatures – Often from deepwater discharges from	- Address warm effluent inflows at source, or by extending time to discharge; - Plant the riparian zone to create shaded, cooler areas – usually using indigenous species (see Chapter 12); -Where a significant problem, dam design may need to be considered – this is only likely to be feasible if dam undergoing upgrading / structural maintenance.

	large dams. **Note** High temperatures may occur only during short periods of the day, but may result in oxygen reaching critically low thresholds	
Acid mine drainage		- Ideally treat through a centralised treatment facility whereby the mine water levels are maintained below the point/s of decant. - Treatment at the points of decant is the next best option, but probably more expensive and difficult to manage due to more numerous and potentially unpredictable localities of decant points; - All of these options require specialist technical input.

INFO BOX

Natural seasonal (or even daily) temperature changes can be important cues for many biological processes, like spawning (e.g. some fish), egg laying or pupating (seasonal invertebrates), upstream migrations (some fish)). Changes in seasonal temperature regime, or altering temperature ranges, can have profound impacts on aquatic ecosystem biodiversity. Such changes can occur as a result of deepwater releases from dams, climate change, discharges of cold or warm water into rivers; abstraction (and therefore reduced water volumes), shading as a result of alien vegetation, heating as a result of loss of indigenous plants.

Approaches to improving water quality

8.1. Addressing water quality at source

Treatment at source is generally accepted as the most effective means of addressing water quality concerns (King *et al.* 2003), and may require a catchment-scale approach. For individual landowners / local residents or activists, such approaches are often best brought about through the application of political or legal pressure on authorities, often through interest groups, environmental forums, etc., and motivating towards:

- Addressing sources of erosion as a result of poor landuse practices (e.g. runoff from ploughed slopes; runoff from developments under construction – particularly those on slopes);
- Ensuring that Best Practice measures (e.g. passage to sewers) are applied at a catchment level to sources of contaminated runoff (e.g. industrial effluent, sewage effluent, runoff from livestock feedlots, agricultural waste);
- Enforcing control measures to prevent seepage of contaminated groundwater into rivers (e.g. incorporation of sealing of contaminated areas, bunding, cutoff diversion drains);
- Discouraging practices that require the application of excessive fertilisers / insecticides / herbicides and encouraging the use of applications that are proven to have low levels of environmental impact, particularly with regard to aquatic ecosystems;
- Encouraging the responsible re-use of treated sewage effluent, rather than its discharge into rivers;
- Exerting pressure on local authorities to improve levels of sewage and solid waste collection and servicing in residential areas, such that high density settlements are achievable without the associated high levels of runoff pollution – measures to address these issues should include
    - Attention to housing design, either so as to prevent or manage backyard settlements – these are often unserviced in practice, and should either be designed to prevent the erection of backyard structures or such that backyard structures are also fully serviced in terms of sewage, water and stormwater connections;
    - Attention to bulk infrastructure, so that it allows for the increased sewage volume of backyard dwellers, over and above that of formal housing (e.g. if a single plot includes three additional backyard dwellings, the actual sewage volume produced would be threefold that allowed for in design for the single residence) – sewer size should be adjusted to the increased volume upfront, as retrofitting is often exorbitantly expensive;
    - Attention to the capacity of Waste Water Treatment Works, to ensure that adequate capacity exists for the increased sewage volume assuming the presence of backyard dwellers.

Critical as the above issues and approaches are, actual implementation of such approaches are beyond the scope of the present manual, which aims to provide some input into approaches that can be tried at the site or reach level.

8.2. Managing diffuse runoff

Inclusion of riparian buffer strips along and/or including the riparian zone of a river is recognised as an effective means of addressing seepage or diffuse surface flows into a river from contaminated areas (DWAF 2005, Rutherford *et al.* 2000, Bidenharn 1997, FISRWG 2001), noting however that it is unlikely that contaminated groundwater flows into a river would be addressed by such approaches, and moreover that buffers would not be effective in managing point source inflows into a river.

While buffers can be recommended to fulfil a variety of purposes, from provision of habitat and ecological corridors, to noise buffers or even recreational / amenity areas (see Section 10.3), the width of buffer required to address water quality contaminants derived from adjacent landuses depends on the type of pollutants, their concentration and the quality and characteristics of the buffer area itself, including its soil and vegetation type and cover (Semlitsch and Bodie 2003, Castelle *et al.* 1994, Day *et al.* 2008, City of Cape Town 2009b).

See **Section 10.7** for guidelines about the use and management of buffer areas.

8.3. Managing point source pollution

Point source pollution is defined as pollution that enters a stream or river at a defined location (Tourbier et al. (2004) EPA 1994) and includes sewage treatment plants, combined sewer overflows, sewer overflows as well as illegal dumping and illegal sewage connections. In South Africa, the most significant forms of point source pollution into rivers are from treated sewage effluent and urban stormwater runoff, contaminated in areas with a high component of so-called backyard dwellings and/or informal settlements by inflows of untreated sewage and grey water (Carden et al. 2007, Cerfonteyn and Day 2011). Other authors have linked high loads of heavy metals in river sediments to discharges from industrial waste and sewage effluent (Jackson et al. (2009) Hutchings and Clark (2009), as well as to runoff from livestock feedlots and waste disposal areas.

Measures to address such impacts could focus on:

- Source control measures (see Sections 8.1 and 8.2);
- Low flow diversions of stormwater into sewers or other specialised water quality treatment areas (Figure 8.2 and Volume 3: Case Study 18);
- Stabilisation of eroding areas contributing to sediment;
- Management of construction processes (including the implementation phases of rehabilitation works);
- Storage and treatment of wet season combined sewage overflows (Tourbier et al. 2004);
- The provision of oil and grit separators in stormwater systems;
- Passage of contaminated water through constructed wetlands;
- Litter and sediment traps in outflows upstream of rivers (see Section 6);
- Incorporation of Water-Sensitive Urban Design (WSUD) approaches for the treatment and management of stormwater runoff in urban areas (see Box 8.2).

Figure 8.2: Low flow diversion to the sewer from a tributary of the Berg River at Mbekweni mixed informal / formal settlement near Wellington in the Western Cape.

Water Sensitive Urban Design and SUDS (adapted from City of Cape Town pamphlet – 2011).

Water Sensitive Urban Design (**WSUD)** is an approach that seeks to draw together all aspects of the water cycle into city management and urban planning and design. It addresses:

- Precipitation (rainfall) – managed through the stormwater system with its flood and flow controls;
- Water supplies – usually supplied from rivers, groundwater or dams (ultimately precipitation-fed);
- Natural aquatic habitats and water courses – require water quality and other controls
- Sewage – domestic water supplies pass into the sewage system and thence into rivers, groundwater or the sea, often affecting water quality and natural flow regimes;
- Re-cycling of water – this entails re-use of water, sometimes with additional treatment being required first.

SUDS (Sustainable Urban Drainage Systems) are a component of WSUDS approaches. They are a sequence of water management practices and facilities designed to drain surface water in a more sustainable manner than conventional water piping or canalisation. SUDS practices involve preventing pollution and reducing the effects of catchment hardening through practices such as adequate waste management, rain harvesting and creating areas where rain water can sink into the ground rather than running into pipes. SUDS facilities

8.4. Instream approaches to addressing water quality pollution

While most studies stress the importance of addressing water quality issues upstream of the receiving water body, some measure of water quality amelioration (i.e. improvement) does occur in water courses themselves (Davies and Day 1998), provided that the level of pollution is not too high, and that there is sufficient physical and biological diversity to perform such services. Kotze *et al.* (2008) for example tabulate ecosystems services that are likely to be performed by different wetland types, including floodplain and valley bottom wetlands. Services such as sediment trapping and (as a result) phosphorus and heavy metal deposition, as well as nutrient uptake would be expected to be performed to various degrees by such systems. However, while the above processes may be taking place, water quality improvement may not be measurable where the loading of these nutrients exceeds the capacity of the system for treatment or uptake (Day and Ractliffe 2002).

Natural water quality amelioration also occurs in channelled river systems (i.e. not simply in vegetated valley bottom and floodplain systems) with distance downstream of a pollution source. This can be attributed both to dilution from cleaner inflows from the catchment, but also the result of natural instream biological processing.

Other instream technologies for water quality improvement include:

- Sediment traps (with designs such as sediment fences (RRC 2002) as well as natural instream reedbed systems (Tourbier et al. 2004) addressing issues relating to sediment control – see Chapter 6 for technical input into instream sediment trap design;
- Revegetation of eroding river beds, to address the sediments at their source;
- Controls on upstream or off-channel abstraction (leading to concentration of pollutants) and/or dilution of river flows (e.g. by passage of stormwater or treated effluent into naturally saline

Salty rivers can be natural !

Naturally brack or saline systems are often the least impacted, and can be readily rehabilitated. This is because their water quality is not valued for stock watering, irrigation or as a domestic water supply, and they are seldom dammed or abstracted from. Don't make the mistake of thinking that "freshening" them with fresher effluent, for example, will improve them. It will just cause species loss and degrade the system or brackish rivers);

- Establishment of plants along river channels, with the purpose of improving erosion control and/or increasing sedimentation and/or nutrient uptake (e.g. Volume 3: Case Study 16 (Langvlei Canal);
- Floating wetlands: various interventions purport to set in place floating or attached wetland systems in watercourses, with a view to improving water quality. Such devices may be useful in addressing water quality either by facilitating the harvesting of plants and their roots, and thus nutrients and other pollutants that have been taken up or trapped. Alternatively, or in addition, their most useful role may be in the creation of more complex structural habitat in otherwise ecologically sterile open water systems, thus supporting more complex ecosystems in which dominance by pest species (e.g. mosquitoes) is less likely.

Remember – it's a river

When selecting the most appropriate approach to address instream water quality, it is important to remember that no matter how appealing some approaches may seem from a water quality perspective, <u>they should not change the fundamental nature of the system you are working with</u>. It should still be a river after the intervention, and not a pond, dam, artificial treatment works or fountain!

While case study documentation of floating wetlands appears to indicate positive results when applied in canalised or otherwise artificial systems, <u>the implications of their introduction to South African water courses that have a large range between base and flood flow volumes, is questioned, as is their impact on natural river structure and function</u>.

This manual cautions that while these devices may address water quality concerns in some systems, their use should be strictly confined to artificial, off-channel environments. <u>They should not be used in rivers</u>. .

CROSS REFERENCE

- Water quality has implications for invasive vegetation (and can in turn be affected by alien vegetation) – see Section 2 of Volume 1 and Section 2 of this Volume
- Water quality in downstream ecosystems is also a consideration in planning for the removal of dams and weirs – as already discussed in Section 7 of this volume
- Water quality can have an overwhelming effect on the rehabilitation potential of rivers – and must be considered in planning for biodiversity rehabilitation and in particular, rehabilitation of fish communities and/or habitat (Sections 10 and 11)

References

Biedenharn, D., Elliott, C. and Watson, C. 1997. The WES Stream Investigation and streambank stabilisation handbook. Presented by US Army Engineer. Waterway Experiment Station (WES). Vicksburg. Mississippi.

Carden, K., Armitage, N., Sichone, O. and Winter, K. 2007. The use and disposal of greywater in the non-sewered areas of South Africa: Paper 2 – Greywater management options. Water SA, Vol. 33, No. 4, pp 433-432, ISBN 0378-4738.

Castelle, A.J., Johnson, A.W. and Conolly, C. 1994. Wetland and Stream Buffer Size Requirements – A Review. Journal of Environmental Quality 23: 878-882.

Cerfonteyn, M. and Day, E. (Liz). 2011. Improving the quality of the stormwater discharging into the Diep River, Milnerton. Final report to the City of Cape Town.

City of Cape Town. 2009b. Management of urban stormwater impacts policy. Roads and Stormwater Department: Catchment, Stormwater and River Management Branch.

Davies, B.R. and J.A. Day .1998. Vanishing Waters. University of Cape Town Press. Cape Town, South Africa.

Day, E. (Liz), Ractliffe, G. 2002. *Assessment of river and wetland engineering and rehabilitation activities within the City of Cape Town. Realisation of project goals and their ecological implications. Volume 1: Assessment process and major outcomes.* Report to Catchment Management. Cape Metropolitan Council. City of Cape Town.

Department of Water Affairs and Forestry (DWAF). 2005. A practical field procedure for identification and delineation of wetland riparian areas. Department of Water Affairs and Forestry, Pretoria, South Africa.

Federal Interagency Stream Restoration Working Group (FISRWG). 2001. Stream Corridor Restoration: Principles, Processes, and Practices. Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

Hutchings, K. and Clarke, B. 2009. Assessment of the effects of heavy metal accumulation from land based sources on the Diep River Estuary. Report to the Department of Environmental Affairs and Development Planning (DEADP) EADP14/2009.

Jackson, V.A., Paulse, A.N., Odendaal, J.P. and Khan, W. 2009. Investigation into the metal contamination of the Plankenburg and Diep Rivers, Western Cape, South Africa. Water SA: 35 (No. 3). ISSN 1816-7950

Kadlec, R.H. and Knight, R.L. 1996. Treatment wetlands. CRC Press LLC. Florida

King, J.M., ACT Scheepers, RC Fisher, MK Reinecke and LB Smith. 2003. River Rehabilitation: Literature Review, Case Studies and Emerging Principles. WRC Report No. 1161/1/03, Water Research Commission, Pretoria.

Kotze, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S. and Collins, N.B. 2008. WET-EcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report No. TT 339/09. Water Research Commission, Pretoria.

Rutherford, I.D., Jerie, K. and Marsh, N. 2000. *A Rehabilitation Manual for Australian Streams, Volumes I and 2*. Cooperative Research Centre for Catchment Hydrology and Land and Water Resources Research and Development Corporation.

Semlitsch, R.D. and Bodie, J.R. 2003. Biological Criteria for Buffer Zones around Wetlands and Riparian Habitats for Amphibians and Reptiles. *Conservation Biology*, Vol. 17, No. 5. pp. 1219-1228.

Tourbier, J.T., Gersdorf, I., Schwager, T. 2004 Urban River Basin Enhancement Methods. 5th Framework Programme, Key Action 4 “City of tomorrow and cultural heritage: Existing Urban River Rehabilitation Schemes. Work package 2. Final Report. Dresden University of Technology (TU Dresden)

Chapter 9:

Rehabilitation and flow regime

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CONTENTS

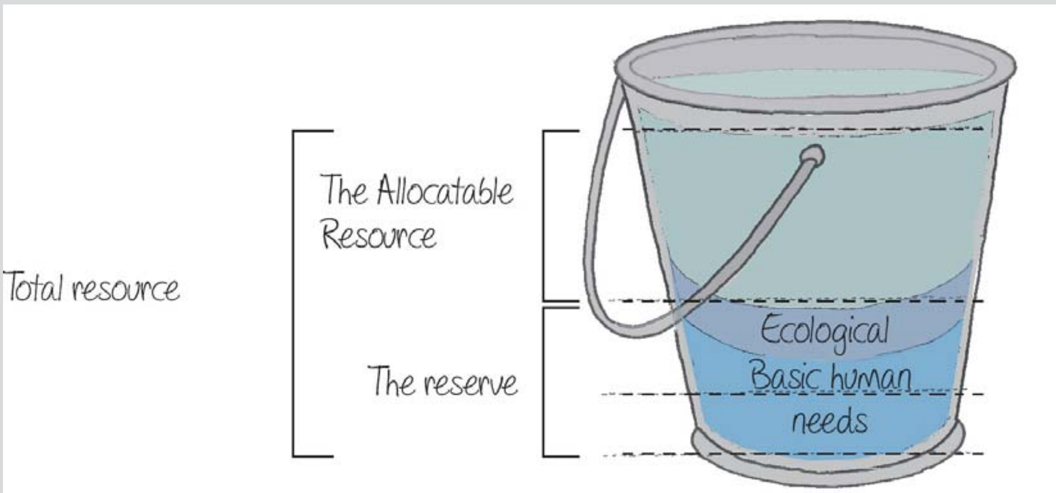
INTRODUCTION

Flow is the defining element of river habitats. Flow creates the patterns and processes commonly associated with fluvial environments and so strongly determines the physical (geomorphological), chemical and biological processes in rivers. It is considered the 'master variable' in river studies (Power et al. 1995, Resh et al. 1988, Poff et al. 1997). Not surprisingly, therefore, ***a crucial component of river condition is the extent to which its natural flow regime is maintained***. Re-instituting natural flows and sediment processes is thus an important part of effecting real river rehabilitation (USDIBR 2006), but, given the scale of flow alterations and often the presence of large dams, the full restoration of natural flow and sediment regimes will often be beyond what is economically and socially possible to achieve. ***Rehabilitation objectives must therefore take into account what is realistically achievable within the context of altered flow regimes*** in the system (Tourbier et al. 2004).

Environmental Flows and the Ecological Reserve

In South Africa, the right to water for the environment is guaranteed under the National Water Act. This means that a portion the flow in a watercourse be maintained in the system to protect and maintain key ecological functions and minimum flows upon which people are directly dependent. This portion of water is "reserved" to (1) sustain an accepted degree of ecological functioning (The Ecological Reserve) and (2) provide for the basin human needs for those people directly dependent on the river for water supply (see Box 9.1, below).

Box 9.1
Environmental flows and the Reserve



The Total Water Resource, comprised of the Reserve and Allocatable Resource.

Under the South African National Water Act, all water resources are considered to be an indivisible natural asset under the custodianship of national government. Thus there is no riparian ownership of water any more. The only right to priority of use is that of the 'Reserve', consisting of a 'Basic Human Needs Reserve' and an 'Ecological Reserve'. The Basic Human Needs Reserve ensures the water that is required by domestic users for drinking, food preparation and personal hygiene. The Ecological Reserve refers to "*the quantity and quality of water required … to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource*" (NWA, Ch 1, para. 1.(xviii)).

The process of determining the Reserve is a very scientifically technical and expensive process administered by the National Department of Water and Sanitation. The Reserve determination studies are undertaken at varying levels of confidence depending on available data and the importance of the water resource, with the result that each major river system in the country has a proportion of the flows reserved for the Ecological Reserve in order to maintain a particular Ecological Category or desired condition of river and associated ecological goods and service delivery.

The Reserve however only protects a small proportion of the flows; with the rest available for other water users such as irrigation agriculture, urban water supply, electricity generation and other water uses. These water users will increasingly compete for available water as the demands of urban areas increase and, through climate change, the reliability of rainfall and flows decreases. Landowners can have a direct impact on improving water availability through the removal and control of invasive alien vegetation. Invasive woody vegetation uses much more water than indigenous vegetation and reduces or can even completely dry up flows in small streams. Improved water use efficiency can also assist to improve flow conditions in our rivers by reducing water use demand.

The amount (magnitude) of flow in a river is important for instream biota (fish, other riverine fauna and vegetation), but so too is the timing (seasonality) of the high and low flows; the duration of the wet and dry flow periods; the frequency of high flows and small floods; and the rate of change between high and low flow periods (especially below large dams, where rapid reductions in flood flows can leave fish stranded on floodplains). The closer that these patterns of flow are to natural, the better chance the indigenous fauna and flora have to adapt to the changed flow characteristics.

CROSS REFERENCE

- See Volume 1: Chapter 2 for a discussion of the natural flow regime as a driver of the above riverine processes and functions, and Volume 1: Chapter 3 for a description of the implications of (*inter alia*) changes in flow regime for river function.
- See Case Study 1 in Volume 3 for an example of the problems of reduced flows and the scale of flow restoration in a large river system.

For any practitioner undertaking rehabilitation activities on a river, some understanding is necessary as to how the river flow regime has changed, in terms of:

- Magnitude of flows;
- Frequency of floods and low flows;
- Duration of the floods, wet season and dry seasons;
- Timing of floods and seasonality of low and high flow periods; and
- Rate of Change of any upstream releases.

The effects of flow changes on riverine fauna and flora, and on the biophysical structure of the river itself, may limit opportunities for rehabilitation at particular sites. For example, the reduction of large flood peaks may promote the invasion of vegetation (both indigenous and exotic – see Chapter 2 (this volume)) into the riparian zone and river channel; very reduced flows in the dry season (such as in the Western Cape, where rainfall is low and irrigation demands are high) may critically impact indigenous fish species and habitat restoration alone would not be sufficient to protect these species.

Setting realistic objectives for rehabilitation outcomes will thus be better informed by an understanding of how the natural flow regime has been altered in any river undergoing rehabilitation, and the implications of such changes for:

- Riverine fauna and flora;
- Short- and long term disturbance processes and associated river "maintenance" functions (e.g. flushing, scouring, channel formation);
- River morphology;
- Riparian quality and function; and
- Water quality.

> If inadequate flows present a critical limitation to restoration activities, the provincial Department of Water and Sanitation should be contacted to confirm the Reserve requirements (flow volumes and patterns) for the river.

Identifying rivers where the flow regime has changed

The following should be used to identify rivers where the flow regime has changed, noting that, except in rivers where there are no dams and limited agriculture, urban or mining activities across the whole river basin, most South African rivers have undergone some level of change in flow regime.

> Caution
> **Interpreting flow data**
> Flow data should only be interpreted by people familiar with the kinds of data provided and the limitations of data collection and measurement at the particular gauging station.

- Check to see if there is a flow gauging record for the river. DWS gauging weir records are available online for easy download (https://www.dwa.gov.za/hydrology) and where long records of many decades exist, trends of the changes in flow can be identified. Contact your regional DWS office to enquire or check the DWS website;
- Look at recent Google Earth imagery of the catchment, and look for dams in the catchment or large dams on the river itself. Small earth farm dams on their own have limited impacts on flow, but if there are many in the catchment, the cumulative impact can be large. Large (cement) dams on the main rivers can store large volumes of water and significantly reduce flood sizes and frequencies downstream, as well as alter the dry and wet season flow volumes, timing and duration.
- Look at historical aerial imagery of the river, and see whether it has undergone significant changes in alignment, size, erosion or depositional features consistent with changes in flow regime over the past few years to decades. For example, downstream of large dams the channel may have narrowed and/or been encroached upon by vegetation in response to smaller and fewer floods. Remember however that there are long term natural flood scour cycles within southern Africa (see section 2.4 of Volume 1).
- Research whether the river receives artificial flows from effluent releases, inter catchment transfers or irrigation releases from dams – Google Earth imagery may be useful in this regard as well;
- Have discussions with long-term landowners / neighbours regarding changes that have taken place in the river during their experience – remember however that humans remember events

over a few decades only – some important natural fluvial processes take place at a frequency of many decades to even a hundred years or more;

- Look for signs of frequent erosion or sedimentation, resulting in high levels of instream and floodplain damage and little recovery of natural vegetation between such events – this may indicate changes in flood size or frequency, indicating climate change effects and/or changes in the character of the upstream catchment such as loss of wetland vegetation (and associated roughness);
- Look at plant zonation on the river bank – does it suggest poor seasonal fluctuation consistent with controlled permanent releases? E.g. is the upper bank above the base flow largely dominated by terrestrial vegetation while the lower bank comprises dense perennial species that show no sign of periodic disturbance by stronger flows?
- Erratic flows, usually in rivers downstream of irrigation dam release points, characterised by sudden drops or rises in river height not linked to rainfall events and sometimes even tying in to a working week, with releases timed for Monday to Friday and the river drying up substantially over the weekend (e.g. some reaches of the Lower Orange River);
- High densities of invasive woody alien plants in the riparian areas and the catchment as a whole, likely to affect base flow volumes to a significant degree.

If consideration of the above questions and /or other factors suggests that the target river is subject to significant changes from its natural flow regime, the implications of these changes for river function and the constraints they impose on achieving significant rehabilitation objectives need to be understood, so that if necessary, rehabilitation objectives can be reformulated to embrace a more pragmatic and realistic outcome.

Identifying interventions that might affect flow regime

While the previous section highlighted how an altered flow regime might limit rehabilitation opportunities / outcomes, it is also noted that some rehabilitation interventions might have knowing or unknowing impacts on flow regime, the implications of which should also be carefully considered during early rehabilitation planning. Some examples include:

- Changes in river base flows – for example as a result of abstraction, diversion of stormwater or sewage flows away from a river, or alternatively, the passage of either into the river (see Chapter 10). The most extreme of this kind of effect would be changes in flows that affect river perenniality, changing seasonal rivers to perennial or vice versa (see Chapter 10). Removal of invasive alien trees might result in an increase in pre-intervention dry season baseflows, and significantly reduce depth to water table in naturally wetland areas abutting river channels;
- Changes in disturbance (flood) regime
    - too much disturbance (magnitude or frequency) may mean that the riverine ecosystem cannot recover between disturbance events, and thus never supports a fully functional ecosystem and gradually degrades; interventions that might promote

Water quality and flow regime

Remember that changes in flow regime will have knock-on effects on water quality – reduced flows (including as a result of drought) increase the concentrations of pollutants as well as natural dissolved salts in the water; increased flows (e.g. of stormwater or effluent) may reduce naturally saline systems, altering habitat quality. In some systems during drought, run of river flow comprises mostly treated sewage effluent !

such changes could include narrowing the floodplain, such that flood flows are concentrated through a smaller channel, at greater velocities;
  - too little disturbance could result in senescence (aging) of plant communities and the accumulation of fine sediment, algae and decaying vegetation in pools and backwaters, without the "resetting" function of floods that scour and flush these areas. Case study 17 (Langvlei) (Volume 3) provides an illustration of this effect.

The degree to which the above effects are either positive or negative from a river rehabilitation perspective depends on:

- The river rehabilitation objectives;
- The natural condition of the system – that is, whether the change is towards a more or less natural condition;
- The degree of change;
- The resilience of the system.

Legal considerations/authorisations

- Surface or groundwater abstraction above certain volumes controlled by NWA and requires licence / permit from DWS
- Flow diversions or storage require authorisation through a water use licence application (if on a wetland) or is generally authorised in terms of NWA GN 1199 but requires registration of use through NWA – consult local DWS officials in this regard;
- Removal of invasive alien vegetation required in terms of NEM: BA.

References

Poff, N.L.R., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C. 1997. The natural flow regime. *Bioscience*, 47: 769-784.

Power, M.E., Sun, A., Parker, G., Dietrich, W.E. and Wootton, J.T. 1995. Hydraulic food-chain models. *Bioscience*, 45: 159-167.

Resh, V.H.; Brown, A.V.; Covich, A.P.; Gurtz, M.E.; Li, H.W.; Minshall, G.W.; Reice, S.R.; Sheldon, A.L.; Wallace, J.B. and Wissmar, R.C. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society:* 433-455.

Tourbier, J.T., Gersdorf, I., Schwager, T. 2004 Urban River Basin Enhancement Methods. 5th Framework Programme, Key Action 4 "City of tomorrow and cultural heritage: Existing Urban River Rehabilitation Schemes. Work package 2. Final Report. Dresden University of Technology (TU Dresden)

USDIBR. 2006. United States Department of the Interior: Bureau of Reclamation. Erosion and Sedimentation Manual. Denver. Colorado. United States of America.

Chapter 10:

Improving Riverine habitat and Biodiversity

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Introduction

This section outlines various approaches for improving river biodiversity and habitat quality, including some approaches that are aimed at facilitating the long-term sustainability of riverine environments, by allowing for ecological buffer areas / corridors, and considering various land-use controls, such as on grazing / livestock access. It is however stressed that the options outlined in this chapter, whilst ideally any selected would have formed part of the natural habitat template of the system, in many cases are at best remediation, aimed at providing (often highly localised) improvement in habitat quality or function, usually in a highly modified, urban environment. Note also that the "options" described are not mutually exclusive, and several different approaches to increasing habitat diversity may be implemented simultaneously within a particular river reach. **Table 10.1** thus lists multiple possibilities, with information regarding their applicability to different situations and requirements, rather than presenting any kind of hierarchy of ecological desirability, as in the case of most of the previous chapters.

Many of the options included in this chapter can be used in conjunction with, or addition to, options for the rehabilitation of rivers affected by alien invasion (Chapter 2), erosion (Chapters 4 and 5), sediment (Chapter 6) or other problems outlined in previous chapters. Given that remediation approaches are themselves often opportunistic, this chapter also aims to highlight those approaches to erosion control, sediment and flood management in particular (Chapters 3 -6) that provide the greatest scope for enhancement of habitat quality, diversity or function in degraded transformed environments. Since an important part of river habitat quality depends on the management of longitudinal ecological corridors and the interface between the river environment and the adjacent landuses, recommendations for the design and management of ecological buffer areas have also been included in this chapter.

> Note that Volume 1 of this series (Rehabilitation Guidelines) should be consulted with regard to basic river ecological function and some of the key concepts that should be considered in rehabilitation design, planning and implementation.

Considerations when selecting options in this chapter

General principles

- Aim towards a more natural state – Interventions that aim towards taking a river to a level that is more like its natural condition will usually be more likely to achieve habitat quality and natural biodiversity objectives than those targeting an artificial condition.
- Increase habitat complexity in degraded rivers – Many real rehabilitation initiatives have the objective of actively restoring specific habitat types that have been lost as a result of various kinds of degradation or past interventions. Since one of the impacts of riverine degradation is often channel simplification, it follows that efforts to restore riverine habitat often focus on <u>increasing habitat complexity or diversity</u>. This can take the form of increased diversity in physical habitat, as well as in hydraulic diversity (slow, fast flowing areas, often achieved by varying physical habitat), and temporal diversity (e.g. seasonal changes in flow regime);

- Ensuring rehabilitation objectives are realistic by recognising rehabilitation constraints – It should be remembered that efforts to improve biodiversity by addressing physical habitat types at the level of a site or reach will not succeed if the river is significantly affected by over-arching problems of water quality, water quantity and flow regime, erosion or sedimentation, and such issues need to be addressed as part of over-arching rehabilitation approaches (refer to Chapters 3 to 6, 8 and 9: this volume). Alternatively, where a new and stable *status quo* has been established, and change to more natural conditions is either undesirable or not feasible, then rehabilitation or remediation efforts need to focus on interventions around this new state (see **Figure 10.1**).

Figure 10.1: The naturally seasonal Kuils River in the Western Cape has been permanently impacted by sewage effluent discharges, stormwater runoff and an (associated) elevated water table. These impacts mean that the river is now perennial and nutrient enriched and restoration to its natural condition is not feasible. Remediation measures that improve existing river ecosystem function and habitat quality and diversity are however quite feasible and could be pursued.

- Restore function and process rather than form. Although it is often much easier to implement individual in-channel structures, aimed at increasing a single component of habitat diversity, "ecosystem restoration" or "ecosystem management" approaches that focus on the chemical, hydrologic, and geomorphic functions of the stream corridor are much more likely to achieve real rehabilitation or restoration objectives that are measurable at the scale of a river or reach. Such approaches assume that communities will recover to a sustainable level if the stream corridor structure and functions are adequate.

Figures 10.2 and 10.3 (taken from Case Studies 16 and 17 respectively in Volume 3) illustrate the importance of process restoration over isolated habitat improvement. The interventions in Case Study 17 (**Figure 10.3**) provide at best rehabilitation of habitat type at a local level only, given that they apply to only a short distance of canalised stream only, while those of Case Study 16 (**Figure 10.2**) allow for rehabilitation of habitat type as well as river processes and connectivity, in that they allow for creation of a new system that mimics natural conditions at a significant scale.

Figure 10.2: Creation of a lowflow valley bottom wetland on the Langvlei Canal, by connecting low flows from the the canal to an excavated, shaped and planted area (arrowed), along a canal length of 140 m with the wetland being up to 52 m at its widest point

Figure 10.3: Removal of canal wall along a length of 60 m and creation of a small area of planted but still hard stabilised riverine habitat, 7 m (maximum) width

Over-arching principles to consider when implementing structural rehabilitation interventions

Before embarking on interventions aimed primarily at increasing habitat diversity, the degree to which they actually address real problems and are appropriate to the affected river reach should be considered, paying particular attention to the following issues (USDA 2001):

- Defining the ecological purpose of a structure and site selection is as important as construction technique;
- Scour and deposition are natural stream processes necessary to create important aquatic habitats, including for fish. Overstabilisation therefore limits habitat potential, whereas properly designed and sited structures can speed ecological recovery;
- The use of local materials (stone and wood) and indigenous vegetation in planted areas is strongly encouraged;
- Periodic maintenance of structures will be necessary and must be incorporated into project planning;
- Natural seasonality in terms of flow regime is critically important and should be maintained as a priority. The temptation to "add" water in terms of effluent or domestic flow, pumped groundwater or even long-term irrigation to improve habitat quality should be avoided, as it is an unnatural and unsustainable approach;
- Structures should never be viewed as a substitute for good riparian and upland management.

Approaches included in this chapter

The most important factors that usually determine the usefulness / relevance of each potential intervention to a particular site / project comprise, in order:

- Desires of local communities and local authorities – the socio-economic location of each proposed rehabilitation is critically important in determining the degree to which different interventions are likely to be appropriate, desirable or sustainable (see Section 10.14).
- Availability of space – apart from water quality improvement options, the most effective rehabilitation interventions usually require space along the river corridor;
- Cost.

Taking cognisance of these factors, the interventions and approaches for general aquatic habitat improvement that are included in this chapter have been critically summarised and rated in Table 10.1 and are compared in Figure 10.4, with comments on desirability, usefulness, applicability, maintenance requirements, sustainability and cost, bearing in mind that, unlike other chapters in the manual, all of the options included in this chapter can have ecological merit in the appropriate situation.

Table 10.1: Descriptions of interventions and approaches used to improve habitat quality and biodiversity
Cost estimates relative only and likely to vary widely on a scale- and site-specific basis

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
Do nothing option				
Do nothing (Section 10.1)	No gains, but easy opportunities for ecological improvements can be lost.	None	None	Consider this option if ecological gains from interventions minor compared to costs / effort
Increasing habitat diversity in unlined, but channelised rivers (Section 10.2)				
Removal of alien vegetation **(Section 10.2.1)**	Positive if carried out properly (See Chapter 2)	None – notify authorities	+ (R4k-R15k/ ha)[5]	Long-term maintenance usually required; Stabilisation of cleared areas necessary
Management of invasive indigenous vegetation **(Section 10.2.2)**	Management often symptomatic and usually needs to be ongoing – ensure that natural function is not being destroyed by process	NEMBA; NEMA, NWA	+	Make sure that implications of removal are clearly understood
Reshaping and planting of banks **(Section 10.2.3)**	Good ecological option	NEMA (if > 5 m^3) NWA (21c and i)	+ - ++	Check that infrastructure not threatened; probably more applicable to low velocity rivers.
Creating riffle/pool sequences **(Section 10.2.4)**	Adds habitat diversity to highly degraded, usually urban, rivers	NEMA (if > 5 m^3) NWA (21c and i)	+ - +++	May have low ecological benefit and will probably require ongoing replacement; check water quality condition does not limit habitat diversity improvement benefits.
Other in-channel habitat options **(Section 10.2.5)**				
Creating pools (Section 10.2.5.1)	Adds habitat diversity to highly degraded, usually urban, rivers	NEMA (if > 5 m^3) NWA (21c and i)	+	Ongoing maintenance required
Creating instream rock and boulder habitat (Section 10.2.5.2)			+=++	
Rehabilitating or recreating meanders (Section 10.2.5.31)	Usually good ecological option		+-++++	Needs land and high levels of technical input

[5] Costing estimates kindly provided by Ms. Heidi Niewoudt (SANBI) are indicated primarily for comparative purposes. Site specific factors, such as access, available materials, environmental authorisations and method of construction will determine final costing. These costs based on 2014 data only.

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
***Creating artificial valley bottom wetlands* (Section 10.2.6)**	May provide useful ecosystem function and amenity value n otherwise sterile usually urban landscape		+-+++	Needs land and high levels of technical input
Increasing habitat diversity in lined canals (Section 10.3)				
***Adding hydraulic diversity and providing instream cover* (Section 10.3.1)**	Adds habitat diversity sterile canals	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+-++	Hydraulic implications must be checked
***Creation of planting ledges in canals* (Section 10.3.2)**				
Retro-fitting canals with planted gabions	Adds habitat diversity sterile canals	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	++	Hydraulic implications must be checked
Retrofitting canals with ledges stabilised with airblock, brick or retaining block walls			+-++	
Use of bagwork and pilings			++	
Use of floating vegetated islands	Not recommended for rivers		+	Likely to wash away in high flows
***Canal removal and/or daylighting of piped river flows* (Section 10.3.3)**				
Diversion of canalized low flows (partial canal removal) (Section 10.3.3.1)	Recommended where possible	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+++	Hydraulic implications must be checked
Partial canal removal – removal of canal base and / or walls and the establishment of plants and rock substrate (Section 10.3.3.2)	Excellent approach where technically feasible and where water quality not major issue		+++	Hydraulic implications must be checked; Water quality issues may over-ride benefits of habitat creation; Should be reconsidered when through area with poor servicing and high levels of poverty
Improving floodplain and off-channel habitat function and diversity (Section 10.4)				
***Retain existing floodplain areas* (Section 10.4.1)**	Best approach (wetlands, riparian zones and floodplains are legally protected water resources).	None	+ (but lost development costs)	Riparian delineation should be undertaken to determine the extent of protected area.
Breaching levees	Highly beneficial for riparian zones –	NEMA (if > 5 m^3)	+	Hydraulic implications must be

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
(Section 10.4.2, and also section 3.5 in Chapter 3)	flood flows are restored to parts of the floodplain/riparian areas.	NWA (21c and i) if natural watercourse		checked
Reconnect existing relict floodplains to the channel **(Section 10.4.3)**	Can involve widespread habitat restoration and reconnection through active habitat reconnection		+++	Hydraulic implications must be checked; May provide useful urban stormwater attenuation and filtration options
Creating off-channel wetlands **(Section 10.4.4)**	Localised ecological value – may be important nodes in highly urbanized area		++	Hydraulic implications must be checked; Desirability of receipt of river flood water to be checked (in terms of quality and quantity / timing)
Creating new floodplain areas **(Section 10.4.5 and see Section 3)**	Limited localized increase in floodplain or wetland habitat, but not natural.	NEMA (if > 5 m^3) NWA (21c and i) if natural watercourse	+++++	Very costly and does not constitute rehabilitation (natural terrestrial or riparian areas sacrificed to create artificial floodplains and detention ponds)
Improving habitat quality in existing erosion control structures (Section 10.5)				
Facilitating plant establishment on hard engineered structures	Best option in case where use of stabilising structures unavoidable	No additional, if approvals for structures already in place	+	Need for structures to be carefully motivated by engineers; Allowance for planting essential, unless size of structure small in relation to area rehabilitated (e.g. there is no need to plant a stabilizing weir)
Removal of weirs to rehabilitate aquatic habitat (Section 10.6 and see Section 7)				
	May provide opportunities to redress past impacts of impoundment, sediment trapping and erosion – but should be carefully motivated and real ecosystem benefits should not be exaggerated	NEMA (if > 5 m^3) NWA (21c and i)	++-++++	Hydraulic and geomorphological implications must be checked; Effects on indigenous fish populations to be checked

Description of options	Ecological implications	Legal authorizations	Costs	Technical limitations and cautions
Design and management of riparian buffer areas (Section 10.7)				
	Critically important aspect of river management and ensuring rehabilitation outcomes are sustainable	NEMA if excavations within 32 m of river bank outside of urban areas	+-++ (land costs)	Must be implemented and managed in the long term
Managing alien fish species (Section 10.8)				
Preventing alien fish introductions **(Section 10.8.2)**	Preferred ecological approach	Required in terms of NEMBA	+	Requires long-term education and consistent management / auditing / control effort
Managing aquaculture facilities	Important to prevent introductions where catchment not invaded already			
Protecting barriers to movement	Important where indigenous fish populations remain upstream of barriers			
Education and Policing	Important and should be ongoing			
Alien fish eradication **(Section 10.8.3)**			+++	
Piscicides (poisoning)	Effective – but targets all gill-breathing fauna; highly specialist application	NEMBA; NWA; notify authorities	+-+++	Full ecological assessment and motivation required with input from multiple stakeholders including anglers, conservation authorities and river ecologists
Manual clearing	Less effective but reduced indirect effects		+-+	
Managing other alien fauna (Section 10.9)				
	Prevention is preferred approach Conservative attitude required	Required in terms of NEMBA	+-++++	Requires long-term education and consistent management / auditing / control effort

Descriptions of interventions and approaches used to improve habitat quality and biodiversity

10.1. Do nothing option

As with other chapters in the Technical Manual, a useful starting point when embarking on a particular project with specific objectives, is to consider the risk and consequences of "doing nothing". In the case of interventions intended specifically to improve habitat quality and /or biodiversity, the following issues should be considered with regard to the alternative of doing nothing:

- Make sure that a "do nothing" approach doesn't result in deterioration in river condition / biodiversity loss – see the Tesselaarsdal Wetland Case study (Volume 3: Case Study 8);
- Don't waste external funds and funding or community good-will on projects that achieve little measurable ecological benefit, where this is the intended main purpose of funding – once funding bodies or community champions are disillusioned as to the manner in which their funds are spent, it is difficult to re-ignite enthusiasm for other rehabilitation projects.
- Utilise opportunities to improve ecosystem function. Projects where rehabilitation is not the primary focus, but where other issues such as the need for erosion or flood control trigger environmental impact assessment processes, can become useful vehicles for achieving legitimate rehabilitation through direct impact mitigation or as offset mitigation.

Pros and Pitfalls of project phasing (Day et al. 2007)

Project phasing is often a component of river rehabilitation projects, on the basis of the following points:

- Phasing allows funds to be sourced over time, making the full cost of the project less daunting;
- It allows uncertainties to be clarified during the course of the project, without delaying the whole implementation;
- It allows for learning and evolution of ideas, as approaches that do not work or could be improved on can be developed iteratively and integrated into design.

Phased projects can however also be risky, because:

- If funds earmarked for rehabilitation are allocated elsewhere, the project may be permanently halted, potentially wasting funds in unachievable outcomes (see Langvlei Case Study: Volume 3: Case Study 16);
- Projects that materialize only very slowly may result in local communities losing enthusiasm for issues for which they had initial buy-in.

10.2. Increasing habitat diversity in unlined, but channelised rivers

Unlined but channelised rivers are common in both urban and rural environments, and usually comprise a fairly uniform bed, in some systems invaded by alien or indigenous reeds or other vegetation, with steep sided banks, sometimes subject to [6]erosion. Efforts to improve river habitat diversity should ideally aim to use examples of similar river types in an unimpacted (i.e. reference) condition as rehabilitation "templates". In many cases such examples are not available, or the rivers have changed too far from natural for such examples to be useful. Historical aerial photographs are available for much of South Africa and can also be used to interpret original river forms. Options for improving habitat quality and/or biodiversity in channelized rivers are outlined below. Note that in some circumstance, the options would provide very limited opportunities for real habitat improvement.

10.2.1. Removal of alien vegetation

Removal of alien vegetation is probably the most repeated recommendation in this manual, with alien plant invasion potentially affecting almost every aspect of river condition and function. Chapter 2 outlines detailed approaches for the identification and classification of alien vegetation, as well as a variety of considerations and alternatives for its removal. Where river habitat quality improvement is desired, removal of alien vegetation, with an emphasis on invasive alien plants, is usually one of the most important, and change-effecting interventions, addressing issues such as shading, smothering of indigenous plants, excessive water uptake, damage to soil and seed stock as a result of excessively hot fires during burning of woody alien vegetation and (in the case of dense invasion by some tree species), precipitation of bed erosion / downcutting and in some cases, exacerbating bank erosion – sometimes on the opposite bank.

Chapter 2 should thus be consulted in this regard, noting however that:

- It is not usually adequate simply to remove alien vegetation, as that may precipitate erosion. Stabilisation of cleared banks with vegetation is also essential – and Chapter 12 should be consulted for recommendations regarding various methods for the establishment of plants;
- Alien plant removal is seldom a once-off exercise, and allowance must be made for long-term maintenance of cleared areas if the establishment of more diverse indigenous vegetation is to be a sustainable outcome;
- In some circumstances, short-term removal of persistent invasive aliens such as kikuyu grass *Pennisetum clandestinum* or Wandering Jew *Commelina benghalensis* may be a reality of a particular site, especially where the range of these species extends on either side of the site and is likely to persist there. In such cases, removal of smothering alien plants may at least provide time for indigenous plants to grow up above levels at which they would be smothered and/ or shaded out by these plants. However, unless allowance is made for at least long-term maintenance of clearing activities (e.g. cutting back and uprooting, even if complete removal cannot be achieved) the initial inputs are unlikely to achieve any long-term biodiversity benefit. Activities such as skimming of soil surfaces to remove the roots and surface growth of kikuyu

[6] For options to address erosion, see Chapters 4 and 5

and nutrient-enriched surface soils may also be helpful in reducing the competitive advantage of these plants.

With regard to the removal of aquatic plants, it is however noted that in some cases, aquatic plant removal will not result in improved biodiversity, with rooted invasive alien plants sometimes significantly improving habitat diversity in modified rivers (e.g. channelized urban rivers). Plants such as *Ceratophyllum demersum* (water hornwort), *Myriophyllum aquaticum* (parrots feather), *Nasturtium officinale* (watercress) and even *Persicaria lapathifolia* (Persicaria) may increase aquatic habitat complexity in otherwise simplified, often regularly dredged, shallow systems with little hydraulic diversity. Such structural complexity, comprising stems and leaves extending up through the water column provide cover and attachment sites for small fish and aquatic invertebrates, and can significantly increase faunal diversity, thus reducing the likelihood of dominance by pest species (e.g. Chironomid larvae that as adults form plagues of flying midges). Unless largescale improvement in river morphology (e.g. the re-establishment of meanders and natural valley bottom wetland across the channel is contemplated). or the reinstatement of indigenous aquatic vegetation is undertaken, removal of the above species will not achieve improved habitat quality or biodiversity, but will simply require ongoing management effort. However, aquatic alien plant removal may be more important in terms of flood or water quality control than for biodiversity improvement (but see caution box opposite).

Caution

Despite any habitat diversity implications, note that removal of aquatic invasive plants is strongly and urgently recommended in the case of newly established species, which should always be removed before they become problematic in a river or catchment.

10.2.2. Management of invasive indigenous vegetation

Indigenous or cosmopolitan vegetation can sometimes invade riverine habitats, to the exclusion of other habitat types or plants species. Examples of such species include *Phragmites australis* (which invades into slow flowing, shallow, sometimes mildly brackish silt-laden rivers), *Typha capensis* (which invades into shallow, very slow flowing, low salinity often nutrient-enriched valley bottom wetlands) as well as, in the Western and Eastern Capes, plants such as *Prionium serratum* (Palmiet) that form dense stands across and along some watercourses, often associated with peat formation.

Increasing habitat diversity in systems dominated by the above species is sometimes argued as an ecological benefit, and can be achieved by removal or management of these species, with interventions such as surface cutting and excavation of roots allowing effective (but often short-term) controls. Such approaches are outlined in Chapter 2, but it is cautioned, as stressed in Chapter 2, that the consequences of plant removal must be clearly understood, and that where the natural habitat template is for near-monospecific stands of a certain plant type, its removal would not be supported with an argument for increasing habitat diversity beyond natural levels.

This said, in reed-dominated (*Phragmites* sp. and *Typha capensis*) rivers or valley bottom wetlands, with low sensitivity and /or low Ecological Importance, habitat quality and structural complexity / diversity can often be improved in the short-term by carrying out regular cutting of stems, to stimulate new growth. This can promote patches of open water habitat, increasing accessibility through the reedbed for small fauna and (in cases where the reeds have developed into dense, senescent stands) allowing a better spread of flows across the system.

The following approaches can be applied:

Timing of reed-clearing activities

Reed clearing activities should take place outside of the breeding / nesting seasons for wetland and riverine fauna, and should also be undertaken outside of the wet season, when water levels are high and the erosion protection capacity for reedbeds is most relevant.

- Cleared plant material should be removed from the river bed and its floodline to prevent blocking of downstream infrastructure and smothering of habitats;
- Reeds should be cut off above the water level, to ensure that there is regrowth
- Plant clearing should not result in the creation of narrow open channels, through which water will be concentrated, as this may result in channel downcutting and long-term habitat deterioration (see Figure 10.4). Rather, vegetation should be cut equally across the full channel width;
- In order to maintain the spread of flows as well as water quality improvement functions (e.g. sediment trapping), particularly in reedbed channels where water quality improvement is a primary management objective (see Figure 10.5), vegetation should be cleared in swathes, extending across the channel, perpendicular to the direction of flow, with stands of reeds left standing between cleared portions, to ensure that flows are respread between cleared portions. Cleared swathes should not exceed the width of swathes left reeded. This approach lends itself to cyclical maintenance activities, with cleared swathes being left reeded in the next clearing cycle, and uncleared swathes being cleared.

Figure 10.4: Clearing of reeds along the length of the channel will increase the risk of channel incision during high flows. In this photograph, clearing of a far wider channel area would have prevented the start of channel downcutting evident here.

Environmental legislation

The removal of plants from threatened ecosystems listed in terms of NEMBA requires a permit;

- Clearing of reeds as described above would probably need to be carried out in terms of a river maintenance and management plan, as it triggers parts of NEMA;
- The use of machinery in a wetland (including valley bottom wetlands) or river may require authorisation in terms of NEMA and the NWA, as it is likely to result in movement of bed material and /or changes in the bed or banks of the river channel.

10.2.3. Reshaping and planting of banks

Concept and rationale

This approach entails reshaping of the channel so that its banks are gently sloping, to facilitate the establishment of vegetation that will contribute to bank stabilization and the establishment of a more spatially complex marginal and riparian habitat that can allow easy movement of riverine animals into and out of the channel. Provision of cover for use by fish, frogs and other small aquatic fauna may also be an objective of bank planting, and it is recognized that plant cover also produces shade, that may reduce temperature in channels otherwise exposed to the sun.

Site suitability

- This approach requires space on the side of the bank being reshaped (ideally both banks), and is problematic if the top of the bank is lined with trees or infrastructure (e.g. paths). If banks are to be pulled back from a 1:1 gradient to a 1:4 to 1:6 gradient, an extra 3 to 5 m width is required on either side of the channel, <u>for every 1 m of bank height</u>;
- This approach is not suitable for channels that are mechanically dredged on a regular basis, as such activities will negate reshaping and planting efforts. In such circumstances, either adjust the maintenance approach / regime or shape and plant one side of the channel only, leaving the other side for machine access.

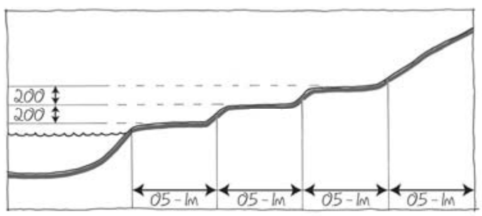


Figure 10.5: Alternative approaches to bank shaping

Where space is limited, banks can be roughly stepped rather than graded, with each step comprising a relatively flat shelf (0.5-1 m wide), stepping up vertically no more than 0.2 m at a time

Technical guidelines

- Work to be conducted in the dry season, allowing adequate time for plant establishment before rains – irrigation through dry season may be necessary, particularly in winter rainfall areas;
- Steep channel banks should be pulled back to gradients no steeper than 1:4 and preferably much gentler, taking care to vary the position of the toe of the slope with distance along the bank, so as to create a meandering effect, and to pull the bank back coarsely, so that the final product has a natural, rough appearance, with vertical and longitudinal heterogeneity;

- Up- and downstream extents of shaped banks to be tied in to remaining, unshaped bank, such that neither protrudes into the channel, where it might trigger erosion;
- Mechanical excavators (back hoe loaders / excavators) or manual labour can be used – but use of mechanical excavators usually results in better final shaping;
- Machine to operate from top of bank, rather than in-channel, to minimise disturbance and downstream sedimentation, and excavated material to be disposed of well away from channel edge;
- Planting to take place immediately after shaping, using appropriate indigenous plants – see Chapter 12 for guidelines as to the selection of plants for use in specific habitat types and for planting guidelines. Where overhanging vegetation is required (e.g. for fish habitat), plant species should be selected accordingly, from available locally indigenous species. In addition, the guidelines for plant root and surface morphological traits that lend themselves to different aspects of erosion control (bank collapse, bed erosion and bank erosion) should be consulted – refer to Volume 1: Section 7.4.3 for guidelines for the selection of plants for erosion control, on the basis of root traits, and for general guidelines for specific conditions lending themselves to stabilization by plants rather than with structural interventions.

Figure 10.6: River connectivity considerations

Reshaping and planting of banks provides opportunities for improving longitudinal connectivity along the river, as well as lateral connectivity with the floodplain and/ or riparian and terrestrial areas. Note though that lateral connectivity is not always advantageous – in the photo below, improving lateral connectivity on the left hand bank will simply promote the passage of river-associated fauna onto a major road! However, improvement in the quality of the lower bank, and the bank opposite the road, could improve habitat quality and connectivity.

Figure 10.7: Planting of recently reshaped and widened stream in Cape Town residential estate. Initial condition was narrow (<1 m wide) trench through alien vegetation

Legal considerations/authorisations

- These measures will trigger NEMA if an excess of 5 m^3 sediment is moved or removed
- Can be carried out under a General Authorisation in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

Cost

- Relatively inexpensive, with main costs comprising machine and/or labour time for bank excavation and shaping, disposal of spoil and replanting;
- Indirect costs in terms of the loss of developable land may be incurred – these should however be considered in terms of increased property value often associated with a more natural, landscaped environment in which natural features such as streams are celebrated as part of open space and not hidden in conveyance channels;
- Costs increase dramatically if trees need to be felled and removed and paths or other infrastructure re-aligned.

Expertise required

- No specialist input required, provided implementer has a clear vision of final outcomes;
- Experienced machine operators will be able to create required effect, especially if shown natural template to emulate, and informed as to the need for final output to be a rough finish.

Useful Case Studies

- Case Studies 2, 4, 11, 16 and 20 (Volume 3) illustrate the implementation of various levels of intervention in different South African social and economic environments, and should be considered with regard to the proposed site.

Maintenance requirements

- Ongoing weeding of alien plants to ensure establishment of indigenous vegetation (see Chapter 2 and Section 10.2.1).

10.2.4. Creating riffle/pool sequences

Concept and rationale

This approach, often used to create specific habitat types in fish habitat remediation or rehabilitation projects (See Chapter 11) can potentially achieve any of the following (Cowx and Welcomme 1998):

- Improve the diversity of hydraulic biotopes (current speed and direction);
- Improve habitat diversity by:
    - Creating pools and riffle areas, or deepening existing pools
    - Collection and holding of spawning gravels
    - Encouraging gravel bar formation by raising water levels
    - Trapping fine sediments in tributaries (and thus protecting downstream systems)
    - Aerating water
    - Slowing currents and allowing organic matter to settle and promote invertebrate production
    - Provision of substrate for invertebrate colonisation

- Act as a bed control structure in a similar manner to gabion weirs and other river bed erosion control structures described in Section 5.

There are two basic approaches to riffle construction, namely:

- Temporary riffles, made up of mobile bed material that migrates over time and must be replenished; the material is deposited on the river bed and left to be sorted by floods, with some of it forming riffles at appropriate locations; and
- Permanent riffles, where particles are sized to resist movement in most flows.

Of these approaches, the former implies that bed material is limited (otherwise riffles would have formed naturally) and must be replenished. Since the riffle material will naturally be transported downstream in floods of various sizes, ongoing replenishment of material is required if this approach is to result in sustained habitat creation. Riffles are spaced and designed as outlined below, with the obvious disadvantages that they require substantial volumes of material and may precipitate bank erosion, either if the riffle material is dumped in piles on the river bed, causing flow diversions instead of being spread out in a line across the full channel width and up onto the banks or because natural riffles form at angles to the bank and induce erosion (leading under natural conditions to the evolution of meanders (Rutherford et al. 2001).

Permanent riffles by contrast are constructed of angular rocks that are packed more tightly, reducing the porosity of the structure. Rutherford et al. (2001) suggest inclusion of oversized rocks in the rifle structure to create a complex hydraulic habitat down its face, including low flow areas where fish and other small fauna can rest as they move upstream through the riffle. Inclusion of a slight depression in the centre of the riffle is also recommended by some authors, to concentrate flows at one point and allow passage by fish during lower flows than if a flat crest is utilized.

Application

In environments where increasing habitat diversity is a strategy aimed at creating more complex ecosystem structure and providing specific habitat types that will create conditions favouring the colonisation of the stream ecosystem by specific faunal communities.

Site suitability

- Suitable for small stream systems, in headwater to lower foothill river systems (Cox and Welcomme 1998), noting that riffles naturally occur in streams with gradients in the range of 0.0015-0.005 and possibly up to 0.01 (Rutherford et al. 2001, citing Keller 1978 for Australian streams);
- The use of woody debris to create pool/riffle sequences in rivers affected by woody alien invasives is specifically discouraged, as these systems can be severely degraded by erosion associated with in-channel log jams or log jams against infrastructure such as bridges and culverts.

Technical guidelines

Many manuals provide guidelines for the creation of riffles, which can be created out of a variety of materials, from stones and gravels, to wood. The guidelines provided here have been adapted largely from Rutherford et al. (2001) and Cox and Welcomme (1998), and recommend:

Natural riffle spacing

Where available, historical aerial photography can be used to estimate natural riffle distances in impacted channels being rehabilitated with artificial riffles (e.g. Newbury and Gaboury 1993)

- A variety of rock sizes should be used in riffle construction, to prevent the structure being too porous, and preventing the formation of a pool structure upstream – porous riffles can act as barriers to the movement of fish and other aquatic fauna and may also result in failure of the riffle through piping;
- Riffles should not be too high or too steep, as this will similarly prevent the movement of fish and other fauna along the river during low flow periods – Rutherford et al. (2001) suggest that as a first step, the gradient of the downstream face of the riffle should be less steep than 1:20 and fish should be able to swim up the riffle during most flow conditions. The slope of the upstream face of the riffle is determined by the angle of repose of the material used to construct it, and is set at 4:1 by the same authors;
- The riffles should completely armour the bed to prevent bed scour;
- Riffles should generally be placed at the inflection point between two river bends (i.e. where the stream approaches a straight course with a symmetrical cross-section);
- The riffles should be fully keyed into the river banks;
- Riffle material should typically be larger than that found in naturally occurring riffles on the same stream, to prevent it being moved during high flows – this is because natural riffles occur as the direct result of the accumulation of rocks, carried through the river at high flows and deposited on the riffle. In an artificial environment, continuous replacement of rocks will be necessary if they are small enough to be readily mobilised;
- Riffle spacing should ideally be similar to meander arc length Rutherford et al. (2001) suggest as a guide that artificial riffles should be spaced on average between five and seven channel widths apart; rudimentary riffle forms (sometimes comprising simply mounds of coarser sediment seen at low flow, often develop on unstable streams quite early on in a process of re-landscaping and design. Such riffles should be used as the core of more substantial, artificial rock riffles, with rocks being spread out across the riffle, and allowed to be redistributed naturally;
- Artificial permanent riffle creation can include excavation of pools between riffles, where required.

Caution:

The need for and design of riffles such as those described in this section must be clearly thought through – Rutherford et al. (2001) designed riffles for Australian streams, and such interventions would not be practical in many South African systems, although they may have value in small, channelized urban streams with little remnant natural habitat .

Expertise required

- Multi-disciplinary teams including hydraulic engineers and ecologists should ideally be engaged in artificial riffle creation, to minimise wasteful expenditure and prevent inappropriate structures that do not achieve their design objectives and/or incur further river bank or bed destabilisation.

Legal considerations/authorisations

- Will trigger NEMA if an excess of 5 m^3 sediment is moved or removed
- Can be carried out in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

Cost

- Relatively inexpensive, with main costs comprising machine and/or labour time for bank excavation and shaping, disposal of spoil and replanting.

Maintenance requirements

- "Natural" riffles will require ongoing additions of material for distribution into the riffles.
- Permanent riffles may require repair following large floods and are moreover likely to sediment up over time, resulting in the need for periodic upstream excavation of sediment, and its potential placement into downstream areas. This should be carried out frequently enough that NEMA is not triggered by a volume of sediment exceeding 5 m^3.

10.2.5. Other interventions

10.2.5.1. Creating pools

Concept and application: Sills

> **Sills** are bed control structures that do not exceed 1.5 m in height and where the overfall is drowned out during average flows (Hader undated).

In addition to the creation of pooled habitat upstream of riffles and the excavation of pools in downstream areas in pool/riffle sequences as described in Section 10.2.4, some effort has also gone into the design of instream devices that promote the creation of scour pools, used in the management of some fish species. Of these, Rutherford et al. (2001) describe the use of Schauberger sills which are primarily a European approach. They comprise V-shaped sills, usually built of 0.3 m diameter logs (see Chapter 5), with the apex of the V pointing upstream, and being the lowest point on the structure, which is set into the river banks on either side. It concentrates flows into the centre of the channel, allowing fish to pass through and into the deep scour hole formed downstream, which can form an important low water refuge area. Maintenance of pool habitat by ongoing scour thus created may be useful in unstable rivers with high sediment loads.

Disadvantages of the approach are that logs are prone to failure over time, and may moreover fail as a result of undercutting by the scour pool (see discussion in Chapter 5). In large South African rivers, many of which are already prone to invasion by woody alien vegetation (see Section 2), the addition of large woody debris liable to wash downstream and precipitate erosion and disturbance as a result of log-jam formation, is not recommended – USDA (2001) also caution against excessive volumes of large woody debris in the floodplain.

Creation of similar structures using rocks to create in-channel sills is also suggested by Rutherford et al. (2001) and such an approach might avoid the negative impacts outlined above. Mangfall sills are also described by this author, and detailed by Hader (undated) for streams in New South Wales, Australia. These sills comprise a single line of boulders, constructed across the stream in a zigzag formation. The zig-zag formation creates a series or arches, which are structurally stable and need to be supported only at their apex. The arches restrict low flow to the central low flow channel or fishway, located at the downstream apex of an arm, so that it is more easily found by aquatic fauna. Rutherford et al. (2001) recommend that the plunge pools downstream of the sill crests should be armoured with rock keyed into the bed, and USDA (2001) notes that such structures can also make for effective low water crossings over streams.

> Caution
>
> In South Africa, the need for such approaches should be determined with input from a fish ecologist, and should always be carried out with detailed engineering input, and consideration of the principles outlined in Chapter 5.

10.2.5.2. Creating instream rock and boulder habitat

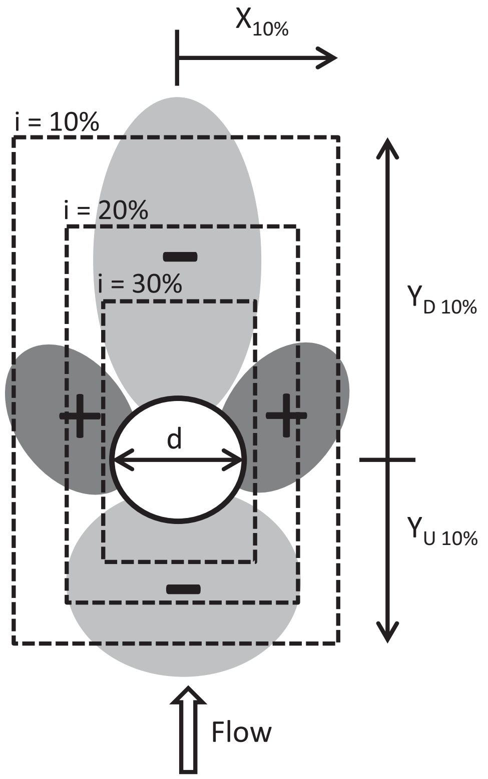
Concept and rationale

Aquatic habitats are defined largely by the substrate type and the hydraulic characteristics of the habitat, particularly flow depth, velocity and turbulence intensity (see Volume 1: Rehabilitation Guidelines – Section 2.7). One way of increasing instream habitat diversity is through the strategic placement of boulders in a stream, so as to increase the diversity of hydraulic characteristics, and hence the heterogeneity of habitat conditions. The effect of a boulder on the flow velocity is illustrated in Box 10.1. The boulder reduces velocity upstream and downstream and increases velocity along its sides.

The resultant areas of low velocity provide resting and feeding areas for invertebrates and refuge during floods (Engström et al. 2009; Huusko and Yrjänä 1997; Merz et al. 2004). The low velocity areas can also be used as resting (and feeding) areas by fish when migrating upstream, so boulders can be used to create fishways. Boulders also induce turbulence and local scour, which provide cover for fish from visual predators. The heterogeneity created by boulders also increases the suitability of habitat for different life stages of some biota (Harvey & Clifford 2009), with different algal and macroinvertebrate taxa, for example, differentially colonizing different portions of the boulder habitat according to their habitat requirements.

Site suitability

- The introduction of boulder habitat would be desirable in highly disturbed mountain stream and foothill river systems, where natural substrate has been removed (e.g. by bulldozing, channelization or channel realignment) and the extant channel lacks the kinds of substrate and hydraulic biotopes that would naturally occur in such reaches. Since such an approach assumes that rock / boulder substrate is a limiting factor in the system (or it would be present), replacement of rocks / boulders may be necessary on an ongoing basis, following floods, although the frequency of replacement would be dependent on both the power of the flood and the size of the boulder;
- In highly unstable, mobile river reaches, prone to high levels of fine to coarse sedimentation and bed movement, the installation of boulder habitat would be expected to have short-lived benefits only, before extensive siltation occurred and the net benefit in terms of hydraulic heterogeneity was lost (note however that in eroding channels, sedimentation of boulders (e.g. in the form of sills or riprap) might result in long-term improvement in habitat as a result of stabilizing highly unstable environments – see Chapter 5).
- Boulder placement may also be valuable in highly transformed habitats, where the introduction of any form of habitat diversity is desirable simply to begin to establish more complex ecosystem structure. Thus in concrete canal environments, such approaches may achieve high levels of relative ecological benefit, particularly where short lengths of canal separate river reaches with more natural levels of function, and the aim of boulder positioning is to create nodes of habitat and shelter, and thus ender the canals less sterile and more able to allow safe passage of fauna between areas of better habitat quality.



Hamuy-Blanco and James (2014) modelled the effects of emergent boulders on the surrounding flow field. They defined a "Zone of Influence" (ZOI) of a boulder group by specifying the upstream (Y_U), downstream (Y_D) and transverse (X) distances within which the disturbed velocities are more than a certain percentage different from the undisturbed velocity. The dimensions of the ZOI can be related to the unit width discharge and slope of the channel (represented by the Froude number), the width of the channel and the size of the boulder or boulder group (d). The variance of the velocity distribution within the ZOI can be related to the undisturbed flow velocity, the channel width and the size of the boulder or boulder group.

Box 10.1

Distribution of velocity around a boulder, showing Zones of Influence (ZOI) for different percentage deviations from the undisturbed flow (Hamuy-Blanco and James 2014).

"+" increased velocity compared to undisturbed velocity; "-" indicates decreased velocity.

Technical guidelines

- Application of the Zone of Influence (ZOI) dimension relationships (see Box 10.1) (Hamuy-Blanco and James 2014) shows that for single boulders, the extent of the ZOI increases significantly with boulder size and flow velocity and decreases with flow depth. The extent of the ZOI and the variance of velocities within it are significantly increased by grouping boulders, however, especially if they are placed in line transverse to the flow. The same ZOI size as for a single large boulder can therefore be obtained by a group of smaller boulders, significantly reducing the total volume of rock and hence the cost. For a typical situation, the volume of rock would be reduced by about 40% using 2 rocks instead of one, and by nearly 60% using 3 rocks. (The size of rock necessary to ensure emergence and stability would also need to be considered).
- If boulders in a group are placed close enough together to induce critical flow locally, the size of the ZOI is further increased. If two boulders are used, the extent of the ZOI is effectively doubled if they are placed close enough to induce critical flow.

- If the effective blockage (ratio of total boulder width to channel width) exceeds about 0.08, the flow backs up across the whole channel and the ZOI extends for a long distance upstream. Hamuy-Blanco and James (2014) also showed that angular boulders are more effective in modifying the velocity distribution than smooth ones.
- With regard to on-site implementation:
  - Rocks can be added using manual labour (smaller rocks only) or placed by machines;
  - In the latter case, machines should access the channel ideally from the top of the bank, rather than from within the channel, where increased disturbance may occur;

Caution

Where rock placement is intended to improve nesting grounds for fish, such rocks should be placed mainly below the water line, so that they don't create shallow feeding grounds for fish-eating birds (Cowx and Welcomme 1998).

Expertise required

- Multi-disciplinary teams including hydraulic engineers and fish and/or river ecologists should ideally be engaged in boulder placement, although the consequences of misplacement is most likely to be a waste of resources, rather than significant environmental damage.

Legal considerations/authorisations

- Will trigger NEMA if an excess of 5 m^3 rock material is installed;
- Can be carried out in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

Cost

Costs dependent on availability of river rock in close proximity of the site.

Maintenance requirements

- Replacement of boulders / rocks likely after storms – frequency of replacement dependent on size of rock and magnitude of flows.
- Where upstream sedimentation occurs, replacement or repositioning of rocks may be required.

10.2.5.3. Rehabilitating or recreating meanders

Concept and rationale

River channelisation and floodplain degradation frequently also results in the loss of meanders. Some options for reconstructing or rehabilitating meanders are outlined here for consideration in floodplain reconnection projects (Roni *et al.* 2005), and comprise:

- Levee setback and the construction of new meanders;
- Meander construction adjacent to the existing channel and diverting flow into the new channel;
- Diverting flows into old meanders;
- Any combination of these methods.

Site suitability

Any of these approaches require space in the vicinity of existing channels, and are unlikely therefore to be applicable in many built-up urban areas, although some examples do exist where sufficient space has been available for some level of rehabilitation of more natural areas – see Volume 3: Case Study 16 (Langvlei Canal Rehabilitation).

Technical guidelines

Chapter 3 should be consulted for technical input into breaching of levees and meander construction, noting however that detailed technical guidelines for this kind of project would need to be developed on a case by case basis, with input from a professional team, in order to achieve the valuable potential improvement in river function that such projects offer.

Expertise required

> Multi-disciplinary teams including an hydrologist, hydraulic engineer, river ecologist, landscaper and fluvial geomorphologist should be engaged in project design and planning, with poor design potentially incurring significant erosion and flood damage to adjacent properties.

Cost

The costs of such projects are potentially very high, including both design phase costs as well as costs of land and structural interventions. These should however be weighed against the real potential ecological benefits of the intervention in terms of water quality improvement, provision of habitat and increased biodiversity, and the associated direct and indirect economic and socio economic benefits of such interventions, including the aesthetic, recreational and amenity benefits often associated with more natural habitats, as well as indirect benefits such as increased property values.

> Note however that the cautions included in Chapter 13 must be considered, with regard to rehabilitation planning in different socio-economic climates in South Africa. Useful Case Studies included in Volume 3 include: Case Studies 2, 4, 11, 16 and 20.

Legal considerations/authorisations

- Will trigger NEMA if more than 5 m^3 rock material is installed;
- Can be carried out in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

Useful guidelines

- River Restoration Centre (RRC). 2002. Manual of River Restoration Techniques. 2002 update. United Kingdom.
- Rutherford, I.D., Jerie, K. and Marsh, N. 2000. *A Rehabilitation Manual for Australian Streams, Volumes I and 2*. Cooperative Research Centre for Catchment Hydrology and Land and Water Resources Research and Development Corporation.

10.2.6. Creating artificial valley bottom wetlands

Concept and rationale

Channelised river systems or artificial conveyance channels may lend themselves to the establishment of broad valley bottom wetlands, if gradients are naturally flat or artificially manipulated as such. Carefully designed, broad valley bottom wetlands can play a role in water quality amelioration, erosion control and provision of longitudinal corridors of wetland habitat, especially in urban or agricultural environments where the surrounding terrestrial areas are increasingly ecologically sterile.

Site suitability

Suitable for implementation in systems that would naturally have comprised valley bottom wetlands, but have since been eroded and/ or channelised, or artificial systems where channeled or un-channeled valley bottom wetlands are ecologically, functionally or aesthetically desirable.

Suitable sites are those where the gradients of wetland sections are as flat as possible – on the basis of Rowntree and Wadeson (1998) they should be no flatter than 1:1000, which is the upper limit for lowland river beds or floodplains.

Note that the flat river channel gradients recommended above may be artificially achieved through the use of low gabion or concrete weirs, as outlined in Chapter 5.

Where these are applied to natural watercourses, their implications for longitudinal migration by aquatic fauna must be checked by an aquatic ecologist, preferably with input from a fish specialist, to ensure that natural migration routes and longitudinal connectivity for aquatic fauna are not compromised.

The implications of gabion weirs on sediment transport should be clearly understood – in some systems, artificial weirs trap sediment in upper reaches resulting in erosion of watercourses downstream.

Technical guidelines

- Channel gradient to be controlled (if necessary) with a series of low (ideally < 1 m above bed level) gabion weirs, designed and constructed as outlined in Chapter 5;
- Weirs to include geotextile lining on upstream side, to prevent "leaking" and loss of sediment;
- Weirs to be castellated or include other measures to allow for passage of broad shallow flows into downstream areas;
- Weedy / alien vegetation that establishes itself in planned wetland areas to be removed on ongoing basis;
- Plants to be selected and established in areas between weirs and their aprons as outlined in Chapter 12.

Expertise required

- Engineer to design weirs;
- Background research required on natural systems to establish likelihood of migration routes being disturbed;
- Design considerations around sediment transport mechanisms and effects;
- Landscaping input.

Legal considerations/authorisations

- Will trigger NEMA if an excess of 5 m^3 rock material is installed;
- Can be carried out in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

Cost

- Depends on need for and number of gabion structures and availability of construction material (rock) in vicinity of site;
- Can be constructed and planted using hand labour.

Maintenance requirements

Over time, shallow vegetated systems will sediment up and, unless maintained by periodic removal of sediment and re-establishment of vegetation, will gradually senesce. Maintenance measures to comprise removal of soils and plant material in 10 m wide, lateral swathes, evenly spaced along the affected corridor.

10.3. Increasing habitat diversity in lined canals

While outright removal of concrete canals and their replacement with more natural systems may be the most desirable long-term objective of many rehabilitation programmes, other techniques may be more practical in situations where spatial and other limitations do not allow the restoration of more natural river forms and functions (Tourbier *et al.* 2004), and the inclusion of soft techniques (mainly centering on creating opportunities for vegetation establishment or the creation of hydraulic shelter in exposed canals) at least allows for improved habitat quality (e.g. provision of vegetated marginal instream habitat, shading, instream cover). The application of such soft techniques in terms of ecological rehabilitation must, however, be understood as limited to situations where denaturalised river corridors are to be improved while perpetuating the physical constraints of the canals (Tourbier *et al.* 2004).

In addition, it is cautioned that the measures outlined in this section are unlikely to achieve any level of ecological merit if the water quality of the canals in which interventions take place is so compromised as to limited ecosystem function, or if the canals are so loaded with solid waste (e.g. plastic litter) that the establishment of vegetation in the canals will be limited by waste accumulation.

10.3.1. Adding hydraulic diversity and providing instream cover

Concept and rationale

Most structures, objects or irregularities in a river channel provide instream biota with some measure of cover against the river current. Where these are dark, shaded areas (e.g. overhanging marginal vegetation) they may also provide species such as fish with resting areas or shelter from predators. Instream and marginal (i.e. bank) vegetation also often plays an important role in river habitat diversity (Rutherford et al. 2001 and USDE 2001).

> Caution
>
> **Know your fish!**
>
> Note that in some systems increased cover (e.g. overhanging alien branches) favours alien fish species, at the expense of indigenous fish (see Volume 1: Section 3.10) and artificial structures should only be added where the habitat requirements of indigenous fauna specifically require such additions (see also Chapter 11**).**

In systems such as lined canals where such variability in habitat is very limited, rehabilitation efforts can seek to add structures that artificially meet some of these requirements for shelter, with some studies using concrete pipes, building blocks and artificial rocks to create such cover (Welcomme and Cowx 1998). See also Section 10.2.5.2).

Site suitability

Such measures apply primarily to <u>lined canal systems</u> and not to channelized streams / rivers where other more natural means of improving habitat diversity and quality are available and should rather be implemented. They would be suitable for slow flowing systems, where loose sand, gravel and boulder vegetation is limited (and will not therefore simply sediment over the structures); where indigenous fish are either present or their presence is limited by habitat availability (rather than poor water quality), and where the planned structures will not encourage alien fauna at the expense of indigenous species.

These approaches must however be used with caution and they are recommended for highly altered rivers only – mainly lined canals. Moreover, care should be taken in the selection of materials that they do not have negative social and aesthetic implications – the use of pipes and bricks, for example, are not recommended for river rehabilitation in this manual, as they are likely simply to create an air of degradation, and be mistaken for casual dumping of waste into the system.

Technical guidelines

- Creation of in-canal planting holes:
    - Roughening of the base of concrete canals by breaking open portions of the bed and sinking round concrete rings in which rocks and /or river plants can be established without jeopardising canal integrity has been tried in some systems, with limited success – the Liesbeek Canal (Cape Town) for example has been treated in this manner, with rocks inserted in the holes thus created; this provides short-term habitat diversity in which macroinvertebrate communities can establish, although strong flows wash the rocks downstream (Volume 3: Case Study 14);
- Cover using overhanging vegetation
    - Canals may lend themselves to the creation of more diverse physical and hydraulic habitat types along their margins if trees or other plants growing on their banks are allowed to hang over the bank and, at least at times, into the water. While lining the banks of unlined channels with tree may be problematic from the perspective of erosion due to resultant constriction of flows (see Chapters 2, 4 and 5 and Volume 1: Section 3.2), in a canalised environment, such impacts are already controlled by channel lining. Establishment or maintenance of trees and /or trailing vegetation in planters or in unlined surface areas abutting the canal edge thus provides a low-risk opportunity to increase canal habitat diversity, noting that trees with extensive root systems (e.g. *Ficus* spp.) may be unacceptable from a canal structure perspective;
    - Where trees and/or marginal vegetation already occur along canal margins, and additional in-stream cover is required, existing maintenance patterns should be adjusted to allow for overgrowth by plants;
- Artificial cover using pipes and rocks:
    - Pipes / rocks to be bundled together (smaller sizes) or laid separately, placed facing out of the main current and in reaches that include the other elements required by the desired fish species (food, water quality, source of colonising populations) – note that grouping structures together and bundling in mesh netting or other appropriate material will make them less likely to be washed away (but may increase risks of downstream flood damage if they do wash away and snag in culverts or against bridges;
    - Section 10.2.5.2 should be consulted for input on rock placement and sizing;
    - Sizing to be based on real ecological requirements likely to support the target taxa (see Section 10.5);
- Increase cover and add to hydraulic diversity, shade and access to sheltered banks in the low water season by encouraging the establishment of vegetation in cracks, irregularities or on sediment on the canal floors (Figure 10.8) (see also Volume 3: Case Study 14):
    - This measure is only applicable where there is scope for canal maintenance activities involving sediment dredging to be reduced, in channels where sediment tends to accumulate. In such cases, riverine / wetland plants may form naturally on sediment bars, or can be artificially planted, noting however that it is not worth costly expenditure on plants that will be likely to require dredging removal or be washed downstream during floods.

- Canals in which temporary (possibly limited to the dry season only) habitat improvement can be sanctioned are generally those in which flood flows are not associated with high velocities; where the wet season is well-defined, the catchment is not flashy, and where sufficient capacity exists in the canal for some level of additional channel roughness / infilling to be accommodated without significantly elevating flood levels;

Figure 10.8: Natural establishment of vegetation on sediment in lined canals

Creation of low-level weirs to maintain open water pools, especially during the summer (Figure 10.9):

- Low level concrete weirs can be used to aerate water, provide pools of permanent standing water supporting flora and fauna that might not survive warm water in dry season (especially in winter rainfall areas) and also play a role in increasing canal security, as criminal elements are less likely to utilise the canals as corridors if they are shallowly inundated (see Volume 3: Case Study 14);
- Low weirs back-packed with rocks may also create a longer-lasting rocky substrate than rocks simply lain on the canal floor, as they are held in place by the low weir structure.

> Caution
> Note that hydraulic input is required to confirm that the height of the weir has no significant effect on flood height.

Figure 10.9: Low weirs increase habitat diversity, limit pedestrian use of canals and have been designed to have a negligible effect on flood levels

Expertise required

- Engineering input when changes in canal structure are sought (e.g. excavation of planting holes);
- Hydraulic assessments, to determine effected on flood levels;
- Ideally, input from fish specialist regarding realistic target species and habitat requirements and specifications.

Legal considerations/authorisations

- Will trigger NEMA if an excess of 5 m^3 rock material is installed;
- Can be carried out in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

Costs

Costs would be dependent on availability of materials in close proximity of the site and extent of additional studies required (e.g. if hydraulic study needed for weir installation).

Maintenance requirements

- Replacement of boulders / rocks likely after storms – frequency of replacement dependent on size of rock and magnitude of flows.
- Where upstream sedimentation occurs, replacement or repositioning of rocks may be required;
- Periodic removal of sediment upstream of weirs;
- Possible ongoing replanting of new sediment beds after dredging.

10.3.2. Creation of planting ledges in canals

Concept and rationale

Canals are inherently ecologically sterile environments where, despite the availability of water, ecological complexity is rare and only the most basic biological activities usually take place. One of the most useful means of improving real habitat diversity as well as of reducing the aesthetic sterility of canals is to install areas in which plants can be established, and be incorporated into the aquatic habitat. Unlike previous options (Section 10.3.1) that included the opportunistic allowing of plants to establish on accumulated sediment in canals, the approaches outlined in this section allow for long-term sustainable plant establishment within the canals.

The underlying concept referred to in this section was developed for improving river habitat in situations where ongoing maintenance dredging and (in some cases) boat-wash meant that steep-sided banks are subject to continual destabilization. An approach included in some European and Northern American literature in this regard entails stabilizing banks from the water surface down to the bed with metal sheet piling or "bagwork", the latter comprising concrete-filled bags, lain on top of each other to form stabilizing walls. While the concept as stated here resulted in both aesthetically and ecologically sterile banks, it can be softened by facilitating planting of the bank just above or at the water level, thus creating a vegetated band (see Figure 10.10 (RCC 2002)).

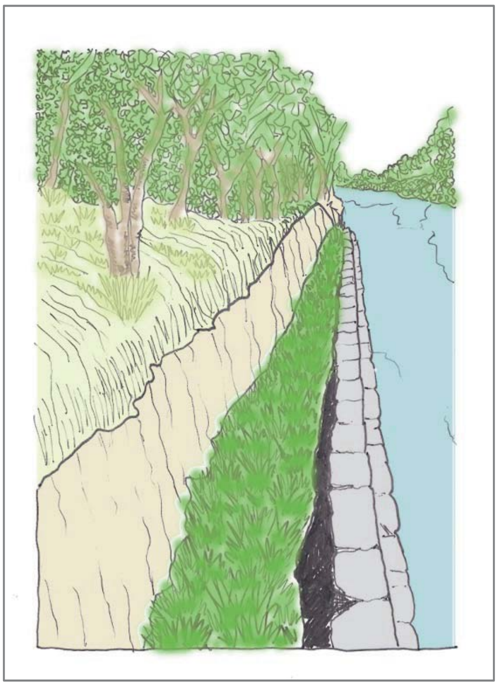


Figure 10.10: Planted ledge instated in channelized river – Examples from RCC (2002)

Site suitability / application

Although South African rivers are not commonly stabilized with sheet piling as in the example above, an adapted approach would potentially be applicable in lined concrete canals, or channels lined with otherwise hard and sterile material, including gabion baskets, and typical interlocking earth retaining blocks (e.g. terraforce®) (see Figure 10.11).

Figure 10.11: Creation of planting areas behind gabions on the Silvermine River, Cape Town. LHS: 2002, immediately after planting; RHS: 2009, showing plant establishment. Planted areas comprised bidim® lined, soil filled spaces behind the lower gabion, allowing plant roots access to water

Site suitability criteria would need to include conditions where there was adequate flood capacity in the canal or channel (vegetation and planting benches / ledges would reduce channel capacity and increase resistance), and where flood velocities are below thresholds likely to result in erosion of introduced planting structures. For this reason, low-energy, low-gradient canals and channels would be the preferred application for these measures, or artificial channels where space can be created for planting.

Note that plant establishment is generally more successful where plants have ready access to water on a permanent basis, and are thus located at or just above base flow water levels (Ractliffe and Day 2002). In deep flowing systems, the height of the planting zone can be adjusted upwards to allow the establishment of plants at the water surface.

Technical guidelines

A. *Retro-fitting canals with planted gabions*

SRK (2002) installed 0.5 m wide by 0.5 m high, rock filled gabions along both sides of the canal, with gabion baskets attached to the canal wall. Gabions were soil filled and covered with a hessian protection bag to ensure vegetation took hold before the bag rotted away.

> **Tech Tip**
>
> **Note that geotextiles such as Bidim® might usefully also have been used as a gabion liner to retain soil.**

The gabions were planted with hardy indigenous emergent sedges and reeds, which rapidly established, being at or just above dry season base flow level, as shown in Figure 10.12.

Alternative planting approaches in Western Cape and Eastern Cape systems where Palmiet reed (*Prionium serratum*) is indigenous would be to attach rooted Palmiet plants to the gabion basket, at or just below low season water level, using plastic cable ties or other devices. Once established, the plant grows quickly, forming dense stands, of value from a water quality and habitat perspective. A more efficient but slower use of Palmiet rooting stock is to cut rhizomes in pieces and plant them individually (see Volume 3: Case Studies 18 and 24 for Palmiet planting guidelines).

Figure 10.12: Planting of gabions, retrofitted along canal edges. Poor water quality and high litter loads reduce the biodiversity and aesthetic value of the planting areas, which today support mainly weeds.

B. Retrofitting canals with ledges stabilised with airblock, brick or retaining block walls

Assuming adequate flood capacity, construction of planting zones in low-gradient canals through the installation of “planters” along canal sides, in which soils can be placed and plants established, offers opportunities to improve habitat quality in generally sterile canals (Figure 10.13). Planting zones should be as wide as possible – planting spaces <0.3 m in width are unlikely to support vegetation of any quality and depth should be sufficient to prevent root scour and soil loss, noting however that many wetland and river plants can establish in very shallow soils. Planting is generally most effective in structures that are located close to the wetted bank, such that irrigation is not necessary and where riverine plants can access adequate supplies of water throughout the year (Day and Ractliffe 2002).

Plants thus established along canal margins can have a real effect in altering flows along the channel edges, and providing localised areas of shade and physical cover. Plants higher up a stabilised bank often play an almost wholly aesthetic role, and do little to achieve actual change in instream river habitats (Day et al. 2007).

Planters should be designed to allow seepage / flow of water from the channel into the planter, using pipes or perforations, particularly when water levels drop below the top height of the planters.

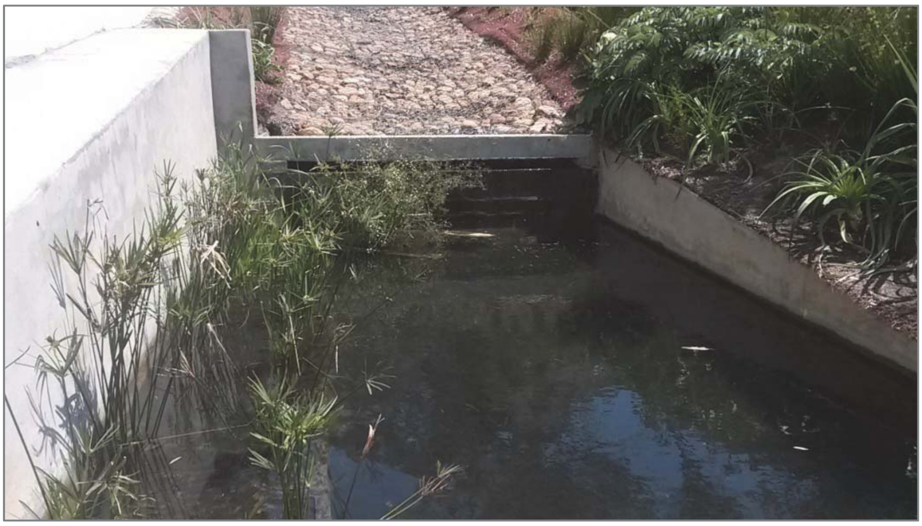


Figure 10.13: Planters established along the edges of a fast-flowing stormwater canal
Photo: Benjamin Stiffler

Note that the scale at which such interventions take place is important – replacement of canal walls with stepped planters, for example, is both costly and ineffectual if it takes place at too small a scale.

C. Use of bagwork and pilings

Note that the bagwork approach as described above is not recommended for use in South African rivers, as it is expensive if used with pilings (as per the RCC 2002 example), while unsupported bagwork is liable to failure over time, with likelihood of failure being exacerbated by vulnerability to exploitation by contractors using poor cement mixes.

D. *Use of floating vegetated islands*

Floating vegetated "islands" have been advocated in some situations for use primarily for water quality improvement in lakes and channels. These "islands" can potentially be created of a variety of materials including (as in Photograph 9.X) cut *Arundo donax* (Spanish reed) frames, anchored to the shoreline or underlying substrate with stainless steel wire or rope, tied to concrete blocks. Rooted plants are wrapped in Bidim and attached to the frame. In other situations, floating islands have been used to create habitat for birds in farm dams (NCC 2015 – Indaba conference paper).

In sterile environments such as concrete canals (or in impoundments – not addressed in this manual) such approaches may allow the rapid creation of more complex instream habitat, that will provide shelter and substrate to fish and aquatic invertebrates, and roosting, resting or perching areas for birds. <u>However, it should be noted that these systems provide a highly manipulated environment, and their use in natural river systems is seriously not recommended.</u> Their use should be strictly limited to the following scenarios:

- Artificial canals and channels where the flow regime is controlled and flood flows likely to dislodge the anchored structures will not occur;
- Artificial canals and channels where habitat diversity cannot be achieved by replanting and shaping of the bank and beds;
- Steep-sided, deep artificial canals and channels where there is no space to reconfigure the channel, and where water quality improvement through active plant harvesting is a management objective for the system.
- Furthermore, only locally indigenous plants should be established on the baskets.

Expertise required (all of the above options)

- Engineering input required for any in-canal constructions;
- Hydraulic modelling required to ascertain effects of structures on flood levels.

Notes on water quality

- It should be stressed that in canals where water is highly contaminated, the provision of areas for the established with plants and the associated improved riverine habitat is likely to fail, unless the over-riding water quality issues can be addressed. See Chapter 8 for water quality improvement options.

Legal considerations/authorisations

- If the canal is considered a natural watercourse, and 5 m^3 or more of soil, rock, brick or other construction material is used, then NEMA would be triggered.
- Similarly, Section 21(c) and (i) of the NWA would apply.

Maintenance requirements

- Depending on plant selection, periodic removal / replacement of senescent plant material may be necessary as well as annual or less frequent cutting and removal of reeds to stimulate growth.
- Inspections of gabion basket or other devices may be necessary from time to time, to highlight any repair needs.

10.3.3. Canal removal and/or daylighting of piped river flows

The most common strategies outlined in reviewed material for improving instream morphology included the removal or replacement of hard construction (including daylighting of formerly piped rivers), initiation of more natural hydro-morphological processes and the rehabilitation of a diverse habitat structure. Complete removal of canals and their replacement with unlined vegetated channels is indeed the ultimate rehabilitation approach for these sterile systems, and where space and funds permit, should be encouraged, noting at the same time that such approaches are significant interventions in the *status quo* of a river, and should not be undertaken lightly or without thorough design and planning input.

This section describes various approaches aimed at achieving at least partial canal removal.

Partial canal removal – Diversion of canalised low flows

Concept and rationale

Outright removal of canals and rehabilitation of flows into more natural river channels is simply not feasible in most canalised examples, particularly where encroachment of infrastructure, urban development or agriculture into the river's original floodplain and even its original course means that there is no space for such measures. There are however some situations where sufficient space remains for the separate treatment of low flows and flood flows, such that low flows at least can be managed in a more natural, non-canalized environment. This approach allows for retention of high flows in the canal, and the controlled diversion of low flows into adjacent areas, rehabilitated as valley bottom wetlands or unlined channels.

Site suitability

Canals where this kind of approach might be considered are those where sufficient space remains for the creation of a substantial length of unlined channel that can be landscaped and planted such that it has a measurably improved impact on local habitat availability, quality and diversity. There is little value in pursuing this kind of option if the availability of space will allow only for the creation of a similarly confined, restricted low flow system.

In situations where conveyance of large floods (e.g. the 1:100 year flood) through an already-urbanised area requires the maintenance of lined, fast-flowing canals, opportunities for more natural channels that can take low flows and small floods should be explored, as such approaches at least allow for longitudinal connectivity and the maintenance of a functional riverine ecosystem rather than a flood conveyance conduit.

Where water quality is moderately impacted, such approaches may also provide opportunities for improving water quality during low flows, by filtration through wetland areas. The degree to which such effects would be measurable will depend on the surface area of vegetated channel created, the efficiency of wetland filtration design and the pollution loading of the water ((Kadlec and Knight 1996) see also Chapter 8: Water Quality Improvement).

Figure 10.14: Low flow outlet (arrowed) from Langvlei Cana, Retreat, Cape Town (left) and downstream inlet from low flow channel (right), showing creation of broad reedbed wetland and low flow channel outside of the lined canal. See Volume 3: Case Study 16

Technical guidelines

The photographs in Figure 10.14 illustrate one example of this kind of approach, described in more detail in Case Study 16 (see Volume 3). The approach included:

- A piped low flow diversion from the main canal, immediately upstream of a low diversion berm constructed across the canal for this purpose – pipe wide enough to minimise the likelihood of blockage;
- Excavation of a low flow channel, that functions as a broad, reeded valley bottom wetland, landscaped to grade gently into the surrounding terrestrial landscape;
- Opening up of the canal at the downstream end of the diversion, to allow re-entry of water into the canal. Note that during high flows, water backs up into the low flow system from the canal;
- Upstream end of the diversion channel managed as a sediment trap, to reduce maintenance frequency in low flow section;
- Periodic narrow bands of grassblock or similar hardened surface installed at intervals along the diversion channel, to guide future maintenance activities (see below)
- Consider installation of larger pipe, installed at high flow level, to allow periodic flushing by high flows.
- The system as a whole included provision of paths and lighting to the local community, which improved community buy-in to the project (see Section 10.12).

Expertise required

- Hydraulic engineer with specific input into pipe sizing
- Possible floodline study
- Structural input regarding maintaining canal integrity after installation of pipes
- Ecological input into diversion channel design.

Legal considerations/authorisations

- Will trigger NEMA if an excess of 5 m^3 sediment is moved or removed from the canal itself;
- NEMA also triggered by general activities / excavations within 32 m of the canal, if considered a natural watercourse;
- Can be carried out in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

Cost

Actual intervention not costly; costly if NEMA and specialist studies triggered.

Maintenance requirements

In natural channels, low flow channels and their associated vegetated areas are maintained by ongoing regular as well as sporadic catastrophic disturbance, mainly in the form of floods.

Caution:

In the absence of floods (an integral element of the design outlined above), the low flow channel will silt up in time, and low flows will eventually remain in the canal.

Maintenance measures would need to address such issues, for example by:

- Allowing periodic flushing floods through the wetland – e.g. by the provision of a larger pipe aperture higher up in the canal wall, that would allow some erosion / scour of the channel
- Simulating disturbance through physical intervention, and allowing for periodic re-excavation of the low flow channel. Such approaches would need to:
    - allow for rescue and re-use of existing plants as far as possible
    - ensure that excavation allowed for reshaping of bed and banks, and did not result in gradual channelization, with steepening of banks and deepening of the channel
    - include allowance for replanting of the channel.

Partial canal removal – removal of canal base and establishment of plants and rock substrate

Concept and rationale

It is seldom feasible to remove a canal entirely, given that the reason for canal construction was often to facilitate the rapid removal of floodwater to allow development across the natural floodplain. Thus existing development usually precludes complete canal removal, and partial removal becomes a more viable, but compromised, approach.

The approach presented here entails removal of the concrete canal base, the placement of boulders and cobbles in the channel to increase instream habitat diversity, and the shaping and planting of the canal banks where possible. **Ideally, reshaping and vegetating banks should be included in this kind of rehabilitation project, provided that adequate bank erosion protection is provided** – either in terms of vegetation or by reducing flow velocities (e.g. by increasing channel capacity) or by including bank stabilization approaches such as riprap or other approaches outlined in Chapter 4 (and bearing in mind comments made in Section 10.5 around the most ecologically desirable of these approaches).

Site suitability

- This approach can be applied only to canals where sufficient space is available for canal capacity to be maintained in the face of increased channel roughness – this means that, unless the canal was over-designed – that is, with excess flow capacity during floods – widening or deepening of the final channel would be required, in order to prevent flooding impacts;
- The approach should also only be applied in situations where instream water quality is relatively un-impacted – there is little point in trying to establish a more natural physical habitat if the chemical composition of the river will prevent the establishment of natural riverine ecosystems;
- Finally, the approach used in the River Medlock for example (see Figure 10.15), where only the base of the canal was removed and not the sides, would not be useable for most modern canals made of reinforced concrete, where steel cables connect the side walls to the floor of the canal. In such cases, it would be necessary to remove the canal side walls as well, and either shape and vegetate them or stabilise with riprap, gabions or other stabilizing material that permits the establishment of plants while retaining river integrity.

Figure 10.15: Un-rehabilitated, canalised section of the river Medlock (Manchester, United Kingdom) (left hand photo) and upstream, post rehabilitation channel (right hand photo), showing removal of concrete channel base, addition of rocks to improve instream habitat diversity and establishment of marginal vegetation. Canal side walls largely retained because of concerns around possible contaminants in fill on either side of the channel. Note how the same discharge is conveyed in each of the two channels, illustrating the role of canals in speeding up rate of flow

Technical guidelines

This approach was applied in the United Kingdom, where the concrete canalised River Marden was rehabilitated to include a meandering system, designed to include planted riverine margins, pool/riffle sequence and gravel shoals (see Figure 10.15). The brick canal base was removed, using excavators, and the resultant base was roughed, through the installation of large boulders and cobbles. The bricked canal sides were largely left *in situ*, to prevent exposure of river water to potentially contaminated soils in adjacent old stock piles.

Where circumstances permit, the following additional measures would be preferred in such rehabilitation project, namely:

- Assuming that issues of contaminated soils on the river margins are not of concern, reshaping and widening of the river bank to improve lateral connectivity would be preferred;
- Provision for the establishment of indigenous plants along the river bank would be desirable, and would be facilitated by bank shaping (see Figure 10—15).

Figure 10.16: Small canals such as this seasonally dry system lend themselves to removal of canal walls and (ideally) base, shaping of the banks and planting with indigenous vegetation.

Expertise required

Projects such as this require input from a diverse team of experts, from early planning stages onwards, with the following specialist input being essential:

- Hydraulic input to determine flood levels and flow velocities;
- Initial water quality analyses and interrogation to ensure that water quality does not constitute a significant barrier to rehabilitation outcomes;
- Input from a river ecologist regarding the kinds of instream, marginal and riparian habitats that should be created and the need to ensure longitudinal and/or lateral connectivity in a rehabilitated context (see Volume 1: Section 2.5);
- Input from a fish specialist regarding indigenous fish habitats that should be created;
- Landscaper and botanical input into the final planting plan, approach and implementation.

Additional cautions

The Medlock River case study entailed removal of the canal base along a substantial stretch of stream, resulting in measurable impacts to habitat quality – e.g. colonization by indigenous trout. Such interventions, if applied to only short lengths of the canal, would be unlikely to yield any measurable impacts, and could potentially simply incur significant costs for little ecological gain. Figure 10.17 illustrates one such example (reported also in Volume 3: Case Study 17), where localized rehabilitation efforts were further hampered by poor maintenance of planted areas, which were soon colonised largely by kikuyu grass.

Figure 10.17: Vegetation established in planter blocks set into canal wall – left hand photo in 2002, one year after construction, and right hand photo 14 years after construction, showing dense kikuyu grass over planted areas (arrowed)

Legal considerations/authorisations

- [redacted] canal is considered a natural watercourse, and 5 m^3 or more of soil, rock, brick or other construction material is used, then NEMA would be triggered.
- Similarly, Section 21(c) and (i) of the NWA would apply.

10.4. Improving floodplain and off-channel habitat function and diversity

Concept and rationale

Off-channel or floodplain habitats are often the only areas that can be rehabilitated in large rivers where impacts to the main channel may be too severe to mitigate, or where the main channel may be too unstable (Slaney and Zaldokas 1997). The basic objective of floodplain rehabilitation is to restore lateral connectivity. Rehabilitation techniques range from most costly and sophisticated, such as those developed

Why bother?

River floodplains and off-channel areas are often important spawning and juvenile rearing habitats for both floodplain and non-floodplain dependent species because of the high diversity of habitats that occur in these areas compared to the main channel. Apart from restoring the natural functioning of river systems, restoration of floodplain habitats is an effective method of intercepting surface runoff from urban areas, ameliorating floods and filtering pollutants (Palmer *et al.* 2005).

for salmonids and which entail the creation and landscaping of entirely new secondary channels, to more simple methods that entail levee breaching.

Broad approaches to rehabilitation of floodplain and off-channel function and habitat diversity are outlined in the following sections. Most aspects of these approaches have however already been covered in other sections of this manual (e.g. **Chapter 3**), so the details of construction are not presented here, and the reader is directed where necessary to the relevant sections of the manual. The relevance of floodplain habitat rehabilitation for fish conservation and management is highlighted in Chapter 11.

10.4.1. Retain existing floodplain areas

The most fundamental aspect that determines opportunities for rehabilitating floodplain function and off-channel wetland habitat is the availability of such areas in an undeveloped state. Particularly in urban environments, such areas have long been ceded to other uses, and opportunities to effect real rehabilitation are highly limited, with remedial efforts having to focus instead on simple habitat improvement in the resultant channels and canals, as described in Chapters 3 and 4.

It is thus critical to remember that, where existing open space exists along river channels, even where the rivers have been channelised or canalised, priority should be accorded to retaining the space to allow for future rehabilitation opportunities, even if no means or will to undertake these measures is presently available. Once developed on, such opportunities are lost forever.

10.4.2. Breaching levees

This is the simplest approach to floodplain rehabilitation where levees (more commonly referred to as berms and “nood-walle” (*Afrik.*) in South Africa) are present along river margins. Where the berms serve as flood protection structures, setting them further back from the river may be a compromise approach to partial restoration of floodplain function without affecting landuse (e.g. agriculture) on adjacent parts of the floodplain. Although this may not restore full connectivity, it may allow some re-establishment of floodplain function (Slaney and Zaldokas 1997) (see Figure 10.18).

Technical guidelines and other decision-assisting criteria for this measure are outlined in Chapter 3.

Figure 10.18: Bermed channel in the Breede River Valley, Western Cape
Floodplain function can be improved by increasing the space between the lowflow channel and berms or other flood control devices, while still protecting development (in this case agriculture) beyond the berms. The additional space thus provided can provide marginal habitat and improve the longitudinal corridor function of the river, but also may decrease flood damage to adjacent fields, by increasing flood capacity in stable, vegetated zone – this would still be overtopped or eroded in severe flood events, but the frequency of this occurrence would be reduced by the increased capacity.

10.4.3. Channel excavation to reconnect existing relict floodplains

The reconnection of existing relict floodplains through excavation is another option for restoring lateral connectivity. In this instance, a major challenge is often the elevation differences between a newly incised channel and the relict floodplain (Roni *et al.* 2005). Re-creating a new floodplain in such conditions would require extensive excavation of the banks to re-align the new bed of the river with re-created floodplain areas. An alternative approach would be to encourage aggradation of mainstem channels using submersible check dams or log jams (see Section 5 and Section 10.2.1). However, this technique only works if the old floodplain remains intact (Pess *et al.* 2005, Roni *et al.* 2005).

Technical guidelines and other decision-assisting criteria for this measure are outlined in Chapter 3.

In the case of the Liesbeek River floodplain reconnection (Figure 10.19), the channel bed level was stabilised by concrete and had not therefore deeply incised relative to the height of the floodplain. A channel excavated from the river to the adjacent low-lying area conveyed water during high flows, when the river channel reaches a specified height.

Figure 10.19: Floodplain reconnection between the channelised / canalised Liesbeek River and adjacent off-channel depressional wetland areas. Rehabilitation works undertaken by Friends of the Black and the Liesbeek River

Legal considerations/authorisations

- Will trigger NEMA if an excess of 5 m^3 sediment is moved or removed from the canal itself;
- NEMA also triggered by general activities / excavations within 32 m of the canal, if considered a natural watercourse;
- Can be carried out in terms of NWA GN 1199, provided no wetland is within 500 m of the activity.

10.4.4. Creating off-channel wetlands

Many natural floodplain wetlands have been infilled to allow the creation of roads and other urban infrastructure, and today their once-wide rivers comprise urban channels. In some cases, opportunities exist for these areas to be remediated as off-channel wetlands, where although in most cases there is little chance (or even desirability) for real floodplain function to be revived, by opening these areas up to inundation from river overflows, there are often opportunities for off-channel wetlands to be created in these areas, fed by an elevated wet season water table and localised runoff, rather than the river itself.

Don't let floodplain rehabilitation destroy ecological assets

Sometimes separation from rivers conserves floodplain habitats – the seasonal wetlands below (inset) have persisted because channelisation of the river has conveyed perennial urban water runoff past the wetlands (left hand photo); the wetlands in Figure 10.20 would be significantly degraded if reconnected to the Black River, which is fed primarily by sewage effluent.

Figure 10.20 shows one such example, where surface fill was excavated down to clean material underneath, at height that was set just above wet season river elevation, and such that road runoff could be directed into the broad seasonal wetlands that result from this approach. The wetlands were landscaped roughly with an excavator, to produce a mosaic of shallow (< 30 cm depth) depressional pans within a broader mosaic of seasonally saturated-to-inundated wetland. The habitat thus created are used as locally scarce feeding areas by wading birds, at the same time as providing a function in terms of water quality filtration and attenuation of flows from the road surfaces.

Figure 10.20: Wetland habitats created by removal of fill and rubble followed by excavation to levels likely to create a variety of seasonally shallowly inundated to saturated wetlands on the floodplain of an urban river. Reconnection with river water not considered as a result of poor water quality but approach provided seasonal pools for wading birds and diverse habitat for frogs and invertebrates. River channel arrowed.

10.4.5. Constructing new floodplain areas

The most costly and sophisticated option is the creation of entirely new floodplain habitats which may be either surface or groundwater-fed side channels or ponds (Slaney and Zaldokas 1997). Sophisticated intake structures may be required upstream. This option incorporates many of the instream rehabilitation techniques already outlined in this section of the Manual.

Technical guidelines and other decision-assisting criteria for this measure are outlined in Chapter 3.

10.5. Improving habitat quality when using erosion control structures

Introduction: Selecting appropriate intervention approaches

Previous chapters in this manual have tended to focus on techniques to address specific aspects of riverine degradation, such as bank and bed erosion or invasion by alien vegetation. The kinds of interventions presented to address these problems are include some that would not be selected in the event that rehabilitation of river function to a more natural state was the primary objective of an intervention, but might be an option, or at least considered in some circumstances, where existing development, for example, precludes the use of “softer” options. Where habitat quality and biodiversity are important issues driving the selection of interventions, then the kinds of approaches outlined in the present chapter should be utilized. In fact, the compilers of this manual are of the view that <u>the options outlined in this section should be considered as a priority, and less ecologically beneficial or benign approaches used only where the need for intervention is proven and based on more pressing needs than a desire for additional developable land, such as safety and threats to existing buildings, infrastructure or people.</u>

The following principles should be applied to choosing or designing the most ecologically benign erosion control structures for rivers:

1. Where existing space permits, and existing buildings, infrastructure or human communities are not threatened, further confinement of river flows, likely to result in speeding up flows, increasing downcutting or precipitating lateral erosion, should be avoided;
2. Removal of alien vegetation contributing to channel constriction, blockages, sedimentation and other effects should be addressed as a priority, before symptomatic erosion protection interventions are embarked upon;
3. The best ecological approach to effecting river erosion control (bank and bed) would usually be to attenuate the effects of catchment hardening, inter catchment transfers and effluent releases outside of the river channel (see Chapter 3) and to maintain the river in its natural morphology;
4. Where erosion control structures must be used, priority must be accorded to those that allow for the establishment of vegetation on the river banks and/or bed, as per the most natural condition of the river, or in rivers that have been permanently altered from their natural function, the most ecologically functional condition for that river. The rest of this section provides guidelines to this effect.

The following guidelines apply to the selection and design of structures that are likely to accommodate vegetation:

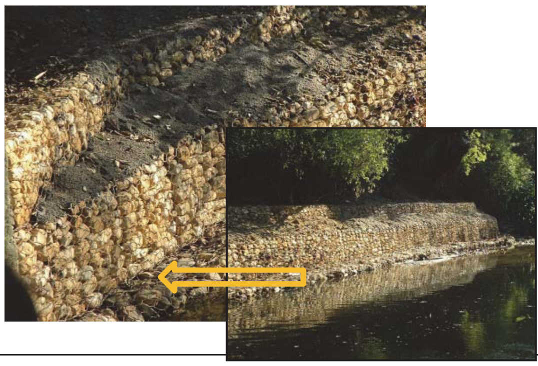
- The greatest level of success in establishment of plants on artificial structures is usually where plants are close to the low season baseflow, and their roots can access water on a permanent basis. Thus:
  - On stepped gabions:
    - the lowest / bottom step(s) are most likely to support vegetation, and should be designed such that at least one step is no greater than 200 mm above the low season base flow level;
    - Steps that are in the water / within 200 mm of the low season base flow should be the widest, as these are likely to support the best quality vegetated habitat. This might mean that other steps going up the bank need to be steeper – this would be a sensible tradeoff where space is limited;
- Plants usually require soil for adequate establishment, and structures that include or can be adapted to hold soil for the establishment of roots or that allow plants to root through the structure and into the soil are preferred;

Many so-called "plant friendly" erosion control structures have small rooting holes only, and generally support only weedy annuals or grasses, thus creating an environment of poor river habitat quality (e.g. no vertical cover; little variation in species or form).

- As a guide, plant holes in stabilizing structures (e.g. permeable plant blocks, planters in gabion mattresses – see Chapters 4 and 5) need a rooting space of diameter at least 10 cm and usually are better with wider spaces;
- The establishment of plants in stabilizing structures is less likely to succeed with distance up the river bank and out of reach of permanent water. This is both because of water stress and often also because concrete structures get too hot for the plants or their roots to thrive, particularly when small. Thus planting of the upper banks of stabilized channels may be more likely to fulfill aesthetic rather than ecological objectives, and hardy ground covers, rooted in soils on the upper bank, may be the most practical approach in such cases – noting the obvious limitation in ecological function and lateral connectivity that this entails;
- Allowance must be made for the establishment of plants, their initial weeding and irrigation (see Volume 3: Case Study 24 (Berg River Rehabilitation), until adequate, specified levels of cover are obtained – the focus of effort and budget in structural interventions on rivers is often on the engineering aspects, with little effort or budget allocated to plant establishment and maintenance, thus often obviating efforts made in ensuring that the design will be ecologically benign.

But note ….Palmiet (***Prionium serratum***) is a Western and Eastern Cape river plant that will root in running water if cut roots are simply cable-tied to gabion structures (see Volume 3: Case Study 3)

The table below provides some examples that illustrate these and other aspects.

	**Riprap** covered with soil on the upper bank of the Lourens River provides structural stability while allowing the establishment of riverine plants likely to create a high quality (if not natural) riverine habitat Photo: Megan Anderson
	**Reno mattress** lined, stepped high flow channel on the urban Keysers River, supporting dense reedbed and other vegetation (including some weedy aliens!)
	Illustration of the potentially sterile nature of **reno mattresses and many other bank stabilizing structures**, above the low season water mark: vegetation established along the toe of the slope, in the water, and on the top of the bank (in soils) but little on the hot, dry bank Photo: Megan Anderson
	**Unstepped gabions** provide bank protection but the height of these gabions prevents lateral connectivity between the aquatic instream habitat and the river bank / riparian areas, making the planting of the upper bank of aesthetic but not ecological value, Small changes in design could have averted this impact – e.g. installing stepped, shorter gabions Photo: Megan Anderson
	**Gabion bank stabilisation on the Liesbeek River** with the 1st step (bottom) set just above water level. No planting was carried out in this case, and no top soil was applied to the bottom step, thus limiting plant establishment, despite possibilities implied by design. In this case, shading by alien trees probably reduces plant growth.

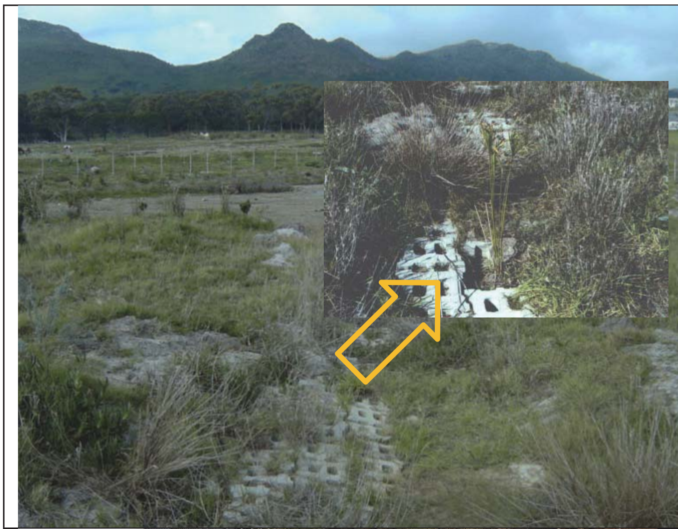
Establishment of plants in **pre-cast concrete blocks** on the Lourens River. These planters allow better connectivity up the bank than tall stepped gabions, and take up less space than stepped gabions, lending themselves to bank stabilisation in confined areas. Note however that unless properly treated (soils, irrigation, planting) they remain however sterile structures.

Photo: Megan Anderson

Photos above show **establishment of indigenous riverine plants on wetted edge of channel**, with poorer quality of plants (mainly groundcover) in the planters. Same bank shown some four years later, showing dense establishment of vegetation on wetted edge. Although this provides aesthetic cover of steep stabilized bank, connectivity issues between the river and the bank are likely.

Photos: Hans King

Precast planting blocks at Langevlei canal (Volume 3: Case Study 17)
Plant survival on upper banks is very low – due to wear and dryness. On wetter lower slopes, improved cover with distance towards water's edge, but species primarily grasses. Large clumps of reeds (*Schoenoplectus maritimus*) shown in channel rooted initially in Winblock® matrix.

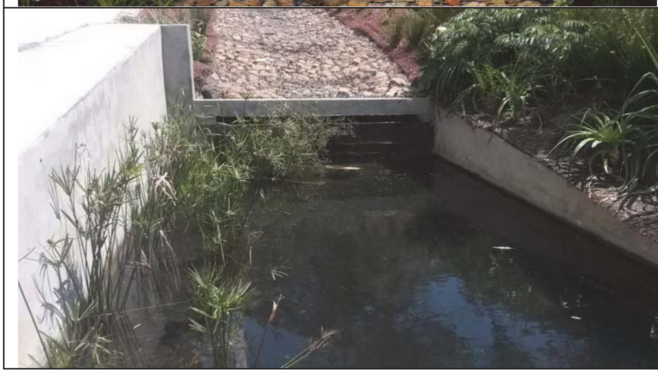


Flexible grassblock channel liners seldom support riverine or wetland vegetation that provides habitat of a quality to mimic the natural environment, largely because the planter spaces are too small, and the structures drain water away from the surface, drying them out. These planter blocks omitted occasional blocks, thus creating intermittent larger planting spaces.

This approach worked in this environment, where flows were relatively low and artificial. It would be a high-risk approach where flows were large – and could risk structural failure unless deep-rooted plants quickly established that rooted down through the structure.

Stormwater channel down steep slope **– side slopes stabilized with geotextile** to prevent erosion during high flows but still allow the establishment of vegetation, at least along the channel margins; little vegetation likely to establish on reno mattress of main channel, as low flows flow with mattress, making surface dry and hot.

Photo: Robert Murray

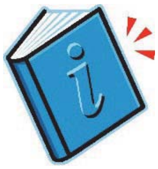


Planting boxes installed in side of steep, fast flowing canal in Lakeside. Depth: top of planter boxes <40 cm below water level; boxes allow the installation of marginal vegetation even where canal depths and velocities would preclude such growth.

Photo: Benjamin Stiffler

Important considerations in deciding on the most ecologically benign structure:

- Do instream fauna migrate up- or downstream as part of their lifecycles and hence would a structure across the channel constitute a problem in this regard?
- Safety issues, such as the height of a gabion weir;
- Maintenance issues – e.g. if sediment clearing is an ongoing issue in a channel, then riprap lining may be problematic;
- Ecological issues – the implications of different approaches in terms of habitat availability and desirability (e.g. hard-lining a channel would reduce habitat diversity, speed up instream flows and may result in bank erosion downstream)



CROSS REFERENCE

Links to other chapters

- Chapter 12: Plant establishment techniques
- Chapter 3: Flood control approaches
- Chapter 4: Bank erosion controls
- Chapter 5: Bed erosion controls
- Chapter 6: Sediment management approaches.

Links to Case Studies: 2, 3, 4, 11, 14, 16, 17, 19, 24

10.6. Removal of weirs to rehabilitate aquatic habitat

Chapter 7 provides broad comments on issues to consider with regard to the removal of weirs. From an ecological perspective, motivations for the removal of weirs may include:

- Rehabilitation of a more natural sediment regime in rivers where erosion occurs downstream of weirs that trap sediment and release sediment-hungry water into downstream reaches;
- Pollution abatement programmes – where contaminated sediment has built up behind weirs, and is being steadily released into downstream waters, or poses a human health or aquatic ecosystem risk to users of water impounded upstream of the weir, removal of sediment and removal of the structure may be required – such interventions would be most likely to be requested in areas of South Africa where mining activities has resulted in heavy metal contamination of in-channel weirs and/or dams as well as systems affected by high levels of sediment from ash, originating from power plants;
- Aquatic ecosystem rehabilitation objectives, particularly removing obstructions to the free movement of aquatic fauna through a river (e.g. migratory fish) and the re-establishment of natural riverine habitat – for example, riffles, pools and backwaters in areas that were previously impounded (see Figure 10.21). The motivation for such rehabilitation may include rivers ear-marked for active rehabilitation to a better Present Ecological State to meet NFEPA conservation planning objectives, particularly for fish (Driver et al. 2011).

Figure 10.21: Site of the now-removed Goshen Weir on the River Roch, Manchester.
This weir was removed by the United Kingdom's Environment Agency, which worked in collaboration with the Irwell Rivers Trust, local authorities and angling groups to take out weirs that were in danger of collapsing. The weirs in many cases were originally constructed to supply water to now dis-used mills, and their removal allowed the restoration of river habitats. **Inset: The weir during removal**. Inset photograph presented by Environment Agency during 2015 Society for Ecological Restoration (SER) conference site visit.

When removal of weirs / dams is being considered from an ecological perspective, or is motivated from the perspective of improved ecosystem function, the following issues / aspects must be considered at the outset:

- The method for weir removal, that will result in the lowest level of downstream impact (see Chapter 7);
- The treatment of sediment accumulated upstream of the weir – the most ecologically benign approach would depend on the volume and quality of sediment, and the nature of the downstream river system. A fluvial geomorphologist and water quality specialist must be consulted (respectively) with regard to the impact of increased sediment loading into downstream reaches and the risk of mobilising contaminants (e.g. heavy metals and in some cases radioactive waste) into downstream reaches through dredging and/or flushing activities;
- The effect of the existing structure on river function and structure – in some cases, deep channel incision has occurred downstream of weirs / dams, with the result that removal of the structure will not result in improved connectivity, but rather the creation of a deep, steeply flowing channel through a degraded environment;
- The feasibility and desirability of rehabilitating river function to a more natural condition, with riverine rather than lacustrine (lake-like) habitat – for example, if water quality is so contaminated that indigenous riverine fish and other fauna are unlikely to survive in the system, the costs of weir removal might rather be spent in effecting water quality improvement.

Caution

Due to the high risks and specialist insight required, qualified environmental practitioners, fluvial geomorphologists and engineers should be consulted prior to any consideration of the removal of dams.

Note also that while removal of weirs may sound ecologically beneficial, in some river systems, the presence of weirs protects upstream river reaches from invasion by alien fish species, thus maintaining populations of sometimes critically endangered fish species (see Volume 1: Section 3.10). Removal of weirs to increase riverine connectivity may put such populations at risk.

10.7. Design and management of riparian buffer / ecological setback areas

Introduction

In a development context (both agricultural and urban), surrounding landuses are frequently incompatible with aquatic ecosystem function (Castelle et al. 1992) and may affect wetlands and river systems through: increased runoff, sedimentation, introduction of chemical and thermal pollutants, diversion of water supply, introduction of invasive and exotic species and reduced populations of indigenous wetland dependent species (reviewed in Castelle et al. 1992). An effective method of reducing the impacts of development on adjacent rivers is to provide a buffer or setback area around the system (Day et al. 2010).

Riverine buffers are defined as areas that abut river banks and reduce the adverse impacts to natural ecosystem functions and values of surrounding landuse (Castelle et al. 1992) – see Figure 10.22.

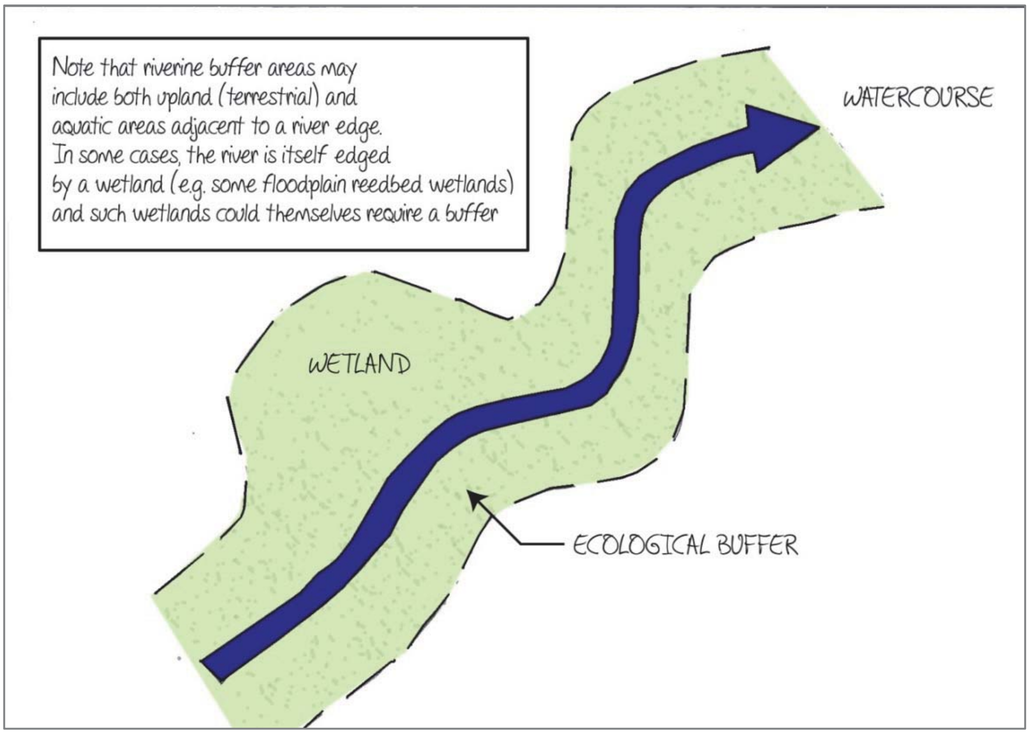


Figure 10.22: Conceptual river buffer (adapted from City of Cape Town 2009)

Buffer functions (after City of Cape Town 2012 pamphlet)

The primary purpose of a buffer is to provide enough space between human development / landuse / infrastructure (e.g. roads, pylons, pipelines, agricultural fields or other developments) to dissipate their negative effects on river ecosystems, such as:

Protection may also be rendered more effective through the installation of physical barriers to vehicle access (e.g. concrete bollards across road edges), which limit dumping and vehicle compaction, while controlled footpaths can also restrict areas of human disturbance.

- Noise and disturbance associated with human movement and vehicles, as well as impacts such as dumping,
- Rapid, concentrated and frequently polluted runoff from hardened surfaces;
- The spread of alien plants found in gardens, which spread into adjacent river corridors. These "garden escapees" include the following riverine pest species: kikuyu grass, nasturtium, morning glory, cannas, sword fern, wandering jew;
- In addition, vegetated buffers assist with stream bank stabilisation and protection from erosion, and also provide habitat and safe continuous corridors for movement of animals and may be associated with indirect benefits such as the creation of space for recreational activities such as walking, horse riding and storm water management.

The actual width of buffer that is required to protect a river depends however on the type of ecosystem, its sensitivity and ecological importance, and the kinds of impacts that are likely to affect it. In South Africa, a methodology for the setting of buffer widths is currently being finalized (WRC TT 610/14). The approaches recommended by this document are supported by the present River Rehabilitation Manual.

Natural floodplain wetland areas in good condition should not be used for stormwater management or buffering purposes, as such activities would simply degrade the kinds of systems that the establishment of river buffers seeks to protect (Schulte-Hostedde et al. 2007).

Using multi-use buffers

Buffer areas should be specifically managed such that their use and management does not detract or conflict with their primary purpose, that of protection of the aquatic resource. Thus where secondary uses for such buffers are required (e.g. recreational picnic areas, playing fields), the buffer should either be widened to accommodate such activities or the quality of the buffer in terms of its plant communities and vegetation

Design and treatment of buffer areas

- Buffer areas should be planted with appropriate indigenous vegetation. Where remnant indigenous vegetation occurs in the corridor or is likely to re-establish once alien removal has taken place, efforts should be made to encourage its re-establishment actively;
- Riverine and valley bottom wetlands that have been identified as currently providing or needing to provide important corridor functions, need to be planted with appropriate locally indigenous vegetation to secure this function. Reshaping of the buffer may be required in some cases.
- Where buffer areas are grassed or similarly planted, they need to be wider than the recommended minimum widths, to compensate for reduced function – similarly, where buffer designs include specific measure to address identified impacts in an efficient manner (e.g. runoff attenuation ponds) then a reduction in their width may be argued;
- Control of alien plants should be one of the management priorities within buffer areas – alien plants often detract significantly from buffer function and are likely to spread along the river corridor;
- Buffer areas should ideally be located outside of private erf boundaries, where they are less likely to be misused or manipulated by often well-intentioned landowners (e.g. creation of paths, patios, ponds and the spread of alien plants).

The following activities should **not** be allowed to take place in buffer areas (and thus, should not take place within the specified setback distance from each river or other wetland):

- Dumping of waste of any kind, including garden litter, rubble, alien plant debris, dredged spoil from the river or wetland and any other waste;
- No infilling should take place;
- No hardened surfaces should be created. This includes structures such as paths, roads, decks, patios, houses. Unlined, informal paths can however be created;
- Stormwater outlets should open into the upland edge of the buffer (i.e. the edge furthest from the channel) and stormwater flows should be managed so as to maximise the function of the buffer area in ameliorating water quality upstream of the aquatic resource. Appropriate management measures may include energy dissipating structures, specific vegetation, etc.;
- No draining of buffer areas by means of channels and subsurface drains can take place, as this directly affects buffer function. This means that the use of buffer areas for sports facilities other than informal "kick-abouts" may not be feasible in an area where the buffers may be saturated in winter;
- No agriculture, heavy grazing, feeding or watering of livestock should take place – note that where agricultural fields abut rivers or other wetlands, even channelised systems, sufficient

space must be left outside of the buffer area to allow for the passage of tractors and other vehicles along the buffer edge;

- Sewers should not be located through buffer areas – where this is unavoidable, manholes should be spaced such that there are no manhole covers in buffer areas or their associated rivers.

Although minimum buffer width guidelines have been proposed, a freshwater ecologist may be required to determine specific buffer widths for new developments on a site but site basis. All land within the 1:100 year floodline or 32 m from the edge of the channel (whichever is the greater) is protected in terms of the National Water Act.

10.8. Managing alien fish species

10.8.1. Problems caused by alien fish

Our alien fish

Most of the alien invasive fauna that have invaded freshwater habitats are fish, with 17 taxa now established in South African waters. *Cyprinus carpio* (Common carp), *Onchorhynchus mykiss* and *Salmo trutta* (Rainbow and Brown trout) and *Micropterus salmoides, Micropterus dolomieu* and *Micropterus punctulatus* (Largemouth, Smallmouth and Spotted bass) were all actively introduced into rivers to enhance freshwater fisheries, while some aquarium fish were introduced accidentally through the aquarium trade. Others escaped from fish farms (e.g. *Hypophthalmichthys molitrix* (Silver Carp), *Ctenopharyngodon idella* (Grass Carp) and *Pterygoplichthys disjunctivus* (Vermiculated Sailfin) (Picker and Griffiths 2011)), and are now well-established in many natural watercourses.

Invasive alien fish have had profound environmental impacts on natural river systems internationally, and in South Africa, with negative impacts including the transfer of parasites (Picker and Griffiths 2011), impacts on aquatic invertebrate communities and knock-on food chain effects (e.g. van Vuuren (2012) found that invasion of Western Cape streams by alien smallmouth bass resulted in greatly reduced algal cover on rocks , as a result of the loss of small indigenous fishes and thus reduced fish predation pressure on grazing invertebrates). Other documented effects of invasive alien fish include direct impacts (in some cases leading to localised extinctions) to indigenous fish taxa through predation, as well competition for food and breeding habitat and changes in habitat quality. Carp for example are bottom-feeders and are known to stir up sediments, leading to increased turbidity that has been linked to long-term changes in aquatic habitat type and quality. FCG (unpublished data) showed increased turbidity caused by Common Carp invasion of a series of canal systems in Cape Town, with a significant decline in extent of the rooted wetland macrophyte *Potamogeton pectinatus* (pondweed) in the water body, and resultant water quality impacts (e.g. increased nutrient concentrations).

Another effect of the transfer of fish into systems where they did not naturally occur is that of hybridisation, if the introduced species is genetically closely related to a species in the recipient system (e.g. the hybrid tilapia "swarm" that has been created in the lower Limpopo River, due to the introduced *Oreochromis niloticus* (Nile tilapia) interbreeding with indigenous *O. mossambicus* (Mozambique tilapia)(D'Amato et al. 2007)

Integral to improving river biodiversity is thus controlling (usually with a view to eliminating) alien fish species where this is practical, feasible and a priority. Anchor (2013) stress that the focus of alien fish control needs to be on preventing the spread or deliberate introduction of problem species to new areas or priority river systems as well as seeking to eradicate fish from systems where their impacts on biodiversity is considered to be unacceptably high.

While the previous sections of this chapter have focused on interventions designed mostly to improve hydraulic and or physical habitat diversity in South African rivers, this section focuses on activities that allow for the long-term control of alien fish populations.

10.8.2. Preventing alien fish introductions

Managing aquaculture facilities

Aquaculture facilities that actively breed invasive alien fish species can pose a risk of spreading these organisms into adjacent river systems. This is why the transport and stocking of live fishes (excluding permitted ornamental fishes for home use) is regulated by permit, either from the Department of Environmental Affairs: Biosecurity section for alien fish species, or by the provincial conservation / environmental agencies.

The Department of Environmental Affairs & Development Planning provides guidelines for the construction of aquaculture facilities and management thereof, designed to reduce biosecurity risks for more risky culture techniques such as pond culture next to rivers or cage culture systems in dams (Hinrichsen 2007). Key points include the following stipulations, namely that:

- Ensure that legal authorisations have been obtained, where needed, for the facility and species to be farmed;
- All new land-based aquaculture facilities should be built above the 1 in 50 year flood line, with infrastructure built to resist the impacts of floods (Hinrichsen 2007);
- The creation of physical barriers around the facility can be effective in preventing spread of invasive species (Novinger & Rahel 2003);
- Farming of triploid stock (i.e. by heating normal female eggs) or using a monosex culture of females (fertilising female eggs with sex reversed masculinised females) (FAO 2012) is encouraged (e.g. for rainbow trout) where practical, as such animals are unlikely to reproduce as wild populations, if they were to escape;
- Secure fencing around aquaculture facilities should be used in combination with restricted access to prevent any person intentionally removing and distributing live individuals (Hinrichsen 2007);
- In order to decrease the risk of escapes, pond and dam culture systems:
    - should be designed with stable walls (free from tree roots or burrowing animals) at a suitable gradient;
    - should include monitoring of their water levels to determine flood threats and also be built with a capacity for overflow, with an option to be drained completely;
    - should include mesh screens on all outflow and inflow pipes, which will prevent the escape of eggs from the hatchery and fry from the grow-out facilities. These criteria are also recommended for tank culture systems (Hinrichsen 2007).

Protecting barriers to movement

Providing connectivity for fish to pass undeterred through river systems is usually seen as essential for maintaining the migratory patterns and genetic diversity of indigenous fish stocks – see Section 11. In some cases, however, there are clear benefits to obstructing fish movement in rivers where alien invasive fish species have been introduced and pose a significant threat to the indigenous populations (see Section 11).

Existing weirs or waterfalls on rivers that separate indigenous and alien fish populations should be maintained, and any efforts to create fish ladders or increased longitudinal connectivity on these systems should be avoided, unless an assessment is done by competent ichthyolgists that advise otherwise. Active removal of alien fish species from such areas can be considered if such areas are priorities for rehabilitation by the provincial conservation agency, and indigenous species can be considered for re-introduction following best practice guidelines, once alien fish have been removed. Any fish control exercise in a river or public dam should be comprehensively monitored (biological, chemical, financial) to evaluate its effectiveness.

Education and Policing

Many populations of alien fish are established in South African water courses and dams to encourage angling. Active education of anglers, riparian land-owners and landusers through posters, signage, articles in magazines and ongoing communication should focus on creating awareness around the problems associated with alien fish introduction, and the urgent need to conserve threatened and / or endemic fishes. This is a priority where rivers or sections of rivers are currently alien free, targets for alien eradication programmes or are protected from alien invasion from downstream by natural barriers to fish movement. An excellent booklet by Garrow and Marr (2012), with beautiful underwater photographs of threatened fishes, entitled “Swimming on the edge of extinction: the perilous state of the indigenous freshwater fishes of the Western Cape” has helped improve public awareness of fish conservation issues in South Africa.

Legal considerations/authorisations

The introduction of alien fish (or other fauna or flora) into a watercourse without a permit is in breach of the National Environmental Management: Biodiversity Act (NEM:BA) (see Volume 1: Chapter 8), as well as provincial conservation legislation which controls fish stockings and sale of certain species, e.g. bass .

10.8.3. Alien fish eradication

Piscicides

Where natural barriers exist, or where they can be easily constructed, one of the most effective means of rehabilitating rivers invaded by alien fish species is through the application of the piscicide rotenone (Finlayson *et al.* 2000). Anti-mycin A has also been effectively used as a piscicide in the USA, but its use has been sporadic because of very limited availability (Finlayson et al. 2000). Once the alien species has been eliminated from the affected reach, fish are prevented from re-invading by a downstream barrier which may be natural, or comprise a specially constructed concrete or gabion weir that fish cannot swim or jump over. Fish can then be re-introduced, or allowed to re-colonise from naturally occurring populations upstream.

What is rotenone and how does it work?

Rotenone is a flavonoid derived from the jewel vine (*Derris* spp.) and lacepod (*Lonchocarpus* spp.) found in certain parts of the tropics which acts by interrupting cellular respiration in fish (Finlayson *et al.* 2000).

At fish killing concentrations, responsible use poses no human health risks either from direct consumption, or the consumption of fish from rotenone treated water. It has limited long term impacts on aquatic ecosystems, when used correctly, since it breaks down quickly through hydrolysis and photolysis and it can be rapidly deactivated at the end of the treated reach by means of potassium permanganate (American Fisheries Society 2010). While rotenone does affect local populations of gilled aquatic macroinvertebrates in the affected reach, re-colonisation from upstream reaches or by aerial phases has been shown in limited South African case studies to be relatively rapid (Woodford et al. 2014, Day in prep). Rotenone has been in use in the United States for conservation purposes since the 1930s and Australia for the last 50 years (Finlayson et al. 2000, Rayner and Creese 2006).

Site suitability

The use of rotenone in alien fish clearing exercises in rivers is limited to relatively small tributaries that can be easily accessed and where barriers are either already in place, or can be easily constructed are suitable. It is important to have land-owners that support the alien fish eradication programme on the river.

Technical guidelines

Rotenone can be applied to rivers, dams or wetlands through direct metering, or using backpack or boat sprayers or aerial spraying.

Since the use of rotenone to remove alien fishes is at present a new methodology in South Africa, treatment protocols are still being developed. CapeNature has however developed a draft piscicide use policy to ensure responsible use. On the basis of considered best practice and experience in the use of rotenone on projects carried out to date, Impson (see Volume 3: Case Study 23: Rondegat project) recommends the following approach:

- Draw up a concise initial project proposal that motivates why the project is necessary, answering questions such as:
    - Whether the project will benefit biodiversity, recreational fisheries or water quality? This must be supported by information regarding the distribution and abundance of different fish species in the water body and must address the ecosystem sensitivity of the water body;

    - Whether there is human and financial capacity to effectively manage and implement the project?
- Establish a capable project team, including persons with knowledge of piscicide projects, to develop and drive the project. Appoint a champion to drive the project.
- Ensure that there is full support for the project from the executive of the implementing agency – projects involving use of harmful chemicals can become controversial.
- Refer to USA Piscicide Use manuals and CapeNature's Piscicide Use Policy to guide planning and implementation of the project. This will ensure that the project has good plans to guide key aspects of project planning and implementation, e.g. Public Involvement Plan, Communications Plan, Fish Removal Plan, Site Safety Plan, Rotenone treatment Plan, Monitoring Plan, Auditing Plan.
- Ensure that any project on public waters (state dams and rivers) is subject to a risk assessment as may be required by provincial or national legislation. This will provide a platform for project approval and support from key authorities.
- Ensure that there is good stakeholder participation at key points of project development (project inception, risk assessment, project final planning, treatment phase, project assessment). Key stakeholders that oppose projects can easily terminate an otherwise good project.
- Ensure that independent biological monitoring is undertaken by a competent team of scientists. This is vital in quantifying the ecological merits of the project.
- Ensure excellent communications throughout the project with key stakeholders using appropriate web-sites, magazine articles, newspaper article and scientific publications. This helps obtain project buy-in and establishes project credibility.
- Ensure scientific integrity of the project through the involvement of a capable project implementation team, independent biological monitoring and high quality scientific papers and presentations.

Expertise required

Rotenone can cause ecological damage if used irresponsibly. It is essential that any rotenone operation is carefully assessed by trained people. In the USA, only accredited people may use rotenone, in accordance with requirements of the label on the chemical containing the rotenone. It is strongly recommended that only persons with accreditation in rotenone uses should be allowed to use the chemical in South Africa as well.

Legal aspects of piscicide fish eradication

The legal requirements for using rotenone in a water body must be considered, and may be quite complex, relating to both the proposed chemical and the water body (public waters being more sensitive than private waters, e.g. farm dams) Legislation in terms of the Water Act, NEM:BA, NEMA and Cape Nature's Piscicide policy all need careful consideration.

Costs

Small dam rehabilitation projects may be simple and relatively cheap (under R100 000 in 2014) but river rehabilitation projects may easily exceed R500 000 in direct costs. For example, where re-invasion of rehabilitated areas must be prevented, this may require costly barriers. Funds are required to purchase the piscicide, undertake a risk assessment (advisable for public waters) and purchase safety equipment. Running the project from inception to completion generally requires a team of three people working for 60% of their time on the project for 2-3 years (Impson 2014).

Manual clearing

Manual clearing of alien fish involves activities such as angling, netting, electro-fishing and spear-fishing. These are generally less costly alternatives to rotenone and can be carried out to some extent by local communities, angling groups and other parts of society. Alien fish clearing initiatives at Hartbeespoort Dam in Gauteng, for example, catch and freeze fish, which are sold at low prices to members of the local community.

Manual removal does however have a much more limited scope for application since it is only suitable for smaller rivers, shorter reaches and (in the case of spear fishing under permit) where visibility is good. Moreover, manual removal of fish is time consuming and relatively inefficient compared to piscicide / chemical applications (Anchor 2013).

10.9. Managing other alien fauna

As with invasive plant control, controlling the spread of invasive faunal species through **prevention** is generally thought to be the most cost-effective means of control (e.g. Leung *et al.* 2002, reviewed in Anchor 2013), with De Moor (2002) for example warning against the further import of live specimens of freshwater crayfish (*C. tenuimanus*), due to the high risk posed by parasites of these species infecting indigenous species, combined with the disappointing results that have been achieved so far in terms of aquaculture. The same guidelines already listed in Section 10.8.2 relating to the management of fish aquaculture facilities apply to the management of other potentially invasive aquatic fauna likely to be associated with aquaculture in South Africa.

Biodiversity effect of cats

Hunting by domestic cats in urban areas has been shown to have a significant effect on biodiversity in open-space areas abutting their home-spaces. Where these open-space areas include riverine corridors (as many urban open spaces do) then the biodiversity effects are magnified. The use of collars with bells and restrictions on cat ownership may be approaches to consider in areas where small vertebrate biodiversity conservation is particularly important.

References

American Fisheries Society. 2010. Maintaining North America's healthy native aquatic ecosystems: rotenone's role in eradicating invasive fishes, parasites and diseases. Fish Management Chemicals Subcommittee – 2010. 9 pp.

Anchor Environmental Consultants. 2013. Risk assessment and recommended control measures for aquatic alien invasive species in South Africa. Report prepared for Department of Agriculture Forestry and Fisheries.

Cowx, I.G. and Welcomme, R.L. 1998. Rehabilitation of rivers for fish. A study undertaken by the European Inland Fisheries Advisory Commission (EIFAC) of FOA, Oxford, Fishing News Books Ltd. 260 pp.

Day, E. (Liz). 2007. Water chemistry. In Ractliffe, G.R. (Ed.) Berg River Baseline Monitoring Programme Final Report. Volume 2. Riverine Baseline Monitoring Programme and

Statement of Baseline Conditions. Pretoria, Department of Water Affairs and Forestry. pp. 262-424.

de Moor, I.J. 2002. Potential impacts of alien freshwater crayfish in South Africa. *African Journal of Aquatic Science* 27: 125-139.

Driver, A, Nel, J.L., Snaddon, K., Murray, K., Roux, D., Hill, L., Swartz, E.R., Manuel, J. and Funke, N. 2011. Implementation Manual for Freshwater Ecosystem Priority Areas. WRC Report No. 1801/1/11. ISBN 978-1-4312-0147-1. Pretoria.

Finlayson, B.J., Schnick, R.A., Cailteux, R.L., DeMong, L., Horton, W.D., McClay, W., Tichacek, G.J. and Thompson, C. 2000. Rotenone use in fisheries management: administrative and technical guidelines manual, Bethesda, MD, *American Fisheries Society*. 214 pp.

Hinrichsen, E. 2007. Generic Environmental Best Practice Guideline for Aquaculture Development and Operation in the Western Cape: Edition 1. Division of Aquaculture, Stellenbosch University Report. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs and Development Planning, Cape Town.

Van Vuuren, L. 2012. Eradicating Invasive Alien Fish – It can be done, project shows. Water Wheel. December 2012. Pp 20-25.

Kadlec, R.H. and Knight, R.L. 1996. Treatment wetlands. CRC Press LLC. Florida.

Leung, B., Lodge, D.M., Finnoff, D., Shogren, J.F., Lewis, M.A. and Lamberti, G. 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. *Proceedings of the Royal Society of London* B 269: 2407-2413.

Moralee R.D., Van der Bank F.H., and Van der Waal, B.C.W. 2000. Biochemical genetic markers to identify hybrids between the endemic *Oreochromis mossambicus* and the alien species, *O. niloticus* (Pisces: Cichlidae). Water SA 26:263-268.

Morling. F. 2014. **Cape Town's Cats: Reassessing predation through kitty-cams.** A thesis submitted to the University of Cape Town in partial fulfilment of the requirements for the Masters degree in Conservation Biology. Percy FitzPatrick Institute of African Ornithology. University of Cape Town

Palmer, M.A., Bernhardt, E.S., Allan, J. D., Lake, P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C. N., Follstad Shah, J., Galat, D. L., Loss, S.G., P. Goodwin, P., Hart, D.D., Hassett, B., JENKINSON, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L. and Sudduth, E. 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology* 42 208-217.

Pess, G., Morley, S., Hall, J.L. and Timm, R.K. 2005. Monitoring floodplain restoration. In: Roni, P. (ed.) Monitoring stream and watershed restoration. Chapter 6. Bethesda, M.D: *American Fisheries Society.* 127-166 pp.

Picker, M. and Griffiths, C. 2011. Alien and Invasive Animals: A South African Perspective. Struik Publishers. pp 248Picker, M. and Griffiths, C. 2011. Alien and Invasive Animals: A South African Perspective. Struik Publishers. pp 248

Rayner, T.S. and Creese, R.G. 2006. A review of rotenone use for the control of non-indigenous fish in Australian fresh waters, and an attempted eradication of the noxious fish Phalloceros caudimaculatus. *New Zealand Journal of Marine and Freshwater Research*, 40: 477-486.

River Restoration Centre (RRC). 2002. Manual of River Restoration Techniques. 2002 update. United Kingdom.

Roni, P., Hanson, K., Beechie, T., Pess, G., Pollock, M. and Bartley, D.M. 2005. Habitat rehabilitation for inland fisheries: global review of effectiveness and guidance for rehabilitation of freshwater ecosystems. *FAO Fisheries Technical Paper* No. 484. FOA, Rome. 116 pp.

Rowntree and Wadeson (1998

Rutherford, I.D., Jerie, K. and Marsh, N. 2000. *A Rehabilitation Manual for Australian Streams, Volumes I and 2*. Cooperative Research Centre for Catchment Hydrology and Land and Water Resources Research and Development Corporation.
Schulte-Hostedde et al. 2007)

Slaney, P.A. and Zaldokas, Z. 1997. Fish habitat rehabilitation procedures. Watershed Restoration Program, Watershed Restoration Circular No. 9. Ministry of Environment, Lands and Parks and Ministry of Forests, Vancouver B.C. 341 pp.

Tourbier, J.T., Gersdorf, I., Schwager, T. 2004 Urban River Basin Enhancement Methods. 5th Framework Programme, Key Action 4 "City of tomorrow and cultural heritage: Existing Urban River Rehabilitation Schemes. Work package 2. Final Report. Dresden University of Technology (TU Dresden)

Welcomme, R., Winemiller, K. and Cowx, I. 2006. Fish environmental guilds as a tool for assessment of ecological condition of rivers. *River Research and Applications* 22: 377-396.

Chapter 11:

Managing Rivers and Dams for Indigenous Fish

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INTRODUCTION

The freshwater fishes of South Africa

South Africa has at least 108 species of freshwater fishes inhabiting its inland waters, comprising 91 indigenous species and 17 established alien species (Skelton 2001). About 33 of the 91 indigenous fish species are endemic to South Africa (Skelton 2001). Over 30 taxa are threatened, of which more than half are Critically Endangered or Endangered (IUCN Red Data website). South Africa has designated a substantial number of fish "sanctuaries" – river catchments that contain threatened fish species – as part of a mapping exercise to identify National Freshwater Ecosystem Priority Areas (NFEPA's)(Nel *et al*. 2011). **The focus of this guide is to rehabilitate rivers for indigenous species.** However, rehabilitation actions would also benefit alien fish species if they share habitat with indigenous fishes.

Regional context of fish

There are six major aquatic ecoregions in southern Africa, five of which are found in South Africa. The majority of indigenous fish species are found in the Tropical East Coast eco-region which has its margins in South Africa (Limpopo and Pongola rivers), whereas most of the endemic species are only found in the Cape Fold Mountains (fynbos) eco-region (Skelton 2001). South Africa has few natural lakes, so its fishes are primarily river dwellers that inhabit a wide range of riverine habitats ranging from fast flowing mountain streams, lowland rivers, floodplains as well as non-seasonal rivers that cease to flow during the dry season.

Habitat requirements of South African freshwater fishes

Different species of fish, and different life history stages of fish, use a wide range of habitat in rivers, and their relative importance in any river rehabilitation intervention will depend on the species occurring in the river reaches under consideration. Adequate knowledge of the depth, substratum, river gradient, velocity and vegetation requirements of the species is essential (Welcomme 2001). In Europe (e.g. ICPR 2009) and the United Sates (e.g. Beechie *et al.* 2012) the task of rehabilitation is made relatively simpler where salmonids, which have been well studied, are the primary targets of initiatives. In South Africa, where the goal is the restoration of a diverse fish community rather than a single target fish species, the ecological requirements of a wide range of species needs to be taken into consideration. However, it may be impossible to assess the needs of all species on a case-by-case basis, particularly where knowledge of the species is poor. In diverse systems, 'functional groups' or 'ecological guild' classifications are especially useful as proxies for individual species.

Rehabilitation caution

Essential to the success of fish population rehabilitation initiatives is that the primary biological and/or physical factors responsible for the decline in a particular fish population need to be established before rehabilitation options are selected. Factors responsible for such declines may include: degradation of instream or riparian habitats, pollution, reduced flows, increased sedimentation, disruption of sediment transport dynamics, or alien fish invasions (Paxton 2013).

Ecological guilds are classification systems that group species according to their morphological, physiological, behavioural and life history adaptations rather than by taxonomic relatedness – the assumption being that species with similar adaptations will respond to environmental change and variability in similar ways. Welcome *et al.* (2006) devised an ecological guild classification system specifically with environmental flow restoration and river rehabilitation in mind (**Table 11.1**). The principal groupings take into account whether a fish species depends on lotic (flowing water) or lentic (standing water) conditions, whether the species occurs in the upper or lower parts of a rivers system and whether they are predominantly a main channel or floodplain dependent species, or both. Different fish species fall into different combinations of these categories, and many may share characteristics between groupings.

Table 11.1 provides an outline of these ecological guilds. Descriptions of typical habitat requirements, key life history features and typical Southern African examples (where these are known) are listed. Grouping a fish community according to their ecological guilds in any river system will provide insight into which habitat types should be targeted for rehabilitation. Decisions around rehabilitation measures that are most appropriate for different fish species or communities should thus be based on an analysis of **Table 11.1**

Table 11.1: Ecological fish guilds suggested by Welcomme *et al.* (2006) adapted for local fish species (where these are known) and modified to be consistent with the terminology used in this chapter. Only obligate freshwater guilds are included: estuarine and coastal lagoon guilds are not considered.

	Ecological Guild	Guild Characteristics	Response to change	Southern African examples
Upper river	*Upper reaches of rivers, fast flowing, turbulent, rheophilic main channel residents, longitudinal pool-riffle-pool sequence*			
	Riffle guild	*Characteristics*: small size, equipped with suckers, spines to grip rocks, elongated or flattened morphology *Reproduction*: guarding and non-guarding lithophilic, eggs between gravel and rocks, riffles for spawning, pools for nurseries *Feeding*: insectivorous, algal scrapers, filter feeders	*Sensitive to*: catastrophic flows, disturbances to pool-riffle structure, seasonal desiccation, sedimentation, loss of interstitial spaces, wash-out, submergence of gravel reaches, loss of connectivity *Rehabilitation actions*: restoration of pool-riffle structure, flow regime and connectivity, river bank rehabilitation	Rock and mountain catfishes: *Chiloglanis* spp., *Austroglanis* spp., *Amphilius* spp.
	Pool guild	*Characteristics*: more limnophilic than riffle community. Pools and slackwaters with aquatic vegetation, well defined home ranges *Reproduction*: lithophilic or phytophilic *Feeding*: insectivorous drift feeders	*Sensitive to*: pool-rifle structure, pool desiccation or extended periods without flow, changes in water level, loss of connectivity *Rehabilitation actions*: restoration of pool-riffle structure, flow regime and connectivity, river bank rehabilitation	Minnows, *Barbus* and *Pseudobarbus* spp.
Lower river – LENTIC	*Lower reaches of rivers, non-migratory floodplain residents, move between floodplain pools, swamps, backwaters, breed during high and low hydrograph phases, strategies to cope with low Dissolved Oxygen (DO), 'black fish' (dark colouration)*			
	Plesiopotamonic guild (Floodplain scour lakes and pools seasonally connected to the main river by flooding) Floodplain – connected	*Characteristics*: tolerant of low DO, but not anoxia, lateral migrants between backwaters and floodplains, dominant in wetlands *Reproduction*: guarding and non-guarding phytophilic and nest-building	*Sensitive to*: descending limb of the annual hydrological cycle, amplitude of flooding regulating connectivity between river and floodplain, channelization, berms and levees disconnecting floodplain from main channel *Rehabilitation*: restoration of	Mozambique tilapia (*Oreochromis mossambicus*), banded tilapia (Tilapia sparrmani, Sharptooth catfish (Clarias gariepinus) *Aplocheilichthys* spp.,

	Ecological Guild	Guild Characteristics	Response to change	Southern African examples
POTAMONIC – LENTIC (cont'd)			floodplain, elimination of levees and berms, seasonal floodplain flooding reinstated	
	Paleopotamonic guild (Floodplain pools and lakes disconnected from the main river, fed by groundwater) Floodplains – disconnected	*Characteristics*: tolerant of complete anoxia, usually non-migratory, sedentary, xerophils resist complete desiccation, rice field faunas, high population densities *Reproduction*: parental care, nest building, viviparity	*Sensitive to*: the descending limb of the annual hydrological cycle, residual floodplain water bodies, land reclamation *Rehabilitation*: restoration of floodplain, elimination of levees and berms, seasonal floodplain flooding reinstated	African lungfishes (*Protopterus*),
	Annual guild	*Characteristics:* seasonal isolated water bodies, completely dry during part of the year, outermost limits of the floodplain. *Reproduction*: aestivating eggs with diapause, complete life cycle in one season.	*Sensitive to*: the descending limb of the annual hydrological cycle, residual floodplain water bodies, land reclamation. *Rehabilitation*: protection of wetlands where such species occur, restoration of floodplain, elimination of levees and berms, seasonal floodplain flooding reinstated.	Killifishes, Spotted killifish (*Nothobranchius orthonotus*)
	Longitudinal migration over long distances, complex migration patterns, one breeding season per year linked to peak flows, flow cues for migration require high DO, 'white fish' (reflective scales)			
POTAMONIC – LOTIC	**Eupotamonic pelagophilic guild** (Main channel – pelagic) Main channel – pelagic	*Characteristics:* main channel residents not entering floodplain, longitudinal migrations between downstream feeding site and upstream spawning. *Reproduction:* lithopelagophils and pelagophils, drifting eggs and larvae, fry may be resident at upstream spawning sites, downstream point bars as nurseries, bred in a single event.	*Sensitive to*: dams block migration, timing and velocity of flow for spawning and needs of drifting larvae, temperature of dam releases, degradation of spawning substratum, removal of instream structure such as wood debris. *Rehabilitation*: respond positively to fish passes, correct timing and	No known South African examples

	Ecological Guild	Guild Characteristics	Response to change	Southern African examples
POTAMONIC – LOTIC (cont'd)		*Feeding:* for piscivorous species – movements linked to prey.	magnitudes of flow for spawning and migration cues and for drifting larvae.	
	Eupotamonic lithophilic guild (Main channel – rock and sand substratum) As above	*Characteristics:* main channel, longitudinal migrations between upstream spawning and downstream feeding sites. *Reproduction*: lithophils and psammophils, single breeding season, some semelparous, fry may be resident in upstream reaches.	*Sensitive to*: dams block migration, timing and velocity of flow for spawning, changes in quality of upstream habitat, temperature of dam releases, degradation of spawning substratum, removal of instream structure such as wood debris. *Rehabilitation*: respond positively to fish passes, correct timing and magnitudes of flow for spawning and migration cues and development of eggs – aerating flows in gravels.	Large cyprinids: yellowfishes (*Labeobarbus* spp.), mudfishes Labeos
	Eupotamonic phytophilic guild (Main channel – vegetation) As above	*Characteristics*: long or short distance longitudinal migrants. Lateral migration onto floodplain for breeding, nursery and feeding by juvenile and adult fish. *Reproduction*: predominantly phytophils, phytolithophils spawning on floodplain margins in flowing channels or floodplain. Some eggs semi-pelagic, carried onto floodplain by rising flood.	*Sensitive to*: dams block migration, lateral connectivity between main channel and floodplain reduced, amplitude and duration of floods, berms, levees, channelization. *Rehabilitation*: respond positively to fish passes, correct timing and magnitudes of flow for access to floodplain, removal of berms and levees.	Alestidae (*Brycinus* spp.), Tigerfish (*Hydrocynus* spp.), *Labeos* spp.
	Parapotamonic guild (Semi-lotic, backwaters and slackwaters formed by remains of old anabranches, disconnected from main channel during low flow) Backwater	*Characteristics*: generalist species, resistant to change. Semi-lotic, intermediate between long distance lotic and lentic guilds. Semi-migratory or sedentary. Short distance non-obligate migrants.	*Sensitive to*: river straightening and bank revetments that reduce main channel diversity and bank structure, stress flows habitat flows for resetting the system.	Likely no South Africa examples

	Ecological Guild	Guild Characteristics	Response to change	Southern African examples
		Reproduction: backwaters, slackwaters and point bars for breeding. Prefer anabranches, backwaters and tributary creeks with low seasonal flows. Lithophils, psammophils, phytophils.	*Rehabilitation*: restore main channel diversity, reconnection of abandoned side arms and active backwaters.	
	Adaptive generalists with flexible behaviour, tolerant of low DO, repeat breeders, short distance migrants or sedentary local populations, rheophilic or limnophilic			
EURYTOPIC	**Eupotamonic benthic guild** (Main channel – bottom dwelling) As above	*Characteristics*: centre of the main channel, benthic sites. Tolerant of low DO for short periods over dry season. Increase in numbers as others decline. *Reproduction*: pasmmophils and lithophils	*Sensitive to*: Sedimentary processes that alter the bed of the river. Deoxygenation in deeper areas during dry season. *Rehabilitation*: restoring sedimentary processes in main channel	Some mormyrids, some *Synodontis*
	Eupotamonic riparian guild (main channel – riparian vegetation) As above	*Characteristics*: riparian zone and vegetation of main channel and floodplain. May use floodplain. Tolerant of low DO. Semi-migratory. Tolerant of modified hydrograph. Behaviourally adaptable, increase in numbers as others decline. Very common. Increase to pest levels in regulated systems. Reproduction: wide range, but predominantly phytophils. Some nest building and parental care	*Sensitive to*: degradation of the riparian zone and vegetation structure *Rehabilitation*: restoring riparian zone, correct timing and magnitudes of flow for access to floodplain	Tilapia and *Oreochromis* spp., , Sharptooth catfish (*Clarius gariepinus*),

Rehabilitation planning

All river rehabilitation actions that are soundly planned and implemented and result in a shift to more natural riverine conditions and improved habitat quality should be of benefit to fish (see Section 10). The information provided in this section is however intended specifically to inform rehabilitation projects where the focus is on fish, and mitigating the threats to fish.

Planning strategic approaches to rehabilitation of rivers for fish

Such projects should focus on the fish "sanctuaries" that are also FEPA's (see Nel et al. 2012).

FEPA's and Fish

The National Freshwater Ecological Priority Areas (NFEPA) programme provided the first comprehensive assessment of South Africa's freshwater and estuarine ecosystems in terms of their conservation worthiness and importance for providing ecosystem services (Nel *et al*. 2011a). Freshwater Priority Areas (FEPAs) were selected by applying systematic conservation planning software (MARXAN) to sub-quaternary catchments in each of the 19 delineated Water Management Areas in South Africa. The resulting FEPA maps which delineate planning units at the sub-quaternary catchment scale provide a strategic conservation framework intended to support water resource management, conservation and bioregional planning (Nel *et al*. 2011a).

FEPAS also contain provision for:

Fish Sanctuaries: which are conservation areas required to meet fish population targets and which were identified at the sub-quaternary catchments.

Fish Migration Corridors: areas identified as important for fish movement between required habitats

Rehabilitation and Translocation Areas: required for the survival of highly threatened fish species

Upstream Management Areas: managed to prevent the degradation of Fish Sanctuaries and Fish Migration Corridors

At this level, effective control of invasive fish and plants should be a priority action, as would be ensuring that such rivers have good habitat, near natural flow and un-impacted water quality. River Health surveys confirm that diversities and densities of indigenous fishes are highest in ecologically healthy rivers, and **fish rehabilitation projects must aim for the establishment or maintenance of Fish Sanctuary rivers in a good to excellent ecological condition with few, if any, alien fish species..**

However, many rehabilitation actions will take place outside of fish "sanctuaries" in areas where fish are present, and it is important that such actions include consideration of the fish community present.

Planning site specific rehabilitation of rivers for fish

Using successful fish rehabilitation approaches in Australia as a guide, the approach to fish rehabilitation projects outlined in **Figure 11.1** is recommended. This approach focusses on a variety of actions and objectives that can lead to river rehabilitation. These include the planting or repairing of riparian buffer zones to improve water quality and reduce sediment loads, restoring braided gravel-bed rivers and eliminating introduced fish species from selected river reaches using piscicides (Parkyn *et al.* 2003, Caruso 2006, Pham *et al.* 2013).

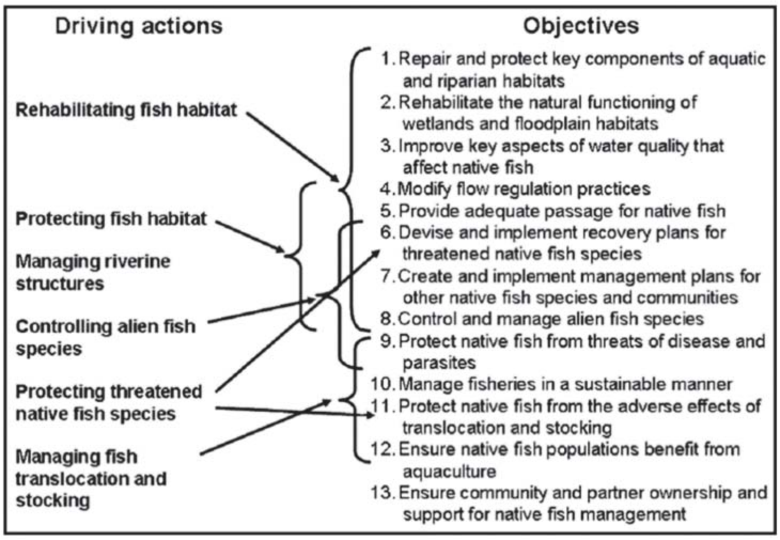

Figure 11.1: Thirteen key objectives and 6 actions identified for the recovery of fish populations in Australia's Murray-Darling River Basin (after Koehn and Lintermans 2012)

Approaches that facilitate river rehabilitation for fish

11.1. Instream habitat rehabilitation

The focus of instream habitat rehabilitation is on ensuring that fish have good habitat quantity and quality for all indigenous fish species present and for all life history stages. This requires the input of fish ecologists that have good knowledge of the species present and their biology and ecology. Good habitat requires adequate pool and riffle depth, cover for fish (rocks, logs, aquatic macrophytes), maintenance of fish migration to enable successful spawning and recruitment, and ensuring suitable water quality.

Many rivers in South Africa have been over-abstracted resulting in poor habitat during the dry season. This may be the first step that needs to be addressed in terms of a proposed rehabilitation project – is flow adequate through the year to sustain fish habitat and associated life forms? If not, can steps be taken to restore flow using legal mechanism that are part of the Water Act (e.g. water use licences, Environmental flows that must be released from dams, resource protection) or through co-operation with the land-owner (See Chapter 9). The next step is addressing water quality needs of the affected species, especially pollution sensitive species. This requires knowledge of what fish species are expected in the river under consideration and what species are currently present, and then using River Health and water quality measurements to note current water quality condition (see Sections 3.6 and 7.7 in Volume 1: Rehabilitation Guidelines). The next step is to identify point sources of pollution and work with regulators and other river rehabilitation partners to stop or reduce pollution levels (see Chapter 8 of this Volume).

Sometimes the river has been bulldozed and severely canalised, reducing instream habitat complexity. Instream habitat rehabilitation is sometimes referred to as habitat 'enhancement' in instances where certain types of habitat may not have been initially present in the system and if rehabilitation is aimed at offsetting habitat losses elsewhere. These techniques require careful planning and are usually expensive, thus often restricting their use to localised sections of urban rivers or other rivers that have been extensively degraded and where adequate funds are available for rehabilitation.

A key objective of instream habitat rehabilitation is to manipulate depths, velocities and substratum conditions in such a way as to increase habitat complexity and flow heterogeneity (e.g. shallow-fast and deep-slow (Kleynhans 1999) for fish spawning and nursery habitats, hydraulic and predation cover, as well as to provide for their migration requirements. It is recommended that these techniques be undertaken in consultation with fish ecologists and hydraulic engineers with careful consideration being given to the prevailing hydrological and geomorphological conditions in the affected reach. It is essential to determine if such rehabilitation actions are necessary, and funds are available before starting to plan and implement them. Failure to take adequate account of the inputs of hydraulic engineers and geomorphologists may result in the integrity of rehabilitation structures being compromised during floods and sediments being washed downstream. Stabilisation of the river banks and riparian zone should be undertaken prior to instream habitat rehabilitation if such actions are required (see Chapter 4 (Managing bank erosion) and Chapter 12 (Establishing plants on rehabilitated rivers as well as Chapter 10 (improving riverine habitat and diversity).

Instream habitat rehabilitation frequently involves the placement of physical structures in the active channel to trap sediments, channel flows and to manipulate the shape of the channel itself (see Chapters 4 to 6 and Chapter 10 for more generic options to improve instream habitat diversity). A list of the more commonly employed methods and structures are shown in **Table 11.2**. These may include gabions, log jams, boulders, or spawning gravel placement. It may also involve excavation of new pools for trapping sediment or the creation of new entirely new channels

Table 11.2: Common rehabilitation structures for enhancing fish habitat in degraded rivers (modified from Roni et al. 2005).

Type of structure	Definition	Typical purpose	Section of Manual where described
Log structures (e.g. weirs, sills, deflectors, logs, wing deflectors)	Placement of logs or log structures into active channel	Create pools and cover for fish, trap gravel, confine channel, or create spawning habitat	Section 5 Section 10.2.1.2
Log jams (multiple log structures, engineered log jams)	Multiple logs placed in active channel to form a debris dam and trap gravel	Create pools for holding and rearing habitat for fish, trap sediment, prevent channel migration, restore floodplain side channels	Section 5 Section 10.2.1.2 Note concerns raised regarding placements of large logs in rivers where they may create debris dams
Cover structures (rock or log shelters)	Structures embedded in the stream bank	Provide fish cover and prevent erosion	Section 10.2.2.1
Boulder structures (weirs, clusters, deflectors)	Single or multiple boulders placed in the wetted channel	Create pools and cover for fish, trap gravel, confine channel, create spawning habitat	Section 10.2.1.4
Gabions	Wire mesh baskets filled	Trap gravel and create pools or spawning	Section 5

Type of structure	Definition	Typical purpose	Section of Manual where described
	with gravel and cobble	habitat	
Brush bundles/rootwads	Placement of woody material in pools or slow water areas	Provide cover for juvenile and adult fish, refuge from high flows, substratum for macroinvertebrates	Section 5
Gravel additions and spawning beds	Addition of gravels or creation of riffles	Provide spawning habitat for fish	Section 10.2.1.2
Rubble mats or boulder additions to create riffles	Addition of boulders and cobble to create riffles	Increase riffle diversity (velocity and depth), create shallow water habitat	Section 10.2.1.4
Sediment traps	Excavation of a depression or pond in active channel to trap fine sediments	Improve channel conditions and morphology and increase grain size	
Channel reconstruction and realignment	Alter channel morphology by excavating new channel to restore meander patterns or return to historic channel	Restore meander patterns, increase habitat complexity and pool-riffle ratio, reduce channel width	Section 10.2.3

11.2. Improving fish passage and longitudinal connectivity

Better connections
There are currently around 57 fishways in South Africa, of which 42 are thought to be functional (Bok *et al.* 2007).

Fish passage facilities should be considered a key component of any rehabilitation project designed to restore fish populations on rivers where instream barriers are present, since many freshwater fishes depend on movement between different habitats in river systems to complete all phases of their life cycle. These movements may include spawning migrations, dispersal of larvae and juveniles, foraging movements and recolonisation after floods or droughts, with many of the larger river-dwelling fish species in South Africa, including yellowfishes, eels and sharptooth catfish being known to undertake migrations, both upstream and downstream (Økland *et al.* 2005, O'Brien and De Villiers 2011, Tómasson *et al.* 1984). There is also evidence that many smaller species also depend on migration during part of the year (Cambray 1990, Bok *et al.* 2007). Instream obstructions also cut off gene flow between populations, potentially affecting genetic diversity.

11.3. Creating connectivity at dams and weirs

Fishways are structures incorporated, or added, to an instream barrier (weir or dam), so as to allow the upstream migration of fish. Fishways are usually very expensive to construct and thus need the input of appropriate specialists, including engineers, before being designed or built. A protocol and scoring scheme has been developed in South Africa for assessing the need for providing a fishway at an instream barrier (Bok *et al*. 2007) (See Volume 1: Rehabilitation Guidelines (Section 7.10).

> **Barriers are sometimes important – Keeping alien fishes out!**
>
> In the rivers of the Cape Floristic Region (CFR) of the Western Cape, alien fish species have eliminated native fish stocks from as much as 80% of river habitat (estimates exceed 90% in some catchments) through predation and competition (Paxton *et al.* 2002, Marr 2011, Woodford *et al.* 2005, Impson *et al.* 2000, Wolhuter and Impson 2007, Jordaan *et al.* 2012). Indigenous fish populations now persist only in those reaches which are, as yet, un-invaded, i.e. those areas upstream of natural or artificial barriers. There is little doubt that without these barriers, many CFR freshwater fish populations would already have been driven to extinction.

Three fishway types, shown conceptually in **Figure 11.2,** have been identified as appropriate to South African conditions:

i. Pool and Weir fishway: this system consists of a sloping rectangular channel divided by a series of weirs that span the full width of the channel creating a succession of pools. The weir crest is notched or sloped to allow water to pass across the weir walls and into the pools (**Error! Reference source not found.** 11.4(b)). By varying the channel slope and the size of the pools, the hydraulics of the fishway can be adjusted according to the swimming abilities of the target species (Heath *et al.* 2005). The main advantage of the Pool and Weir fishway is that it is capable of passing fish at relatively low flows. Its principal disadvantage is that it does not operate over a wide range of headwater pool levels (Bok *et al.* 2007).

ii. Vertical Slot fishway – this system is similar to the Pool and Weir fishway, comprising a sloping rectangular channel with a series of weir walls separating pools. However, in the Vertical Slot fishway, the weir walls don't extend the full length of the channel (see Figure 11.2(c)). Rather than flowing through a notch in the weir crest, the water flows through a gap that extends full depth of the interlinked pools (Heath *et al.* 2005). The main advantage of Vertical Slot fishways is that they are able to operate over a wide range of headwater pool levels. However, they aren't able to pass climbing or crawling species effectively (elvers, shrimp and prawns) (Bok *et al.* 2007) and therefore should not be used where these are an important component of the migratory biota.

iii. Natural Bypass channels – these consist of a natural landscaped channel adjacent to the obstruction, are in many cases the preferred fishway design. This is firstly because they are able to provide passage for a greater diversity of species and size classes than artificial structures and secondly because they provide important habitats in themselves and can be integrated into existing river rehabilitation initiatives (Heath *et al.* 2005). The major disadvantage of the Natural Bypass fishway is that its appropriateness depends almost exclusively on the suitability of the topography adjacent to the obstruction (Bok *et al.* 2007).

Figure 11.2: (a) A natural bypass channel on the Lenne River in France; (b) Pool and Weir fishway (notched) on the Lebombo gauging weir, Komati River; (c) a Vertical Slot fishway in Germany and (d) the Nhlabane fishway on the Nhlabane estuary showing the attraction water (from Bok et al. 2007).

Important factors to take into consideration when choosing a suitable fishway design are the swimming capacities of the target migratory biota and their expected size classes. This information will be essential for feeding in to the hydraulic characteristics of the fishway itself (i.e. slope and pools size). The location of the attraction water—fast flowing water at the base of the fishway that draw fish to the fishway—is another important consideration. An example of attraction water is shown in Figure 11.2(d). If the attraction water is not strong enough, or if the outlet is not at a suitable site along the transvers profile of the river channel, fish may not be able to find their way to the fishway. The quality of water at the fishway is also important. For example, the location of effluent outlets in the vicinity of a proposed fishway may prevent its successful functioning, despite adequate physical controls and structures.

11.4. Creating connectivity at road culverts

In addition to dams and weirs, road culverts often represent impassable barriers to fish. Because road culverts have a smaller cross-sectional area than river channels, water flows at a high velocity and may be shallower than flows in the natural channel. This may significantly reduce fish passage between reaches. Erosion and downcutting on the downstream end of the culvert can contribute to this. Solutions to providing fish passage vary from stipulating specific hydraulic criteria (minimum depths and maximum velocities) if the swimming abilities of the fish are known, to constructing baffles in the culvert to slow velocities and increase depths (Whyte *et al.* 1997). Hydraulic criteria need to be stipulated on a case-by-case basis depending on the species present in the river, their average size, swimming ability and migration requirements. Reinforcement of the river bed and / or bank downstream by means of gabions may reduce the probability of downcutting (see **Section 4**).

11.5. Riparian habitat and bank stabilisation

The principals of riparian habitat restoration are dealt with elsewhere in this document (**Section 10.2.1.1; Section 10.2.1.6** and **Section 12**) and are not repeated here. It should be stressed though that in terms of fish populations, aquatic and emergent vegetation in and alongside rivers is very important for ameliorating water quality impacts (Babakaiff *et al.* 1997), reducing sediment loads, as habitat for fish, as well as for maintaining the quality of instream habitat. Riparian habitat restoration is particularly important in South Africa where alien invasive plants have colonised the riparian zone, altering bank structure and stability and sediment dynamics. It is also important in areas that have been bulldozed for flood control purposes. Here the river bank needs to be re-established, and an adequate buffer created or maintained between the river and agricultural or urban development. This buffer is critical to protect the river and its fishes and ideally it should extend to include the natural 1 in 5 year floodplain (see Volume 1: Rehabilitation Guidelines – Section 7.9.2 for guidelines for the treatment, sizing and management of buffer areas). The removal of alien vegetation also requires careful planning and the use of approved techniques; and in areas which have dense and long lasting invasions, re-plantings of locally present indigenous plants may be needed before rehabilitation is successful (see Chapters 2, 10 and 12 of this Volume).

11.6. Use of piscicides as a tool for rehabilitation

Invasive alien fishes are a serious threat to indigenous fishes, especially in the Cape Fold Ecoregions, and can also be a major problem to water quality (carp). Generally, it is not possible to eradicate an invasive fish from a whole river system because of the complexity of the task. However, they can be successfully eradicated from parts of rivers (usually between two barrier, e.g. waterfall and weir) as well as in dams using piscicides (see Volume 1: Rehabilitation Guidelines – Section 7.11) and Volume 3: Case Studies (Case Study No 23: The Rondegat River)).

Piscicide projects can be challenging and are frequently controversial (Finlayson *et al*. 2005, Marr *et al*. 2012), because the piscicide not only kills fish but can have impacts on non-target fauna such as aquatic insects (Vinson *et al*. 2010, Woodford *et al*. 2013). Two piscicides are commonly used – rotenone and anti-mycin. They are naturally occurring chemicals, with the bulk of projects having used rotenone because it is readily available and effective under a wider range of conditions.

Piscicide projects must be well planned and carefully implemented to maximise benefits and minimise risks. They require comprehensive pre- and post-treatment monitoring to quantify the outcomes of the treatment from a biological and chemical perspective.

Environmental legislation

The use of piscicides in South Africa requires a water use licence / general authorisation from the Department of Water Affairs and Sanitation.
Other approvals may be needed, e.g. provincial nature conservation department.
Only an approved piscicide may be used.
Project leaders should have accreditation in the use of piscicides, to ensure that piscicide projects are properly conceived, planned and implemented.

ESSENTIAL REFERENCES

Fortunately, there are comprehensive manuals to guide the effective use of both rotenone and anti-mycin, namely.

- The American Fisheries Society has published a manual entitled: "Planning and Standard Operating Procedures for the use of rotenone in fish management" (Finlayson *et al*. 2010).
- The National Parks Service of the USA Department of the Interior has published a manual entitled "A field manual for the use of anti-mycin A for restoration of native fish populations (Moore *et al*. 2008).
- CapeNature has developed draft guidelines to guide the use of piscicides in the Western Cape.

According to the AFS Rotenone manual (Finlayson *et al*. 2010), there are five essential phases to any rotenone project, namely preliminary planning, intermediate planning, project implementation and management, treatment and project critique.

Preliminary planning involves: i) public involvement, ii) compilation of a Fish Management Plan, iii) a statement of need, iv) determination of applicable laws and regulations, and v) internal agency review and approval. It is recommended that a preliminary treatment plan is developed as described in the rotenone manual.

Intermediate planning refines the preliminary project plan and clears obstacles to treatment before Project Implementation and Management. Intermediate planning involves the following: i) Environmental Laws – ensure that legal approval has been obtained prior to proceeding to the next phase, ii) Environmental analysis – this focuses on the rational for the project and likely environmental impacts of the project as well as methods of reducing environmental damage through mitigation or alternatives, iii) waste discharge requirements – does the Water Affairs Department require a permit, and iv) presence of Endangered (TOPS listed) species – the use of rotenone should not jeopardise the existence of Endangered species or adversely affect their habitat, v) Public and agency issue identification and notification, and vi) the development of a monitoring programme to ensure that the proposed treatment will be effective. The monitoring programme will focus on determination of rotenone concentrations and the biological impacts (positive and negative) of the treatment, thus helping address potential public fears about the project.

The Project Implementation and Management phase includes all the plans that will guide the treatment, for example a Fish Rescue Plan, Rotenone Application Plan, Monitoring Plan, Site Safety and Security Plan, Fish Removal and Disposal Plan, Rotenone Deactivation Plan and Communications Plan. Thereafter the Treatment phase takes place which should run smoothly and effectively if the previous phases have been implemented.

The treatment phase includes the potential for crises (chemical spill, deactivation failure, excessive public opposition as treatment time) and hence the need for a Crises Management Plan.

Project Critique Phase – this is the final phase of the project – a Written Critique assesses the effectiveness of the treatment and deactivation, and the recovery of baseline environmental conditions through the monitoring the project.

Cross-references and Case Studies:

- Case Study 23 (The Rondegat River) (Volume 3) provides a useful Case Study for effective rotenone application;

- Sections 10.8 and 10.9 outline other forms of alien faunal controls and management approaches for use in general river rehabilitation.

11.7. Re-introduction /stocking of indigenous fish species into rivers

It is sometimes essential to re-introduce indigenous fishes to a river area for a variety of reasons. There may be loss of the species in the affected area because of alien fish impacts or pollution or loss of habitat (e.g. excessive abstraction, extensive bulldozing). Or the species has been reduced to a very low density, and may need augmentation to overcome genetic constraints that can affect small populations. Before re-introduction can be considered, the threat which caused the fish to disappear must be reduced and preferably removed. In addition, any re-introduction needs to be carefully considered and the expertise of a fish conservation specialist must be sought. There are legal considerations too, and all provincial conservation agencies require permits before indigenous fish can be introduced into inland waters. Some species identified for re-introduction may be TOPS listed, requiring further permits at national level before re-introductions can be considered.

The IUCN has developed very useful guidelines (IUCN 2013) to assist organisations wanting to re-introduce indigenous fish species into inland waters, and these should be consulted and used before any re-introduction is considered. The guidelines assess the following issues:

i. deciding when a re-introduction is acceptable;
ii. planning a re-introduction;
iii. the feasibility and design of the project;
iv. social considerations and regulatory compliance;
v. a risk assessment;
vi. the release and implementation stage; and
vii. monitoring the re-introduction and identifying future management needs.

The project design and feasibility stage includes considerations such as biological knowledge of the candidate species, its habitat requirements, number and source of founder stock and disease and parasite considerations. Any re-introduction project should be documented, preferably in peer reviewed literature, so that re-introductions can be monitored and assessed for success.

Caution

Obviously, stocking or introduction of alien species into rivers needs very careful consideration. No alien fish may be introduced into any rivers without a permit from the Department of Natural Resource Management Programmes of DEA. The proposed introduction of any alien fish into a river or a dam on a river or in a catchment where it does not already occur requires the proponent to undertake a Risk Assessment to motivate for the introduction. See also Section 10.5 (Alien faunal removal and management)

REFERENCES

Acreman, M. and Dunbar, M.J. 2004. Defining environmental river flow requirements-a review. *Hydrology and Earth System Sciences,* 8**:** 861-876.

Adams, M.A. and Whyte, I.W. 1990. Fish habitat enhancement: a manual for freshwater, estuarine and marine habitats. *DFO 4474*. Department of Fisheries and Oceans Canada. 330 pp.

Allibone, R.; David, B.; Hitchmough, R.; Jellyman, D.; Ling, N.; Ravenscroft, P. and Waters, J. 2010. Conservation status of New Zealand freshwater fish, 2009. *New Zealand Journal of Marine and Freshwater Research,* 44**:** 271-287.

American Fisheries Society. 2010. Maintaining North America's healthy native aquatic ecosystems: rotenone's role in eradicating invasive fishes, parasites and diseases. *Fish Management Chemicals Subcommittee – 2010*. 9 pp.

Armstrong, J.D.; Kemp, P.S.; Kennedy, G.J.A.; Ladle, M. and Milner, N.J. 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research,* 62**:** 143-170.

Babakaiff, S.; Hay, D. and Fromuth, C. 1997. Rehabilitating stream banks. *In:* Slaney, P. A. and Zaldokas, Z. (eds.) *Fish habitat rehabilitation procedures. Watershed Restoration Program, Watershed Restoration Circular No. 9.* 5. Vancouver B.C: Ministry of Environment, Lands and Parks and Ministry of Forests. 5-1; 5-13 pp.

Balon, E.K. 1975. Reproductive guilds of fishes: a proposal and definition. *Journal of the Fisheries Research Board of Canada,* 32**:** 821-864.

Balon, E.K. 1990. Epigenesis of an epigeneticist: the development of some alternative concepts on the early ontogeny and evolution of fishes. *Guelph ichthyology reviews,* 1**:** 1-48.

Barret, J. and Mallen-Cooper, M. 2012. Fish finding a new way from the sea to Hume Dam. *RipRap. Edition 34***:** 5-6.

Barrett, J. 2004. Introducing the Murray-Darling Basin Native Fish Strategy and initial steps towards demonstration reaches. *Ecological Management & Restoration,* 5**:** 15-23.

Barrett, J. and Mallen-Cooper, M. 2006. The Murray River's 'Sea to Hume Dam' fish passage program: Progress to date and lessons learned. *Ecological Management & Restoration,* 7**:** 173-183.

Baumgartner, L.J.; Stuart, I.G. and Zampatti, B.P. 2008. Synthesis: what have we learnt about fish passage in the Murray-Darling Basin. In: Barret, J. (ed). *The Sea to Hume Dam: restoring fish passage in the Murray River*. Murray-Darling Basin Commission, Canberra, Australia. 98 pp.

Beechie, T.; Pess, G. and Imaki, H. 2012. Estimated changes to Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) habitat carrying capacity from rehabilitation actions for the Trinity River, North Fork Trinity to Lewiston Dam. Fish Ecology Division, Northwest Science Center, National Marin Fisheries Service, NOAA, Seattle, Washington. 39 pp.

Beechie, T.J.; Liermann, M.; Pollock, M.M.; Baker, S. and Davies, J. 2006. Channel pattern and river-floodplain dynamics in forested mountain river systems. *Geomorphology,* 78**:** 124-141.

Bernhardt, E.S.; Sudduth, E.B.; Palmer, M.A.; Allan, J.D.; Meyer, J.L.; Alexander, G.; Follastad-Shah, J.; Hassett, B.; Jenkinson, R. and Lave, R. 2007. Restoring rivers one reach at a time: results from a survey of US river restoration practitioners. *Restoration Ecology,* 15**:** 482-493.

Blumm, M.C. and Eriksen, A.B. 2012. Dam Removal in the Pacific Northwest: lessons for the nation. *Environmental Law,* 42**:** 1043-1099.

Bok, A.; Kotze, P.; Heath, R. and Rossouw, J. 2007. Guidelines for the planning, design and operation of fishways in South Africa. *WRC Report WRC Report No. TT 287/07*. Water Research Commission, Pretoria. 158 pp.

Bölscher, T.; van Slobbe, E.; Vliet, M.T.v. and Werners, S.E. 2013. Adaptation Turning Points in River Restoration? The Rhine Salmon Case. *Sustainability,* 5**:** 2288-2304.

Brown, C. and King, J. 2011. Modifying dam operating rules to deliver environmental flows: experiences from southern Africa. *International Journal of River Basin Management,* 10**:** 13-28.

Brown, C.A. and King, J.M. 2003. Environmental Flows: concepts and methods. *In:* Davis, R. and Hirji, R. (eds.) *Water Resources and Environment Technical Note C.1.* Washington: The World Bank. 28 pp.

Bunte, K. 2004. Gravel mitigation and augmentation below hydroelectric dams: a geomorphological perspective. *State of the Science Review*. Rocky Mountain Research Station, Fort Collins, Colorado. 144 pp.

Cambray, J.A. 1990. Adaptive significance of a longitudinal migration by juvenile freshwater fish in the Gamtoos River system, South Africa. *South African Journal of Wildlife Research,* 20**:** 148-156.
Caruso, B. 2006. Project River Recovery: Restoration of Braided Gravel-Bed River Habitat in New Zealand's High Country. *Environmental Management,* 37**:** 840-861.
Cowx, I.G. and Welcomme, R.L. 1998. *Rehabilitation of rivers for fish. A study undertaken by the European Inland Fisheries Advisory Commission (EIFAC) of FOA,* Oxford, Fishing News Books Ltd. 260 pp.
Crass, R.S. 1964. *Freshwater fishes of Natal,* Peitermaritzburg, Shuter & Shooter. 167 pp.
Dudgeon, D.; Arthington, A.H.; Gessner, M.O.; Kawabata, Z.I.; Knowler, D.J.; Lévêque, C.; Naiman, R.J.; Prieur-Richard, A.H.; Soto, D. and Stiassny, M.L.J. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews of the Cambridge Philosophical Society,* 81**:** 163-182.
Erskine, W.D. and Webb, A.A. 2003. Desnagging to resnagging: new directions in river rehabilitation in southeastern Australia. *River Research and Applications,* 19**:** 233-249.
Finlayson, B.J.; Schnick, R.A.; Cailteux, R.L.; DeMong, L.; Horton, W.D.; McClay, W.; Tichacek, G.J. and Thompson, C. 2000. *Rotenone use in fisheries management: administrative and technical guidelines manual,* Bethesda, MD, American Fisheries Society. 214 pp.
Frissell, C.A.; Liss, W.J.; Warren, C.E. and Hurley, M.D. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental management,* 10**:** 199-214.
Froehlich-Schmitt, B. 2004. Rhine Salmon 2020. Available: http://www.iksr.org/index.php?id=265&L=3&pdfPage=1 [Accessed 1 August 2013].
Harris, J.H. and Gehrke, P.C. 1997. Fish and rivers in stress: the New South Wales rivers survey. NSW Fisheries and CRC Freshwater Ecology, Cronulla, NSW. 298 pp.
Heath, R.; Bok, A.; Fouche, P.S.O.; Mastenbroek, W.K. and Forbes, A.T. 2005. Development of criteria for the design of fishways for South African rivers and estuaries. *WRC Report 1310/1/05*. Water Research Commission, Pretoria.
Hildrew, A.G. and Giller, P.S. 1992. Patchiness, species interactions and disturbance in the stream benthos. *In:* Giller, P. S. H., A.G. and D.G. Raffaelli (ed.) *Aquatic biology: scale, pattern and process.* 2. Oxford: Blackwell Science. 21-62 pp.
Hoopa Valley Tribe; McBain & Trush Inc and Northern Hydrology and Engineering. 2011. Channel rehabilitation design guidelines for the mainstem Trinity River. Prepared for the Trinity River Restoration Program, Hoopa CA. 318 pp.
ICPR. 2001. Rhine 2020: Program on the sustainable development of the Rhine. Conference of Rhine Ministers 2001. Available: http://www.iksr.org/fileadmin/user_upload/Dokumente_en/rhein2020_e.pdf [Accessed 1 August 2013].
ICPR. 2009. Master Plan Migratory Fish Rhine. *Report 179e*. International Commission for the Protection of the Rhine, Koblenz, Germany. 27 pp.
Impson, N.D.; Bills, R.I. and Cambray, J.A. 2000. State of Biodiversity: Western Cape Province, South Africa: freshwater fishes.
IUCN. 2012. *2012 IUCN Red List of Threatened Species. Version 2012.2.* [Online]. Available: www.iucnredlist.org [Accessed 5 Sep 2013].
Jordaan, M.; Impson, D. and van der Walt, R. 2012. Freshwater Fishes. *In:* Turner, A. A. (ed.) *Western Cape Province State of Biodiversity.* Chapter 4. Stellenbosch: CapeNature Scientific Services. 68-86 pp.
Kleynhans, C.J. 1999. The development of a fish index to assess the biological integrity of South African rivers. *Water SA,* 25**:** 265-278.

Koehn, J.D. and Harrington, D.J. 2006. Environmental conditions and timing for the spawning of Murray cod (Maccullochella peelii peelii) and the endangered trout cod (M. macquariensis) in southeastern Australian rivers. *River Research and Applications,* 22: 327-342.

Koehn, J.D. and Lintermans, M. 2012. A strategy to rehabilitate fishes of the Murray-Darling Basin, south-eastern Australia. *Endangered Species Research,* 16: 165-181.

Kondolf, G.M. 1997. Hungry Water: effects of dams and gravel mining on river channels. *Environmental Management,* 21: 533-551.

Kondolf, G.M. 2000. Some Suggested Guidelines for Geomorphic Aspects of Anadromous Salmonid Habitat Restoration Proposals. *Restoration Ecology,* 8: 48-56.

Kondolf, G.M.; Vick, J.C. and Ramirez, T.M. 1996. Salmon spawning habitat rehabilitation on the Merced River, California: An evaluation of project planning and performance. *Transactions of the American Fisheries Society,* 125: 899-912.

Marr, S.M. (2011). *Conservation of the native freshwater fishes of the Cape Floristic Resion (South Africa): Management of non-native species*. PhD Thesis. University of Cape Town, Cape Town. 358 pp.

Marr, S.M., N.D. Impson, and D. Tweddle. 2012. An assessment of a proposal to eradicate non-native fish from priority rivers in the Cape Floristic Region, South Africa. African Journal of Aquatic Science 37: 131-142.

Moore, S., Kulp, M., Rosenlund, B., Brooks, J. and Propst, D. 2008 A Field manual for the use of Anti-Mycin A for restoration of native fish populations. USA Department of the Interior, Fort Collins, Colorado.

Moyle, P.B. and Leidy, R.A. 1992. Loss of biodiversity in aquatic ecosystems: evidence from fish faunas. *Conservation Biology.* Springer. 127-169 pp.

Mthombeni, V.G. (2009). *The biology of Austroglanis gilli and Austroglanis barnadi (Siluriformes: Austroglanididae) in the Olifants River system, South Africa*. Masters Thesis. Rhodes University, Grahamstown. 129 pp.

Nel, J.L., Driver, A., Strydom W.F., Maherry, A., Petersen, C., Hill, L., Roux, D.J., Nienaber, S., Van Deventer, H., Swartz, E. and Smith-Adao, L.B. 2011. Atlas of freshwater ecosystem priority areas in South Africa. WRC Report No. TT 500/11.

Niehaus, B.H.; Steyn, G.J. and Rail, J.L. 1997. Habitat preference and population structure of the rock catfish (*Austroglanis sclateri*) in the Senqunyane River, Lesotho. *Water S.A.,* 23: 404-410.

Nilsson, C.; Reidy, C.A.; Dynesius, M. and Revenga, C. 2005. Fragmentation and flow regulation of the world's large river systems. *Science,* 308: 405.

O'Brien, G. and De Villiers, P. 2011. Biology and ecology of the Orange-Vaal largemouth and smallmouth yellowfishes in the Vaal River. *Research Report No TT 508/11*. Water Research Commission, Pretoria. 245 pp.

Ock, G. and Kondolf, G.M. 2012. Assessment of ecological roles of gravel bar features restored by gravel augmentation and channel rehabilitation activities below Lewiston Dam in the Trinity River, California. USBR Science and Technology Program Scoping Report, Weaverville, California. 24 pp.

Økland, F.; Thorstad, E.B.; Hay, C.J.; Næsje, T.F. and Chanda, B. 2005. Patterns of movement and habitat use by tigerfish (*Hydrocynus vittatus*) in the Upper Zambezi River (Namibia). *Ecology of Freshwater Fish,* 14: 79-86.

Palmer, M.A.; Bernhardt, E.S.; Allan, J.D.; Lake, P.S.; Alexander, G.; Brooks, S.; Carr, J.; Clayton, S.; Dahm, C.N.; Follstad Shah, J.; Galat, D.L.; Loss, S.G.; Goodwin, P.; Hart, D.D.; Hassett, B.; Jenkinson, R.; Kondolf, G.M.; Lave, R.; Meyer, J.L.; O'Donnell, T.K.; Pagano, L. and Sudduth, E. 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology,* 42: 208-217.

Parkyn, S.M.; Davies-Colley, R.J.; Halliday, N.J.; Costley, K.J. and Croker, G.F. 2003. Planted riparian buffer zones in New Zealand: do they live up to expectations? *Restoration Ecology,* 11**:** 436-447.

Pawlowski, S.; Jatzek, J.; Brauer, T.; Hempel, K. and Maisch, R. 2012. 34 years of investigation in the Rhine River at Ludwigshafen, Germany – trends in Rhine fish populations. *Environmental Sciences Europe,* 24**:** 1-8.

Paxton, B.R.; Clark, B.M. and Brown, C.A. 2002. An assessment of the effects of habitat degradation and exotic fish species invasions on the distribution of three endemic cyprinids: *Barbus capensis*, *Barbus serra* and *Labeo seeberi* in the Olifants and Doring Rivers, Western Cape. *DWAF Report No. PB E000-00-1302*. Prepared for the Department of Water Affairs and Forestry and Department of Agriculture by Southern Waters Ecological Research and Consulting cc. 53 pp.

Paxton, B.R. and King, J.M. 2009. The influence of hydraulics, hydrology and temperature on the distribution, habitat use and recruitment of threatened cyprinids in a Western Cape river, South Africa. *WRC Report No. 1483/1/09*. Water Research Commission, Pretoria. 170 pp.

Pess, G.; Morley, S.; Hall, J.L. and Timm, R.K. 2005. Monitoring floodplain restoration. *In:* Roni, P. (ed.) *Monitoring stream and watershed restoration.* Chapter 6. Bethesda, M.D: American Fisheries Society. 127-166 pp.

Pham, L.; West, D. and Closs, G.P. 2013. Reintroduction of a native galaxiid (Galaxias fasciatus) following piscicide treatment in two streams: response and recovery of the fish population. *Ecology of Freshwater Fish,* 22**:** 361-373.

Philippart, J.C. and Ruwet, J. 1982. Ecology and distribution of tilapias. *In:* Pullin, R. S. V. and Lowe-McConnell, R. H., eds. *International Conference on the Biology and Culture of Tilapias*, 2-5 September 1980 1982 Bellagio, Italy. WorldFish, Issue 7 of ICLARM Conference Proceedings, 432 pp.

Poff, N.L.R.; Allan, J.D.; Bain, M.B.; Karr, J.R.; Prestegaard, K.L.; Richter, B.D.; Sparks, R.E. and Stromberg, J.C. 1997. The natural flow regime. *Bioscience,* 47**:** 769-784.

Power, M.E.; Sun, A.; Parker, G.; Dietrich, W.E. and Wootton, J.T. 1995. Hydraulic food-chain models. *Bioscience,* 45**:** 159-167.

Pringle, C.M.; Naiman, R.J.; Bretschko, G.; Karr, J.R.; Oswood, M.W.; Webster, J.R.; Welcomme, R.L. and Winterbourn, M.J. 1988. Patch dynamics in lotic systems: the stream as a mosaic. *Journal of the North American Benthological Society,* 7**:** 503-524.

Rayner, T.S. and Creese, R.G. 2006. A review of rotenone use for the control of non-indigenous fish in Australian fresh waters, and an attempted eradication of the noxious fish Phalloceros caudimaculatus. *New Zealand Journal of Marine and Freshwater Research,* 40**:** 477-486.

Resh, V.H.; Brown, A.V.; Covich, A.P.; Gurtz, M.E.; Li, H.W.; Minshall, G.W.; Reice, S.R.; Sheldon, A.L.; Wallace, J.B. and Wissmar, R.C. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society***:** 433-455.

Richter, B.D. and Thomas, G.A. 2007. Restoring environmental flows by modifying dam operations. *Ecology and Society,* 12**:** 12.

Roni, P.; Hanson, K.; Beechie, T.; Pess, G.; Pollock, M. and Bartley, D.M. 2005. Habitat rehabilitation for inland fisheries: global review of effectiveness and guidance for rehabilitation of freshwater ecosystems. *FAO Fisheries Technical Paper No. 484*. FOA, Rome. 116 pp.

Roper, B.B.; Scarnecchia, D.L. and La Marr, T.J. 1994. Summer distribution of and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. *Transactions of the American Fisheries Society,* 123**:** 298-308.

Rosenberger, A. and Angermeier, P.L. 2003. Ontogenetic shifts in habitat use by the endangered Roanoke logperch (Percina rex). *Freshwater Biology,* 48**:** 1563-1577.

Sabo, M.J. and Orth, D.J. 1994. Temporal variation in microhabitat use by age-0 smallmouth bass in the North Anna River, Virginia. *Transactions of the American Fisheries Society,* 123**:** 733-746.

Salo, J. 1990. External processes influencing origin and maintenance of inland water-land ecotones. *The ecology and management of aquatic-terrestrial ecotones.* Carnforth, England: The Parthenon Publishing Group. 37-64 pp.

Schlosser, I.J. 1991. Stream fish ecology: a landscape perspective. *Bioscience,* 41**:** 704-712.

Schlosser, I.J. 1995. Critical landscape attributes that influence fish population dynamics in headwater streams. *Hydrobiologia,* 303**:** 71-81.
Schlosser, I.J. and Angermeier, P.L. 1995. Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation. 1995. 392-401 pp.
Schmidt, J.C.; Webb, R.H.; Valdez, R.A.; Marzolf, G.R. and Stevens, L.E. 1998. Science and Values in River Restoration in the Grand Canyon. *Bioscience,* 48**:** 735-747.
Skelton, P.H.; Cambray, J.A.; Lombard, A. and Benn, G.A. 1995. Patterns of distribution and conservation status of freshwater fishes in South Africa. *South African Journal of Zoology,* 30**:** 71-81.
Slaney, P.A. and Zaldokas, Z. 1997. Fish habitat rehabilitation procedures. *Watershed Restoration Program, Watershed Restoration Circular No. 9*. Ministry of Environment, Lands and Parks and Ministry of Forests, Vancouver B.C. 341 pp.
Tómasson, T.; Cambray, J.A. and Jackson, P.B.N. 1984. Reproductive biology of four large riverine fishes (Cyprinidae) in a man-made lake, Orange River, South Africa. *Hydrobiologia,* 112**:** 179-195.
Valdez, R.A.; Hoffnagle, T.L.; McIvor, C.C.; McKinney, T. and Leibfried, W.C. 2001. Effects of a test flood on fishes of the Colorado River in Grand Canyon, Arizona. *Ecological Applications,* 11**:** 686-700.
Welcomme, R. 2001. *Inland Fisheries: ecology and management,* Oxford, Fishing News Books. 358 pp.
Welcomme, R.; Winemiller, K. and Cowx, I. 2006. Fish environmental guilds as a tool for assessment of ecological condition of rivers. *River Research and Applications,* 22**:** 377-396.
Whyte, I.W.; Babakaiff, S.; Adams, M.A. and Giroux, P.A. 1997. Restoring fish access and rehabilitation of spawning sites. *In:* Slaney, P. A. and Zaldokas, Z. (eds.) *Fish habitat rehabilitation procedures. Watershed Restoration Program, Watershed Restoration Circular No. 9.* 5. Vancouver B.C: Ministry of Environment, Lands and Parks and Ministry of Forests. 5-1; 5-13 pp.
Wolhuter, L. and Impson, N.D. 2007. The State of Yellowfish in South Africa. *WRC Report TT302/07.* Water Research Commission, Pretoria. 186 pp.
Woodford, D.J.; Impson, N.D.; Day, J.A. and Bills, I.R. 2005. The predatory impact of invasive alien smallmouth bass, *Micropterus dolomieu* (Teleostei: Centrarchidae), on indigenous fishes in a Cape Floristic Region mountain stream. *African Journal of Aquatic Science,* 30**:** 167-173.
Zeug, S.C.; Sellheim, K.; Watry, C.; Rook, B.; Hannon, J.; Zimmerman, J.; Cox, D. and Merz, J. 2013. Gravel augmentation increases spawning utilization by anadromous salmonids: a case study from California, USA. *River Research and Applications***:** n/a-n/a.

Chapter 12:

Establishing Plants on Rehabilitated Rivers

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INTRODUCTION

The appropriate establishment of plants as a means of improving habitat diversity, providing specific habitat types for species of concern, managing issues such as water temperature and shading and, in particular, for addressing issues of bank and bed erosion is a critical part of most river rehabilitated projects. Virtually all of the previous chapters of this manual have referred to the need to undertake replanting as part of meeting overall rehabilitation objectives. This chapter provides guidance and specifications for the actual planting process, and should be read in conjunction with whichever other chapters address particular sources of river degradation.

The chapter has been structured to guide readers through planning of the planting process, to implementation and maintenance activities.

12.1. Planning Phase

While seemingly a small part of the overall river rehabilitation process, the establishment of plants in rehabilitated areas requires a thorough planning process to ensure that the required outcome is achieved.

This planning process needs to commence at the start of overall river rehabilitation , as in certain instances the lead time to provide the required plants may take 12 months or more. For example, where plant material must be collected from other areas, it will take time for collected plants, seeds and or cuttings to be propagated and ready to re-plant, while in other cases, the timing of collection of vegetation for planting or propagation may need to be synchronised around the timing of other rehabilitation or development activities as well.

The Planning Process should include the following components :

12.1.1. Develop a Project Brief:

A clear project brief must be developed, as follows:

- Identify Principles (broad objectives), Policies (directives) and Priorities:
    - Why are plants being established? – this will define what species are planted and if the genetic gene pool is to be local, e.g. is the objective to:
        - stabilise the river banks and reduce erosion?
        - maximize biodiversity?
- Define the scope of work, tasks and products;
    - what is the extent of the planting area?
    - is plant material (seed, cuttings, transplants) to be collected from site and propagated?
    - are plants to be commercially sourced and bought?
    - will irrigation be required?
    - will specialists (botanist, horticulturist, draughtsperson) need to be consulted to assist in the various tasks?
- Agree on the:
    - programme
        - programming the rehabilitation process for the optimum re-vegetation season;
        - collecting, storing and propagating suitable local plant material before the area is cleared for rehabilitation; and
        - collecting and storing suitable soil, if appropriate, from site for the re-vegetation process;
    - time frame – allow enough time to source and order the required plant material; and

- o budget for establishing plants that are either commercially bought or specifically propagated, including a 12 month maintenance period;
- Discuss the plant establishment requirements with others involved in the project so that they are aware of planting requirements, including the season to be planted, time required to propagate or source plant material, need for topsoil to be stockpiled, etc.;
- Access available data (plans, drawings, maps) from managers, the client or others to be able to draw up a concept plan and get an idea of quantities.

12.1.2. Finalise the Project Concept

Prepare and finalise the project concept in accordance with the brief, considering the scope, character, function and viability of the project. The following activities should be included in this phase:

- Collect information through a desk top study and going to site and investigating river and section of river to be planted;
- Understand the area where plants are to be established, by considering:
  - o is it in a summer or winter rainfall area?
  - o what is the micro climate – is it on a south facing or north facing slope and does this affect the plant species required? Is the site exposed to strong winds?
  - o what river reach it is in? (headwaters/upper/source area, mountain stream, foothills, lower (or lowland river) or Estuary (see Volume 1: Section 2.5) – often, different species are found in different reaches;
  - o what river zones will be planted? (e.g. the permanently wet zone, the seasonally wet zone and/or the temporarily wet zone) – different plant species will be required for different zones (see Figure **12.1**)

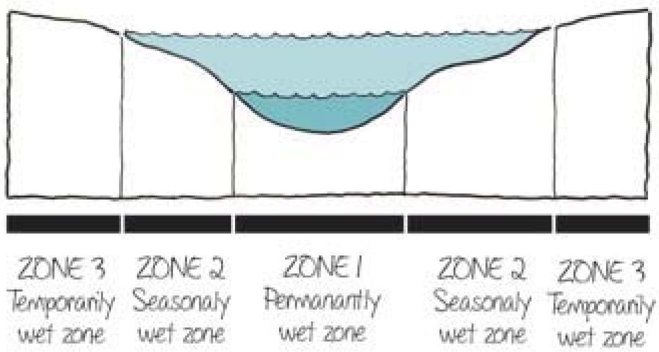

Figure 12.1: River Zones

  - o what is the surrounding landuse? For example, if a residential area, safety requirements may dictate the use of low plants that do not provided visual screening or places to hide;
  - o what is the conservation status of the river – is the biodiversity of utmost importance and will only genetic material from the river itself be allowed?
  - o identify useful resources (e.g. vegetation for propagation or transplanting and soil) and constraints (the presence of alien vegetation and seedbanks);
  - o how accessible is the site? Can plants be delivered by vehicle or is there a long stretch with pedestrian access only (this may affect costs, labour requirements and timeframes);
  - o what is the naturally occurring vegetation in the area? Savanna, Grassland, Nama Karoo, Succulent Karoo, Desert, Thicket (Albany Thicket of the Eastern Cape), Forest, Indian

Ocean Coastal Belt (that is, KwaZulu-Natal vegetation) and Fynbos; (Mucina and Rutherford 2006)

What is the natural vegetation for an area?

Use the maps provided in Mucina and Rutherford (2006)'s volume "The Vegetation of South Africa, Lesotho and Swaziland" to establish the natural biome name of your site. Data also available in GIS format.

+What are Ecoregions?

An Ecoregional classification divided South Africa's rivers into 31 distinct ecoregions, or groups of rivers which share similar physiography, climate, geology, soils and potential natural vegetation. Consideration of the ecoregion in which a particular river or river reach falls is an important informant of both the identification of causes of river degradation, and the most appropriate manner of addressing such issues in a rehabilitation context. Maps showing the distribution of these ecoregions can be accessed in Kleynhans et al. (2005)

Refer also to Volume 1, Section 2.3 and Figure 2.2

- Prepare a Concept Plant Plan – this will assist in identifying the zones of the river to be planted, what species and how many species to plant and where (Figure 12.2).

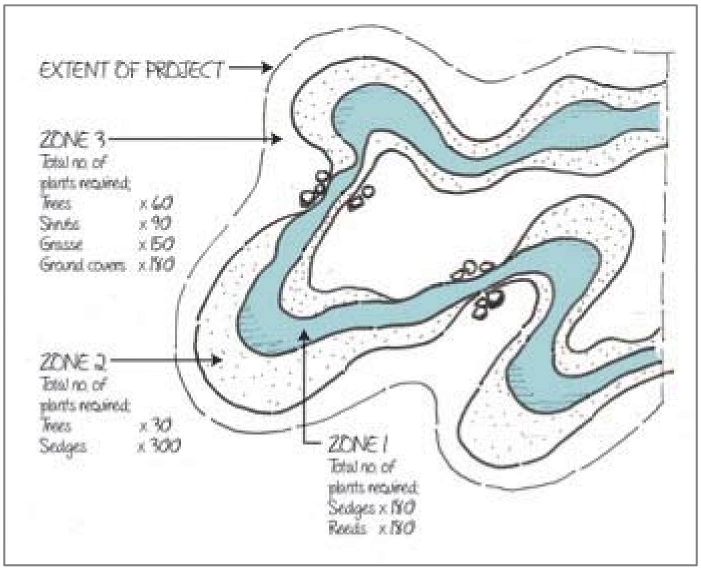

Figure 12.2: Concept Plan

- Doing cross sections through the river at typical points will help to understand the site and what to plant where (see Figure 12.3).

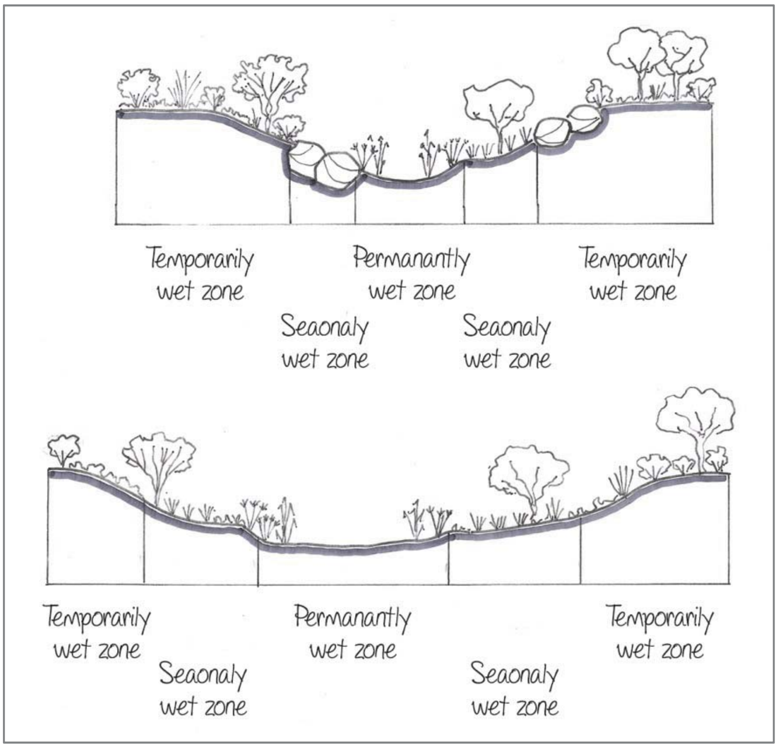

Figure 12.3: Cross Sections through the river

- Prepare a Schedule of Quantities (SoQ) – this is a quantified schedule of activities and materials required to complete the planting, which can be priced to estimate the cost of the project. A typical example is attached in Appendix 12A-1. While a Schedule of Quantities is essential for large projects, the same basic process should be followed when implemented for a smaller project by a single person.
- Discuss the concept plan and cost estimate with the project team/ managers/ client to get comments and approval of the plan and approach;
- Discussing the planting plans and approach with others may assist in getting clarity on certain issues and helping to identify shortfalls or omissions.
- Finalise Plant Plans, SoQ and Programme;
- Place plant orders and plan the implementation process.

Both the drafting of plans and drawing up of Schedules of Quantities (SoQ) are trained skills. If one feels the need to get assistance with this, a Landscape Architect, Landscape Technologist or draugtsperson could be approached for assistance to draught a plan and draw up a SoQ. A Quantity Surveyor can also assist in drawing up the SoQ.

12.1.3. Identification of climatic region and planting season

Winter rainfall areas have a warm temperate, Mediterranean – type climate with dry, warm, subtropical summers (normally above 10^{o} C) and cool, wet winters. This climate is confined to the southern part of the Western Cape. The optimum planting season in the winter rainfall areas is late autumn.

Summer rainfall areas by contrast have hot summers and cold winters with frost in some parts. This climate is typical of most of the Gauteng and Limpopo Provinces, the Free State and Mpumalanga Highveld, North West and Northern Provinces and KwaZulu-Natal. The optimum planting season in summer rainfall areas is in spring and early summer – the beginning of the plant's growth season

Considerations for planting in wet versus dry seasons

- Planting in the wet season, i.e. during the rainfall season, runs the risk of the plants or seed being washed away by high river flows, erosion and or deposition of material on top of plants
- Planting in the dry season will require irrigation.

Planting works thus need to be programmed carefully for the specific area that the project is located in. This may mean that certain zones of the river are planted in certain times, e.g. in winter rainfall areas, the permanently wet and seasonally wet zones could be planted in spring or early summer as the plant will still get water, but chances of flooding, and plants being washed away, is less. By the following winter, the plant should be well rooted and anchored enough to withstand strong water flows.

However, in the summer rainfall areas where the chances of flooding are greater in summer, which is also the optimum planting season, plants should be planted early in the spring so that they get a chance to establish their roots in time for summer high flows and floods. Additional protection may also be required – this is discussed later.

Where planting does take place in a time when flows are high and erosion of planted areas occurs, allowance needs to be made for additional planting later, outside of the wet season, to replace lost plants and restore bank stability.

12.1.4. Plant species selection

Plants typical, under natural conditions, to the river reaches and zones may vary from river region to region. Some plants are common throughout.

A list of plants suitable for steambank stabilization is provided in Appendix 12A-2 .

It is recommended that one consult or appoint a botanist, working for wetlands managers and other specialists for the species best suited to their conditions and ecoregion. In some instances it may just be necessary to discuss the matter with a local botanical society, nurseryman or landscaper. The scale of the project would indicate which is best.

CROSS REFERENCE

Refer to Volume 1: Section 7.4.3 for guidelines for the selection of plants for erosion control on the basis of root traits, and for general guidelines for specific conditions lending themselves to stabilization by plants rather than with structural interventions.

Where possible, plants with such traits should preferentially be selected in river bank stabilisation projects. However, the project objectives must be borne in mind – in some cases water quality improvement is the main objective, and plants that address this objective should be prioritised. As a general rule, though, plant selection for river rehabilitation projects should ideally use:

- Locally indigenous species
- Species suitable for the rehabilitation objectives
- Species for which the availability, costs and maintenance requirements thereof are in keeping with realistic overall cost and other parameters for the project.

12.1.5. Programming

In programming river planting, the following questions should be asked and the programme may need to be revised a few times by the time all the questions have been answered:

- What is the optimum time to plant – it is possible that the planting can all be done at once, e.g. in summer rainfall areas it would be best to plant all zones in early spring, while in winter rainfall areas it may be necessary to plant the upper riparian zone in autumn and the aquatic and marginal riparian zone in spring

Activity/Season	Spring	Summer	Autumn	Winter
Planting in Summer Rainfall Area	All zones	Temporarily Wet Area		
Planting in Winter Rainfall Area	Permanently and seasonally wet areas		Temporarily Wet Area	

- Where will the plants be sourced?
    - will plants be commercially sourced? In this case material may be readily available and lead times will not be required to get the plants to site; or
    - Will plants need to be propagated from material on site? In this case the material will need to be collected from seed or cuttings or direct transplants which will need to be done in the spring months for the two former instances (seeds and cuttings) and in winter for the transplanting when the plant is dormant.

Activity/Season	Spring	Summer	Autumn	Winter
Planting in Summer Rainfall Area	All zones	Temporarily Wet Area		
Sourcing Plant Material Commercially – readily available – no lead time	All zones	All zones	All zones	All zones
Sourcing Plant Material from site in the form of seed, cuttings or transplants	Collect seed and cuttings to propogate – will need at least a			Transplant plants

	year before these can be planted out			
Planting in Winter Rainfall Area	Aquatic and Marginal Riparian Zone		Temporarily Wet Area	

- Depending on the plant species, the propagation period will vary. It will be a minimum of 12 months before plants propagated from seeds or cuttings will be ready to plant out on site, in some cases longer. In such instances, a phased planting approach would be recommended to ensure plant material is ready for transplanting out;
- An establishment maintenance period is necessary to monitor the growth of the plants – a minimum of 12 months is usually required, with a minimum of weekly site visits to monitor watering, erosion, pest and diseases and weed encroachment.

12.1.6. Choosing plant density

One should observe the planting density and patterns in a healthy vegetated section of the river where ever possible. This is however not always possible and one should then revert to the guidelines below where typical densities are suggested or seek advice from a landscaper, horticulturalist or nurseryman..

The following densities are recommended as a guideline:

i) Trees:
Where tree planting is appropriate and suitable, these should be planted randomly or staggered (see Figure 12.4), with gaps of between 3 to 5 m between stems – they should not be planted in straight lines.

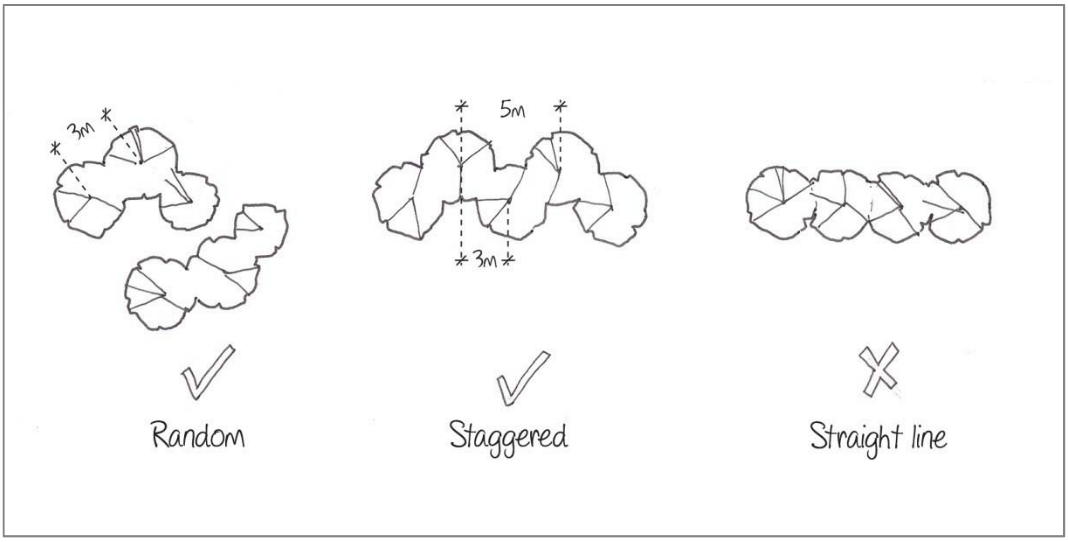

Figure 12.4: Tree planting configurations and densities

ii) Large shrubs which will grow up to 3 metres in height and spread:
These should be planted in groups at 2 or 3 metre centres.

iii) Medium shrubs which will grow up to 1,5 metres in height and spread:
These should be planted in groups of 3 to 5 at 1 or 2 per m^2 (see Figure 12.5).

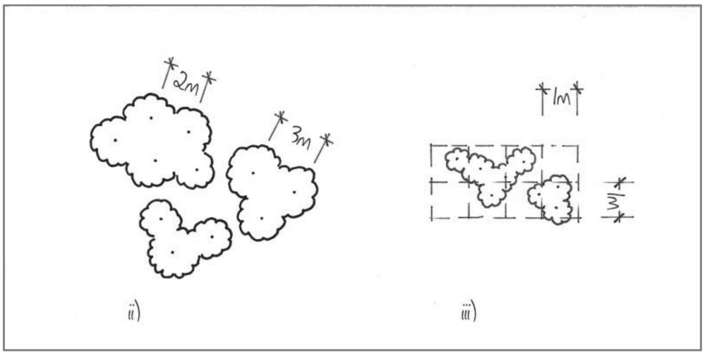

Figure 12.5: An example of the configuration and densities of large and small shrubs

iv) Small shrubs which grow up to approximately 750 mm height and spread:
These should be planted in groups of 3 to 5 (or more) per m^2.

v) Herbaceous non woody plants, grasses and sedges (see Figure 12.6):
These should be planted in groups of 3-5/$m^{2.}$

vi) Goundcovers ,low growing and spreading plants (see Figure 12.6):
These should be planted at a rate of between 5-7/m^2.

vii) Veld sods, usually grasses, sedges, groundcovers, transplanted directly from adjacent areas with clumps of soil around roots:
These should be planted at densities of 3-5/m^2 (see Figure 12.6).

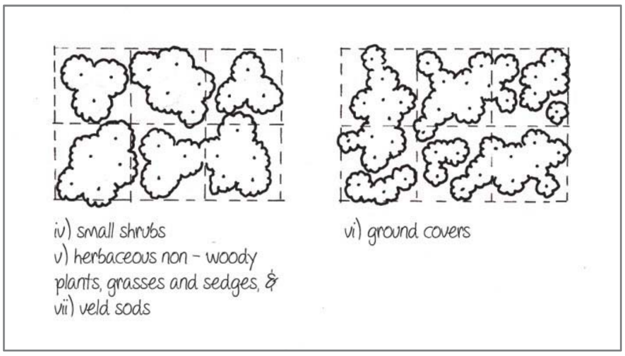

Figure 12.6: An example of the configuration and densities of small shrubs, groundcovers, grasses, sedges and veldsods

viii) Palmiet:
This should be planted with spacings of 1-2 m apart.

When combining trees, shrubs, herbaceous plants and groundcovers, these can be in a number of configurations, some examples being as follows:

ix) When combining shrubs and trees (see Figure 12.7):
There should be 5 trees + 36 medium shrubs/1-3 m^2 = 41

x) When combining shrubs, trees and groundcovers (see Figure 12.7):

There should be 5 trees + 36 shrubs + 90 groundcovers /6 m^2 = 53

xi) When combining shrubs and ground covers/herbs, there should be 2 small shrubs + 3 groundcovers /m^2, i.e. 5 plants/m^2

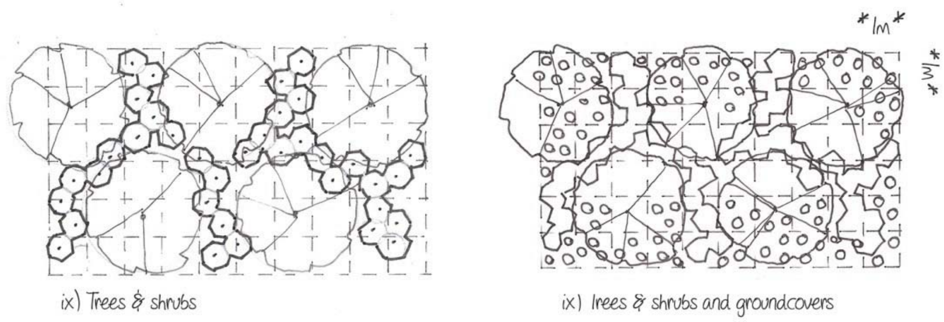

Figure 12.7: An example of the configuration and densities of trees, shrubs and groundcovers combined

General Guidelines for plant layout:

- *Plant the selected plants in the specific riverbank zone to which they belong;*
- *Do not plant trees and shrubs in rows or on their own, rather use small groups of the same plant.*
- *These plants support each other and have a better chance of survival.*

12.1.7. Plant material – size and source

<u>If plants are commercially sourced:</u>

Trees are available in bags ranging between 4 litres and 1000 litres. It is recommended that trees planted in the seasonally wet area should be planted when in bag sizes of between 10 and 50 litres – the root boles of these trees are small enough to be planted on the river slopes and the stems flexible enough to adapt to the fluctuating river conditions while large enough to remain in place in seasonal high flows.

Trees planted in the temporarily wet zone can be as large as required because access to this zone is relatively easy, being on gently sloping land, and handling of larger trees is relatively easy. Shrubs, groundcovers and herbaceous plants are commercially available in:

- plastic pots typically between 12 and 23 cm in diameter (12, 13, 15, 17, 21 and 23 cm);
- plastic bags ranging between 2 and 20 litres (2, 4, 5, 10 and 20 l sizes);
- trays of 4, 6 and 12 packs;
- ecotrays of 20 plantlets.

Depending on the river area/zone, access (how easy it is to get to the planting area) and budget, any size of plant can be planted. It is easier to carry trays of many, smaller plants further than it is to carry larger bags.

Planting smaller plants in steeper marginal areas is also easier than planting larger plants.

Each area to be planted must be evaluated as to what is the most practical and likely to succeed. If plants are to be propagated from material on site, then it is most likely that the majority of plants will be in trays or smaller pots and bags (12-14 cm/2-4 l), as time allowed to grow plants is at best 12 months and the majority of plants don't get much bigger than this in that time span.

There will be a few plants that will be transplanted from site and could be in 4 to 10 l bags and perhaps small trees in 20 l bags.

Pros and cons of commercial as opposed to own propagation:

Commercial :

- Pros:
  - readily available in a variety of sizes and quantities
- Cons:
  - Limited to type of plants available – perhaps not a wide enough range or the species required

Propagating plants:

- Pros:
  - can propagate the specific plants and numbers thereof required
  - can limit the genetic material to that from the river catchment itself
- Cons:
  - the lead time to planting is at least 6 to 12 months;
  - one needs propagating facilities such shade/hot houses, hot beds, automated irrigation and skilled labour

12.1.8. Paths

Pathways are beneficial to safely and efficiently navigating along or through the rehabilitated area for planting and maintenance, but they also provide the opportunity for recreational activities such as walking, running, cycling and horse riding and in certain instances for commuting.

The pathway development (material, width and alignment) will be site-specific and depends on many factors, including the types of path users and their needs (pedestrians, hikers, commuters, cyclists, mountain bikers, horse riders, wheelchair users), the level of development, the setting, land availability, safety, potential conflicts, local expectations, and maintenance concerns.

12.1.8.1.Pathway alignment

The pathways should be aligned in the areas that do not get inundated or that very rarely get temporarily inundated. This will result in less erosion and path maintenance. There may be areas where the path will need to be aligned in the seasonally wet areas of the rivers but these must be minimised and raised boardwalks used preferably.

Similarly there will be areas where the path leads to a stream or river crossing. Where a path leads to a crossing, this must be at 90 degrees to the flow of the water as this will mitigate erosion of the pathway.

12.1.8.2.Pathway widths

The width of the pathway will depend on its function, amount of land available and gradient of the slope.

A pathway primarily used for maintenance need only be 0,5 to 1 metre wide as people will not need to walk side by side.

The width of a recreation pathway, i.e. hikers, walkers, joggers and runners, should allow for 2 people side by side in which case the path width needs to be about 1,2 to 1,5 metres wide.

The minimum width required for a wheelchair is 0,8 metres wide, for cyclists is 1,2 metres wide and for horse riding is 1,2-1,5 m.

In many instances, the path will be used by a combination of users and the width must be able to satisfy the needs of multiple users (see Figure 12.8).

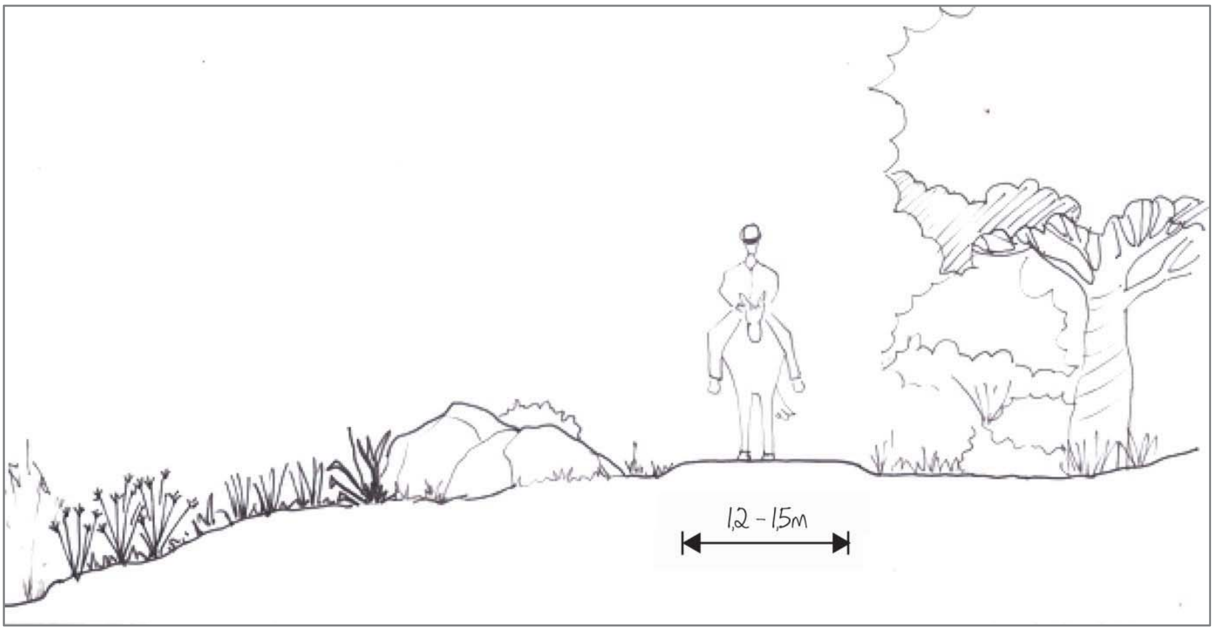

Figure 12.8: Illustration of a path along a river which would accommodate most users

12.1.8.3.Pathway materials

The chosen materials used will depend on the:

- function of the path (maintenance, recreation or commuter)
- how much traffic will use the path
- who the users will be and if this will include wheelchair users
- the surrounding landuse (wilderness, conservation, rural and urban)

Pros and cons of different material options

- *in-situ* soil pathways:

  Pros:
  - cost effective
  - if the in situ soil is well draining (permeable) then suitable
  - allows rainfall to percolate into the substrate

  Cons: .
  - If in-situ soil has a high clay content, it will not drain well (impermeable), the path will become slippery and hazardous
  - If the in-situ soil is too sandy, it becomes difficult to walk on and the path will be more susceptible to wind and water erosion
  - Difficult for older people to walk on and not suitable for wheelchair users

- Woodchip or shredded bark pathways:

  Pros:
  - cost effective if trees and woody shrubs were removed from the area during the rehabilitation process (or if there is a sawmill close by) these could be chipped and the woodchip produced used to surface the in situ path
  - natural material provides a cushioned pathway and natural look which will enhance a wilderness, conservation or natural landscape setting
  - allows rainfall to percolate into the substrate

  Cons: .
  - the woodchip pathways are however short-lived as the material breaks down relatively quickly, requiring refreshing every year.
  - difficult for older people to walk on
  - not suitable for wheelchair users

- Stone chip pathways

  Pros:
  - relatively economical if in close proximity to a quarry and crusher that produces the material
  - natural material provides an attractive pathway
  - easy to install
  - allows rainfall to percolate into the substrate
  - are longer lasting than in-situ soil and woodchip pathways

  Cons: .
  - heavier material that needs to be transported to the path, limiting if a long distance
  - difficult for older people to walk on
  - not suitable for wheelchair users

- Gravel/laterite pathways

  Pros:
  - relatively economical if in close proximity to a quarry that produces the material
  - natural material provides an attractive pathway
  - relatively simple to install
  - allows rainfall to partially percolate into the substrate
  - longer lasting than in-situ soil and woodchip pathways
  - suitably smooth surface for older persons to walk on

- wheelchair friendly

Cons: .

- bulkier material that needs to be transported to the path, limiting if a long distance
- needs some skill and machinery (compactor) to install
- can be slippery when first installed, does improve with age

• Paved pathways – premix , concrete or pavers

Pros:

- longer lasting than in-situ soil, woodchip, stone chip and gravel pathways
- suitably smooth surface for older persons to walk on
- wheelchair friendly
- variety of finishes to suit surrounding environment

Cons: .

- bulkier material that needs to be transported to the path, limiting if a long distance
- needs skill and machinery (compactor) to install
- more expensive than previous options
- not suitable for horses
- rainfall does not percolate through paving (unless permeable pavers), but runs off hardened surface

12.1.8.4. Lighting

Lighting of pathways along rivers will be determined by the function of the path, the level of development, the setting, the types of path users and their needs safety.

It is most likely that a river path will require to be lit when that path is within an urban area and is used after dark by commuters and recreational users who need light for safety concerns.

Typical lighting is 3 m high post top lighting or bollard lighting which will provide lighting for the users without light pollution to the riverine area.,

12.2. Implementing Phase

The implementation phase or Planting phase includes the preparation of the area to receive the plants.

The preparation includes excavating suitably sized holes for the receiving plants, preparing soil into which the plant is to be planted and planting the plant into this prepared area.

12.2.1. Excavating the plant hole

As a general rule, plants should be planted into a hole which is double its size (see Figure 12.9):

• 100 litre trees	1 m x 1 m and 1 m deep
• 20 and 50 litre plants	0,5 m x 0,5 m and 0,5 m deep
• 4 and 10 litre plants	0,3 m x 0,3 m and 0,3 m deep.
• Tray plantlets	0,1 m x 0,1 m and 0,1 m deep

12.2.2. Soil preparation – including (imported) topsoil, compost, fertilisers

- Where possible, topsoil from the site or the soil excavated from the tree hole, should be used as part of the plant mix, as long as this is free of invasive alien plant seeds.
- If topsoil is to be imported from elsewhere, then this too must be free of invasive alien plant seeds and weeds. Weed-free topsoil can be commercially acquired but it is recommended that the source of such material is inspected to make sure that this is so.
- Similarly, imported compost should be free of invasive alien plant seeds and weeds and should be verified.
- Fertilisers should generally be organic, slow release type fertilisers of which there are numerous types. It is recommended that one discusses with local nurserymen which type of slow release fertilizer should be used in the area. Fynbos has specific fertilisation requirements in that Potassium and Phosphorous do not benefit the plants, but rather harm the growth thereof.
- There are products available which act as water retention substances as well as fertilisers, or in some cases just water retainers. These will assist in areas where water or irrigation will be limited.

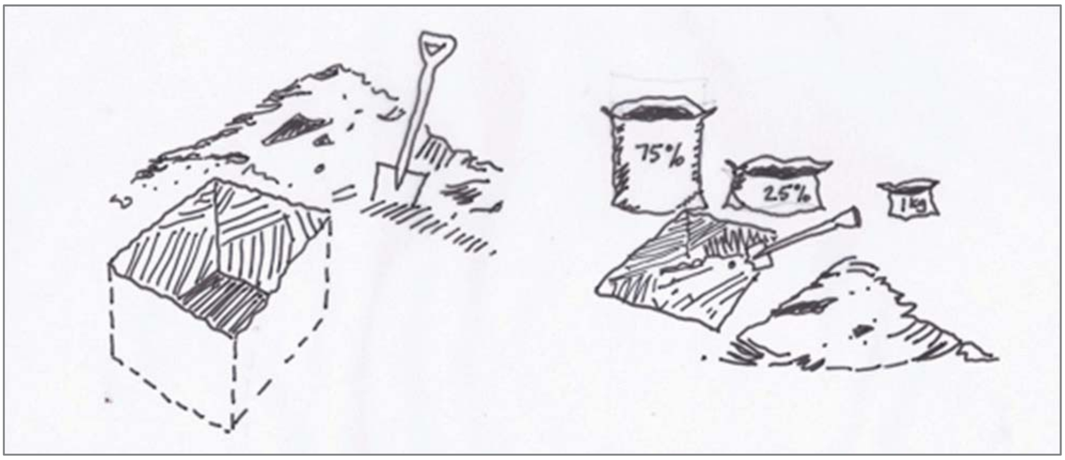

Figure 12.9: Excavation of the plant hole – different dimensions for different container sizes.

12.2.3. Planting the plants into the prepared hole

- The excavated hole should be backfilled to half its depth/height with the prepared soil mix (see Figure 12.10).
- The plant should be carefully removed from its container and placed in the middle of the plant hole.
- The level of the soil around the plant must be at the same height as the top of the hole. If the level is lower, then the soil backfilled around the plant will cover the base of the plant stem which will lead to the bark rotting and the dying. Similarly, if the level of the plant soil is higher than the surrounding area, the roots of the plant will in time be exposed by the soil eroding and the plant stressing or dying.
- The remainder of the prepared soil should be backfilled and the plant watered.
- If the plant is a tree, then a stake should be provided to which the tree may be tied and thereby stabilising it until the roots are able to do this.

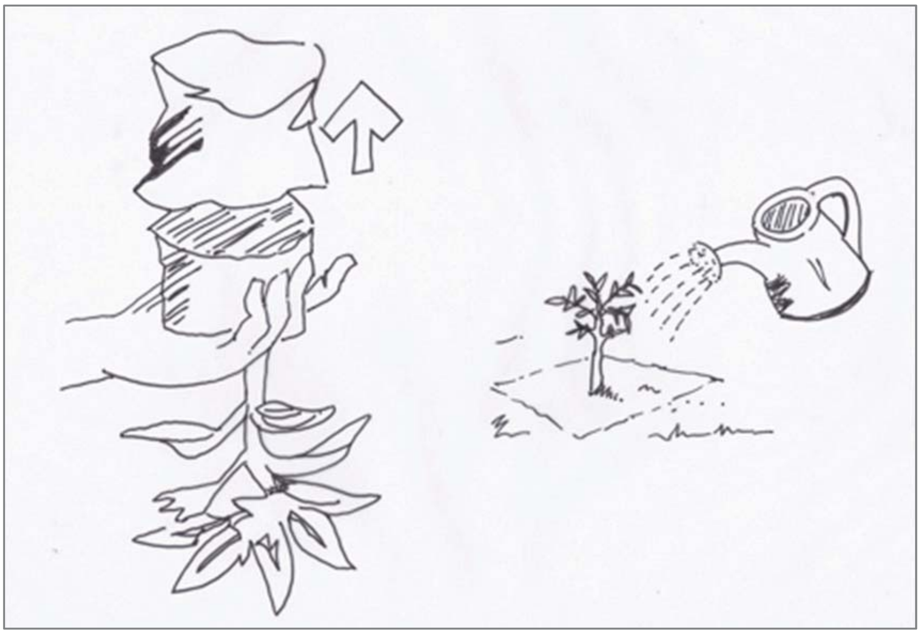

Figure 12.10: Planting plants into excavated hole

12.2.4. Planting in artificial structures

It is often required that planting be done in artificial erosion protection structures such as gabions and reno mattresses to green these extensive rock expanses (see Sections 4, 5 and 10). The following recommendations should be considered:

- Planting pockets need to be created within the gabion or reno mattress, which need to be large enough for the receiving plant, see hole sizes above, and must be lined by a geo-fabric that will retain the soil mixture but let through water. It is imperative that water retention and slow release fertilisers are added to the planting mix (see Figure 12.11).

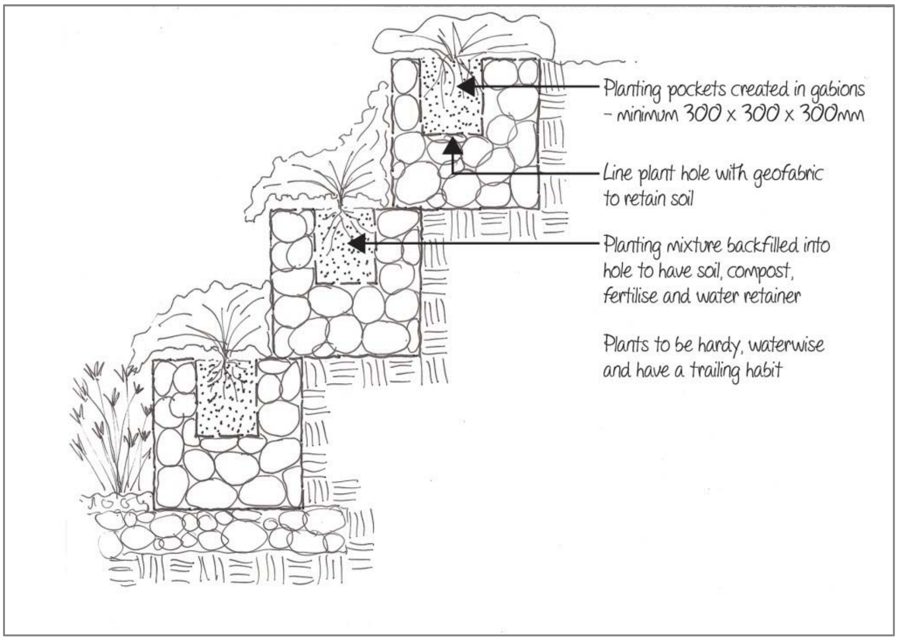

Figure 12.11: Planting plants into gabions

- Concrete block type retaining walls (e.g. terraforce and loffelstein) provide opportunities for planting but these are often small openings with place for little soil, with the soil drying out quickly. The plant species selected is very importance and must be able to survive the extreme hot and dry conditions (i.e. be waterwise) and then seasonal inundation. The geo-fabric and drainage gravel/stone chips required at the back of these walls for drainage purposes, further compromise successful plant growth as it restricts root growth into the adjacent in situ soil. In certain instances, e.g. where the in situ soils have more clay composition and are less likely to collapse, the possibility of omitting the geo-fabric should be discussed with the manufacturer so that the plant roots can get to from the concrete container into the *in situ* soil at the back of the retaining wall without the geo-fabric obstructing this process.

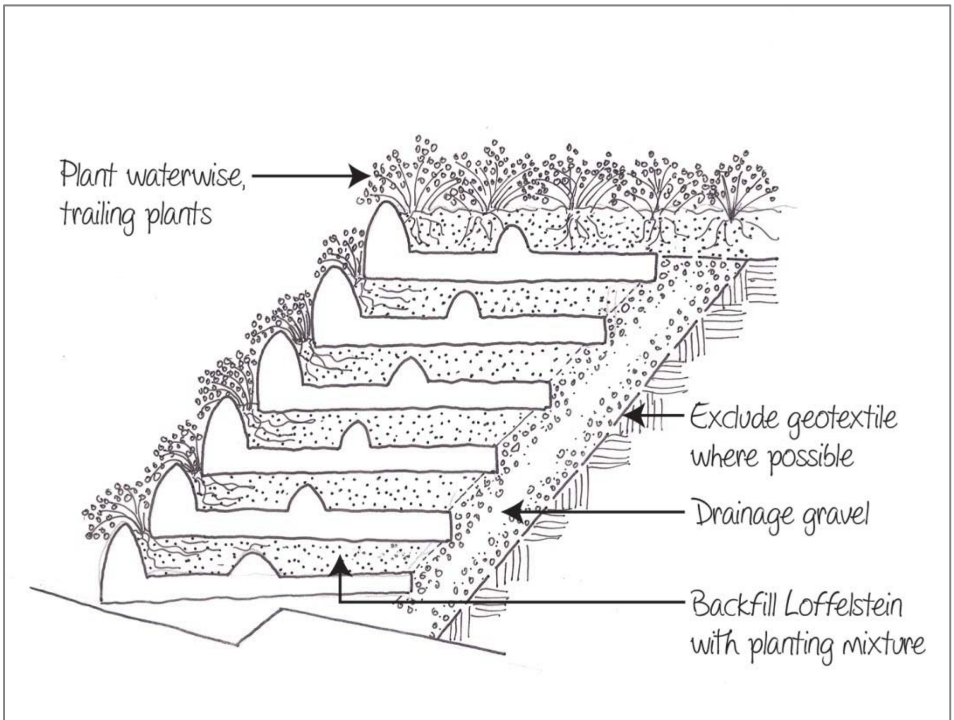

Figure 12.12: Planting in 'Loffelstein' units

12.2.5. Irrigation

It is often both necessary and beneficial to water newly planted areas during the first 2-5 dry seasons, particularly in the winter rainfall areas where the summers are hot and dry. It is particularly important during the first and second annual dry season, as this is the period when plants are establishing and require regular maintenance (watering, weeding and feeding) to get a good start and develop healthily.

In certain circumstances, it is necessary to install an automatic (electrically controlled) or manual (turf valve) irrigation system which can be used to water the newly planted areas. If water is not available via a pipe, a water usage licence may be applied for from DWS to pump water out of the river.

These systems are often vandalized in urban and suburban areas, so a suitable system should then be installed. For example installing an underground pipeline with turfvalves at 60 m intervals will have less irrigation sprayers exposed. This system will then be a manual system with an irrigation sprayer attached to the end of a hoseline which is moved around until all areas are suitably irrigated.

12.2.6. . Establishment and Maintenance phases

Establishment maintenance periods should be a minimum of 24 months and ideally up to 60 months, by which stage the plants will have established themselves and are able to maintain themselves.

Maintenance is to consist of watering, weeding, disease and insect pest control, pruning, replacement of unacceptable material, irrigation and accessory maintenance, litter removal, clearing and any other procedure necessary to ensure normal, vigorous and healthy growth of all planted areas.

The extent of the planted area will determine how often the maintenance visits must occur and the size of the team required to undertake the maintenance tasks. As a general rule of thumb, the area should be visited on a weekly basis in the first 12 months to inspect and monitor the area for any damage, invasive and alien weed growth and disease and pest control. Actual maintenance work such as weeding, pruning or attending to diseased plants will probably only be necessary every second week. During the dry season or drought periods, visits may need to be more regular to water the plants, particularly if there is not an automatic irrigation system.

All woody alien and invasive species, including kikuyu grass, must be controlled. Where seedlings occur sparsely, they should be removed manually. Larger individuals of alien/ invasive species shall be controlled by cutting or lopping. Freshly cut stumps should be treated immediately with herbicide, registered for use on that species, to prevent regrowth. The herbicide solution or mixture should be coloured with a red dye (e.g. EcoRed/ Sudan Red) to indicate which stumps have been treated).

Alien/ invasive plants and weeds should not be stock-piled, they should be removed from the site and dumped at an approved site.

All plant materials should be regularly inspected to locate any diseased or insect pest infestation.

All plant material should be kept free from dead wood, broken branches, dead flower heads or otherwise harmful or objectionable branches or twigs.

Secateurs and other cutting equipment should be sterilised regularly to avoid spreading fungal infestations and bacterial infections.

Plants should be watered three times weekly in summer and once weekly in winter unless sufficient rain (i.e. a minimum of 25 mm of rainfall) occurs.

Plants that die or become unhealthy from any cause or appear to be in a badly impaired condition should be promptly removed and replaced, or as soon as the weather permits,

In the case of surface wash-away or wind erosion appropriate remedial erosion control/ soil stabilisation measures should be implemented.

All accessories such as stakes, ties and pathways should be maintained in good condition.

Tree ties should be checked on a monthly basis to ensure that they are not too tight, restricting the tree trunk growth or cutting into the stem. If these are too tight, they should be loosened.

Tree stakes and ties should be removed after 2 or 3 years as by that stage the roots will have established well enough to anchor the plant sufficiently.

Excepting for desert and karoo regions, the indigenous plant cover, after 12 months, should be 75% of the area and there should not be bare patches, excluding pathways, of more than 500 mm in maximum dimension.

Legal considerations/authorisations

- Simple revegetation with indigenous species would not on its own require any prior approvals.
- Removal of invasive alien vegetation required in terms of NEM: BA;
- Any excavations of more than 5 m^3 of soil or sediment will require approval in terms of NEMA. Consult your provincial Dept. of Environmental Affairs for further details;
- Note that any landscaping activities that entail excavation into a river bank or bed, changes in bank or bed profile, or the addition of material (rocks, soil, etc.) could trigger the NWA, but may be Generally Authorised under some circumstances. Consult local DWS officials in this regard.

Useful references

DWAF. 2008. *Updated Manual for the Identification and Delineation of Wetlands and Riparian Areas,* prepared by M. Rountree, A. L. Batchelor, J. MacKenzie and D. Hoare. Report no. xx. Stream Flow Reduction Activities, Department of Water Affairs and Forestry, Pretoria, South Africa.

Wyatt J, 1995. Wetland Fix-. Assessment, management, and restoration of South African wetlands. Part 1: Introduction and wetland assessment. Renfreight Wetlands Campaign.

Wyatt J, 1995. Wetland Fix-. Assessment, management, and restoration of South African wetlands. Part 2: Wetland burning and grazing guide. Renfreight Wetlands Campaign.

Wyatt J, 1995. Wetland Fix-. Assessment, management, and restoration of South African wetlands. Part 3. Streambank stabilisation and channel plug development Renfreight Wetlands Campaign.

Wyatt J, 1995. Wetland Fix-. Assessment, management, and restoration of South African wetlands. Part 4. Indigenous plants suitable for streambank stabilisation and channel plug development. Renfreight Wetlands Campaign.

Wyatt J, 1995. Wetland Fix-. Assessment, management, and restoration of South African wetland. Part 5. Stream source wetlands spring protection guide. Renfreight Wetlands Campaign.

Wyatt J, 1991. Wetland Fix-. Assessment, management. and restoration of South African wetlands. Part 6. Alien plant control. Renfreight Wetlands Campaign.

APPENDIX 12A-1:

EXAMPLE OF A SCHEDULE OF QUANTITIES

ITEM	DESCRIPTION	SIZE	UNIT	QTY	RATE	TOTAL
1,0	**PREPARATION FOR PLANTING**					
1.1	Trim area prepared by others, repair any minor erosion		m^2	100		
2	**Planting in Permanently Wet areas**					
2.1	Supply and plant into water's edge:					
2.1.1	*Cyperus latifolius*	4 kg	no	20		
3	**Planting in Seasonally Wet areas**					
3.1	**Trees (10):**					
3.1.1	Excavate tree holes (1 m x 1 m x 1 m)	1 m^3	no	10		
3.1.2	Backfill tree holes with mixed planting mix		m^3	10		
3.1.3	Supply and plant trees:					
a	*Combretum erythrophylum*	100 kg	no	5		
b	*Rhus viminalis*	100 kg	no	5		
3.2	**Shrubs (50)**					
3.2.1	Excavate shrub holes (0,5 m x 0,5 m x 0,5 m)	0,125	m^3	6		
3.2.2	Backfill shrub holes with mixed planting mix		m^3	10		
3.2.3	Supply and plant shrubs:					
a	*Juncus krausii*	4 kg	no	10		
b	*Imperata cylindrical*	4 kg	no	15		
c	*Setaria megaphylla*	4 kg	no	15		
	Amount carried forward Amount brought forward					

ITEM	DESCRIPTION	SIZE	UNIT	QTY	RATE	TOTAL
4	**Planting in Temporarily Wet Areas**					
4.1	**Trees (10):**					
4.1.1	Excavate tree holes (1 m x 1 m x 1 m)	1 m^3	no	10		
4.1.2	Backfill tree holes with mixed planting mix		m^3	10		
4.1.3	Supply and plant trees:					
a	*Celtis Africana*	100 kg	no	5		
b	*Halleria lucida*	100 kg	no	5		
4.2	**Shrubs (50):**					
4.2.1	Excavate shrub holes (0,5 m x 0,5 m x 0,5 m)	0,125	m^3	6		
4.2.2	Backfill shrub holes with mixed planting mix		m^3	10		
4.2.3	Supply and plant shrubs:					
a	*Pelargonium capitatum*	4 kg	no	15		
b	*Searsia crenata*	4 kg	no	10		
c	*Helichrysum territifolium*	4 kg	no	15		
5,0	**MAINTENANCE**					
5.1	Maintenance for one year with team of 5 people visiting site every second week to weed, water, check for pests and treat, repair erosion and prune where necessary.		month	12		
	TOTAL					

APPENDIX 12A-2: PRELIMINARY LIST OF OBLIGATE RIPARIAN PLANTS

The Table below lists what are considered to be obligate riparian plants, as well as indicating in what province/s of South Africa these species are likely to occur in such a setting (*MP: Mpumalanga; LP: Limpopo; GA: Gauteng; NW: North-West; NC: Northern Cape; EC: Eastern Cape; WC: Western Cape; FS: Free State; KN: KwaZulu-Natal*). The list includes alien weeds and invader plants.

FAMILY	TAXON	HABITAT	WC	NC	EC	FS	KZN	NW	G	LP	MP
SALICACEAE	**Populus x canescens*	Variable, but especially vleis and in river valleys	X	X	X	X	X	X	X	X	X
SALICACEAE	**Salix babylonica var. babylonica*	Along streams.	X	X	X	X	X	X	X	X	X
FABACEAE	*Acacia xanthophloea*	Low-lying, swampy areas					X			X	X
ANNONACEAE	*Annona senegalensis*	Sandy soils along rivers, also in mixed scrub or woodland, on rocky outcrops and in swamp forest.					X			X	X
POACEAE	*Arundinaria tessellata*	Margins of high altitude forest, along streams and among rocks on mountain tops			X	X	X				
VERBENACEAE	*Avicennia marina*	Common in mangrove swamps; also encroaching back up feeder streams, and growing on banks of fresh water rivers.			X		X				
SALVADORACEAE	*Azima tetracantha*	Low altitudes in bush, scrub, woodland and thornveld, frequently along watercourses and in riverine thicket.	X		X		X			X	X
FABACEAE	*Baphia racemosa*	Usually in riverine forest.			X		X				
LECYTHIDACEAE	*Barringtonia racemosa*	Always near water, along banks of rivers, in fresh water swamps and occasionally in less saline areas of					X				

FAMILY	TAXON	HABITAT	W C	N C	E C	F S	KZ N	N W	G	L P	M P
		mangrove swamps.									
PROTEACEAE	*Brabejum stellatifolium*	Riverine species with water-dispersed fruits, occurring in sheltered valleys and along streams.	X								
ASTERACEAE	*Brachylaena neriifolia*	Stream banks and moist mountain forest.	X		X						
RUBIACEAE	*Breonadia microcephala*	Along banks of permanent streams and rivers, in riverine fringe forest.								X	X
EUPHORBIACEAE	*Bridelia micrantha*	Riverine forest; patches of relic forest, or in open woodland.			X		X			X	X
RHIZOPHORACEAE	*Bruguiera gymnorrhiza*	On seaward side of mangrove swamps.									
FABACEAE	*Cassia petersiana*	Most frequently found along rivers and streams in riverine fringe thicket.					X			X	X
ULMACEAE	*Chaetacme aristata*	Along streams in wooded grassland, in riverine fringe thicket, in wooded ravines and near the coast, often in scrub and forest.			X		X	X	X	X	X
COMBRETACEAE	*Combretum caffrum*	Along river and stream banks and in moist areas.			X						
COMBRETACEAE	*Combretum erythrophyllum*	Along river banks where it can form thick stands, with trunks reclining in and overhanging the water.		X	X	X	X	X	X	X	X
COMBRETACEAE	*Combretum imberbe*	Medium to low altitudes, in mixed woodland, often along rivers or dry watercourses, particularly on alluvial soils.					X	X	X	X	X
FABACEAE	*Cordyla africana*	Low altitudes in hot areas, most often forming part of riverine forest, and also in swamp					X				X

FAMILY	TAXON	HABITAT	WC	NC	EC	FS	KZN	NW	G	LP	MP
		forest.									
EUPHORBIACEAE	*Croton megalobotrys*	On alluvial flats and almost always a constituent of riverine fringe forest or thicket.						X		X	X
LAURACEAE	*Cryptocarya angustifolia*	River valleys of the south-western Cape.	X								
CUNONIACEAE	*Cunonia capensis*	On stream banks and in moist forest, being abundant in the high, wet forests and in very wet scrub forests around Knysna; under harsher conditions it becomes shrubby.	X		X		X				
CYATHEACEAE	*Cyathea dregei*	Forest margins, wooded kloofs and along streams on grassy mountainsides	X		X		X			X	X
STERCULIACEAE	*Dombeya cymosa*	In coastal bush or, further inland, along river and stream banks.			X		X			X	X
STERCULIACEAE	*Dombeya pulchra*	In wooded river valleys and along stream banks, also on mountainsides at high altitudes.								X	X
EUPHORBIACEAE	*Drypetes arguta*	Evergreen forest, often along streams			X		X				
ACANTHACEAE	*Duvernoia adhatodoides*	Evergreen forest, often along stream banks and in ravines.			X		X				
ERICACEAE	*Erica caffra var. caffra*	Mountain ravines, on cliffs, generally in damp situations	X		X		X				
MORACEAE	*Ficus capreifolia*	Swamps, and frequently forming tangled thickets along river banks and on sandy islands in the larger rivers.					X			X	X
MORACEAE	*Ficus sycomorus*	Frequently along river banks, forming a					X			X	X

FAMILY	TAXON	HABITAT	WC	NC	EC	FS	KZN	NW	G	LP	MP
		distinctive part of the riverine thicket; also in mixed woodland									
SCROPHULARIACEAE	*Freylinia lanceolata*	Wide range of altitudes in moist areas, along stream and river banks and fringing vleis.	X		X						
GREYIACEAE	*Greyia radlkoferi*	In mountain forested gullies, along stream banks, fringing evergreen forest and among rocks.					X			X	X
CELASTRACEAE	*Gymnosporia bachmannii*	Rocky banks of rivers and streams in evergreen forest.			X		X				
ANACARDIACEAE	*Harpephyllum caffrum*	Riverine forest.			X		X				X
MALVACEAE	*Hibiscus diversifolius subsp. rivularis*	In damp places, along rivers or lining lakes, and in thickets.	X		X		X				
MALVACEAE	*Hibiscus tiliaceus*	Along the coast often fringing estuaries and tidal rivers.	X		X		X				
SAPINDACEAE	*Hippobromus pauciflorus*	Riverine thicket, scrub, along stream banks and at margins of evergreen forest.	X		X	X	X			X	X
LAMIACEAE	*Iboza riparia*	Rocky outcrops and margins of evergreen forest, often near water.					X			X	X
AQUIFOLIACEAE	*Ilex mitis*	Most frequently along river banks and stream beds, in moist evergreen forest, sometimes straggling and leaning over the water. It is believed that the presence of this tree is an indication of underground water near the surface.	X		X	X	X	X	X	X	X

FAMILY	TAXON	HABITAT	WC	NC	EC	FS	KZN	NW	G	LP	MP
PROTEACEAE	*Leucadendron conicum*	In mountainous areas from 300 to 1000 masl, always in damp places, in valleys, ravines and along streams.	X		X						
PROTEACEAE	*Leucadendron eucalyptifolium*	Coastal mountains at altitudes 150 to 1600 masl, favouring moist conditions; frequent at edge of forests and along streams.	X		X						
PROTEACEAE	*Leucadendron salicifolium*	On acid soils from 0 to 1000 masl, characteristically forming almost hedge-like screens along the banks of streams.	X								
ROSACEAE	*Leucosidea sericea*	At high altitudes along streams and in kloofs, where it forms dense stands			X	X	X	X	X	X	X
OLEACEAE	*Lincociera battiscombei*	Occurring on banks of mountain streams, most frequently in riverine fringes and forested ravines.								X	
ACANTHACEAE	*Macaya bella*	Evergreen forest, often along stream and river banks.			X		X			X	X
CAPPARACEAE	*Maerua gilgii*	Arid areas of stony desert, often along river beds and dry watercourses.		X							
MYRSINACEAE	*Maesa lanceolata*	Margins of evergreen forest, almost always along rivers and streams, occasionally in open mountaingrassland.			X		X			X	X
MYRTACEAE	*Metrosideros angustifolia*	In mountainous areas, along watercourses and river banks where it can become locally common.	X	X							

FAMILY	TAXON	HABITAT	WC	NC	EC	FS	KZN	NW	G	LP	MP
RHAMNACEAE	*Noltia africana*	High altitudes, occasionally in open scrub and along stream banks.	X		X						
LOGANIACEAE	*Nuxia oppositifolia*	Along rivers and streams, in riverine thicket, among rocks and reeds.					X			X	X
OLEACEAE	*Olea africana*	Variety of habitats, usually near water, on stream banks, in riverine fringes, but also in open woodland, among rocks and in mountain ravines.	X	X	X	X	X	X	X	X	X
ARECACEAE	*Phoenix reclinata*	Along river banks in low-lying open grassland			X		X			X	X
EUPHORBIACEAE	*Phyllanthus reticulatus*	Low altitude riverine vegetation and thicket.					X			X	X
PIPERACEAE	*Piper capensis*	Moist, shady places, in forests and along streams	X		X		X			X	X
CUNONIACEAE	*Platylophus trifoliatus*	In forest or on stream banks	X		X						
URTICACEAE	*Pouzolzia hypoleuca*	Open woodland, wooded ravines, riverine thicket and sheltered among boulders on rocky koppies.					X	X	X	X	X
PRIONIACEAE	*Prionium serratum*	In water courses and river beds.	X		X		X				
CELASTRACEAE	*Pseudosalacia streyi*	Among rocks along river banks in evergreen forest, seldom far from the sea.			X		X				
APOCYNACEAE	*Rauvolfia caffra*	Nearly always associated with available ground water, along wooded stream banks and at the margins of evergreen forest.			X		X	X	X	X	X
RHAMNACEAE	*Rhamnus prinoides*	Along watercourses, in riverine forest and at margins of evergreen forest.	X		X	X	X		X	X	X

FAMILY	TAXON	HABITAT	W C	N C	E C	F S	KZ N	N W	G	L P	M P
RHIZOPHORACEAE	*Rhizophora mucronata*	On inter-tidal mud flats, usually on the seaward side of mangrove swamp forests.			X		X				
ANACARDIACEAE	*Rhus incisa*	Scattered through open scrub and frequently occurring along the banks of rivers.	X	X	X						
ANACARDIACEAE	*Rhus montana*	Mountain areas, often along river banks.			X	X	X			X	X
ANACARDIACEAE	*Rhus viminalis*	Along river and stream banks.	X	X	X	X					
LYTHRACEAE	*Rhyncocalyx lawsonioides*	Margin of evergreen forest and along rivers.			X		X				
VERBENACEAE	*Rotheca myricoides*	Rocky places in thickets along streams, also in open woodland often associated with termite mounts.					X	X	X	X	X
SALICACEAE	*Salix mucronata subsp. mucronata*	Stream and river banks, in a wide range of habitats.	X	X	X	X	X	X			
SALICACEAE	*Salix mucronata subsp. subserrata*	Occurs along river and stream banks and on islands, in places likely to become inundated for at least part of the year.				X	X			X	X
CHENOPODIACEAE	*Salsola aphylla*	Frequently in dry, arid hot areas along dry watercourses.	X	X	X	X		X		X	
FABACEAE	*Sesbania sesban subsp. sesban*	In low lying areas usually near water, often on river or stream banks.			X		X			X	X
EUPHORBIACEAE	*Spirostachys africana*	Low altitude bush, often along rivers and streams.					X	X	X	X	X
MYRTACEAE	*Syzygium cordatum subsp. cordatum*	Along stream banks, in riverine thicket and forest, always near water or along watercourses, and in KZN, forming			X		X			X	X

Chapter 13:

River rehabilitation and human society –

Techniques to improve public safety and the recreational value of watercourses

Author: Liz Day (Freshwater Consulting Group)

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Introduction

In addition to improving river biodiversity value and/or preventing erosion or other forms of degradation of watercourses, there is also often demand for some level of river rehabilitation or at least remediation, from the perspective of addressing public safety, aesthetic or recreational requirements (e.g. RRC 2002, Day and Ractliffe 2002). These may or may not be coupled to a broader range of ecological activities taking place at a site, but even where these are not driving factors in a rehabilitation project, it is crucial to the long-term success of project that they are given early recognition in project planning, and that /or indirect implications of rehabilitation projects are identified and their implications assessed and included in the overall project plan (Ractliffe and Day 2002 and Day *et al.* 2005).

South African social contexts

The rehabilitation of rivers in South Africa takes place against a wide variety of social, political, security and economic backgrounds, which often play fundamental roles in determining both the scope of rehabilitation projects and their long-term outcomes. In urban areas in particular, both real and perceived security issues are frequently over-riding concerns for residents abutting or commuting through open spaces, which often include riverine corridors. In other areas, recreational or amenity / aesthetic requirements, as well as security concerns, may pose significant competing interests to those of biodiversity maintenance or improvement, or the simple improvement of river ecosystem function or provision of ecosystems services. In addition, limited finances, both at the level of local communities / landowners and at the level of municipal and national authorities, pose significant constraints as to what is achievable in any community / area. As a result, river rehabilitation projects, unless opportunistic indirect spinoffs of broader service delivery or engineering projects designed to protect infrastructure and/or property, may lose out in competition with what are often over-riding concerns regarding human health or well-being.

Caution

Such concerns and competing demands on limited resources need to be acknowledged and dealt with in river rehabilitation planning, if local communities are expected to buy in to such projects, instead of seeking alternatives that are ecologically sterile (at best) – for example, covering over or piping watercourses, to avoid living with areas prone to the establishment of reeds and dense vegetation in which criminal elements lurk (see Volume 3: Case Studies 2, 10 and 16).

Social and security considerations in river rehabilitation projects

The following approaches have been developed as a result of experience with the issues described above, and their relevance should be carefully considered in the context of any planned river rehabilitation project:

- In areas where security is an issue and open spaces prone to use by criminal elements, the installation of raised lighting along pathways and attention to the establishment of low-growing riverine vegetation, rather than shrubs, and tall trees that provide shade and not hiding areas, are important considerations if community support for rehabilitation efforts is to be obtained (Volume 3: Case Studies 16 and 17);

- The establishment of benches, landscaped mounds for playing areas and playing facilities are all sometimes viewed as problematic from a safety perspective in areas vulnerable to gangster activity, as they tended to attract gangsters into open spaces (Volume 3: Case Study 17);
- In densely populated areas, particularly within low cost housing and informal settlement areas, riverine corridors are often the only open public spaces available for communities, and rehabilitation activities need to allow safe amenity use as well – along the Moddergatspruit in Cape Town, a dual flow system, comprising a riprap lowflow channel, with gabion weirs to address channel gradient provides a relatively diverse riverine habitat, with (artificial) riffle and marginal vegetation, while a stepped floodplain on either side of the channel has been grassed. While the latter provides little in the way of services such as water quality amelioration, sediment trapping or wetland habitat, it does provide safe recreational space, and flood attenuation (Volume 3: Case Study 2);
- Boardwalks allow access to and across river and wetland areas without disrupting shallow surface and subsurface flows and with minimal damage to natural plants – the choice of materials should however consider the likelihood of theft and vandalism;
- Aesthetic and/or safety concerns by local communities may mean that rehabilitated riverine zones cannot be planted using reference conditions as a template, although a measure of compromise between grassed (often kikuyu) lawns to the river edge, and densely reeded and planted margins, should usually be sought;
- Where river banks are steep, consideration should be given to providing areas where children, dogs and other animals can safely climb out of channels if they fall in;
- Management of livestock, particularly from urban kraal areas where grazing space is limited, is often essential;
- Some compromise between ecological and social amenity requirements is usually necessary in urban environments.

Effects of river rehabilitation on human health

While it is usually assumed that effective river rehabilitation will result in improved environmental conditions that are beneficial to local communities (e.g. more stable and natural riverine environments with space for recreational and various other activities in an environmentally uplifted surrounding, and potentially better water quality). However, this is not always the case. Some studies have considered the role of rivers in disease, with Msiska (2001) noting that aquatic plants in some subtropical rivers provide habitat for *Bulinus globosus*, the snail host for *Schistosoma haemotobia* (bilharzia). Since increased plant cover particularly along river margins is often a desired outcoime of river rehabilitation (see Chapters 4 and 10), increased habitat for this pest species may be an unwelcome outcome of such rehabilitation in some areas.

Knock-on effects of the changes in river function and structure may also result in at least the short-term proliferation of certain nuisance aquatic species that are able to thrive as new niches open up for exploitation in an altered river state. The removal of carp fish during a large-scale urban canal rehabilitation project in Cape Town resulted, for example, in the proliferation of nuisances midges (Chironomidae) over the first year, before aquatic invertebrate populations stabilised and were able to compete with these nuisance organisms (Day 2008).

Possible indirect effects of river rehabilitation interventions should be identified during rehabilitation planning, so that affected communities are prepared for short-term pest species, and/or pre-warned regarding long-term changes in aquatic biodiversity, which while positive from the perspective of river rehabilitation, may not always be seen as desirable by local communities. Examples include increased reed growth, in the case of Typha capensis promoting the annual release of quantities of fine, nuisance seeds (Hall 1990), as well as increased populations of fauna such as frogs (possibly associated with noise during breeding seasons) and natural increases in flying invertebrates such as dragonflies, midges and (if standing water wetlands are created) mosquito larvae. Such changes arguably reflect improved habitat quality. Efforts must be taken to educate and/or inform local communities around such issues, and ideally generate long-term buy-in to the notion that rivers should be natural ecosystems associated with fauna and flora that may not be convenient for abutting communities at all times, but contribute to improved ecosystems services, catchment function and the possibility for beneficial use of rehabilitated rivers, for example for resources such as fish and certain plants.

Need for effective resource prioritisation

While it is often tempting to promote and motivate for direct river rehabilitation interventions, it is cautioned that pragmatic prioritisation of expenditure of limited resources on broader issues such as adequate sewage conveyance and treatment, and effective stormwater management, may sometimes result in better long-term outcomes for river systems, than direct river rehabilitation interventions (see Chapters 8 and 10). However, even where direct rehabilitation interventions are forgone, it is important that sufficient open space is left along river corridors to provide space for future rehabilitation interventions (e.g. bank shaping and planting) and that issues that will result in significant deterioration of the resource if left unattended (e.g. headcut or bank erosion) are still addressed as a priority.

Figure 13.1: In some circumstances, focusing efforts on the provision of adequate sewage and stormwater services may provide a more effective tool for river rehabilitation than direct rehabilitation interventions

References

Day, E. (Liz), Ractliffe, G. 2002. *Assessment of river and wetland engineering and rehabilitation activities within the City of Cape Town. Realisation of project goals and their ecological implications. Volume 1: Assessment process and major outcomes.* Report to Catchment Management. Cape Metropolitan Council. City of Cape Town.

Day, E. (Liz), Ractliffe, J. and Wood, J. 2005. An audit of the ecological implications of remediation, management and conservation of urban aquatic habitats in Cape Town, South Africa, with reference to their social and ecological contexts *Journal of Ecohydrology and Hydrobiology*. Vol. 5 (4).

Hall, D.J. 1990. The ecology and control of *Typha capensis* in the wetlands of the Cape Flats, South Africa. Unpublished PhD Thesis, Zoology Department, University of Cape Town.

Msiska, O.V. 2001. A Review of Limnology in Malawi. IN: Ed Wetzel, R.G. and Gopal, B. Limnology in Developing Countries. International Association for Limnology. Pp 121-189.

USDIBR. 2006. United States Department of the Interior: Bureau of Reclamation. Erosion and Sedimentation Manual. Denver. Colorado. United States of America.

Chapter 14:

RESEARCH AND GUIDELINE NEEDS

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Rationale

During the compilation of this manual, a number of areas were identified in which additional research is required, in order to improve the level of guidance that can be provided to inform river rehabilitation interventions. In addition, a number of topics were identified that were beyond the already expanded scope of this project, but which the project team considers would be well-suited to inclusion in a proposed, separate but complementary Guidelines document.

This chapter briefly lists topics for suggested inclusion in both these areas.

Recommendations for further research

- Testing of the application of "green options" in river rehabilitation in South Africa – a number of design options have been described in this Manual, but remain untested in South African conditions and cannot therefore be recommended;
- Further work to allow more quantitative guidelines for the use of plants in river rehabilitation – specifically, in compiling more detailed guidelines for the stabilization of banks using the functional traits of roots. During the course of this project, Prof Chris James and Ms Megan van der Haar (Wits University) developed guidelines for the use of the functional traits of roots in erosion control. Their work was however forced to reply on functional trait classes developed for conditions and plant species that occur in Europe and North America. Their adaptation to South African species and conditions was thus undertaken with difficulty and at a relatively low confidence level. Tremendous value could be added to this aspect, with additional work that included the following:
    - Establishment of functional traits for local plant species to enable overseas data and experience to be matched with conditions in South African rivers and / or the classification of key South African plant species in terms of classes that matched those used in America. This would entail the following components:
        - Development of a database for the relationships between root diameter, root length and corresponding root tensile strength and pull out strength for South African plant species – this would make it possible for functional root traits to be matched to appropriate plant species and further enable the development of a guideline in determining which plant species would be suitable for the stabilization of a wide range of riverbanks;
        - Field tests – these would need to be carried out in order to populate the above database, noting that the most important property is the pull out strength value since pull out strength is indicative of the plant species' resistance to uprooting. From field tests, it would also be beneficial to record root length for different plant species in order to determine whether the plant roots are able to penetrate through the slip surface zone predicted from analysis;
        - Further research into the effects on plant survival and growth rate of flooding within the drawdown zone;
        - The time taken for plant species to grow and to allow roots to reach an adequate depth must be taken into consideration and precautionary measures should be put into place until such time that the root properties are fully mobilized and activated.

Recommendations for complementary guidelines – "Best practice guidelines for the design of infrastructure near rivers"

This proposed document would include guidelines as to how to limit the ecological impact and long-term environmental and financial damage often associated with:

- The design of bridges, causeways and other river crossings;
- Design of culverts;
- Stormwater outlets;
- Sewer and other infrastructure crossings;
- The effect of climate change on river function and infrastructure;
- Fencing design at river crossings.

In addition, the following challenges affecting river management in South Africa must be highlighted:

- The implications of climate change;
- Principles of water demand management;
- The need to address sewage as a river pollutant.

Re-consideration of existing legislation with specific regard to river rehabilitation

Clear, consistent and unambiguous interpretations of the legislation from the relevant authorities would facilitate improved and more widespread river rehabilitation and management. At present the overly legislated environment, and inconsistent interpretations thereof between different government departments, deters or prohibits responsible and interested landowners from engaging in effective river rehabilitation activities. A clear guideline from the DWS and DEA for the agricultural sector, as well as for private landowners and conservationists, advising them on what specific activities would be permissible to undertake to maintain and improve the watercourses on their properties, would probably be the best thing to be done for river rehabilitation and management in the country as it would enable a large group of land owners to with support from government, engage in minor river rehabilitation works. These activities, undertaken at scale across the country, would move us beyond "citizen science" to direct engagement and involvement of landowners in rehabilitation rather than just monitoring.

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