BUFFER ZONE GUIDELINES FOR WETLANDS, RIVERS AND ESTUARIES

Douglas Macfarlane and Ian Bredin



PART 1: TECHNICAL MANUAL

WATER RESEARCH COMMISSION

TT 715/1/17

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WATER RESEARCH COMMISSION

water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

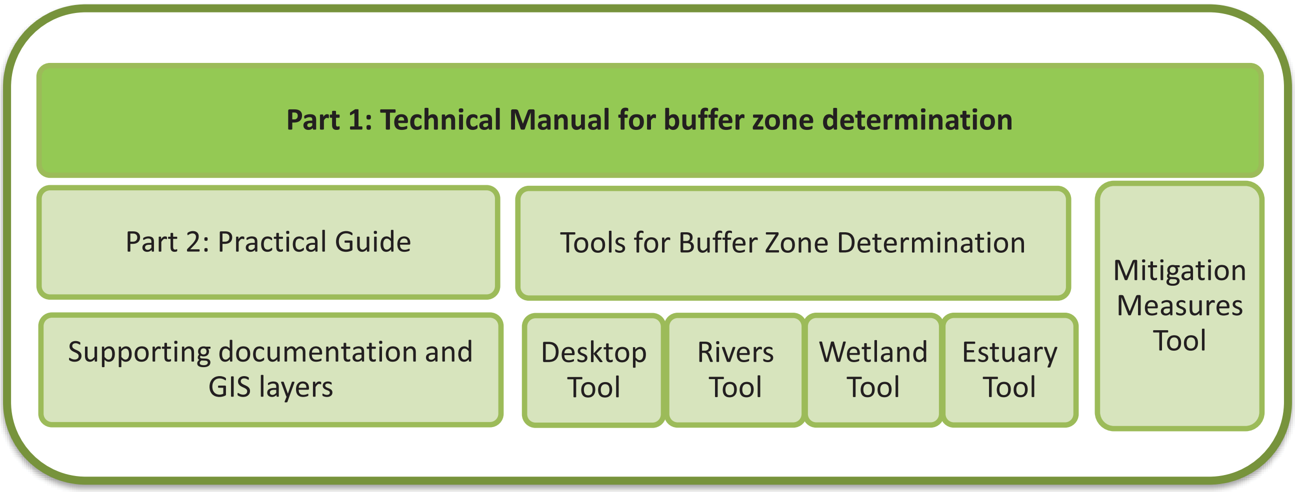
Institute of Natural Resources

eco-pulse
environmental consulting services

OVERVIEW OF PROJECT OUTPUTS

This Technical Manual is one of the key outputs of a research project funded by the Department of Water and Sanitation through the Water Research Commission. This report is designed to be used together with a range of accompanying outputs that were produced as part of this project. A brief summary of each product is outlined and the relationship between them is shown diagrammatically below:

- **Part 1: Technical Manual (this document):** This report documents the step-wise assessment procedure developed to determine appropriate buffer zones for rivers, wetlands and estuaries. This includes the rationale for the approach taken, together with important supporting technical information which was used as a basis for developing the tools for buffer zone determination.
- **Part 2: Practical Guide:** The Practical Guide was developed to assist users with the practical application of the Buffer Zone Tools. It includes field sheets and practical guidance for collecting and interpreting relevant desktop and field information. Supporting information required to assess selected criteria has also been compiled, and includes a range of spatial datasets [shapefile or Keyhole Mark-up Language (KML) format].
- **Tools for Buffer Zone Determination:** A range of spreadsheet-based tools has been developed to help users determine suitable buffer zone requirements. These include a rapid desktop tool for determining potential aquatic impact buffer zone requirements, as well as three site-based tools for determining buffer zone requirements for rivers, wetlands and estuaries. Once completed, the outcomes of the site-based assessments can be exported as a formal record of the buffer zone assessment process.
- **Mitigation Measures Tool:** This tool is essentially a consolidation of supplementary mitigation measures from a wide range of reference material. It is designed as a quick access point for users with a broader interest in impact mitigation or those who advise on measures to mitigate impacts on water resources.



Buffer Zone Guidelines for Rivers, Wetlands and Estuaries

Part 1: Technical Manual

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by

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Insets: Allendale wetland, mountain stream, and Ntafufu estuary

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EXECUTIVE SUMMARY

South Africa's aquatic ecosystems are under increasing pressure with impacts such as regulation of flow by impoundments, pollution, over-extraction of water, and the breakdown of natural biogeographical barriers, which all affect the ecological condition of these resources. The need for preventative measures to avoid further degradation of these resources has therefore been highlighted. It is in this context that establishing buffer zones to rivers, estuaries and wetlands can play a meaningful role in reducing impacts to aquatic resources and in doing so, protect the range of goods and services that these resources provide to society.

This *Technical Manual* provides detail on the assessment procedure, and acts as the primary reference point for anyone wishing to determine an appropriate buffer zone around a river, wetland or estuary. It presents the concepts, background and technical aspects of the approach required for determining appropriate buffer zones. The accompanying *Practical Guide* includes information to assist users in selecting appropriate options for each of the criteria that should be considered when populating the site-based Buffer Zone Tools. These tools have been developed both to determine appropriate buffer zones for rivers, wetlands and estuaries, and to provide a record that assessors have taken due consideration of key aspects outlined in this manual. Various interim project reports, which are not included in this report but which may be of interest to readers, are also available. These are:

- An initial literature review undertaken at the start of this project (Macfarlane et al., 2009).
- A practical testing report (Bredin et al., 2014).
- The preliminary guideline for buffer zone determination (Macfarlane et al., 2014).
- A national training and development workshop report (Zungu et al., 2015).

What are buffer zones?

Definitions of buffer zones vary depending on their purpose. In the context of this guideline, buffer zones have been defined as a strip of land with a use, function or zoning specifically designed to protect one area of land against impacts from another. This project specifically focuses on aquatic buffer zones, which are typically designed to act as barriers between human activities and sensitive water resources to protect them from adverse negative impacts. The need to ensure that buffer zones provide adequate protection for biota and species movement is also addressed in these guidelines.

Why are buffer zones regarded as important?

Buffer zones associated with water resources have been shown to perform a wide range of functions, and have therefore been adopted as a standard measure to protect water resources and associated biodiversity. Some of these key functions include:

- Maintaining basic aquatic processes.
- Reducing impacts on water resources from upstream activities and adjoining land uses.
- Providing habitat for aquatic and semi-aquatic species.
- Providing habitat for terrestrial species.
- A range of ancillary societal benefits.

What do buffer zones not do?

Despite the range of functions potentially provided by buffer zones, they do not address all water resource related problems. They should ideally be implemented with a range of complementary mitigation and management measures. Although buffer zones can be effective in addressing diffuse source pollution in storm water run-off, they should typically be seen as part of a treatment train designed to address storm water impacts. It is important to note that buffer zones can do little to address impacts such as hydrological changes caused by stream flow reduction as a result of afforestation. Buffer zones are not the most appropriate tool for militating against point-source discharges (such as sewage outflows), which can be managed more effectively by targeting these areas through specific

source-directed controls and treatment options. Buffer zones also do not address groundwater contamination or use and complementary approaches to address these impacts are necessary.

Selecting an appropriate approach to setting buffer zones

The literature review identified three generic approaches. These included fixed-width, modified fixed-width, and variable-width approaches. Each approach has several advantages and disadvantages, but the modified fixed-width approach was identified initially as appropriate in the South African context. This was because of the need for a tool that could be applied across different levels (namely, desktop and site-based), while maintaining a level of predictability and consistency between approaches. Although the method outlined in this document was initially developed around a modified fixed-width approach, it has matured into what is essentially a variable-width method. This results from the integration of a range of variables in the Buffer Zone Models to reflect the variability of both risks posed by developments and the inherent variability in climatic, buffer and water resource characteristics. However, an attempt has been made to bring some level of predictability to buffer zone recommendations by incorporating starting risk ratings for different land uses and by defining standard risk-based minimum buffer zone requirements.

The assessment procedure

The Technical Manual sets out a step-by-step approach for determining best practice buffer zone requirements for rivers, wetlands and estuaries. This includes guidance on how to complete both desktop and site-based assessments, with further guidance included in the accompanying Practical Guide.

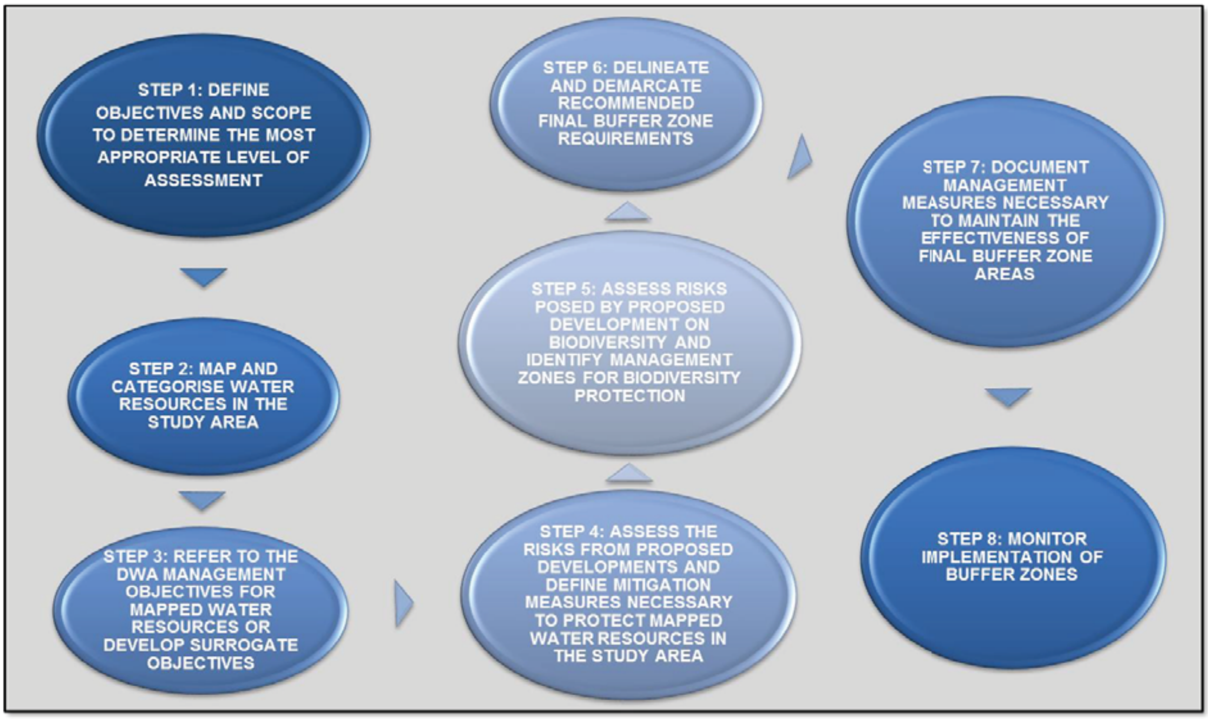

Figure 1 – Approach for determining best practice buffer zone requirements

Buffer Zone Tools

A series of Excel™ based Buffer Zone Tools have been developed to help users determine suitable buffer zone requirements. These include a rapid desktop tool for determining potential aquatic impact buffer zone requirements together with three site-based tools for determining buffer zone requirements for rivers, wetlands and estuaries. Central to these tools is a buffer model, which is populated automatically from the data capture sheets provided. This is based on best available science and is used to generate buffer zone recommendations as part of the assessment process.

Determining appropriate management and monitoring of buffer zones

Once a final buffer zone area has been determined, appropriate management measures should be documented to ensure that the water quality enhancement and other buffer zone functions, including biodiversity protection, are maintained or enhanced. Key aspects addressed include:

- Demarcating buffer zones.
- Defining suitable management measures to maintain buffer functions.
- Reviewing the need to integrate protection requirements with social and development imperatives.
- Monitoring to ensure that buffer zones are implemented and maintained effectively.

Conclusions and recommendations

These guidelines are the first attempt to develop nationally applicable guidelines for buffer zone determination in South Africa, and to provide guidance for activities planned adjacent to rivers, wetlands and estuaries. They have been endorsed by the Department of Water Affairs and are to be used and applied as part of a broader suite of tools to ensure that water resource management is appropriately integrated into development planning and land use management.

The approach presented in the guidelines is based on best available science. However, the authors recognise that ongoing research, changes in government policies or challenges with the practical application of the guidelines may need to be revised over time. We also realise that the guidelines will have limited value unless integrated into existing policies and legislated decision-making processes. We therefore encourage both government departments and the business sector to promote the application of the guidelines and to identify and address conflicts with other guidelines that may exist – both locally and nationally. Training and capacity building are also critical for the effective use of these guidelines. Government is therefore encouraged to provide focused training on these guidelines and to support learning institutions in developing and running suitable training courses.

Determining appropriate management measures for aquatic impact buffer zones

Determining appropriate management measures for aquatic impact buffer zones is largely dependent on the threats associated with the proposed activity adjacent to the water resource. These threats include:

- Increases in sedimentation and turbidity.
- Increased nutrient inputs.
- Increased inputs of toxic organic and heavy metal contaminants.
- Pathogen inputs.

Determining appropriate management measures for biodiversity conservation

A review of international literature found that the buffers required for the protection of biodiversity dependent on a water resource are significantly larger than those adequate for water quality protection. Not only do many aquatic and semi-aquatic species depend on water resources for some portions of their life cycles but they also require terrestrial habitats adjacent to the water resources to meet the rest of their life cycle needs. Without access to appropriate terrestrial habitats and the opportunity to move safely between habitats across a landscape, it will not be possible to maintain viable populations of many species. Therefore, core habitats and corridors need to be developed for the protection of species or habitats of conservation concern.

Additional aspects requiring consideration to ensure effective management of final buffer zone areas

There are many aspects that need to be considered to ensure that, once established, the final buffer zone area continues to provide the required functions. Overlooking the following aspects may result in the degradation of the final buffer zone areas over time:

- Regulating aquatic impact buffer zones.
- Aquatic impact buffer zone demarcation.
- Aspects that may require the expansion of the aquatic impact buffer zone.
- Maintenance of supporting mitigation measures.
- Buffer zones in urban areas.
- Rehabilitation or enhancement of buffer zones.
- Buffer zones and climate change.

Conclusions and recommendations

The assessment procedure detailed in this report, as well as the management practices that need to be considered, provide the guidelines for determining and managing appropriate buffer zones. The Buffer Zone Tools developed in conjunction with this report provide the user with the primary tool for determining appropriate buffer zones (https://sites.google.com/site/bufferzonehub/). In addition, the accompanying Practical Guide for determining aquatic impact buffer zones provides key information for making informed and consistent decisions when applying the Buffer Zone Tools. Supporting documents attached as annexures, either in hardcopy or as electronic copies, also provide extensive background information.

Hopefully this Technical Manual for the determination of buffers for rivers, wetlands and estuaries, along with the Practical Guide and the Buffer Zone Tools will meet the demand for a scientifically defensible approach to determining buffer zones.

ACKNOWLEDGEMENTS

The Technical Manual and accompanying Practical Guide of the *Buffer zone guidelines for rivers, wetlands and estuaries* refine the *Preliminary guideline for the determination of buffer zones for rivers, wetlands and estuaries*. We would specifically like to acknowledge Prof. Janine Adams, Prof. Guy Bate, Ms Adwoa Awuah and Mr Manqoba Zungu for their contributions to the development of the buffer zone guidelines.

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The Reference Group consisted of:

- Mr Bonani Madikizela (WRC).
- Dr Wietsche Roets (DWS).
- Ms Nancy Job (Private Consultant).
- Dr Denise Schael (Nelson Mandela Metropolitan University).
- Dr Nicky Allsopp (South African Environmental Observation Network).
- Dr David Turner [Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW)].
- Ms Naomi Fourie (DWS).
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- Dr Wynand Vlok (BioAssets).

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- Dr Wietsche Roets (DWS) for his advice on incorporating regulations on use of water for mining and related activities aimed at the protection of water resources.
- Mr Leo Quayle (Institute of Natural Resources) for his assistance in developing the Buffer Zone website.
- Mr Adam Teixeira-Leite (Eco-Pulse Environmental Consulting Services) for his contributions in developing an initial draft method and model, and for guidance on how best to address channel migration.
- Prof. Roland Schulze (University of KwaZulu-Natal) for sharing data that included the Soil Conservation Services method for Southern Africa (SCS-SA) data. This contributed towards development of the methods for determining the inherent run-off potential of catchment soils.

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LIST OF ABBREVIATIONS

WRC	Water Research Commission
NEMA	National Environmental Management Act
NWA	National Water Act
RQO	Resource Quality Objective
DWA	Department of Water Affairs
ISO	International Organization for Standardization
GIS	Geographic Information System
AMSL	Above Mean Sea Level
DWS	Department of Water and Sanitation
DWAF	Department of Water Affairs and Forestry
CSIR	Council for Scientific and Industrial Research
HGM	Hydrogeomorphic
PES	Present Ecological State
EIS	Ecological Importance and Sensitivity
REC	Recommended Ecological Category
WRCS	Water Resource Classification System
NEC	Nested Ecological Categories
GLV	General waste water Limit Value
SLV	Special waste water Limit Value
EMC	Event Mean Concentration
MAP	Mean Annual Precipitation
CRS	Climate Risk Score
MAR	Mean Annual Run-off
SuDS	Sustainable Drainage Systems
SFR	Stream Flow Reduction
BMP	Best Management Practice
EMP	Environmental Management Plan
AMD	Acid Mine Drainage
ARD	Acid Rock Drainage
ACRU	Agricultural Catchment Research Unit
BSP	Biodiversity Sector Plan
SCS-SA	Soil Conservation Services method for Southern Africa
NBA	National Biodiversity Assessment
FCB	Faecal Coliform Bacteria
EIA	Environmental Impact Assessment

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1 INTRODUCTION

1.1 Purpose of the Technical Manual

This report refines the *Preliminary guideline for the determination of buffer zones for rivers, wetlands and estuaries* (Macfarlane et al., 2014). The Water Research Commission (WRC) project K5/2463 provided an opportunity for testing the preliminary guideline at a series of national training and development workshops. A key recommendation from the workshops was to compile a Technical Manual and a separate Practical Guide. As such, the original guideline developed by Macfarlane et al., (2014) was revised into the Technical Manual and a standalone Practical Guide for determining buffer zones for rivers, wetlands and estuaries. This Technical Manual provides detail on the assessment procedure. It acts as the primary reference point for anyone wishing to determine an appropriate buffer zone around a river, wetland or estuary. The Technical Manual presents the concepts, background and technical aspects of the approach required for determining appropriate buffer zones.

The supporting Practical Guide provides users with the information necessary to determine buffer zones consistently. In addition, a suite of Buffer Zone Tools was developed for determining desktop buffer zones, and buffer zones for rivers, wetlands and estuaries. The Technical Manual therefore needs to be used in conjunction with the Practical Guide and supporting Buffer Zone Tools.

It is envisaged that the Buffer Zone Tools will be the primary products from this project, and that users will use this Technical Manual and accompanying Practical Guide to enhance the application of the above tools. For this reason, a website (https://sites.google.com/site/bufferzonehub/) with the Buffer Zone Tools, additional deliverables of interest, the Mitigation Measures Tool, and data that will be helpful for the buffer zone determining process, has been developed to assist with data distribution.

1.2 What Are Buffer Zones?

Definitions of buffer zones vary and depend on their purpose. Buffer zones have been used in land use planning to protect natural resources and limit the impact of one land use on another. This project specifically looks at aquatic buffer zones, which are typically designed to act as a barrier between human activities and sensitive water resources to protect them from negative impacts. The importance of other functions, particularly the provision of habitat necessary for wetland-dependent species needing both aquatic and terrestrial habitats, is also catered for when establishing final buffer zone requirements. For the purposes of this project, a working definition for buffer zones is:

Buffer zone: A strip of land with a use, function or zoning specifically designed to protect one area of land against impacts from another.

1.3 Why Are Buffer Zones Important?

Buffer zones associated with water resources have been shown to perform a wide range of functions, and on this basis, have been proposed as a standard measure to protect water resources and associated biodiversity. These functions include:

- Maintaining basic aquatic processes.
- Reducing impacts on water resources from upstream activities and adjoining land uses.
- Providing habitat for aquatic and semi-aquatic species.
- Providing habitat for terrestrial species.
- Providing a range of ancillary societal benefits.

A brief description of each of the functions and associated services is outlined in Table 1.

Table 1 – Summary of roles and associated functions provided by buffer zones

Primary Role	Buffer Functions
Maintaining basic aquatic processes, services and values	• **Maintaining channel stability:** Riparian vegetation, particularly root systems, strengthens stream banks and groundcover increases erosion resistance. This improves channel stability and reduces impacts on aquatic systems and downstream users. Stream bank stability is particularly important during flood events, with the amount of erosion being reduced greatly by good vegetation cover along stream banks. Buffer zones can also prevent direct access of livestock to waterways, thereby preventing hoof damage to stream banks and direct input of nutrients, organic matter and pathogens in dung and urine. • **Control of microclimate and water temperature:** Riparian vegetation may affect the microclimate of the stream area nearest the stream bank and reduce water temperatures. This can have serious consequences for aquatic biota as water temperature plays a key role in the life cycles of many species. The occurrence of riparian vegetation also has a significant effect on aquatic plant growth, as light incidence is the main variable controlling productivity in shaded streams. Removing stream bank vegetation is likely to increase primary stream productivity, increase the risk of eutrophication and change the species structure and community composition in the water body. The lower temperature caused by shading also has important consequences for other water quality variables such as the dissolved oxygen concentration, which increases with lower temperatures. • **Flood attenuation:** Well-developed riparian vegetation increases the roughness of stream margins, slowing down flood flows. This may reduce flood damage in downstream areas. Aquatic buffers are therefore a cost-effective alternative to engineered structures to reduce erosion and control flooding, particularly in urban settings. • **Maintenance of general wildlife habitat:** Riparian zones typically have intrinsically high biodiversity value due to their structural diversity and location at an interface between aquatic and terrestrial systems.
Reducing impacts from upstream activities and adjoining land uses	• **Storm water attenuation:** Flooding into the buffer zone increases the area and reduces the velocity of storm flow. Roots, branches and leaves of plants provide direct resistance to water flowing through the buffer, decreasing its velocity and thereby reducing its erosion potential. • **Sediment removal:** Surface roughness provided by vegetation or litter reduces the velocity of overland flow and enhances settling of particles. Buffer zones thus act as effective sediment traps by removing sediment from run-off water from adjoining lands and thus reducing the sediment load of surface waters. • **Removal of toxics:** Buffer zones can remove toxic pollutants such as pesticides, metals and other chemicals that would otherwise affect the quality of water resources and thus their suitability for aquatic biota and human use. • **Nutrient removal:** Riparian vegetation and vegetation in terrestrial buffer zones may significantly lower the level of nutrients (nitrogen and phosphorus) entering a water body, thereby reducing the potential for excessive outbreaks of microalgae that can adversely affect both freshwater and estuarine environments. • **Removal of pathogens:** By slowing faeces-contaminated water, buffer zones encourage deposition of pathogens, which soon die when exposed to elements.

Primary Role	Buffer Functions
Meeting life-need requirements for aquatic and semi-aquatic species	• **Provision of habitat for aquatic species:** Riparian vegetation along stream lines provides food that supports in-stream food chains. Branches and trees falling into the stream also provide vital habitat for some aquatic fauna. • **Provision of habitat for semi-aquatic species:** Many semi-aquatic species rely on terrestrial habitats to recruit juveniles successfully and to maintain optimal adult survival rates. • **Screening of adjacent disturbances:** Anthropogenic disturbances to aquatic and semi-aquatic species may be direct (for example human presence and traffic), or indirect (for example through noise and light). These adversely affect species survival either by disrupting natural wildlife activities, such as feeding, breeding and sleeping, or affecting habitat quality. • **Habitat connectivity:** Buffers along water resources provide potentially useful corridors, thus allowing the connection of breeding, feeding and refuge sites crucial for maintaining the viability of populations of semi-aquatic species.
Providing habitat for terrestrial species	• **Provision of habitat for terrestrial species:** In certain situations, buffers established alongside water resources may be critical for terrestrial species to persist. This is particularly likely in highly developed landscapes where undeveloped buffers may provide the only remaining terrestrial habitat. • **Habitat connectivity:** Buffers along water resources provide potentially useful corridors, allowing the connection of breeding, feeding and refuge sites crucial to maintain the viability of populations of terrestrial species.
Providing ancillary societal benefits	• **Reduces flood risk:** Through increased resistance to flow, riparian areas and buffer zones can increase residence time of floodwaters, reducing flow velocities and thereby reducing flood peaks. This can reduce safety risks to people and property in the downstream catchment. • **Enhances visual quality:** Buffer zones can create visual interest and screen undesirable views, thereby enhancing visual quality, particularly in urban areas. • **Control noise levels:** Wooded buffer zones can reduce noise from roads and other sources to levels that allow normal outdoor activities to occur. • **Improve air quality:** Vegetation in buffer zones can affect local and regional air quality by reducing temperature and removing air pollutants. • **Provides recreational opportunities:** The availability of open space associated with buffer zones provides opportunities for a range of recreational activities. This is particularly important in urban areas where there often are not enough open spaces. • **Economic benefits:** The proximity of residential areas to well-managed buffer zones can lead to increased property values because of perceived aesthetic, recreational and other benefits. Such areas can also offer opportunities for tourism activities and provide a sustainable supply of natural resources for local communities.

1.4 What Buffers Do Not Do

Despite the range of functions potentially provided by buffer zones, **buffer zones are far from addressing all water resource related problems**. Buffers do little to address impacts such as hydrological changes caused by stream flow reduction activities or changes in flow brought about by abstractions or upstream impoundments. Buffer zones are also not appropriate for militating against point-source discharges (such as sewage outflows), which can be managed more effectively by targeting these areas through specific source-directed controls. Contamination or use of groundwater is also not well addressed by buffer zones and requires complementary approaches such as controlling activities in sensitive groundwater zones. The role that buffers can play must therefore be well understood when applying these guidelines. For an overview of typical threats posed to water resources and the role that buffers and other management measures can play in addressing these concerns, refer to Annexure 1.

Despite clear limitations, buffer zones are well-suited for performing functions such as sediment trapping and nutrient retention that can significantly reduce the impact of activities taking place adjacent to water resources. **Buffer zones are therefore proposed as a standard mitigation measure to reduce impacts linked with diffuse storm water run-off from land uses/activities planned adjacent to water resources.** These must, however, be considered in conjunction with other mitigation measures that may be required to address specific impacts for which buffer zones are not well-suited.

Note: Mining is recognised as an activity with potentially high risks to water resources. A number of these risks are not addressed by buffer zones as they focus primarily on mitigating impacts from diffuse source pollutants in surface run-off. For example, buffer zones do not specifically address impacts of mining on groundwater and hillslope hydrological processes. These may be important aspects to consider when establishing final buffer requirements. It is therefore critical that final buffer requirements for mining activities are informed by supplementary geohydrological and hydropedological studies, where necessary.

2 CONCEPTUAL FRAMEWORK FOR DEVELOPING A BUFFER ZONE METHOD

In developing an approach for buffer zone determination, several key decisions were made that informed the development of the method presented in this report. The rationale and consequent assumptions are presented in the section that follow.

2.1 Design Criteria Used to Inform the Development of a Method and Model for Buffer Determination

Based on the review of generic approaches and specific methodologies, a broad set of design criteria was used to guide the development of an appropriate approach. These criteria are listed below and set the goals that informed the design of a conceptual framework and method for buffer zone determination in the South African context.

Levels of expertise: As far as possible, the method should be easy and quick to apply by personnel with little training or experience in ecology or water resource management. Any approach must, however, recognise that a greater level of expertise may be necessary to inform detailed assessments where there is a high risk factor or where there are potentially significant impacts associated with the proposed development at a particular site.

Precautionary principle: Where there is no information or only little information is available to inform the establishment of a buffer zone, a cautious approach, which recognises the potential shortfalls and inaccuracies of the assessment, is recommended. However, in situations where adequate information is available and where buffer zone widths are informed by a sound understanding of requirements, a less conservative approach should be followed. This is consistent with the precautionary principle set out in the National Environmental Management Act (NEMA), which recommends following a risk-averse cautious approach that considers the limits of current knowledge about the consequences of decisions and actions.

Predictability and administration: A level of predictability in model outcomes is preferred across different assessment levels. It is, however, recognised that buffer widths may need to be refined for site-based assessments where additional information is available for buffer determination. There is a need for clear guidelines to ensure that the method can be applied consistently by a range of users.

Data collection and assessment: Buffer width determination should rely as far as possible on existing information or information collected during current aquatic assessments to ensure that additional expenditure necessary to inform buffer determination is kept to a minimum. The approach should therefore use existing methods of assessment as far as possible. Collection of detailed site-specific information should also be the exception rather than the rule. It is, however, recognised that it may be necessary to tailor the level of data collection according to the levels of assessment being undertaken (regional planning through to site-level).

Buffer widths should be tailored according to risk: This criterion recognises the importance of using risk as basis for establishing an appropriate buffer width. Where risk or uncertainty is high, ecologically conservative buffers should be established whereas less conservative buffers are appropriate for low risk situations. Several key risk factors were identified for possible consideration in the approach. These included:

- Risks posed by adjacent land uses or activities.
- The importance and sensitivity of the water resource.
- The conservation status (risk of extinction) of aquatic and semi-aquatic species.
- Characteristics of the buffer affecting the functionality of the buffer.
- Supplementary mitigation measures that may be applied to reduce risks.

2.2 Select an Appropriate Approach for Setting Buffers

The literature review revealed that international methods used to determine required buffer zone widths varied considerably from simple one-size-fits-all approaches to others relying on extensive site-specific information. Three generic approaches were identified in the literature, and are briefly outlined below:

- **Fixed-width:** The fixed-width approach typically applies a standard buffer width to a particular water resource type. In some instances, a generic width is applied regardless of any characteristics of the water resource. However, this approach is more typically applied to a class of wetland or river type, or a specific land use type/activity.
- **Modified fixed-width:** In this approach, a matrix of factors is typically used to categorise wetlands and/land uses with category-specific standard buffer widths applied to the resource. These widths may be modified based on relevant on-site factors where more detailed information is available.
- **Variable-width:** This approach usually requires developing a detailed formula and methodology for considering site-specific factors such as wetland type, adjacent land use, vegetation, soils, wildlife habitats, slope, desired function and other site-specific characteristics to calculate buffer widths.

Each approach has many advantages and disadvantages, but the modified fixed-width approach was identified initially as appropriate in the South African context. This was principally because of the need for a tool that could be applied across different levels (desktop and site-based) while maintaining a level of predictability and consistency between approaches. Although the method outlined in this document was initially developed around a modified fixed-width approach, it has matured into what is essentially a variable-width method. This results from the integration of a range of variables in the Buffer Zone Model to reflect the variability of both risks posed by developments and the inherent variability in climatic, buffer and water resource characteristics. An effort has, however, been made to bring some level of predictability to buffer zone recommendations by incorporating starting risk ratings for different land uses and by defining standard risk-based minimum buffer zone requirements.

2.3 Design an Approach to Cater for the Full Range of Buffer Functions

Buffer zones established around water resources perform a wide range of roles and functions. The importance of each of these roles is likely to be case-dependent, and as such, the approach needs to be flexible so that buffers can be tailored to site-specific requirements. Note that this guideline has not been designed to address all these roles and functions, and is focused specifically on protecting water resources and associated biota. The approach adopted as part of this guideline has therefore been developed to ensure that relevant functions are adequately catered for. These functions include:

- **Maintaining basic aquatic processes, services and values:** As a minimum, this requires that any direct impact to water resources is limited as far as possible. Delineation and protection of water resources, as defined in South African legislation, is regarded as a critical first step to inform the development planning process. The method developed is therefore designed to ensure that such areas are identified, mapped and included within any recommended final buffer area. The need for additional management measures, including potential additional management buffers to safeguard intact riparian habitat, is also addressed.
- **Reducing impacts from adjacent land use activities**: This requires an understanding of specific risks associated with planned land uses/activities and the degree to which buffer zones can address these impacts. Risk assessment is therefore the basis on which buffer zone guidelines have been developed. This includes assessing potential land use impacts, and scientifically understanding the potential effectiveness of buffer zones in performing certain functions in the context of the sensitivity of the receiving environment. The limitations of buffer zones are acknowledged, as is the need to implement supplementary mitigation measures that adequately address potential land use impacts.
- **Meeting life-need requirements for aquatic and semi-aquatic species:** Although there is an apparent widespread application of buffers for biodiversity protection in international literature, it is regarded as an overly simplistic approach for biodiversity protection. What is required, however, is

an appropriate understanding of the habitat and protection requirements necessary to safeguard any important species present. This method has therefore been designed to help ensure that biodiversity values are identified and that appropriate steps are taken to cater for the protection of important species and habitats. This moves beyond the simple concept of buffer zones and considers aspects such as core area requirements, connectivity and management.

Functions not specifically addressed as part of this guideline include reducing impacts from upstream activities, and providing habitat for terrestrial species and ancillary societal benefits. Suggestions how these can be included in an assessment are:

- **Reducing impacts from upstream activities:** Buffer zones are not designed specifically to address catchment impacts. However, retaining and establishing buffer zones (including riparian habitat) can help to enhance reach level water resource functions, such as improved water quality and flood attenuation. The primary emphasis should be on addressing impacts at source through appropriate catchment level interventions.
- **Providing habitat for terrestrial species:** Establishing buffer zones for water resource protection may well contribute to the protection of terrestrial habitat and species that use the habitat within delineated buffer zones. Buffer zones established according to these guidelines do not specifically cater for the protection of terrestrial species or associated habitat. Additional specialist input will therefore be required to ensure that terrestrial conservation requirements are adequately catered for in any land use change applications.
- **Providing ancillary societal benefits:** In many instances, buffer zones can be designed and managed in ways that enhance societal benefits. This could involve manipulating species composition and habitat structure to improve aesthetics or incorporating foot paths and other low-intensity infrastructure to improve amenity values. There are, however, situations where buffer zones may need to be enlarged to cater for specific societal needs. In the case of flood-prone areas, for example, buffer zones may need to be expanded to incorporate areas at high risk of flooding.

2.4 Develop an Approach in the Absence of a Formally Structured Assessment Framework

At the time of developing this guideline, there was no formal structured framework to guide water resource protection and assessment processes. The legislation supporting implementation of buffer zones, though present, is also fragmented and provides little guidance as to when and how this buffer zone guideline should be applied. Without a legislated assessment framework, there is a legitimate concern that these buffer zone guidelines may be advocated or applied without due consideration of the full suite of potential impacts associated with developments and other tools available for water resource protection. In response to this concern, we have expanded the scope of this guideline in several ways:

- Contextualising the use and applicability of buffer zones within a broader suite of management measures to protect water resources.
- Including objective setting as a separate step in the guidelines to ensure that decision-making is informed by sound information with specific outcomes in mind.
- Broadening the risk assessment framework to flag a broad suite of potential impacts rather than simply focusing on those impacts that buffer zones are specifically designed to address.
- Collating information on additional mitigation measures that can be used to address development impacts.

3 OVERVIEW OF THE ASSESSMENT PROCEDURE

The assessment procedure has been structured in an eight-step process as outlined in Figure 2. This provides a broad overview of the process, but is expanded with considerable detail in the chapters that follow. Explicit instructions for populating the Buffer Zone Tools used to determine buffer zone requirements are also provided.

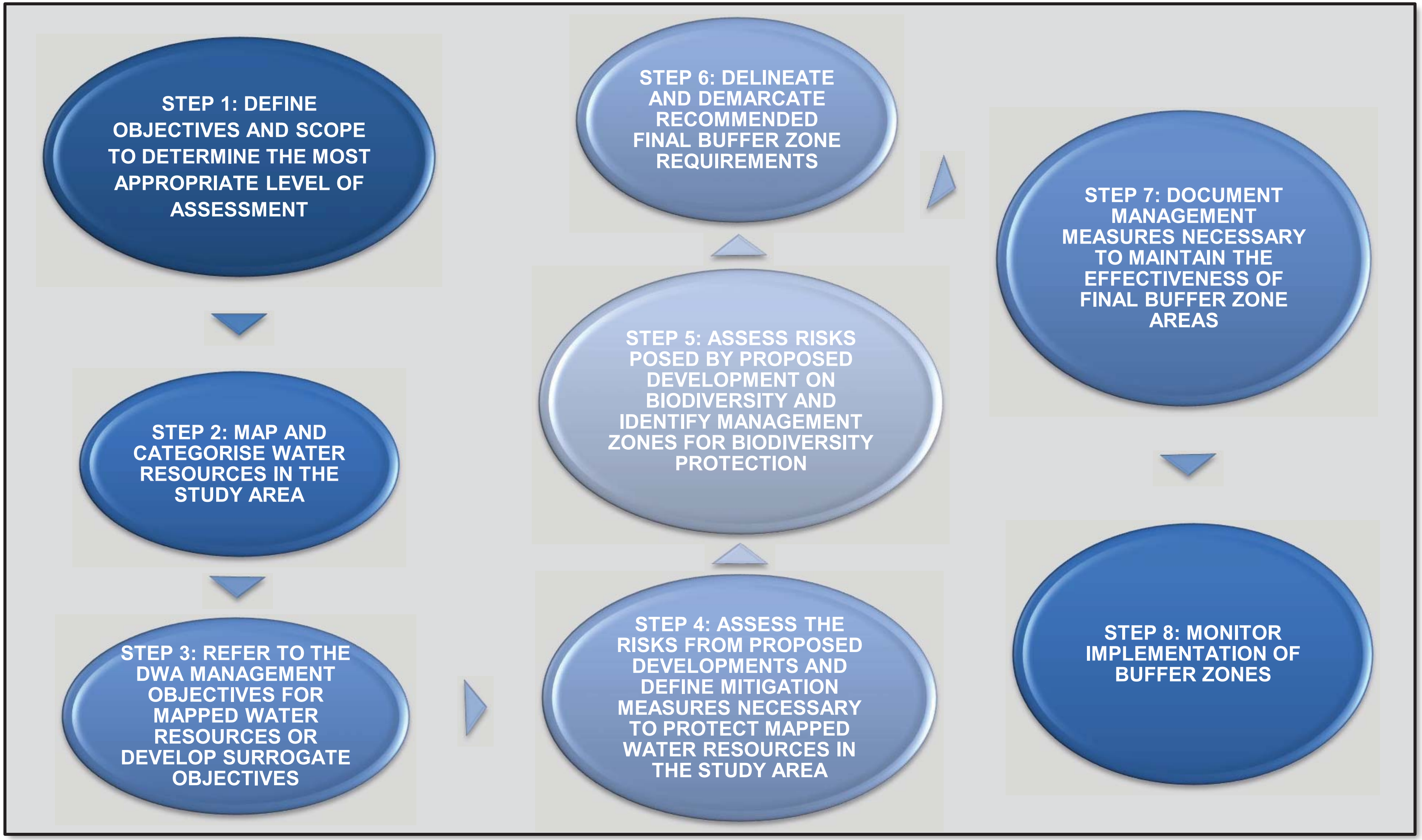

Figure 2 – Overview of the step-wise assessment process for buffer zone determination

4 STEP 1: DEFINE OBJECTIVES AND SCOPE TO DETERMINE THE MOST APPROPRIATE LEVEL OF THE ASSESSMENT

4.1 Define Objectives and Scope of the Assessment

The motivations for assessing potential impacts and establishing buffer zone requirements may be diverse. It is therefore important that the specific objective for the assessment is clearly understood before starting. Some instances in which this is both necessary and appropriate are:

- Flagging areas with potential constraints to development as part of an environmental management framework or biodiversity sector plan.
- Rezoning an area from residential to industrial land use and identifying property-specific limitations to developments within the rezoned areas.
- Assessing potential impacts and identifying appropriate mitigation measures as part of an environmental impact assessment application for a development proposed within 32 m of a wetland.
- Assessing the risks and potential impacts to water resources as part of a licensing process involving impeding or diverting the flow of water in a watercourse [Section 21(c)] or altering the bed, banks, course or characteristics of a watercourse [Section 21(i)] as required by the National Water Act (NWA Act No. 36 of 1998).
- Complying with resource quality objectives (RQOs) where establishing buffer zones have been recommended in line with management objectives for the water resource.
- Applying best practice guidelines as part of an environmental certification scheme (such as ISO 14001) aimed at minimising or reducing potential environmental impacts.

It is also important to clarify the geographical boundaries of the assessment and to consider the resources available to undertake the assessment, as these could affect the level of assessment undertaken. In some instances, the assessment needs to be applied across a large geographic area covering numerous water resource types and potential activities. In other situations, the approach is applied to assess the impacts of a specific development to inform site-based decision-making.

4.2 Determine the Most Appropriate Level of Assessment

Given the range of potential users and applications, two options for buffer zone determination have been developed:

Desktop	Site-based
✓	✓

- **Desktop assessment**: This is designed to identify risks at a desktop level to red-flag land located adjacent to water resources that should potentially be set aside and managed to limit impacts on water resources. The Desktop Buffer Tool provides a range of potential aquatic impact buffer widths including minimum, median and worst-case buffer requirements. These requirements can be tailored further with a basic understanding of the site, but desktop buffer zones should not be used as a basis for authorising developments or activities with a potential impact on water resources as the tool only indicates buffer zone requirements and does not cater for biodiversity considerations or other site-specific factors.
- **Site-based assessment**: This assessment is designed for detailed planning and includes a more rigorous assessment of risks as well as incorporating site-specific factors that can affect buffer requirements. Separate Buffer Zone Tools have been developed for rivers, wetlands and estuaries for detailed development planning while also providing an appropriate level of information for authorisation purposes.

Buffer zone requirements may be assessed at either of these levels and should be informed by:

- The intended purpose of buffer zone determination.
- The approach to be followed.
- The level of expertise available to undertake the assessment.
- The time and cost required to undertake the assessment.

Table 2 provides an overview of the different assessment levels and should be used to select an appropriate approach and associated Buffer Zone Tool.

Table 2 – Summary of the different assessment levels for buffer zone determination

Level of assessment	Desktop	Site-based
Purpose	To identify areas of potential development constraints at a regional scale or to flag potential buffer zone requirements during initial site-level planning. **Priority users**: National, provincial and municipal planners, owners and developers.	Establish buffer zone requirements to inform detailed development planning at a site-level. **Priority users:** Developers and environmental impact assessment consultants.
Approach followed	Potential buffer zone requirements are determined by accounting for generic risks associated with different land use activities. A range of potential aquatic impact buffer widths including minimum, median and worst-case buffer requirements are provided. These requirements can be tailored further with a basic understanding of site attributes. Biodiversity aspects are not considered.	Buffer zone requirements are based on detailed site information. This includes local climatic conditions, risks associated with the specific land use activity, the sensitivity of the receiving environment, and local buffer attributes. Specific consideration is also given to the maintenance of biodiversity attributes.
Level of expertise	Basic understanding of water resources and buffer zone guidelines.	Specialist aquatic ecologist. May need to supplement with further studies from a biodiversity specialist if important biota is present.
Time and cost	Rapid desktop assessment, with very low cost implications.	Comprehensive site assessment with moderate cost implications. Costs will increase if a biodiversity assessment is required.

To help guide users through the steps, a simple tab has been included at the start of each step to indicate whether the step is relevant for the level of assessment. Where not required, the assessor can simply move to the next step.

Buffer Zone Tools:

- For a desktop assessment, use the Desktop Buffer Zone Tool.
- For site-based assessments, select the appropriate site-based Buffer Zone Tool for the type of water resource under investigation (wetland, river or estuary).

5 STEP 2: MAP AND CATEGORISE WATER RESOURCES IN THE STUDY AREA

5.1 Map Water Resource Boundaries

Desktop	Site-based
✓	✓

After establishing the scope and appropriate level of the assessment, the assessor must generate a map delineating the boundaries of the water resources potentially affected by proposed developments within the study area[1]. A geographic information system (GIS) is particularly useful during the mapping process. A GIS provides very useful spatial information to inform the assessment, especially where buffers need to be applied across a broad spatial scale. Where these facilities are not available, orthophotos (1:10 000) or Google Earth™ maps may be used to inform site assessments.

To ensure that mapping is undertaken in a consistent manner, water resources have been defined according to current South African legal definitions and best available science. Definitions for relevant water resource types[2] and associated elements are briefly described:

- **Estuary**: In line with the National Wetland Classification System (SANBI, 2009) and in terms of the recently enacted Integrated Coastal Management Act (Act No. 24 of 2008), an "*estuary*" is defined as "*a body of surface water – (a) that is part of a water course that is permanently or periodically open to the sea; (b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the water course is open to the sea; or (c) in respect of which the salinity is measurably higher as a result of the influence of the sea*"[3]. This is in line with the following definitions for the boundaries of an estuary contained in the Resource Directed Measures Manual for Estuaries (DWAF, 2008):
    - **Downstream boundary:** The estuary mouth, or where the mouth is closed, the middle of the sand berm between the open water and the sea.
    - **Upstream boundary:** The extent of tidal influence (the point up to where tidal variation in water levels can still be detected), or the extent of saline intrusion, or the extent of back-flooding during the closed mouth state, whichever is furthest upstream.
    - **Lateral boundaries:** The 5 m above mean sea level (AMSL) contour along each bank. From consultations during the development of a National Wetland Classification System (SANBI, 2009), the above-mentioned definitions are regarded as more appropriate than those contained in the NWA (Act No. 36 of 1998), which are based on the more dated definition, whereby saline intrusion was the sole criterion for determining the upstream boundary of an estuary[4].
- **Rivers and streams**: This type of water resource is described as a "*channel*" (river, including the banks) in the National Wetland Classification System (SANBI, 2009). This is defined as *"an open conduit with clearly defined margins that (i) continuously or periodically contains flowing water, or (ii) forms a connecting link between two water bodies. Dominant water sources include concentrated surface flow from upstream channels and tributaries, diffuse surface flow or interflow, and/or groundwater flow. Water moves through the system as concentrated flow and usually exits as such but can exit as diffuse surface flow because of a sudden change in gradient. Unidirectional channel-contained horizontal flow characterises the hydrodynamic nature of these units."*

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[1] Where a water use licence is being applied for, all wetlands within 500 m of the proposed development should ideally be mapped.

[2] According to the definitions in the National Water Act (Act No. 36 of 1998), "water resource" includes a watercourse, surface water, estuary, or aquifer.

[3] Historically, estuarine systems that are no longer connected to the sea (they are permanently closed) are not considered to be estuarine systems, even though they often retain the saline character and much of the fauna associated with estuaries, such as many of the "coastal lakes" in South Africa. These aquatic ecosystems are, rather, considered to be inland systems because they do not have an *existing* permanent or periodic connection to the sea.

[4] According to the National Water Act (Act No. 36 of 1998), an "*estuary"* is defined as "*a partially or fully enclosed water body – (a) that is open to the sea permanently or periodically; and (b) within which the seawater can be diluted, to an extent that is measurable, with freshwater drained from land*".

According to the classification system, channels generally refer to rivers or streams (including those that have been canalised) subject to concentrated flow on a continuous basis or periodically during flooding. This definition is consistent with NWA (Act No. 36 of 1998) that refers to (i) a river or spring and (ii) a natural channel where water flows regularly or intermittently within the definition of a water resource. Because of the erosive forces associated with concentrated flow, characteristically channels have relatively obvious active channel[5] banks that can be identified and delineated.

- Wetland: This means "*land which is transitional between a terrestrial and aquatic system 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*". (NWA (Act No. 36 of 1998)).

Note that "riparian habitat" may be associated with either of these systems. The Department of Water and Sanitation (DWS) regards it as part of the water resource and "regulated area". "*Riparian habitat"* is defined in the NWA (Act No. 36 of 1998) as *"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 land areas."* Areas of riparian habitat that are saturated or flooded for prolonged periods would be considered "wetlands" (in terms of NWA) and should be mapped as such. Some riparian habitats, however, are not "wetlands" (where characteristic riparian trees have very deep roots drawing water from many metres below the surface). These areas do, however, provide a range of important services that maintain basic aquatic processes, services and values requiring protection. Where present, the riparian habitat boundary should also be delineated clearly. Figure 3 and Figure 4 show riparian habitats associated with two different river systems.

Figure 3: Narrow riparian zone dominated by grasses and small shrubs along a stream line in the KwaZulu-Natal Midlands

Figure 4: Large trees occupying a broader riparian zone along a river in the lowveld of Mpumalanga

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[5] According to the National Wetland Classification System (SANBI, 2009), active channel is defined as "*a channel that is inundated at sufficiently regular intervals to maintain channel form and keep the channel free of established terrestrial vegetation. These channels are typically filled to capacity during bank full discharge (i.e. during the annual flood, except for intermittent rivers that do not flood annually). [NOTE: Mid-channel bars (associated with braided river systems) and side bars (associated with meandering river systems) are unvegetated, transient features that are considered to be part of the active channel.]*".

A useful description and illustration of the differences between the active channel and riparian zone of a river are included in Box 7 of the user manual for the classification system for wetlands and other aquatic ecosystems in South Africa (Ollis et al., 2013).

Mapping requirements are tailored according to the level of assessment being undertaken. For the desktop assessment, water resources are mapped using available data, which is often low resolution. Where site-based assessments are required, accurate mapping of water resources is an essential first step in the assessment process. Guidelines for minimum mapping requirements for different assessment levels are detailed in Table 3. It is important to note that although minimum mapping requirements are indicated, the best available information for the area under investigation should be used. The approach used to delineate the water resource should be documented as part of the specialist report.

Table 3 – Minimum requirements for mapping the boundaries of water resources

Level of Assessment	Boundary Line	Minimum Mapping Required
Estuaries		
Desktop	5 m AMSL line	Use 5 m AMSL line available for 299 estuarine systems along the South African coastline (CSIR, 2009).
Site-based		5 m AMSL line verified and refined based on more detailed topographical information if available.
Rivers		
Desktop	Edge of riparian habitat	Estimate of riparian zone width based on maximum of 1:100 flood line or relevant alluvial vegetation types included in the vegetation map of South Africa (Mucina and Rutherford, 2006). Where available, aerial photography can be used to map the extent of the active channel and any associated riparian areas at a desktop level more accurately.
Site-based		Site-based delineation of active channel and associated riparian zone based on the Department of Water Affairs and Forestry (DWAF) delineation manual (DWAF, 2008).
Wetlands		
Desktop	Edge of temporary zone	Wetlands included in the most up-to-date National Wetlands Map. This is typically available from Biodiversity GIS website (http://bgis.sanbi.org). Where available, wetlands mapped at a finer catchment scale (1:10 000) or at a desktop level from aerial photography should be used.
Site-based		Site-based delineation of wetland boundary based on DWAF delineation manual (DWAF, 2008).

5.2 Map the Line from Which Aquatic Impact Buffer Zones Will Be Delineated

Desktop	Site-based
✓	✓

Although the edge of the water resource (described above) must be delineated accurately, this line is only used as the starting point for delineating aquatic impact buffer zones in the case of wetland ecosystems. In the case of rivers and streams (where the extent of the water resource may also include terrestrial habitat features), an alternative starting line from which buffer zones are delineated needs to be clearly defined and delineated. A summary of the delineation requirements for each water resource type, depending on the level of assessment being undertaken, is presented in Table 4. Further details on the approach to be followed in the case of rivers and estuaries are provided in the sections that follow.

Table 4 – Minimum requirements for mapping the line from which aquatic impact buffers will be determined

Level of Assessment	Boundary Line	Minimum Mapping Required
Estuaries		
Desktop	Upper edge of the supratidal zone	Use the broader boundary of either (i) the open water boundary area available for 299 estuarine systems along the South African coastline (CSIR, 2012) or (ii) South African Vegetation Map (water bodies and estuarine vegetation).
Site-based		Site-based delineation using GPS or delineation from 1:10 000 orthophotos or other available imagery.
Rivers		
Desktop	Edge of active channel or the edge of the macro channel floor	Use river lines and areas of open water areas obtained from 1:50 000 topo-cadastral maps for regional scale assessments. Desktop mapping of channel features may also be undertaken from available aerial photography.
Site-based		Site-based delineation of the outer edge of the active channel or macro channel floor.
Wetlands		
Desktop	Edge of temporary zone	Wetland boundary delineated according to the guidance provided in Table 3.
Site-based		

5.2.1 Estuaries

In the case of estuaries, a zone of terrestrial habitat is typically included within the delineated water resource boundary. In the case of steep-sided valleys, this zone may be limited, but in regions of low topographic relief, large areas of terrestrial vegetation may be included within the delineated estuary (5 m AMSL line). To be consistent with other water resource types, the aquatic impact buffer zone should therefore be measured from a comparative point. This is taken as the upper edge of the supratidal zone, defined as the area that is periodically inundated by tidal or flood waters and within which the sub-surface water is saline and generally between 2.0 m and 3.5 m AMSL (SANBI, 2009).

Note: In estuaries, it is also important to ensure that any freshwater wetland areas that extend beyond the supratidal zone are also mapped and included as part of the assessment. This is also relevant to estuaries dominated by freshwater inflows that therefore do not have the salt-tolerant plant species typical of most supratidal zones. In such instances, users may need to apply the Estuary Buffer Zone Tool to the main estuary body (and associated fringing wetland habitat) and the Wetland Buffer Zone Tool to fringing wetlands that are largely disconnected from tidal influence.

5.2.2 Rivers

In the case of rivers and streams, the extent of any riparian habitat is included as part of the delineated water resource boundary and needs to be protected and managed appropriately. It is important to recognise that these areas provide a wide range of important functions, and also play an important role in assimilating diffuse source pollutants emanating from adjacent land use activities. As such, riparian habitat is treated as part of the aquatic impact buffer zone as illustrated in Figure 5. Should the riparian zone extend beyond the aquatic impact buffer zone, final buffer zone requirements would need to accommodate the full extent of the riparian zone and any additional requirements that may apply to managing this area (riparian management zone).

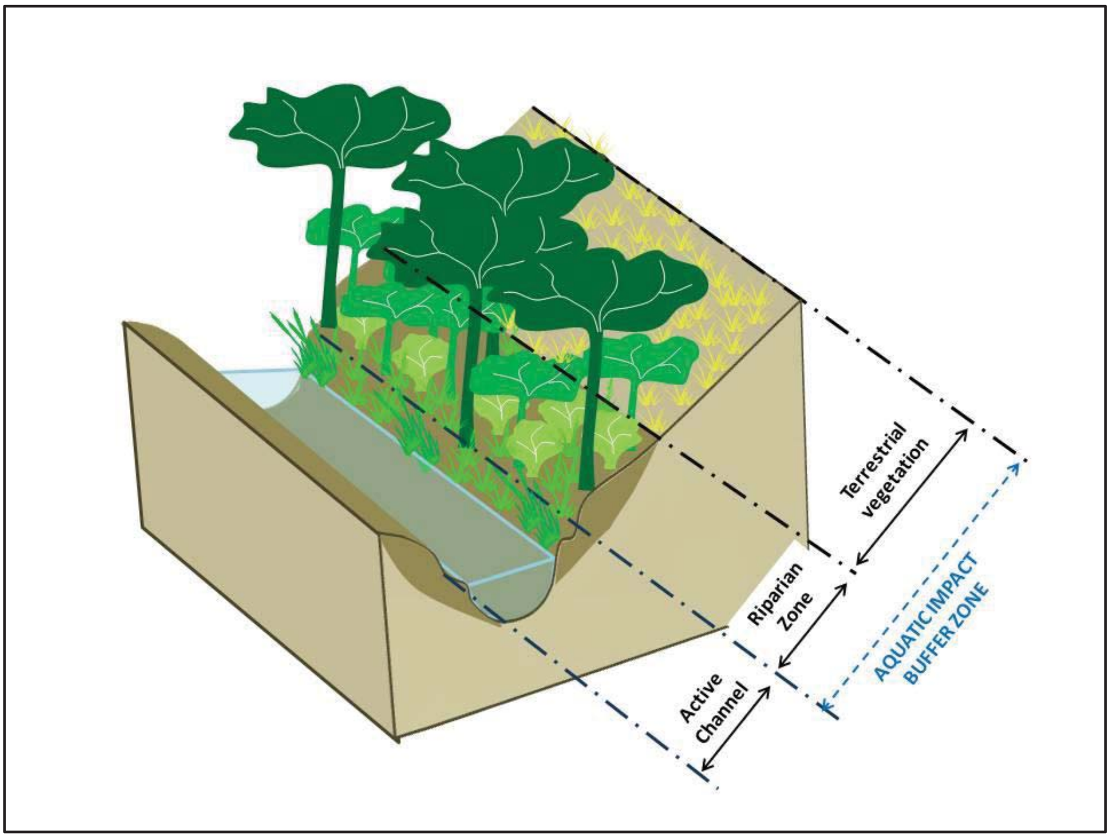

Figure 5 – Schematic diagram indicating the boundary of active channel and riparian habitat, and the areas potentially included in an aquatic impact buffer zone

The edge of the "active channel" is therefore used as the starting point from where aquatic impact buffer zones are delineated. According to the National Wetland Classification System (SANBI, 2009), "active channel" is defined as "*a channel that is inundated at sufficiently regular intervals to maintain channel form and keep the channel free of established terrestrial vegetation*". These channels are typically filled to capacity during bank full discharge (namely, during the annual flood, except for intermittent rivers that do not flood annually)[6]. A useful description and illustration of the differences between the active channel and riparian zone of a river are included in Box 7 of the user manual for the classification system for wetlands and other aquatic ecosystems in South Africa (Ollis et al., 2013).

The possibility of channel migration in a river also needs to be considered to ensure that the buffer zone continues to function over the long term and that risks associated with migration are considered adequately. Channel migration can occur gradually, as a river erodes one bank and deposits sediment along the other. However, it can also occur as an abrupt shift of the channel to a new location, called an avulsion, which may happen during a single flood event. The risk of channel migration is typically low in the upper reaches of a river but can become a common feature in the middle to lower reaches of rivers. These risks are typically highest in areas characterised by naturally intense rainfall events or erodible soils and in urban catchments with elevated flood peaks.

Where it is necessary to account for channel migration, the starting line for delineating aquatic impact buffer zones must be taken from the outer edge of the area affected by the possible migration of the active channel. Since channel migration typically takes place within the floor of the macro channel, this zone, referred to as the "macro channel floor" must be delineated and used as the preferred starting point for buffer zone determination. Further details on the typical difference in river channel features, together with schematic diagrams to assist in delineation, are provided in Table 5.

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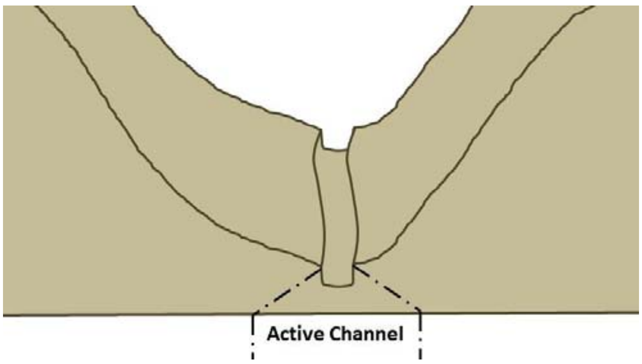
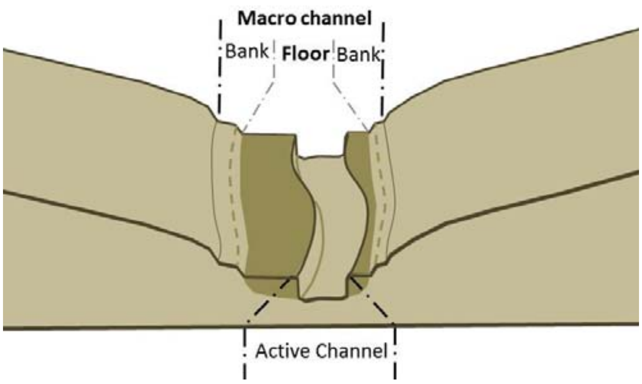
6 Note: Mid-channel bars (associated with braided river systems) and side bars (associated with meandering river systems) are unvegetated, transient features that are considered to be part of the active channel (Ollis et al., 2013).

Table 5 – Guidance for delineating starting line to map aquatic impact buffer zones in river reaches

	Channel Cross-Section	River Channel Features
Upper Reaches		**Typical Characteristics** • Entrenched/confined channels[7] • Steep/V-shaped valley • Narrow/shallow channel • Steep longitudinal profiles • Dominated by vertical erosion • Boulders and stones eroded *in situ* • Biotopes present usually include waterfalls, cascades and pool-rapid sequences • Floodplain absent • Riparian zone often absent **Guidance for Buffer Zone Delineation** • Buffer delineated from edge of active channel • Buffer delineated from edge of active channel

	Channel Cross-Section	River Channel Features
Middle Reaches		**Typical Characteristics** • Moderately confined channels • Wider and deeper channel • Moderately steep longitudinal profiles • Narrow channel within a broader valley floor characterised by alluvial deposition • Vertical and lateral erosion leading to migration of active channel • Biotopes present usually include cascades, pool-rapid and pool-riffle sequences • Very limited to no floodplain development • Riparian zone often present and may extend up macro channel banks

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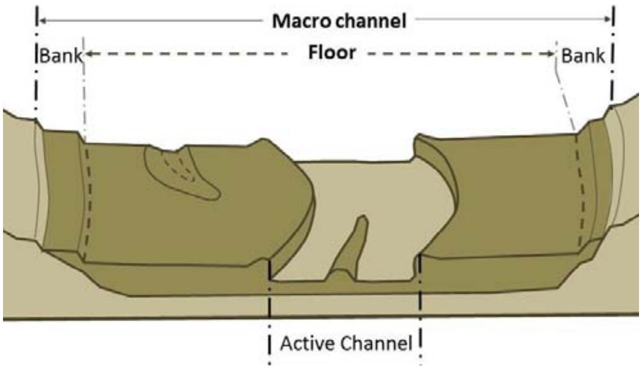
[7] Degrees of channel confinement (Rowntree, in prep.):
Entrenched: the active channel is confined by steep banks and/or terraces.
Confined: the channel is laterally confined by steep, often V-shaped, valley-side walls (and/or with the presence of bedrock controls such as resistant geology).
Moderately confined: channel course is determined by macro-scale features, with some lateral channel migration possible.
Non-confined: the channel is free to migrate laterally over the valley floor/floodplain

	Channel Cross-Section	River Channel Features
		Guidance for buffer zone delineation
		• Buffer delineated from edge of macro channel floor
Lower Reaches		**Typical Characteristics**
		• Non-confined channels • Wide shallow valleys with clear floodplains and meanders or broad braided channels • Dominated by lateral erosion processes with a highly dynamic active channel(s) (old meaner cut-offs may be evident) • Low gradient and high levels of alluvium • Riparian zone typically present and may extend some distance up macro channel banks where regular flooding occurs
		Guidance for Buffer Zone Delineation
		• Buffer delineated from edge of macro channel floor

A note on ephemeral drainage features: These guidelines are not specifically designed to cater for ephemeral drainage features that lack active channel characteristics. As such, it is essential to differentiate between a stream (albeit ephemeral) with a clear “active channel” and ephemeral drainage features that lack such characteristics.

This differentiation should be based on the classification of river channels outlined in the DWAF delineation guideline for wetlands and riparian areas (DWAF, 2005). The channel network is divided into three types of channels, which are referred to as A Section, B Section or C Section channels as shown in Figure 6. The essential difference between the A, B and C Sections is their position relative to the zone of saturation in the riparian area. Figure 6 shows two levels of the water table; the one marked “wet” depicts the highest level that the water table would reach in a wet period when recharge of the zone of saturation has taken place. The one marked “dry” depicts the level of the water table at its lowest after a dry period. The zone of saturation must be in contact with the channel network for base flow to take place at any point in the channel. The classification separates the channel sections that do not have base flow (A Sections) from those that sometimes have base flow (B Sections) and those that always have base flow (C Sections).

A Section channels are regarded as the least sensitive from a water yield and contaminant risk perspective as they typically only carry water after storm events. Therefore, while aquatic impact buffers cannot be accurately determined for A Section channels, it is recommended that minimum buffer zone requirements for the relevant change in land use/activity are applied as far as possible. (Minimum buffer requirements are discussed in detail in Section 7.11.) The implementation of minimum buffer requirements for these least sensitive channels is considered an appropriate practical measure to limit the risk of diffuse source pollutants entering such sections. There may, however, be circumstances where application of even smaller buffer zones may be appropriate. An example is where a forestry plantation is established in steep topography with a dense network of A Section channels. Under such a scenario, it may not be feasible to delineate and buffer all such features as it may undermine the viability of the operation. In such instances, an appropriate justification will need to be provided for impinging on such areas.

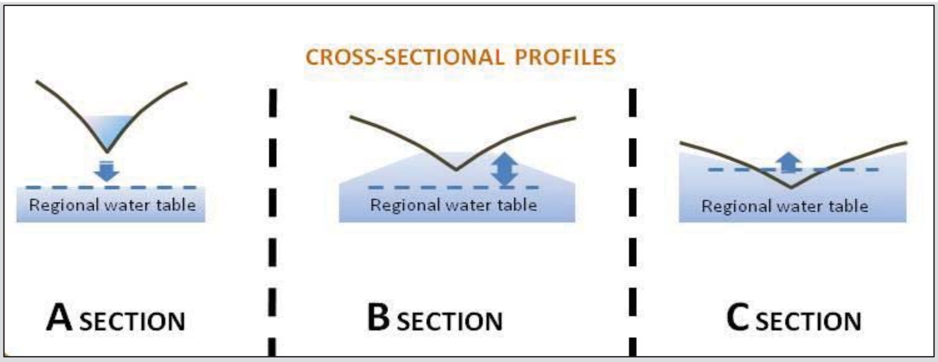


Figure 6 – Classification of river channels (Adapted from DWAF, 2005)

5.2.3 Wetlands

Although some arguments have been made that temporary zones around the periphery of a wetland provide similar functions to a riparian habitat and should therefore be treated in the same way, there has not been widespread support for such an approach. The aquatic impact buffer zone is therefore delineated from the edge of the temporary zone or wetland boundary in the case of wetland systems.

5.3 Identify Water Resource Type

Desktop	Site-based
	✓

Once water resources have been mapped, they should be fully identified in line with the level of assessment undertaken. Hydro-geomorphological (HGM) classification systems have been developed to categorise wetlands, estuaries and rivers into appropriate types. For the purposes of this assessment, the refined National Wetland Classification System for South Africa is recommended (SANBI, 2009; Ollis et al*.,* 2013). Although classification is not necessary, classification of each water resource to Level 4 (Hydrogeomorphic unit) is recommended for site-based assessments.

A breakdown of the classification structure for each water resource type is provided in Table 6 to Table 8. For further details on the definitions of water resource types and for guidance in applying the classification system, users are encouraged to obtain a copy of the classification document and associated user manuals.

Table 6 – Proposed classification system for estuaries (SANBI, 2009)

Level 2: Regional Setting	Level 3: Subsystem	Level 4: HGM Unit
Biogeographic Zones	***Periodicity of Connection***	***Landform and Hydrodynamics***
Cool Temperate Zone **Warm Temperate Zone** **Subtropical Zone**	Permanently open	Estuarine bay
		Estuarine lake
		Open estuary
		River mouth
	Temporarily open/closed	Estuarine lake
		Closed estuary
		River mouth

Table 7 – Proposed classification system for rivers (adapted from SANBI, 2009; Ollis et al., 2013)

Level 3: HGM Type	**Level 4: HGM Unit**
HGM Type	***Longitudinal Zonation/Landform***
A	**B**
River	Mountain headwater stream
	Mountain stream
	Transitional
	Upper foothill
	Lower foothill
	Lowland river
	Rejuvenated bedrock fall
	Rejuvenated foothill
	Upland floodplain

Table 8 – Proposed classification system for inland wetlands (adapted from SANBI, 2009; Ollis et al., 2013)

Level 3: Landscape Unit	**Level 4: Hydrogeomorphic (HGM) Unit**		
Landscape Setting	***HGM Type***	***Longitudinal Zonation/ Landform***	***Drainage – Outflow***
	A	**B**	**C**
Slope	Seep	[not applicable]	With channelled outflow
			Without channelled outflow
	Depression	[not applicable]	Exorheic
			Endorheic
			Dammed
Valley Floor	Channelled valley bottom wetland	Valley bottom depression	[not applicable]
		Valley bottom flat	[not applicable]
	Unchannelled valley bottom wetland	Valley bottom depression	[not applicable]
		Valley bottom flat	[not applicable]
	Floodplain	Floodplain depression	[not applicable]
		Floodplain flat	[not applicable]
	Depression	[not applicable]	Exorheic
			Endorheic
			Dammed
	Valley head seep	[not applicable]	[not applicable]

Level 3: Landscape Unit	Level 4: Hydrogeomorphic (HGM) Unit		
Landscape Setting	***HGM Type***	***Longitudinal Zonation/ Landform***	***Drainage – Outflow***
	A	**B**	**C**
PLAIN	Floodplain wetland	Floodplain depression	[not applicable]
		Floodplain flat	[not applicable]
	Unchannelled valley bottom wetland	Valley bottom depression	[not applicable]
		Valley bottom flat	[not applicable]
	Depression	[not applicable]	Exorheic
			Endorheic
	Wetland flat	[not applicable]	[not applicable]
Bench (Hilltop/ Saddle/Shelf)	Depression	[not applicable]	Exorheic
			Endorheic
	Wetland flat	[not applicable]	[not applicable]

Site-Based Buffer Zone Tools:

- Clarify the approach used to delineate the water resources in the study together with the water resource type based on drop-down lists provided.

6 STEP 3: REFER TO THE DWS MANAGEMENT OBJECTIVES FOR MAPPED WATER RESOURCES OR DEVELOP SURROGATE OBJECTIVES

Understanding the rationale and objective for resource protection is a key step in informing management and protection requirements for water resources. Although not specifically required for establishing buffer zone requirements, such objectives effectively provide the vision for water resource management and inform decision-making, including water resource mitigation requirements. Management objectives is routinely established as part of the RQO approach aligned with the water resource classification of the resource, which is the responsibility of the DWS.

Where neither the RQO nor the reserve has been established, the assessor may require an investigation to help set management objectives for the water resources under consideration. These management objectives will not have the same validity as the DWS RQOs because the process in this determination has less stakeholder inclusion.

The level of assessment required for a particular site is typically determined by DWS based on a number of criteria, including:

- Type of proposed development (abstraction, in-stream dam, off-channel dam, forestry, etc.).
- Anticipated impact of the proposed development.
- Ecological importance and sensitivity of the water resource.
- Degree to which the catchment is already used.
- Regulated systems.
- Existing developments.
- Socio-economic importance.

In the absence of DWS providing appropriate guidance (for example, in the case of small streams or wetlands), it may however be necessary for provincial or local authorities to evaluate development applications and advise on the level of specialist investigations required through a similar screening process.

Once the appropriate level of assessment has been defined, it will guide the level of data collection required to set the management objective for the water resource under consideration. In the absence of classification, this requires an assessment of present ecological state (PES), ecological importance and sensitivity (EIS) and social importance. To do this, it is recommended to follow a process similar to the current accepted reserve process to define surrogate management objectives to inform the need for mitigation measures, including aquatic buffer zones.

It is however worth noting that where impacts are likely to be low, it may be appropriate to simply set a management objective to "maintain" the *status quo*. This ensures that existing impacts are managed to a certain level without forcing applicants to undertake extensive surveys to establish whether improvement in water resource quality is required. This would also move away from an approach in which the environment may be given precedence – by setting a management objective to "improve" without considering the impacts that such a decision would have on current users of the water resource.

6.1 Determine the PES and Anticipated Trajectory of Water Resource Change

Desktop	Site-based
	✓

The PES refers to the current state or condition of the water resource in terms of all its characteristics and reflects the change from its reference condition. This is expressed in terms of its biophysical components (characteristics) including:

- Drivers (physico-chemical, geomorphology, hydrology) providing a particular habitat template.
- Biological responses (for example, fish, riparian vegetation, aquatic invertebrates and diatoms).

Ecological categories that can be defined for each of these components range from A to F where A is the unmodified state and F is the critically modified state (Table 9). The scale represents a continuum as illustrated in Figure 7 – the boundaries are notional.

Table 9 – Generic ecological categories for ecostatus components (modified from Kleynhans, 1996; Kleynhans, 1999)

Ecological Category	Description	Score (% of Total)
A	Unmodified, natural.	90-100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-89
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39
F	Critically/extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

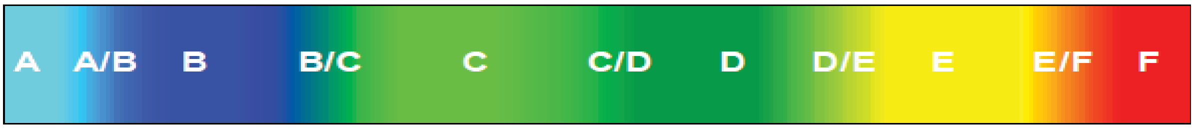


Figure 7 – Illustration of the distribution of ecological categories on a continuum

The so-called ecostatus (integrated state) is regarded as the totality of the features and characteristics of a water resource affecting its ability to support natural fauna and flora (Table 10). The state also has an indirect link to the capacity of the system to provide a variety of ecosystem goods and services. The components selected to determine the ecostatus are dependent on the water resource type and the level of assessment undertaken.

Table 10 – Illustration of the summary of an ecostatus assessment for a river system

Driver Component	Component Ecological Categories
Hydrology	E
Geomorphology	E
Water quality	B/C
Response Components	**Component Ecological Categories**
Fish	C
Aquatic invertebrates	D
In-stream	C/D
Riparian vegetation	D
Ecostatus	D

A range of tools has been developed to determine the present state of different water resources and associated components at a site or reach level. These tools should be applied as directed for site-based assessments. Where a PES determination is required, guidance from DWS should be obtained regarding the level of detail required and relevant assessment methods[8].

Trajectory of change is relevant because it can be used to understand how the current PES is likely to change and help to understand what may be attainable as a future management class. For example, a largely natural wetland (B Category) may be in a predominantly undeveloped catchment with a new development planned adjacent to this water resource. Recent authorisations may however have been given to develop much of the upper catchment to residential housing, which will substantially impact on the hydrology of the system in the near future. Setting a local management objective may therefore need to reflect a lowered management category considering anticipated future impacts.

6.2 Determine the Importance and Sensitivity of the Water Resources

Desktop	Site-based
	✓

Understanding the importance and sensitivity of the water resource in ecological, social and economic terms helps to highlight functions that need to be maintained or enhanced. Where importance is regarded as high, this may provide an appropriate motivation to improve water resource management, whereas simply maintaining the *status quo* may be acceptable where importance is moderate to low. To determine the overall importance and sensitivity of a water resource, both the ecological and social importance should be considered. The next section provides guidance as to how this assessment should be undertaken.

6.2.1 Assess EIS

Ecological importance of a water resource is an expression of its importance to the maintenance of ecological diversity and functioning on local and wider spatial scales. Ecological sensitivity (or fragility) refers to the system's ability to tolerate disturbance and its capacity to recover from disturbance once it has occurred (resilience).

When determining EIS, an ecological specialist typically considers the following ecological aspects:

- The presence of rare and endangered species, unique species (such as endemic or isolated populations) and communities, intolerant species and species diversity.
- Habitat diversity, including specific habitat types such as sites with a high diversity of habitat types (for example pools, riffles, runs, rapids, waterfalls and riparian forests).
- The importance of the particular resource unit (for example, river or reach of river) in providing connectivity between different sections of the whole water resource (whether it provides a migration route or corridor for species).
- The presence of conservation areas or relatively natural areas.
- The sensitivity (or fragility) of the system and its resilience (the ability to recover following disturbance of the system) to environmental changes is also considered. Consideration of both the biotic and abiotic components is included here.

As with PES, desktop EIS scores are available for some resources and may be used in some instances (such as desktop assessments) to obtain an indication of ecological importance. However, in most cases it is anticipated that site-specific information will need to be collected to assess the importance of the particular water resource under consideration. DWS have developed several tools that should be selected according to the level of assessment required and the type of water resource being assessed.

Table 11 provides a breakdown of the EIS categories typically applied.

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[8] It is worth noting that a desktop assessment of PES is available for all estuaries from the NBA (Van Niekerk and Turpie, 2012) and is auto-populated in the Estuary Buffer Zone Tool. This status may need to be checked and updated for site-level assessments but provides a useful starting point for assessment purposes.

Table 11 – Generic EIS categories

EIS Category	Description
Low/marginal	Not ecologically important and sensitive at any scale. Biodiversity ubiquitous and not sensitive to flow and habitat modifications (Wetlands: play an insignificant role in moderating water quality and quantity.)
Moderate	Ecologically important and sensitive on provincial/local scale. Biodiversity not usually sensitive to flow and habitat modifications. (Wetlands: play a small role in moderating water quantity and quality.)
High	Ecologically important and sensitive on a regional scale. Biodiversity may be sensitive to flow and habitat modifications. (Wetlands: play a role in moderating water quality and quantity.)
Very high	Ecologically important and sensitive on a national (or even international) level. Biodiversity usually very sensitive to flow and habitat modifications. (Wetlands: play a major role in moderating water quantity and quality.)

An importance rating/index for all South African estuaries is available from Turpie and Clark (2007). This index rates the importance of an estuary for maintaining biological and ecological diversity and functioning on a national scale. Importance of the estuary and the PES are used to set the recommended ecological category (REC). The estuary importance score considers size, the rarity of the estuary type within its biographical zone, habitat and biodiversity of the estuary. Biodiversity importance is based on assessing the importance of the estuary for plants, invertebrates, fish and birds. All scores are presented on a scale of 0 (totally unimportant) to 100 (critically important) (Annexure 3).

6.2.2 Assess social importance

Social importance reflects the dependency of people on a healthy functional water resource and how people value the resource. It considers the economic, cultural and tourism potential of the water resource. Such an assessment should ideally be undertaken with input from a social specialist and within a similar framework as ecological importance. In many instances, a course indication of social importance can be obtained by using existing tools to help assess the provisioning and cultural services provided by water resources. Aspects included in the assessment of social importance of the water resource are typically:

- The extent to which people are dependent on its natural ecological functions for basic human needs (sole source of supply).
- Dependence on the natural ecological functions for subsistence agriculture or aquaculture.
- Use for recreation.
- Historical and archaeological value.
- Importance in rituals and rites of passage.
- Sacred or special places (for example, where spirits live).
- The use of aquatic plants (for example, for grazing, building or traditional medicine).
- The intrinsic and aesthetic value for those who live in the catchment, or who visit it.

Guidance for undertaking this assessment can be obtained from DWS, who are responsible for developing appropriate tools for different water resources. Although some element of subjectivity is inevitable in assessments such as these, the results are intended to be as objective as possible and a reflection of the relative importance.

6.3 Determine the Management Objectives for Water Resources

The process required for determining appropriate management objectives is dependent on whether the Water Resource Classification System (WRCS) has been applied and if RQOs have been determined. Guidance for setting appropriate management objectives with and without classification is described in the sub-sections that follow.

Desktop	Site-based
	✓

6.3.1 With classification

Where the WRCS has been applied and especially where RQOs have been set, then both ecological and user requirements have been considered and a management class and associated nested ecological categories (NECs) have been agreed, based on due consideration of relevant management implications. In this case, the management objective is determined simply by comparing the PES with the gazetted NEC for the water resource being assessed using Table 12.

Table 12 – Determining the management objective where the WRCS has been applied

		NEC			
		A	**B**	**C**	**D**
PES	**A**	A Maintain	B Controlled degradation	C Controlled degradation	D Controlled degradation
	B	A Improve	B Maintain	C Controlled degradation	D Controlled degradation
	C	A Improve	B Improve	C Maintain	D Controlled degradation
	D	A Improve	B Improve	C Improve	D Maintain
	<D	A Improve	B Improve	C Improve	D Improve

A description of possible management objectives is:

- **Improve:** Employ management measures to improve the resource class.
- **Maintain:** Employ management measures to maintain the resource class as is.
- **Controlled degradation**: Employ management measures to allow controlled degradation of the water resource.

It should also be noted that only Class A to Class D are acceptable ecological management classes. Assessment categories less than a Class D are not acceptable as future ecological management classes as they represent degrees of modification that have already resulted in, or carry an unacceptably high risk of irreversible degradation of resource quality, a condition that does not allow sustainable use of a water resource (MacKay, 1999).

6.3.2 Without classification

Classification results are not likely to be available for most site-based assessments. This applies particularly to wetlands and smaller rivers and streams, as classification typically targets large rivers and estuary systems. Under this scenario, an REC and associated management objective for the water resource is informed by an understanding of PES, EIS and social importance (where available). Trajectory of change should be considered here by selecting a PES that is attainable rather than using the current PES, which may be subject to rapid change in a high threat environment or to improvement through planned rehabilitation interventions. The default table used to inform this process is Table 13, but may be further informed through formal consultation and participation where a more comprehensive study is done.

Table 13 – Determining the management objective based on PES and importance of the water resource

		Importance			
		Very high	High	Moderate	Low
Attainable PES	A	A Maintain	A Maintain	A Maintain	A Maintain
	B	A Improve	A/B Improve	B Maintain	B Maintain
	C	B Improve	B/C Improve	C Maintain	C Maintain
	D	C Improve	C/D Improve	D Maintain	D Maintain
	<D	D Improve	D Improve	D Improve	D Improve

In the absence of classification, the precautionary principle is applied and the management objective for the water resource is based primarily on ecological criteria. The management objective will thus be either to improve the ecological class, or to maintain the ecological class. No opportunity is provided to allow controlled degradation under this scenario.

While this framework is useful in deciding on broad management objectives, it is very simplistic and should ideally be adjusted based on an understanding of the rationale for water resource protection. This thinking is in line with ideas of Dufour and Piegay (2009) who challenge resource managers to move away from decision-making dictated purely by reference conditions. They must rather follow an objective-based approach where objectives are defined with reference to a broad array of factors, including conservation, aesthetics, resource extraction, water quality, heritage protection and flood management. The stated objective should therefore be appropriately justified and used to inform how management and mitigation measures are selected and described.

Site-Based Buffer Zone Tools:

- Select the appropriate “PES” and “EIS” classes based on assessments undertaken on the water resource from the drop-down list provided.
- Select the “Management Objective” for the water resource under consideration from the drop-down list provided.

7 STEP 4: ASSESS THE RISKS FROM PROPOSED DEVELOPMENTS AND DEFINE MITIGATION MEASURES NECESSARY TO PROTECT MAPPED WATER RESOURCES IN THE STUDY AREA

A sound understanding of the risks posed by proposed land uses/activities is critical for managing water resources effectively and is central when determining appropriate buffer zones. However, the risk assessment addresses a far broader suite of potential impacts than those which can be mitigated adequately by establishing buffer zones. This has been done to ensure that a wide range of risks is considered as part of a development application process.

It is important to note that this assessment is not intended to replace comprehensive risk assessments or to assess the significance of potential impacts. This is particularly relevant to high risk activities, such as industrial and mining operations where risks are best assessed through a thorough understanding of processes and practices. It is also important to note that the risk assessment included in the Buffer Zone Tools specifically excludes risks associated with point-source discharges and groundwater use and contamination. The assessor must therefore consider the full suite of potential impacts when recommending suitable mitigation measures. In most instances, this will result in a range of complementary mitigation measures being identified, in addition to establishing suitable buffer zones.

7.1 Do a Risk Assessment for Potential Impacts of Planned Activities on Water Resources

The risk of a proposed activity for water resources is used as the primary driver for defining the level of mitigation (including buffer zone width) required. In this context, a risk assessment is a process of gathering data and making assumptions about the probable effects on the environment based on the probability of an event occurring, the factors that could bring about that event, likely exposure levels and the acceptability of the impact resulting from exposure.

Where risk is high, a more conservative approach (such as larger buffer zone) is recommended, whereas a less conservative approach (such as narrower buffer zone) is regarded as appropriate where risks are low. In this assessment, risk is based on two criteria, namely:

- The threat or potential impact of the activity on the resource.
- The sensitivity of the water resource that would be affected by the proposed development/activity.

These are integrated into a risk score, which is then used to inform the level of mitigation required.

It is also worth noting that the risk assessment considers both the construction and operational phases. This is important because some risks (such as sedimentation) may be very high during the construction phase but decline considerably in the operational phase, while other risks (such as toxic contamination) may be much higher during the operational phase. Some mitigation measures may therefore be crucial for the construction phase of the project but have little relevance during the operational phase.

7.2 Evaluate the Threats Posed by Land Use/Activities to Water Resources

Desktop	Site-based
✓	✓

This step involves evaluating the level of threat posed by proposed land uses/activities to water resources to inform the level of mitigation required. In keeping with the design criteria for the development of this method, a basic threat assessment is initially undertaken at a desktop level to inform decision-making. This relies on generic threat tables, which have been developed to inform development planning. Threat ratings must be reviewed by an aquatic specialist as part of the site-based assessment.

Generic threat tables have been developed for this assessment for both construction and operational phases across a wide range of sectors and sub-sectors ranging from agriculture to industry and mining activities (Table 14). Wherever possible, activities have been grouped into uniform classes based on the primary threat type identified [for example, mining activities have been grouped according to the risk of toxic contaminants; Mining Hazard Classes – DWAF (2007)]. For a full description of sub-sectors, please see Annexure 4.

Table 14 – List of sectors and sub-sector land use classes/activities

	Sector								
	Agriculture	**Industry**	**Mixed use/ commercial/ retail/business**	**Civic and social**	**Residential**	**Open space**	**Transportation**	**Service infrastructure**	**Mining**
Sub-sector Land Use Classes/Activities	Forestry/timber	High risk chemical industries	Core mixed use	Government and municipal	Residential low impact/ residential only	Parks and gardens	Paved roads	Above-ground communication/power (electricity) infrastructure	Prospecting (all materials)
	Nurseries and tunnel farming operations	Chemical storage facilities	Medium impact mixed use	Place of worship	Residential medium impact	Sports fields	Unpaved roads	Below-ground communication/power (electricity) infrastructure	High risk mining operations
	Dryland commercial cropland (annual)	Drum/container reconditioning	Low impact mixed use	Education	High density urban	Golf courses – fairways	Paved trails	Hazardous waste disposal facility	Moderate risk mining operations
	Dryland commercial cropland (longer rotation)	Paper, pulp or pulp products industries	Multi-purpose retail and office	Cemetery	Resort	Golf courses – tee boxes and putting greens	Unpaved tracks and trails	General solid waste disposal facility	Low risk mining operations
	Irrigated commercial cropland	Petroleum works	Petrol station/ fuel depot	Health and welfare	Hotel	Maintained lawns and gardens	Parking lots	Sewage treatment works	Plant and plant waste from mining operations – high risk activities
	Subsistence cultivation	Livestock processing operations	Maintenance and repair facilities		Informal settlements		Airport – runways and taxiways	Sludge dams associated with concentrated livestock operations	Plant and plant waste from mining operations – moderate risk activities
	Extensive livestock grazing operations	Medium-risk chemical industries	Offices		Residential high impact		Railway	Pipelines for transportation of hazardous substances	Plant and plant waste from mining operations – low risk activities

Sector								
Agriculture	**Industry**	**Mixed use/ commercial/ retail/business**	**Civic and social**	**Residential**	**Open space**	**Transportation**	**Service infrastructure**	**Mining**
Intensive livestock grazing operations	Ceramic works						Pipelines for transporting wastewater	Moderate risk quarrying operations
Concentrated livestock operations	Electricity generation works							Low risk quarrying operations
Aquaculture or marine culture	Timber milling or processing works							Exploratory drilling
	Dredging works							
	Cement/concrete works							
	Breweries/distilleries							
	Industries processing livestock derived products							
	Composting facilities							

Threats posed by land uses/activities associated with each sub-sector were qualitatively assessed on the level of threat they pose to the following aspects:

- Water quantity – volumes of flow.
- Water quantity – patterns of flow.
- Sedimentation and turbidity.
- Water quality – increased inputs of nutrients.
- Water quality – increased toxic contaminants.
- Water quality – changes in pH.
- Water quality – concentration of salts (salinization).
- Water quality – temperature.
- Water quality – pathogens (such as disease-causing organisms).

This threat assessment was informed as far as possible by an understanding of current legal obligations for managing impact to water resources. Although diffuse source impacts are not specifically regulated at present, waste water discharges are currently regulated through a licensing process. A General Authorisation[9] has been issued for activities disposing <2000 ℓ/day provided that it complies with the waste water limit values[10] defined in the General Authorisation. The authorisation defines both general waste water limit values (GLVs) set for non-listed water resources, and stricter special waste water limit values (SLVs) set for listed water resources requiring more careful management. Given that diffuse source impacts can have similar effects than waste water, these limits were used to inform the threat ratings applied in the threat assessment[11].

This concept is further illustrated in Figure 8. The diagram shows a container filled with diffuse source discharges of varying pollutant loadings which reflects the level of threat posed by a development. Where discharge concentrations are likely to be below SLV levels, the threat is regarded as very low (as represented by a small volume in the cup), while a discharge up to the GLV limit is considered low, in line with current general authorisations. Additional threat classes are defined based on the anticipated exceedance of GLV standards in diffuse run-off from a development in the absence of mitigation, as reflected by increasing volumes of water in the container.

The threat rating applicable is provided in

Table 15, which includes reference to GLVs and SLVs. For more details of the specific limits set for evaluating different threat types, see Annexure 5.

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[9] Government Notice 399. Revision of General Authorisations in terms of Section 39 of the National Water Act, 1998 (No. 36 of 1998).

[10] According to the National Water Act, "waste water limit value" means the mass expressed in terms of the concentration and/or level of a substance which may not be exceeded at any time. Waste water limit values shall apply at the last point where the discharge of waste water enters into a water resource, dilution being disregarded when determining compliance with the waste water limit values. Where discharge of waste water does not directly enter a water resource, the waste water limit values shall apply at the last point where the waste water leaves the premises of collection and treatment.

[11] It is worth noting here that many water quality experts felt that these standards were insufficient to ensure an adequate level of protection to water resources. While this perspective is noted, no better guidelines were available to inform this assessment. There may therefore be a need to update and refine these threat ratings if more appropriate water quality standards are made available.

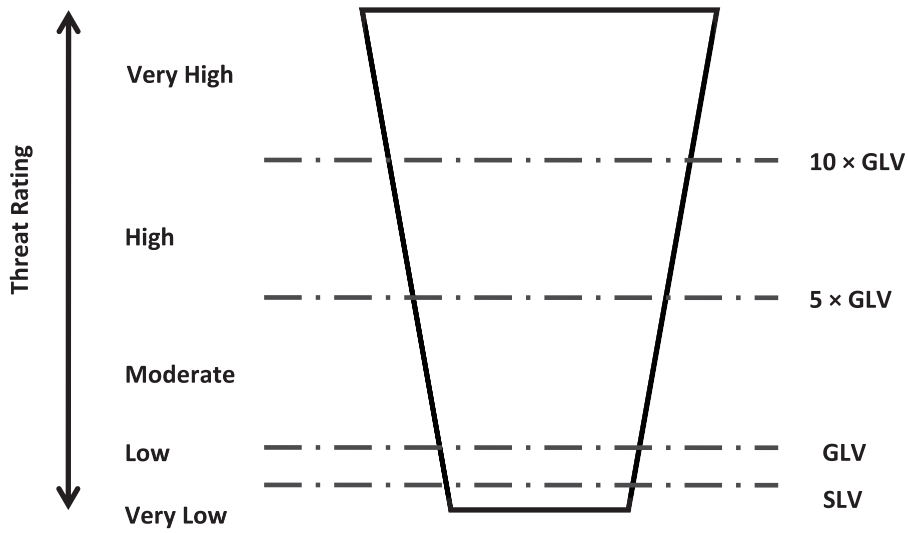

Figure 8 – Diagram illustrating how threat classes relate to SLV and GLV limits

Table 15 – Ratings used to evaluate the level of threat posed by diffuse surface run-off from various land uses/ activities located adjacent to water resources

Threat Rating	Symbol	Threat Score	Description
Very low	VL	0.2	The level of threat (based on likelihood, magnitude and frequency of potential impacts) posed by the land use/activity to water resources is very low for the threat type assessed. In the case of water quality impacts, SLV limits are unlikely to be exceeded in diffuse surface run-off.
Low	L	0.4	The level of threat posed by the land use/activity to water resources is low for the threat type assessed. In the case of water quality impacts, GLV limits are unlikely to be exceeded in diffuse surface run-off.
Moderate	M	0.6	The level of threat posed by the land use/activity to water resources is moderate for the threat type assessed. If not managed, pollutant loads in diffuse surface run-off may range up to 5× the GLV limit.
High	H	0.8	The level of threat posed by the land use/activity to water resources is high for the threat type assessed. If not managed, pollutant loads in diffuse surface run-off may range up to 10× the GLV limit.
Very high	VH	1	The level of threat posed by the land use/activity to water resources is very high for the threat type assessed. If not managed, pollutant loads in diffuse surface run-off may exceed 10× the GLV limit.

An initial threat rating exercise was carried out through an expert-workshop, mostly comprising DWS personnel. In the case of potential water quality impacts, land use threats were evaluated primarily based on the anticipated pollutant loading from surface run-off, although the effects of land use on run-off characteristics (such as increased surface run-off in land uses characterised by hardened surfaces or bare ground) was also considered. This process was informed by quantitative information pertaining to the event mean concentration (EMC)[12] values obtained from research undertaken in the United States (US EPA, 2001; Lin, 2004). EMCs are reported as a mass of pollutant per unit volume of water (usually mg/ℓ), which allowed these values to be compared to waste water limit values and defined threat ratings. A summary of the average EMC values from a range of studies is provided in Annexure 6, with further details from specific studies included in Annexure 7. A conservative approach was adopted by considering not only the realistic 'worst-case' scenario but also given standard accepted management measures where appropriate[13]. For example, in the case of extensive livestock grazing, the ratings reflect potential risks associated with an extensive grazed system with stocking rates up to (but not exceeding) maximum carrying capacity.

Preliminary threat ratings assigned by DWS personnel were then reviewed by the specialist team while developing and refining the Buffer Zone Model. The outcome is a rating of threats of each sector and sub-sector for the range of potential threats identified (Annexure 8). These ratings are a key driver for establishing the risk posed by land uses/activities on water resources as part of this assessment[14]. When using the Buffer Zone Tools, the assessor simply selects the sector and appropriate sub-sector relevant to the assessment, and desktop threat ratings are auto-populated for each threat type. The threat assessment is used in different ways depending on the level of assessment being undertaken:

- **Desktop assessment:** This tool includes desktop threat ratings for all sectors and sub-sectors, with a specific focus on threat ratings relevant to buffer zone determination.
- **Site-based assessment**: Desktop threat ratings are used as a starting point for buffer zone determination. While desktop threat ratings provide an indication of the level of threat posed by different land uses/activities, there is likely to be some level of variability between activities occurring within a sub-sector. **It is therefore important that these threat ratings be reviewed based on specialist input and that a justification for any changes is documented in the Buffer Zone Tools**. When reviewing the threat ratings, the following aspects should be considered:
    - **Development-specific information:** Specific knowledge about the planned development may provide a strong basis for refining desktop threat ratings.

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[12] "Event mean concentration" is defined as the mean concentration of pollutants in the run-off from a storm event. EMCs are typically used for calculating run-off pollutant loads for watersheds based on the occurrence of land use types present.

[13] As part of the desktop threat assessment, the following assumptions were made:

- The development being planned is directly adjacent to the water resource (no buffer in place).
- The sub-sector assessed is the dominant land use and occurs at intensities typical of that sub-sector.
- Where intensities are variable (for example, informal development/subsistence cultivation), the typical realistic worst-case scenario was assessed.
- In the case of sub-sectors that address linear developments (for example, footpaths/roads); assessments were based on typical width and characteristics of the specific sub-sector, and associated construction and operational activities.

[14] It is important to note that desktop threat ratings were developed in a workshop environment using individuals with an understanding of different sectors. In some situations, however, confidence in ratings applied was poor, requiring further consideration. Although these preliminary scores were updated through further input from the project team, it is anticipated that they will be reviewed over time and be used to update the Buffer Zone Tools accordingly.

- **Intensity of development:** Desktop scores have been rated based on a realistic worst-case scenario, but there may be justification for reducing threat scores in instances where development density/intensity is considerably lower than that typical for the sub-sector.
- **Site attributes:** There may be situations where site attributes such as slope steepness, slope length, soil depth and soil erodibility, exacerbate potential impacts at a site-level.

Refined threat ratings should be based on standard accepted management and operational practices. A range of additional management and mitigation measures can also be used to motivate for reducing the levels of threat posed by different land uses. These are catered for elsewhere in the assessment by identifying and implementing additional site-specific mitigation measures (see Section 6).

Threats to water quality are restricted to an assessment of threats posed by pollutants in diffuse surface run-off. Other key threats, including threats to groundwater and threats from point-source discharges, were not considered. These aspects should be considered by the aquatic specialist when defining mitigation measures to reduce potential impacts to water resources[15].

Precautionary approach to threat assessments: A conservative and long-term view to water resource management has been taken when developing these buffer zone guidelines. The approach adopted therefore encourages individual land owners to manage their impacts in such a manner that they take responsibility for their own impacts rather than passing such responsibilities onto future users. Under this approach, threats are internalised and appropriately mitigated by each development, irrespective of scale and the level of existing impacts to the water resource. It is only by adopting this precautionary approach that cumulative impacts can be managed over the long term. The threat of a small industrial site or residential development is therefore treated the same as if this land use was planned along the entire perimeter of the water resource. As such, threat ratings should not be reduced simply based on the scale of the planned development or the assimilative capacity of the receiving environment.

Desktop Buffer Zone Tool:

- Selection of "Sectors" and/or "Sub-sectors" is not required. The tool lists and uses relevant threat ratings for all sector and sub-sectors in defining desktop buffer requirements. Threat ratings cannot be changed at a desktop assessment level.

Site-based Buffer Zone Tools:

- Select the "Sector" and/or "Sub-sector" for the activity being investigated.
- For the site-based assessment, review desktop threat ratings and capture specialist threat ratings based on best available information.
- Provide a clear justification for any deviations from the desktop threat ratings provided.

7.3 Integrate Climatic Factors into the Threat Assessment

Desktop	Site-based
✓	✓

Although potential impacts to water resources are driven primarily by the threats associated with different land uses/activities, surface run-off and associated contamination risk are also influenced by climatic factors. Indeed, areas of higher mean annual precipitation (MAP) (Figure 9) characterised by more intense rainfall events (Figure 10) will experience a higher frequency and intensity of storm water run-off than areas characterised by low rainfall and less intensive rainfall events. This was clearly demonstrated in a hydrological simulation study undertaken for this project (Annexure 9).

[15] Note that specific questions have been included in the Buffer Zone Tools to flag this issue and to give the assessor an opportunity to provide some detail on the nature of any additional mitigation measures proposed.

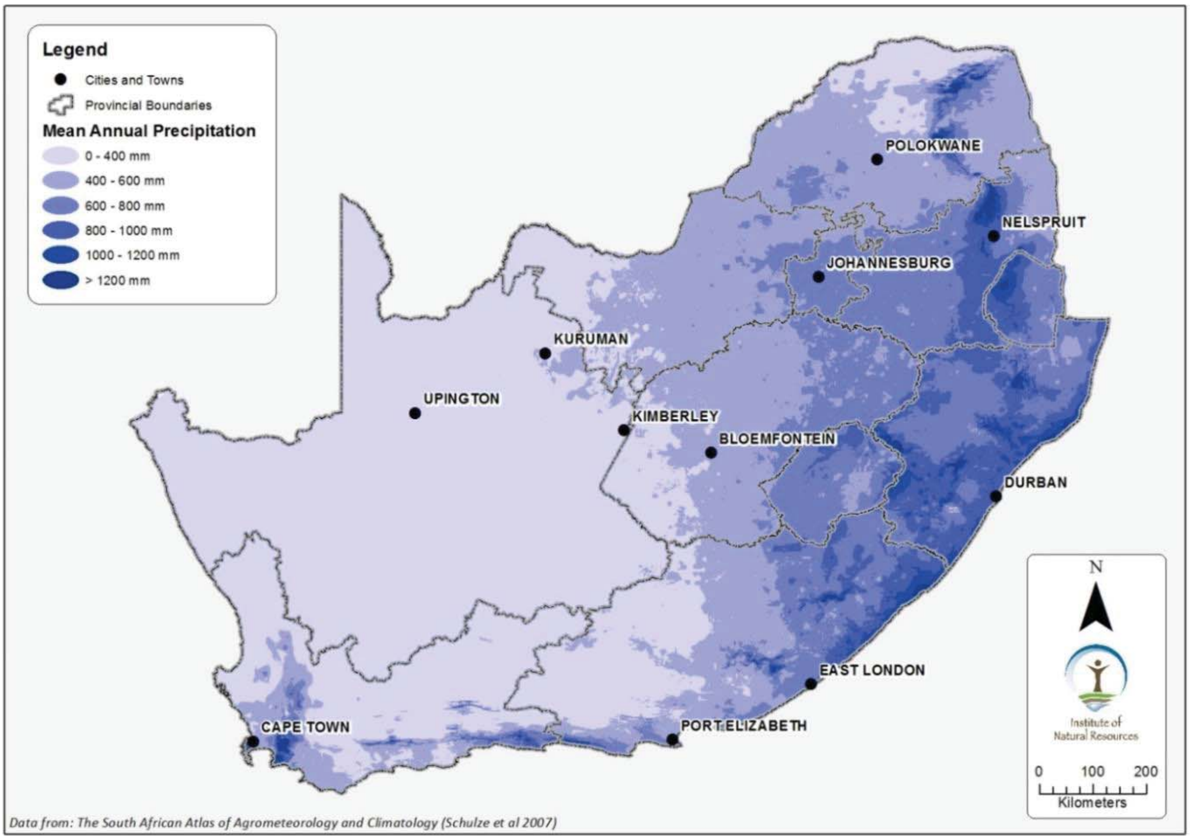

Figure 9 – MAP (adapted from Schulze, 2007)

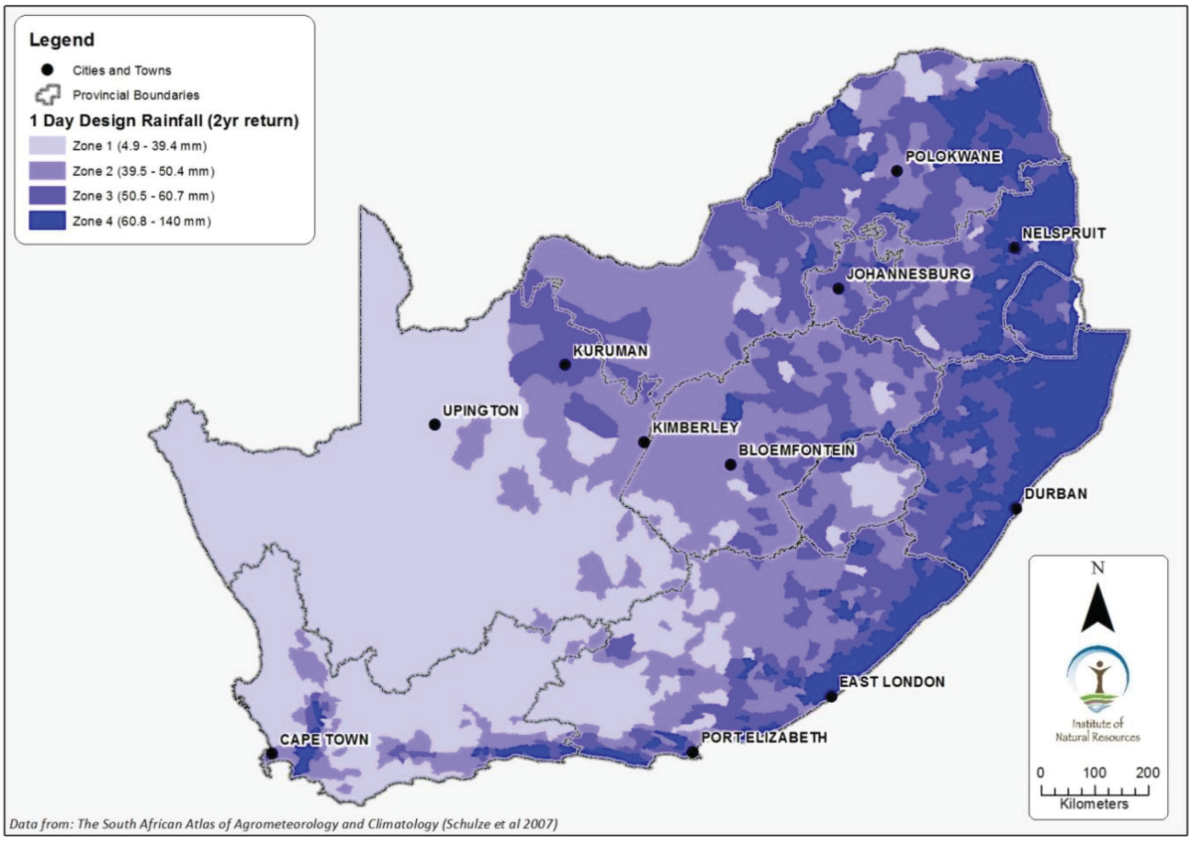

Figure 10 – Rainfall intensity zones based on one day design rainfall over a two-year return (adapted from Schulze, 2007)

To account for this variability, the threat score used to inform buffer zone determination is adjusted for these basic climatic factors. This is included in the Buffer Zone Model as a “climate risk score” (CRS) that reflects the variability in peak discharges likely to result from changes in the climatic criteria relative to “reference” conditions. The reference conditions were taken as a MAP range of 1000-2000 mm and a moderately high rainfall intensity zone (Zone 3). The CRS is calculated based on the modifiers for MAP and the rainfall intensity zone in which the land use/activity is proposed, and converting these values to a range from 0-1 (Table 16).

Table 16 – Modifiers used to calculate a CSR

MAP	**Class**	**0-400 mm**	**401-600 mm**	**601-800 mm**	**801-1000 mm**	**1001-1200 mm**	**>1201 mm**
	Modifier	0.01	0.25	0.5	0.75	1.0	1.25
Rainfall Intensity Zone (MAP)	**Category**	Zone 4	Zone 3	Zone 2	Zone 1		
	Modifier	1.25	1.0	0.75	0.5		

The threat score is adjusted automatically in the Buffer Zone Model by applying an adjustment factor based on the CRS[16]. This effectively increases the threat ratings in high rainfall environments or areas located within intense rainfall intensity zones[17].

Buffer Zone Tools:

- Select the appropriate MAP class for the area under investigation.
- Select the appropriate rainfall intensity zone for the region.
- Based on this information, threat scores are automatically adjusted in the Buffer Model to account for climatic factors.

7.4 Assess the Sensitivity of Water Resources to Threats Posed by Lateral Land Use Impacts

Desktop	Site-based
✓	✓

The sensitivity of water resources to lateral impacts is another factor affecting the level of risk posed by a development. A more risk-averse approach is therefore required when proposed developments take place adjacent to water resources that are sensitive to lateral impacts, as opposed to the same development taking place adjacent to a water resource which is inherently less sensitive to the impacts under consideration. For example: agriculture, posing a high siltation threat (for example, sediment inputs and

[16] Note that the degree of alteration in flow volumes [mean annual run-off (MAR)] and flow patterns are linked primarily to land use attributes and are unlikely to be significantly altered by climatic factors. As such, climatic factors were not used to adjust the threat ratings for these two potential impacts types.

[17] Typical pollutant loading of different land uses (as expressed by the desktop threat score) is regarded as being of overriding importance when assessing buffer zone requirements. However, given that storm flow is the primary mechanism for diffuse pollutant inputs, climatic factors have also been integrated into the model. The influence of climatic factors on buffer requirements has been moderated by restricting the change in threat score to a maximum of one threat class. By following this approach, buffer zone requirements for land uses in arid climates with low rainfall intensities therefore score one threat class less than when the same land use is located in moist climates characterised by intense rainfall events. It is worth noting, however, that there is little scientific basis for this approach other than that provided, and a sensitivity analysis which revealed that allocating a higher weighting to climatic factors would introduce too much variability into model outcomes (to the extent that climate rather than land use could easily have an overriding influence on buffer zone requirements). There is however, room for refining this approach in future if research reveals that buffer widths should be more strongly influenced by climatic factors.

turbidity) may be planned alongside a small and isolated depression wetland (pan) that is highly sensitive to lateral sediment inputs. The risk posed by agricultural activities in this instance is far higher than for agricultural activities adjacent to a large floodplain wetland, characterised by inherently high natural sediment inputs. In the case of a desktop assessment, the following sensitivity ratings are used to inform buffer requirements:

- **Median buffer (desktop):** Water resource is assumed to be moderately sensitive to all threat types.
- **Worst-case buffer (desktop):** Water resource is assumed to have a very high sensitivity to all threat types.
- **Customised buffer (desktop):** A sensitivity score is allocated by the user based on available information.

In the case of site-based assessments, sensitivity is scored by rating a range of key attributes of different water resources that act as easily measurable indicators[18]. The sensitivity assessment has therefore been tailored for wetlands, rivers and estuaries based on an assessment on a set of key indicators[19]. Sensitivity scores and classes used in the assessment are described in Table 17.

Table 17 – Sensitivity classes used to guide the assessment of sensitivity of water resources to lateral impacts[20]

Sensitivity Class	Symbol	Sensitivity Score	Description
Very low	VL	0.85	Water resource is likely to have a very low susceptibility to the specific impact type.
Low	L	0.93	Water resource is likely to have a low susceptibility to the specific impact type.
Moderate	M	1.00	Water resource is likely to be moderately susceptible to the specific impact type.
High	H	1.08	Water resource is likely to have a high susceptibility to the specific impact type.
Very high	VH	1.15	Water resource is likely to have a very high susceptibility to the specific impact type.

It is important to point out that this assessment is designed to assess the inherent sensitivity of the water resource rather than the sensitivity of important biota reliant on the water resource. Where there are important biodiversity elements, buffer requirements are adjusted to account for these features.

[18] This assessment is different to that used to define EIS, as the focus is specifically on the sensitivity of water resources to lateral impacts rather than broader catchment impacts.

[19] Note that indicator selection has been tested and refined through stakeholder interaction and practical testing, so better indicators are likely to emerge over time. The set of indicators used for buffer zone assessments should ideally be reviewed and refined over time to make use of the best available information.

[20] Note that the range in sensitivity scores was again informed by a sensitivity assessment undertaken as part of development of Buffer Zone Models. Based on this assessment, a higher weighting was allocated to risk ratings than to sensitivity scores. As such, risk ratings have a greater bearing on the risk assessment and associated buffer requirements than sensitivity scores that have only a moderating effect.

7.4.1 Assess the sensitivity of wetlands to lateral land use inputs

The sensitivity of wetlands to lateral impacts is assessed using a range of indicators outlined in Table 18. These were selected with expert input and refined through a practical testing process. For details on the rationale for indicator selection and the scoring of each criterion, refer to Annexure 10. The method to be followed in rating each indicator is described in the accompanying Practical Guide and is also captured as comments in the Wetland Buffer Zone Tool.

Table 18 – Indicators used to assess the sensitivity of wetlands to lateral land use impacts

Indicator
Overall size
Size of the wetland relative to (as a percentage of) its catchment
Average slope of the wetland's catchment
The inherent run-off potential of the soil in the wetland's catchment
The extent to which the wetland HGM setting is generally characterised by sub-surface water input
Perimeter-to-area ratio
Vulnerability of the HGM type to sediment accumulation
Vulnerability of the site to erosion given the site's slope and size
Extent of open water, particularly water that is naturally clear
Sensitivity of the vegetation to burial under sediment
Peat/high organic content versus mineral soils
Inherent level of nutrients in the landscape
Sensitivity of the vegetation to increased availability of nutrients
Sensitivity of the vegetation to toxic inputs, changes in acidity and salinization
Natural wetness regimes
Natural salinity levels
Level of domestic, livestock and contact recreational use
Mean annual temperature

7.4.2 Assess the sensitivity of rivers and streams to lateral inputs

The sensitivity of rivers and streams to lateral impacts is assessed using a range of indicators outlined in Table 19. These were selected with expert input and refined through a practical testing process. For details on the rationale for indicator selection and the scoring of each criterion, refer to Annexure 11. The method to be followed in rating each indicator is described in the accompanying Practical Guide and is also captured as comments in the River Buffer Zone Tool.

Table 19 – Indicators used to assess the sensitivity of rivers and streams to lateral land use impacts

Indicator
Stream order
Channel width
Perenniality

Indicator
Average catchment slope
Inherent run-off potential of catchment soils
Longitudinal river zonation
Inherent erosion potential (K-factor) of catchment soils
Retention time
Inherent level of nutrients in the landscape
Inherent buffering capacity
Natural salinity levels
River depth-to-width ratio
Mean annual temperature
Level of domestic, livestock and contact recreational use

7.4.3 Assess the sensitivity of estuaries to lateral inputs

The sensitivity of estuaries to lateral impacts is assessed using a range of indicators outlined in Table 20. These were selected with expert input and refined through a practical testing process. For details on the rationale for indicator selection and the scoring of each criterion, refer to Annexure 12. Details on the method to be followed in rating each indicator is described in the accompanying Practical Guide and is also captured as comments in the Estuary Buffer Zone Tool.

Table 20 – Indicators used to assess the sensitivity of estuaries to lateral land use impacts

Indicator
Estuary size
Estuary length
Perenniality of river inflow
The inherent run-off potential of the soil in the estuary's catchment
Mouth closure as a measure of water exchange
Water clarity
Biogeographic zone
Presence of submerged macrophytes
Level of domestic, livestock and contact recreational use

7.5 Assess the Sensitivity of Important Biodiversity Elements to Threats Posed by Lateral Land Use Impacts

Desktop	Site-based
	✓

Although the sensitivity of the water resource to threats posed by lateral inputs may be low, specific important biota or habitats may be sensitive to such impacts. Where relevant, it is important to consider the sensitivity of any important biodiversity elements identified, and to adjust the sensitivity scores upwards if necessary. This can only be done once a basic understanding of the biodiversity value of the site has been assessed as outlined in Step 5 of this guideline. Further guidance on how biodiversity considerations should be incorporated into an assessment of aquatic impact buffer requirements is also provided in Section 6.3.

7.6 Determine the Risk Posed by Proposed Activities on Water Resources

Desktop	Site-based
✓	✓

Once both threats posed by potential land uses/activities and the inherent sensitivity of receiving water resources have been assessed, this information is used to evaluate the risks posed by such activities on the water resource under consideration. Risk scores are calculated by multiplying threat and sensitivity scores to obtain a risk score for each impact type evaluated as illustrated in Table 21[21].

Table 21 – Table used to integrate threat and sensitivity scores into a composite risk score as part of the Buffer Zone Model

		Inherent Sensitivity				
Potential Threat of Land Use/Activity		**VH**	**H**	**M**	**L**	**VL**
		1.15	1.080	1.0	0.930	0.85
VH	1	1.15	1.075	1.0	0.925	0.85
H	0.8	0.92	0.860	0.8	0.740	0.68
M	0.6	0.69	0.645	0.6	0.555	0.51
L	0.4	0.46	0.430	0.4	0.370	0.34
VL	0.2	0.23	0.215	0.2	0.185	0.17

From a technical perspective, it is important to note that sensitivity scores for moderately sensitive water resources have been set at 1. This is consistent with the approach used to link risk classes with buffer zone widths in Step 3.4.2. This links required buffer zone efficiency to compliance with GLV standards appropriate for moderately sensitive systems. Where water resources are more sensitive, the risk class and associated requirement for mitigation typically increases, highlighting the need for more stringent controls (more effective buffer zones). However, where sensitivity is regarded as low, mitigation requirements are relaxed accordingly, as indicated by lower risk scores for water resources with a low or very low sensitivity. Risk scores calculated are then grouped into one of five risk classes for reporting purposes as described in Table 22.

Table 22 – Risk classes used in this assessment

Risk Class	Risk Score	Description
Very low	<0.3	The proposed development/activity poses a very low risk to the water resource under investigation for the threat type assessed.
Low	0.3-0.5	The proposed development/activity poses a low risk to the water resource under investigation for the threat type assessed.
Moderate	0.51-0.7	The proposed development/activity poses a moderate risk to the water resource under investigation for the threat type assessed.
High	0.71-0.9	The proposed development/activity poses a high risk to the water resource under investigation for the threat type assessed.
Very high	>0.91	The proposed development/activity poses a very high risk to the water resource under investigation for the threat type assessed.

[21] Note that the range of sensitivity scores was tested as part of a sensitivity analysis of the model while defining and refining Buffer Zone Models. Based on this testing, a narrow range of sensitivity scores (0.85 to 1.15) was included in the final Buffer Zone Models to limit the variation in buffer widths within an acceptable range (Bredin et al., 2014).

Desktop Buffer Tool:

- Select a sensitivity score class based on available information for the site.

Site-Based Buffer Zone Tools:

- Using the Practical Guide, collect desktop and site-based information necessary to assess the sensitivity of the water resource.
- Review sensitivity scores and select a sensitivity class for biodiversity where this is likely to be higher than that for the water resource.
- Risk scores are automatically calculated in the Buffer Model based on the threat and maximum sensitivity scores.

7.7 Determine Desktop Aquatic Impact Buffer Requirements for Selected Impacts

Up to this point, the assessment focused on assessing the level of risk from lateral impacts posed by proposed land uses/activities on water resources. The next step requires identifying relevant mitigation measures to address the risks identified. Although a range of mitigation measures can be applied to address these risks, there is good scientific evidence to indicate that establishing vegetated buffer zones can be very effective at addressing several of these impacts. As such, **buffer zones are advocated as a standard mitigation measure to reduce the impact of pollutants entering the water resource via diffuse surface run-off.**

It is important to note that buffer zones can only assist in mitigating some of the risks identified and that other mitigation measures will typically also be necessary. For example, while buffers can help to reduce the impact of afforestation on stream flow, the area of the catchment planted to commercial species is the primary determinant of hydrological impacts. Buffers are most effective in reducing pollutants in diffuse surface run-off while their ability to remove pollutants from sub-surface flows has not been documented as effectively. Buffers also do little to address pollutants discharged at point-sources or in concentrated flows (such as those released through piped storm water outlets). Therefore, buffers should be seen as only one of a suite of possible mitigation measures to reduce potential impacts of land uses/activities on water resources. Table 23 serves to highlight situations where establishing buffer zones is advocated while also highlighting a range of threats to be addressed through alternative mitigation measures.

Table 23 – Common threats posed by adjoining land uses/activities on water resources and typical approaches to addressing them. Instances where buffer zones can play a particularly important role are highlighted in blue

Threat	Source of Impact	Approach for Addressing Threats
Water quantity – volumes of flow	Reduction in water inputs	Source-directed controls, including sustainable drainage systems (SuDS)[22] options to manage storm water run-off, particularly in urban areas. Restricting stream flow reduction (SFR) activities *(including application of buffer zones)*.
	Increase in water inputs	Control of water inputs (such as piped water) and other mitigation measures.

[22] There is a growing awareness and application of water sensitive urban design that includes using SuDS to address storm water management challenges. Readers working in urban areas are specifically encouraged to understand and apply the South African Guidelines for Sustainable Drainage Systems (Armitage et al., 2013) and to recognise that establishing buffer zones can complement other control measures as part of a “treatment train” to address storm water management challenges.

Threat	Source of Impact	Approach for Addressing Threats
Water quantity – patterns of flow	Concentrated flows	Source-directed controls, including SuDS options to manage storm water run-off, particularly in urban areas.
	Diffuse run-off	Best management practices (BMPs) to control run-off and mitigation measures (*including buffer zones*) to address increased storm flows.
Sedimentation and turbidity	Concentrated flows	Address through on-site BMPs and mitigation measures including SuDS options.
	Diffuse run-off	Buffer zone together with other mitigation measures and BMPs.
Water quality – increased inputs of nutrients	Concentrated flows	Address through on-site BMPs and mitigation measures including SuDS options.
	Diffuse run-off	Buffer zone together with other mitigation measures and BMPs.
Water quality –increased organic contaminants	Concentrated flows	Address through on-site BMPs and mitigation measures including SuDS options.
	Diffuse run-off	Buffer zone together with other mitigation measures and BMPs.
Water quality – increased toxic contaminants (heavy metals)	Concentrated flows	Address through on-site BMPs and mitigation measures including SuDS options.
	Diffuse run-off	Buffer zone together with other mitigation measures and BMPs.
Water quality – changes in acidity (pH)	Concentrated flows	Address through on-site BMPs and mitigation measures.
	Diffuse run-off	
Water quality – concentration of salts (salinization)	Concentrated flows	Address through on-site BMPs and mitigation measures.
	Diffuse run-off	
Water quality – temperature	Concentrated flows	Address through on-site BMPs and mitigation measures (*including maintenance of riparian zones*).
	Diffuse run-off	
Water quality – pathogens (i.e. disease-causing organisms)	Concentrated flows	Address through on-site BMPs and mitigation measures including SuDS options.
	Diffuse run-off	Buffer zone together with other mitigation measures and BMPs.

The risk assessment has been undertaken for a wide suite of potential impacts, and buffer zone requirements are only advocated where scientific studies have shown that they can be effective mitigation measures. Buffer zone recommendations are therefore calculated for the following potential impacts associated with diffuse lateral surface water inputs:

- Increased sedimentation and turbidity.
- Increased nutrient inputs.
- Increased organic contaminants.
- Increased toxic contaminants (heavy metals).
- Increased pathogen inputs.

A buffer zone identified to perform these functions is referred to as an aquatic impact buffer zone:

Aquatic impact buffer zone: A zone of vegetated land designed and managed so that sediment and pollutant transport carried from source areas via diffuse surface runoff is reduced to acceptable levels.

7.8 Determine Initial Aquatic Impact Buffer Zone Width Required to Mitigate Risks Identified

Determining the required buffer width is largely an exercise of assessing the situation and linking it to an acceptable level of risk. In this approach, threats have already been defined for each of the required buffer functions with reference to existing standards. Determining buffer zone width is therefore guided by the level of effectiveness required to mitigate risks to acceptable limits. The relationship between risk classes and buffer zone effectiveness is illustrated in Table 24.

Desktop	Site-based
	✓

Table 24 – Guideline for linking buffer width with buffer zone effectiveness

Risk	Effectiveness (%)	Rationale
Very low	25	Threats are either low or very low and associated with water resources of moderate to very low sensitivity. Although no buffer is necessarily required, a minimum buffer zone providing a basic level of protection is advocated.
Low	50	Risks are regarded as low based on anticipated threats and sensitivity of the water resource. A narrow buffer zone providing some level of protection is advocated to reduce risks to an acceptable level.
Moderately low	80	Risks are regarded as moderately low based on anticipated threats and sensitivity of the water resource. In this case, a buffer zone that is 80% effective will be necessary to reduce impacts to within an acceptable target range.
Moderately high	90	Risks are regarded as moderately high based on anticipated threats and sensitivity of the water resource. In this case, a buffer zone that is 90% effective will be necessary to reduce impacts to within an acceptable target range.
High	95	Risks are regarded as high based on anticipated threats and sensitivity of the water resource. In this case, a buffer zone that is at least 95% effective will be necessary to reduce impacts to within GLV requirements.
Very high	98	Risks are regarded as very high based on anticipated threats and sensitivity of the water resource. In this case, a buffer zone that is at least 98% effective will be necessary to reduce impacts to within GLV requirements. In many cases, this will not be achievable and therefore additional alternative mitigation measures will have to be implemented.

Rule curves have been developed, based on the best available science, to link buffer width and buffer effectiveness. These relationships are summarised below, while further information, including reference to relevant studies that support these relationships, are included in Annexure 13 of this report[23].

The relationships assume that buffer width is the most important factor for effective mitigation, which is consistent with findings in international literature (Macfarlane, et al., 2009). Other factors that affect buffer zone efficiency, such as slope and vegetation cover, are not considered explicitly at this stage but are dealt with later at a site-level (see Section 7.9). Details of each of the relationships used to establish initial buffer requirements are presented here.

Desktop aquatic impact buffer zone requirements are automatically calculated in the Buffer Zone Tools based on the level of risk defined for each of the five potential impacts considered[24]. The aquatic impact buffer zone width required is then taken as the maximum of the buffer zone widths proposed for each of the potential impacts evaluated (if a buffer of 20 m is recommended for sediment retention and one of 30 m to address nutrient risks, a 30 m buffer zone is recommended).

7.8.1 Increased sedimentation and turbidity

Numerous studies have been undertaken to assess the effectiveness of buffer zones in retaining sediments washed off in surface run-off. These suggest that the relationship between the length covered by the run-off (buffer width) and sediment removal is not linear, with most sediment being deposited in outer portions of the buffer. Although there is considerable variation in reported efficiencies, it is clear that high efficiencies can be obtained from small buffer zones (<10 m), but that wider buffer zones are required to remove greater amounts of suspended sediment effectively. Based on a review of available literature, standard buffer widths of between 2 m and 50 m have been proposed for sediment removal, depending on the effectiveness of the buffer zone required (Figure 11).

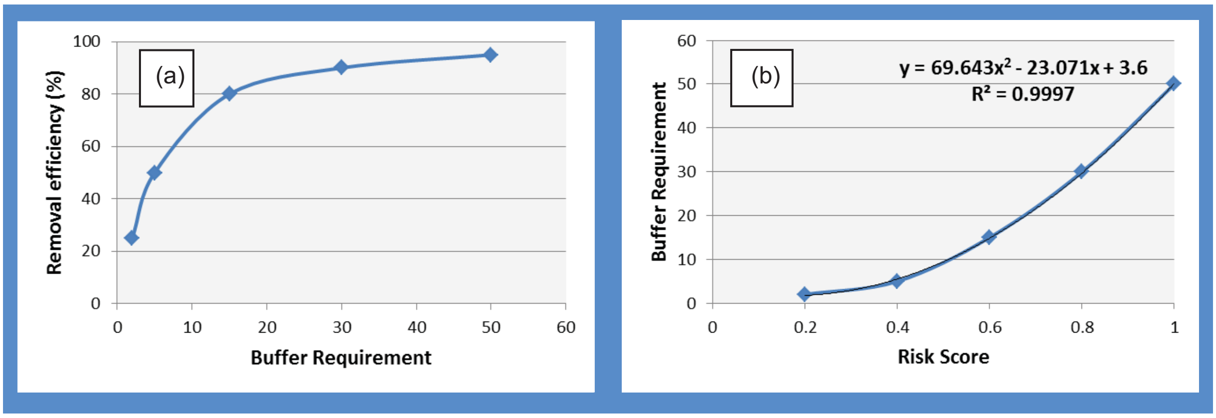

Figure 11 – Relationship between (a) sediment removal efficiency and buffer width, and (b) risk of sediment inputs and buffer requirements used to calculate aquatic impact buffer requirements

7.8.2 Increased nutrient inputs from lateral inputs

Many studies have shown that buffer zones can be very effective at removing nitrogen and phosphorus from lateral water inputs. Although removal effectiveness varied widely amongst studies, there is a clear

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[23] It is important to note that the development of these rule curves was based on a suite of default or "reference" buffer zone attributes (see Section 7.10). Site-specific buffer requirements may therefore vary considerably depending on local buffer zone attributes that affect the ability of buffer zones to trap pollutants.

[24] It is important to follow a precautionary approach when calculating desktop buffer requirements. Where the sub-sector cannot be determined, buffers should be determined using the worst-case scenario for the relevant sector. This assumes that the receiving water resource is very sensitive (maximum sensitivity score) and that the characteristics of the buffer zone are poorly suited to address diffuse source pollutants (worst-case site-based attributes).

relationship between buffer width and buffer effectiveness. As with sediment removal, a curvilinear relationship is typically used to describe the relationship between buffer width and nutrient removal efficiency. This relationship is presented in Figure 12, and suggests that high levels of buffer efficiency can be achieved with small buffers of <20 m in width. However, very wide buffers may be necessary to effectively remove nutrients in high risk situations.

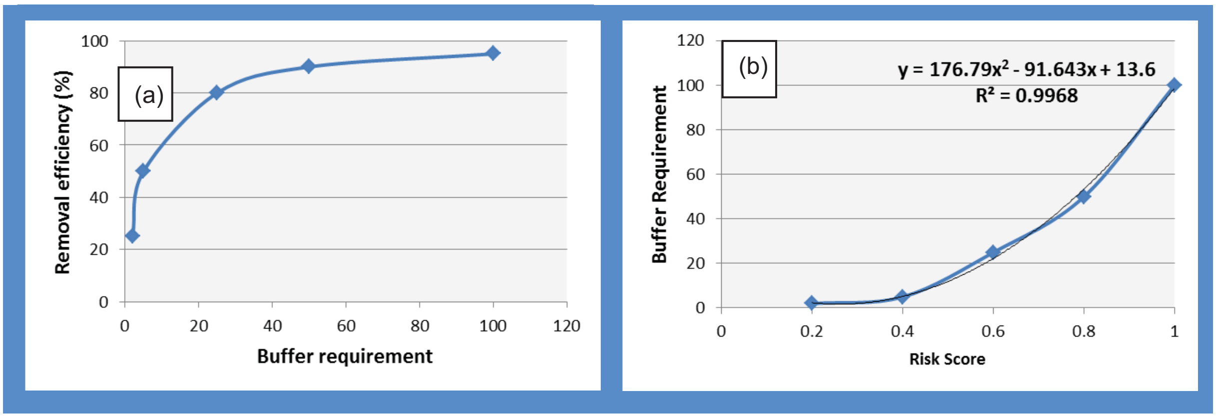

Figure 12 – Relationship between (a) nutrient removal efficiency and buffer width, and (b) risk of nutrient inputs and buffer requirements used to calculate aquatic impact buffer requirements

7.8.3 Increased toxic and organic contaminants from lateral inputs

Toxic contaminants cover a broad range of potentially toxic substances. These include toxins such as toxic metal ions (for example, copper, lead and zinc), toxic organic substances (which reduce oxygen availability), hydrocarbons and pesticides. In addition, the efficiency of a buffer at trapping toxic substances is dependent on a wide range of factors, such as residence times, flushing rates, dilution and resuspension rates of the toxic substances.

As an initial approach to determine the effectiveness of a buffer zone at trapping toxic substances, toxic contaminants have been considered under two broad categories, namely, organic contaminants (which include pesticides) and toxic heavy metals. Buffer widths proposed for these groups have been based on available information. In addition, the precautionary principle was applied. These relationships are presented in Figure 13 and Figure 14 respectively and suggest that for toxic metals, high levels of buffer efficiency can be achieved with small buffers (approximately 20 m wide). However, wider buffers of up to 80 m may be necessary to remove toxic metals effectively in high risk situations. For organic pollutants including pesticides, a buffer of 20 m would be effective. However, for high risk situations, a larger buffer of approximately 40 m would be required.

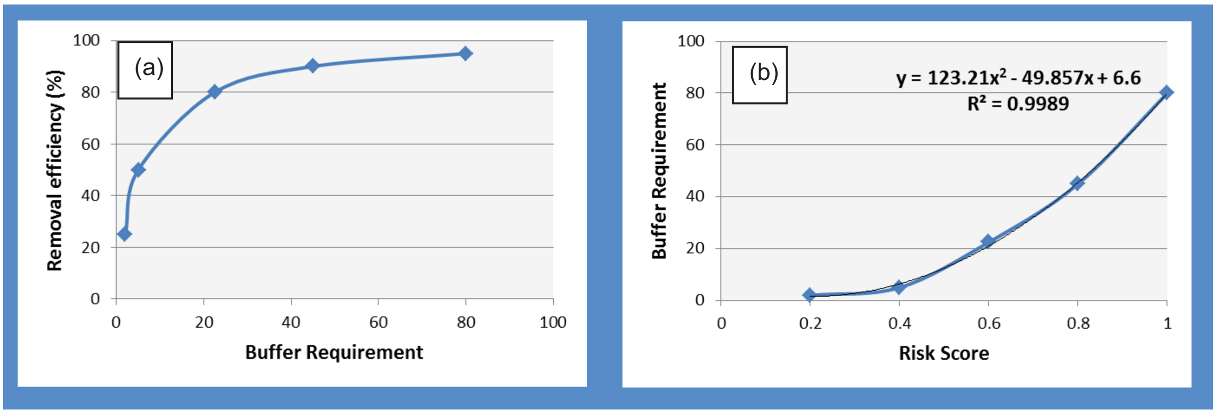

Figure 13 – Relationship between (a) toxic metal removal efficiency and buffer width, and (b) risk of toxic metal inputs and buffer requirements used to calculate aquatic impact buffer requirements

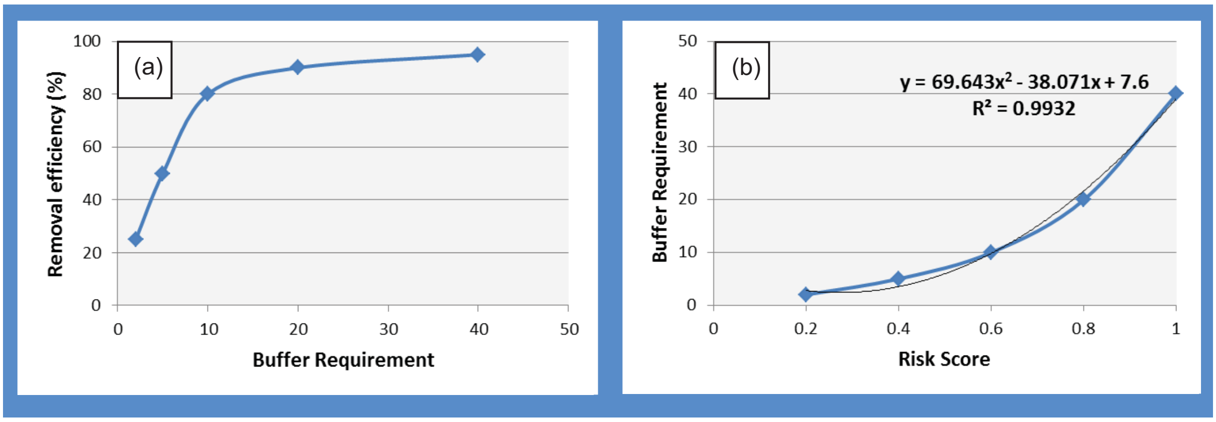

Figure 14 – Relationship between (a) organic pollutants and pesticide removal efficiency and buffer width, and (b) risk of organic pollutants and pesticide inputs and buffer requirements used to calculate aquatic impact buffer requirements

7.8.4 Increased pathogen inputs from lateral sources

Studies undertaken on the effectiveness of buffers in removing pathogens suggest that small buffers may be effective. Based on the information available, maximum recommended buffers for pathogen removal were set at 30 m, reduced to 2 m in the case of low risk activities. Given that research suggests that very small buffers are effective at removing pathogens, a curvilinear relationship was again assumed as illustrated in Figure 15.

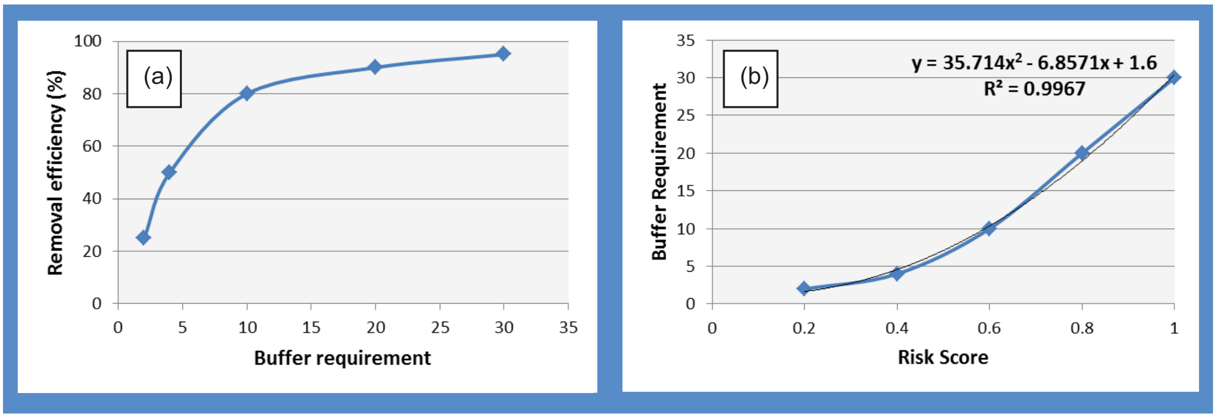

Figure 15 – Relationship between (a) pathogen removal efficiency and buffer width, and (b) risk of pathogen inputs and buffer requirements used to calculate aquatic impact buffer requirements

Site-Based Buffer Zone Tools:

- Initial buffer zone requirements for the construction and operational phases are automatically calculated for each threat type based on risk ratings already calculated.
- The maximum of the buffer widths for construction and operational phase are then used to define initial (desktop) buffer requirements.

7.9 Refine Initial Buffer Requirements Based on Site-based Investigations

Desktop	Site-based
	✓

Although buffer width is widely regarded as the most important factor in determining the level of effectiveness of buffer zones, large variations in effectiveness can be explained by site-specific differences. The characteristics of the buffer zone either detract from or contribute to, specific functions. As such, it is important to consider site-based buffer attributes when determining appropriate buffer requirements.

For the site-based assessment, site-specific buffer characteristics are included and are used to adjust the initial buffer requirements already calculated. Based on the literature review undertaken and practicalities associated with undertaking a buffer zone assessment, four buffer zone attributes were selected to refine buffer zone requirements at a site-level. These are:

- Slope of the buffer.
- Vegetation characteristics.
- Soil permeability.
- The micro-topography of the buffer zone.

The reasons for selecting these criteria for each buffer zone function are included in Annexure 14. Further guidance on undertaking the assessment is provided in the Practical Guide.

Buffer width "modifiers" are defined for each buffer characteristic based on the anticipated effect of possible attributes on buffer zone effectiveness across different buffer functions. These characteristics are rated relative to default or "reference" buffer characteristics[25]. In this manner, buffer requirements are reduced for buffer zones that are particularly well-suited for providing water quality enhancement functions, but increased in instances where buffer zone attributes make the buffer zones less effective.

When undertaking this assessment, variability in buffer zone attributes must be assessed during the site visit using the Practical Guide. **This assessment should focus on buffer characteristics within 50 m of the delineation line from where aquatic impact buffer zones are determined**. In the case of small sites, it should be feasible to describe buffer attributes that reflect typical buffer characteristics for the site as a whole. However, in many instances, there may be significant variability in buffer zone characteristics that need to be accounted for. In such cases, existing **buffer zones should be sub-divided into discrete segments with comparable buffer zone attributes**. Buffer characteristics should then be described by selecting buffer attributes in the Buffer Zone Tool that best reflect local buffer attributes for each buffer segment. In the case of vegetation, buffer attributes should be assessed according to current characteristics for the construction phase. If specific management measures are proposed to rehabilitate or in any other way alter vegetation attributes during the operational phase, these must also be captured in the tool and be specifically addressed as management measures.

A modifier rating for each buffer zone function[26] is calculated automatically in the Buffer Zone Tool based on the defined buffer attributes. This is then used to adjust the initial buffer zone recommendation for each of the buffer segments identified[27].

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[25] "Reference" buffer zone attributes were defined as follows:

- **Slope of buffer**: Moderate (10.1-20%).
- **Vegetation characteristics (basal cover)**: High (dense vegetation, with good basal cover; for example, natural grass stands).
- **Soil permeability**: Moderate. Moderately textured soils (such as sandy loam).
- **Topography of the buffer zone**: Dominantly smooth topography with few/minor concentrated flow paths to reduce interception.

[26] Site-based modifiers are determined by calculating a weighted average of site factors. The weighting applied to each criterion was informed by available literature regarding the importance of different buffer zone attributes in determining buffer zone effectiveness. The following weightings were applied to slope; vegetation characteristics; soil permeability and buffer topography respectively:

- Sedimentation and turbidity (2; 1.5; 1; 1).
- Nutrient inputs (2; 2; 1; 1).
- Toxic organic contaminants (2; 1.5; 1; 1).
- Toxic metal contaminants (2; 1.5; 1; 1).
- Pathogens (2; 1.5; 1; 1).

[27] Maximum buffer zone widths were integrated in the model to limit the possible upper range of buffer recommendations in line with those cited in the literature review (Macfarlane et al., 2009). In the case of sediment retention, a maximum buffer of 125 m is applied, while values of 260 m and 90 m were applied for nutrient and pathogen removal respectively. In the case of toxics contaminant, a maximum of 200 m was applied.

Site-Based Buffer Zone Tools:

- Capture the site attributes for each buffer segment identified.
- Site-based modifier scores are used to refine the initial buffer requirements automatically for each potential threat considered.
- Site-based aquatic impact buffer requirements for construction and operational phases are then automatically calculated based on the maximum of the buffer width requirements for all the threat types considered.

7.10 Identify Additional Mitigation Measures Where Appropriate and Refine the Aquatic Impact Buffer Width Accordingly

Desktop	Site-based
	✓

Although buffer zones are advocated as standard mitigation measure to address a range of threats, they are only one of a suite of mitigation measures that can be used to reduce potential impacts. Pollution prevention, on-site mitigation (such as water treatment/water reuse and reclamation) and effective storm water management controls are regarded as critical for effective mitigation instead of simply relying on buffer zones as a last form of defence. An opportunity is therefore provided for the assessor to identify suitable supplementary mitigation measures that will reduce the threats posed by the development/activities and in so doing, reduce associated buffer zone requirements.

To help practitioners identify suitable additional complementary mitigation measures, various potential mitigation options have been identified from existing literature[28]. These have been consolidated into a user-friendly Excel™-based Mitigation Measures Tool[29]. An overview of the Mitigation Measures Tool is given in Annexure 15. The look-up lists provided in this tool can be used to identify a suite of additional potential mitigation measures for different impact types relevant to the sector of interest.

Once supplementary mitigation measures have been identified, they must be documented. They are typically included in an accompanying specialist report and should be referenced correspondingly in the Buffer Zone Tool. Refined threat ratings can be selected for the affected risks, provided that such a rating is accompanied by an appropriate justification. For risks that have a bearing on buffer zone width, buffer zones are adjusted accordingly to obtain a revised aquatic impact buffer zone requirement.

Site-Based Buffer Zone Tools:

- Consult the “Mitigation Measures Tool” and supporting references to identify potential mitigation measures that could be used to reduce the key risk(s) identified.
- Where relevant, describe additional mitigation measures to be implemented to address risks associated with construction and operational phases of the proposed development/activity (such as part of an accompanying specialist report).
- Where appropriate, select a refined threat rating and document the justification for the revised ratings based on an understanding of the effectiveness of mitigation measures proposed.
- A refined risk rating is automatically calculated, and is used to update buffer zone requirements.
- Consider the need for additional mitigation measures to cater for point-source discharges and potential groundwater impacts and note additional mitigation measures if relevant.

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[28] The Mitigation Measures Tool does not provide a comprehensive list of mitigation measures but includes references to some 69 reports and guidelines all prepared prior to 2010. Users should therefore also be aware of other additional guidelines such as The South African Guidelines for Sustainable Drainage Systems (Armitage et al., 2013) and consult these as needed.

[29] The Mitigation Measures Tool (https://sites.google.com/site/bufferzonehub/).

7.11 Review and Refine Aquatic Impact Buffer Requirements to Cater for Practical Management Considerations

The Buffer Zone Tool provides a recommended buffer width to address potential risks from adjacent land use activities. Nonetheless, it is essential that buffer zones cater for risks of buffer zone failure and are sufficiently wide to allow the buffer and any important attributes to be managed and maintained. A fixed minimum buffer width of 15 m was recommended in the preliminary guideline for determining the buffer zone. However, participants at the national training and development workshops called for a review of the fixed minimum buffer width as they were in favour of a risk-based approach to minimum buffer widths.

A review of international literature was conducted to determine best practice in terms of minimum buffer zone requirements to allow for effective management and maintenance. This highlighted that buffer widths less than 10 m were sufficient to mitigate low impacts from adjacent developments (Zhang et al., 2009). However, it was considered that these widths were too narrow for management and maintenance, and would degrade over time. Participants in the national training and development workshops supported the view that buffer zones less than 10 m were inadequate because of the high risk of mismanagement.

According to the rule curves developed (Annexure 13), a 10 m buffer would be effective for trapping approximately 70% of sediments, 60% of nutrients, 60% of heavy/toxic metals, 80% of organic pollutants and pesticides, and 80% of pathogens. These are above the required effectiveness of 50% for activities with a low threat rating (assuming a well-vegetated buffer, flat slope and well-drained soils). An absolute minimum of 10 m was considered acceptable and manageable by most participants at the national training and development workshops for land use/activities deemed to have an anticipated low impact on water resources. Considering the effectiveness of a 10 m buffer zone, a range of minimum buffer widths of 10-25 m, increasing in 5 m increments, was considered acceptable to address minimum buffer zone requirements across all sub-sectors. A list of the minimum buffer widths recommended across all sub-sectors is provided in Annexure 16 and should be adhered to in most situations.

In addition to minimum buffer widths, consideration should also be given to provide additional protection to riparian habitats. This is particularly relevant when a determined aquatic impact buffer zone does not extend beyond the edge of a riparian zone, or is situated right on the edge of a riparian zone. In these instances, expanding the buffer zone is recommended to ensure the land use/activity does not encroach into the riparian habitat. A minimum management zone of 5 m is recommended for all developments regarded as having a low risk of encroachment and disturbance. A management zone of at least 10 m is recommended when the threat of the development is anticipated to be high or very high.

7.12 Evaluate Aquatic Impact Buffer Zone Requirements in Light of Management Objectives

Desktop	Site-based
	✓

For the purposes of this guideline, mitigation guidelines have been developed to reduce potential risks to a desirable level such that water resource quality should not be compromised. There may, however, be an argument to increase or reduce mitigation requirements in line with management objectives or special local circumstances. Table 25 provides guidelines for interpreting these requirements.

Table 25 – Guideline for identifying appropriate management and mitigation measures

Management Objective	Guidelines for Identifying Mitigation and Management Measures
Improve	Any potential risks must be managed and mitigated to ensure that no deterioration to the water resource takes place. In addition, relevant on-site management measures should be identified to help improve the present state of the water resource (for example, through rehabilitation interventions).

Management Objective	Guidelines for Identifying Mitigation and Management Measures
Maintain	Any potential risks must be managed and mitigated to ensure that no deterioration to the water resource takes place. Standard management measures should be implemented to ensure that any ongoing activities do not result in a decline in water resource quality. Consideration should also be given to the rehabilitation of watercourses where feasible.
Controlled degradation	It may be permissible to impact the water resource by implementing less stringent management or mitigation measures. Where relaxation of requirements is proposed, these would first need to be authorised by the relevant implementing authority to prevent undue deterioration of the water resource.

Although not advocated, should relaxation of buffer widths be proposed, the potential reduction in buffer zone effectiveness can be estimated based on an understanding of the relationship between buffer width and buffer zone effectiveness as described in this document[30]. This could be used by the DWS to the degree to which relaxation of buffer zones may be acceptable, and to motivate for introducing further supplementary mitigation measures.

Where an improvement in water resource quality is required, standard buffer recommendations are appropriate but may be increased when a greater level of confidence is regarded as necessary. However, it is the implementation of additional management measures (both at the site and catchment level) that is likely to improve water resource quality.

Note: It should be left up to the relevant authorities to review and/or motivate for a change in buffer requirements based on management objectives. As such, recommended aquatic impact buffer zones should be documented without specifically considering management objectives.

[30] There may be some instances where a convincing argument can be made for following a less conservative approach than advocated in these guidelines. For example, an isolated lodge may be proposed on the edge of a large natural lake within a protected area where no further development is proposed. In this instance, the risk that pollutants from this isolated development would have a significant impact on the water resource with high assimilative capacity is likely to be low. Setting a precedent to other developers is also not an important consideration in this instance. In such an instance, recommended final buffer zone areas should be documented as per this guideline. A motivation for relaxing these requirements should then be provided by the aquatic specialist in the specialist aquatic report for the proposed development.

8 STEP 5: ASSESS RISKS POSED BY PROPOSED DEVELOPMENT ON BIODIVERSITY AND IDENTIFY MANAGEMENT ZONES FOR BIODIVERSITY PROTECTION

Although the protection of riparian areas and aquatic impact buffer zones may be adequate to protect many aquatic species, these buffers may be insufficient to protect a range of aquatic and semi-aquatic species that rely on terrestrial habitat for their survival. Indeed, the review of international literature found that, in general, significantly larger buffers are required to protect biodiversity that is dependent on water resources than those buffers adequate for providing water quality protection (as illustrated in Figure 16).

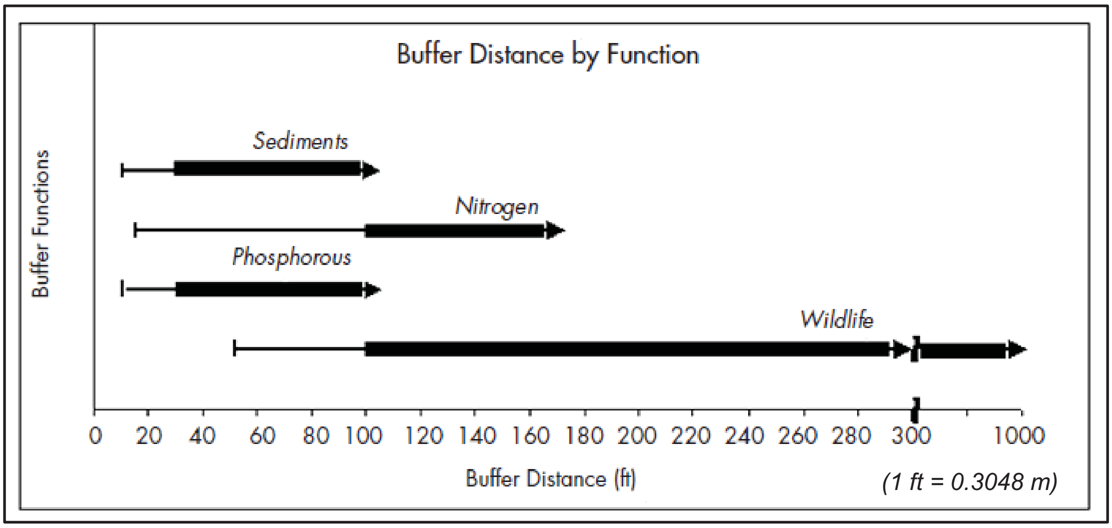

Figure 16 – An illustration of the significant difference between reported biodiversity buffer requirements and water quality protection requirements (Nichols et al., 2008)

There are several examples in international literature where buffers are simply calculated as a horizontal distance from the aquatic resource boundary, but such an approach does not cater for several important considerations. These include:

- **The location of critical habitat for the species within the aquatic resource**: For some species, this may be a small reed bed, an area of permanent wetland or open water. Under such a scenario, simply buffering the entire water resource would overestimate conservation requirements for the species.
- **Specific terrestrial habitat requirements of semi-aquatic species**: Some species are likely to have specific habitat requirements that may not be protected adequately by applying a fixed-width buffer area around the resource. For example, crowned cranes specifically forage in grassland areas around nest sites, avoiding wooded or transformed habitats. Identifying and protecting suitable grassland habitats within a reasonable distance from the nest site would therefore be critical for this species to survive.
- **The condition of adjoining habitat**: In some circumstances, very little natural habitat may remain and, despite these areas being located a little distance from the aquatic resource, residual fragments of natural habitat may be critical for the species to survive. Inclusion of degraded areas in a buffer zone developed without consideration may therefore provide little benefit for a species.

Rather than simply allocating arbitrary buffers around water resources, a more scientifically correct approach is presented. This includes identifying core habitat and considering a range of other protection measures to limit impacts from adjoining land uses/activities on these core habitats.

This assessment should be undertaken in parallel with the assessment of risks posed to the state and functionality of the water resource in Step 4. The guidelines presented here have been tailored for aquatic and semi-aquatic species, which rely, at least in part, on water resources for their persistence.

The approach is, however, equally relevant to terrestrial species, for which a similar assessment should be undertaken.

Note: Undertaking this assessment may be quite arduous for a developer with financial constraints and where there are potentially minor impacts to water resources. The need for following this process should therefore be informed by relevant criteria that include:

- The type and scale of the proposed development.
- Anticipated risks associated with the development.
- The importance of the area for biodiversity conservation.

In some situations, it may be appropriate for the local authority or provincial conservation body to undertake such an assessment at an appropriate scale and to identify appropriate zones for biodiversity protection. This would certainly have significant cost advantages over numerous site-based assessments, where risks of not considering landscape-level processes and interactions are also high. Such an approach would be particularly useful in development nodes where future applications with a potential impact on biodiversity are anticipated.

8.1 Undertake a Desktop Assessment to Determine Whether There are Important Biodiversity Elements

Desktop	Site-based
	✓

The first step required is determining the potential occurrence of important biodiversity elements that could be impacted by the proposed development. Important elements may include, amongst others, threatened vegetation types, threatened animal or plant species, or significant concentrations of an important species. For a list of important biodiversity elements, users should liaise with provincial conservation bodies to obtain a list of priority species and ecosystems requiring protection. This requires a desktop assessment of available information, including consultation with local stakeholders (such as landowners, conservancies and birding clubs). Key sources of information that should be consulted include:

- Existing biodiversity surveys undertaken in the area.
- Provincial and local conservation plans for the area.
- Maps of national freshwater priority areas.

If no biodiversity elements have been flagged through this investigation, no further assessment is required unless specifically requested by a key stakeholder (namely, provincial conservation body or interested and affected parties). Where important elements have been flagged, further effort is required to determine whether they occur at the site and what mitigation measures are necessary to protect them.

For biodiversity elements that have been flagged, information sheets, where available, should be obtained from provincial conservation bodies. Examples of draft information sheets for a range of biodiversity features have been included in Annexure 17. These information sheets have been designed to facilitate the assessment process, and include the following information:

- **Scientific and common names**.
- **Description**: A description of the species to facilitate identification, including key features that distinguish the species from similar species. Where appropriate, reference is provided to other documents with more detailed descriptive information.
- **Conservation status**: This section documents the conservation status (both nationally and internationally) together with a description of relevant criteria that informed the threat status at a national level. Any information on legislation governing protection of the species, such as national threatened or protected species listing or provincial legislation, together with any permit requirements, is also included.

- **Distribution**: A description of the species' distribution range is provided. Where possible, this should include a map of known and potential occurrence within South Africa. For migratory species, appropriate descriptive information and a link to a broader distribution map must be provided where appropriate.
- **Current level of protection within protected areas**: This section provides an indication as to the degree to which conservation requirements (targets) for the biodiversity element are already accounted for through an existing protected area network. This should inform the need for additional protection of remaining sub-populations.
- **Key threats to the species:** Key threats to the species identified at a national/provincial level are included to flag issues of potential concern.
- **Priority actions required to protect the species:** Key actions/management priorities, which are required to protect the species at a provincial/national level, are documented. This includes a consideration of the need/importance of protecting sub-populations outside of protected areas.
- **Guidelines for species surveys**: Relevant guidelines to inform survey requirements linked to the ecology of the species are provided in this section. This may include appropriate seasons for sampling, reference to appropriate survey techniques and the level of expertise required to undertake the survey. Additional information such as bird or frog calls, and track and scat descriptions are also included where possible.
- **Description of core habitat characteristics:** This includes both areas where the species occurs and associated areas required for the species to persist. Key habitat characteristics required for the species to live, breed and persist are identified. These requirements differ for different specie groups and are therefore tailored accordingly. This information is provided to help direct survey efforts, and to identify key areas of habitat requiring protection to ensure the persistence of the species.
- **Guidelines for identifying and mapping core areas:** Guidelines are provided to guide decision-making to protect of sub-populations of the species encountered. This may include, for example, information on recommended minimum patch size or the need to limit development within a distance from breeding areas to facilitate other life history activities (such as foraging/hibernation).
- **Sensitivity to potential site-based impacts:** Sensitivity of the species to potential site-based impacts is provided to inform development planning and associated activities. These may include:
    - Sensitivity to direct disturbance (such as human presence, noise, dust, light, physical disturbance) from peripheral development or associated activities (such as tourism activities) that need to be considered to ensure the species is not unduly disturbed.
    - Sensitivity to pollutants that could have a direct effect on the species (for example, pesticides, nutrients and salts). These may be higher than the sensitivity of the water resource per se, potentially requiring the implementation of more stringent mitigation measures than those necessary to protect the water resource.
    - Sensitivity to factors that may affect species habitat (for example, alteration of hydrological regimes and burning practices).
- **Key management considerations**: Management measures necessary to maintain the functionality of core habitats that need to be considered are highlighted. This includes aspects such as fire management, livestock management, management of tourism or recreational activities.
- **Relevance of corridors for species persistence**: An indication of the likely importance of establishing corridors between sub-populations for the persistence of the species is provided.
- **Corridor design requirements**: Where corridors are regarded as important, guidance to inform corridor design is provided.
- **References**: A list of key references used to develop the information sheet is provided.

Note: There is a clear need for information sheets to be generated for all relevant biodiversity features to assist in undertaking this assessment. It is hoped that provincial conservation bodies will take responsibility for drafting and maintaining these documents. This would substantially improve biodiversity assessments by ensuring that appropriate guidance is available to inform decision-making. Where such information is lacking, relevant information will need to be obtained from available literature to guide the assessment.

Site-Based Buffer Zone Tools:

- Note whether any important biodiversity elements have been flagged for specific consideration.

8.2 Undertake a Survey to Verify and Establish the Need for Site-based Conservation Efforts If There are Important Biodiversity Elements

Desktop	Site-based
	✓

Where the desktop assessment has flagged the potential occurrence of important biodiversity features, a survey must be undertaken to assess whether the species occurs at, or near, the proposed development site. The scope, timing and survey methods should be guided by an understanding of the ecology of the species being investigated. Where possible, such information should be included in species information sheets. Depending on the potential importance of connectivity, consideration should also be given to extending surveys beyond the immediate site location to assess whether corridor design is likely to be necessary.

Site-Based Buffer Zone Tools:

- Note if a survey has been undertaken to verify occurrence and to establish the need for conservation efforts within the development planning.

8.3 Identify Core Areas Required to Protect any Important Biodiversity Features

Desktop	Site-based
	✓

The primary role of identifying areas of core habitat is to ensure that such areas are set aside and managed in an appropriate manner to secure the persistence of important biodiversity elements. A definition for core habitat is provided, together with a description of key buffer functions that would be provided for aquatic and semi-aquatic species by such areas (Table 26).

Core habitat: The area of natural habitat essential for the long-term persistence of a species and processes in its current distribution range.

Table 26 – Key buffer functions provided by a core habitat

Buffer Function	Description
Maintenance of habitat for aquatic species	Vegetation along stream lines provides food that supports in-stream food chains. These areas are therefore vital for a range of aquatic species that are dependent on these resources for their survival.
Provision of habitat for semi-aquatic species	Many semi-aquatic species rely on both aquatic habitats and terrestrial areas to successfully recruit juveniles and to maintain optimal adult survival rates. Such areas are therefore necessary to meet the living requirements of these species and thus enable such species to persist in the area.

Identifying areas of core habitat for important biodiversity elements necessitates a sound understanding of living needs of important species and processes, which are required to ensure the maintenance of important ecosystems and habitats. Only a small number of experts are typically privy to this knowledge, so, if it is not captured in a meaningful way, specialist input would be required wherever such species were identified. Interpretation of living requirements amongst 'experts' is also likely to vary, which could lead to differences in approaches under different scenarios. Guidelines for identifying and mapping such areas have therefore been included in information sheet templates. These must be used to help identify areas of core habitat and to map out the area required to ensure that species persistence is promoted. Where such information is not available, requirements will need to be established through a literature review and consultation with relevant specialists and conservation agencies.

Site-Based Buffer Zone Tools:

- Note if core areas required to protect any species of conservation concern have been identified and mapped.

8.4 Review and Update Aquatic Impact Buffer Requirements Based on Sensitivities of Any Important Biota Identified

Desktop	Site-based
	✓

Although the establishment of suitable core areas is designed to cater for habitat requirements of important species, this may not specifically address threats posed by diffuse source pollutants from planned land uses/ activities. It is therefore necessary to reassess the sensitivity scores used to define aquatic impact buffer requirements and to adjust these where necessary to account for the susceptibility (sensitivity) of biodiversity elements to lateral impacts. For example, the sensitivity of a floodplain system to sediment inputs may be low, but an important population of endangered plant species may occur down-slope of the proposed development, which could potentially be impacted significantly if there are not stringent sediment control measures in place. In this case, the buffer zone should be adjusted outwards to ensure appropriate protection of this plant community. This is accounted for in the Buffer Zone Tools by selecting a higher sensitivity class for biodiversity where this is relevant and providing an appropriate justification. This refined sensitivity score is then used to refine aquatic impact buffer requirements.

Site-Based Buffer Zone Tools:

- In instances where the sensitivity of biota is likely to be higher than that of the water resource, rate the sensitivity and provide a written justification for increasing the sensitivity to cater for any important biodiversity elements including special habitats and species of conservation concern.

8.5 Identify any Additional Biodiversity Buffer Requirements

Desktop	Site-based
	✓

Identification of areas of core habitat is necessary to ensure the persistence of important biodiversity elements. However, these areas may be prone to disturbance and degradation from adjacent land use/activities. Disruption of natural wildlife activities, such as feeding, breeding and sleeping, and negative impacts on habitat quality can affect wildlife survival adversely. The degree to which wildlife is affected by disturbance is dependent upon many factors, including intensity of the disturbance, duration, species, and the life-cycle stage of the species.

The flushing of birds due to human presence is one example of the impact of disturbance on biota. Such disturbance may cause birds to leave their nests, which can cause clutch failure or the abandonment of the nest altogether, thereby reducing breeding success of the species.

There may, therefore, be a need to apply additional biodiversity buffers to important biodiversity features including core areas and corridors, to ensure that these areas continue to provide valuable biodiversity functions. A working definition for biodiversity buffer zones, together with a description of key functions that would be provided by such areas, is included in Table 27.

Biodiversity buffer zone: A buffer zone designed to adequately mitigate adverse effects of adjacent land use activities on important biodiversity features.

Table 27 – Description of key biodiversity buffer function

Buffer Function	Description
Screening of adjacent disturbances	Anthropogenic disturbances to aquatic and semi-aquatic species may be direct, such as human presence and traffic, or indirect, such as noise and light. Disruption of natural wildlife activities, such as feeding, breeding and sleeping, and negative impacts on habitat quality can adversely affect wildlife survival. Biodiversity buffers can mitigate these impacts, thereby maintaining values of important biodiversity features.

The width of the biodiversity buffer should be informed by the specific threats identified and the sensitivity of the species or habitat to disturbance. In the case of species of conservation concern, the need for additional biodiversity buffers should be informed by species information sheets, where available, or with appropriate specialist input.

Site-Based Buffer Zone Tools:

- Note whether any additional biodiversity buffers have been defined to protect core areas and important habitat from outside disturbances.

8.6 Assess the Need for Connectivity and Delineate Corridors Where Appropriate

Desktop	Site-based
	✓

Maintaining connectivity is another key consideration which can rarely be addressed at local site scale only. Landscape-scale corridors are typically identified in regional conservation plans but need to be considered at a site scale to ensure that these linkages are not undermined by narrowly focused site-level planning. Such areas are often hundreds of metres wide and are designed to provide functions over an extended period (Bennett, 2003). Finer scale local corridors are also important for local species movement and may be particularly important for linking habitats of threatened species and in so doing, improving dispersal between sub-populations which is important for long-term persistence. A definition for biodiversity corridors is included, together with a description of key functions that would be provided by such areas (Table 28).

Biodiversity corridor: Typically, linear habitats that differ from a more extensive, surrounding matrix, designed to link one or more patches of habitat to improve species movement and dispersal.

Table 28 – Description of key biodiversity corridor function

Buffer Function	Description
Habitat connectivity	Buffers along water resources provide potentially useful corridors, allowing the connection of breeding, feeding and refuge sites crucial for maintaining the viability of populations of semi-aquatic species.

Where there are opportunities for creating or enhancing corridors on a particular site, corridor design should be undertaken with due consideration of particular species, particularly where rare, threatened or endangered species are known to use the area. The seven-step approach, as described in Annexure 18, can be used as a guideline for ecological corridor design:

- **Step 1** • **Identify priority species requiring protection**
- **Step 2** • **Understand the biology of the priority species identified**
- **Step 3** • **Assess whether there are other viable patches in the surrounding landscape that support priority species**
- **Step 4** • **Identify focal species for further consideration**
- **Step 5** • **Evaluate feasibility for implementing corridors**
- **Step 6** • **Refine the list of focal species based on the availability of suitable corridor options**
- **Step 7** • **Design the ecological corridor**

Note: Provincial conservation agencies should be consulted regarding local and landscape-level corridors to ensure that these are not undermined during site-level planning.

Site-Based Buffer Zone Tools:

- Note whether the planned development/activity could affect an important local or regional ecological corridor.
- If connectivity is important, note whether corridor design guidelines have been considered when defining corridor requirements.
- Note if terrestrial habitat protection and management have been considered.

9 STEP 6: DELINEATE AND DEMARCATE FINAL BUFFER ZONE REQUIREMENTS

Once protection requirements for water resources and associated biodiversity have been established, the buffer zone requirements have to be finalised and delineated on a layout plan and in-field. Final buffer zone requirements must also cater for a range of other potentially important management, functional and legal requirements.

Desktop	Site-based
	✓

9.1 Delineate the Boundary of Water Resources

Water resource boundaries must be mapped according to the guidelines provided in Section 5.1 of this report. This area effectively represents the preliminary 'no-go' area for development.

Site-Based Buffer Zone Tools:

- Note whether the water resource boundary has been delineated.

9.2 Map the Extent of Aquatic Impact Buffer Zones

Once the starting point for mapping aquatic impact buffers has been delineated (Section 5.2), aquatic impact buffer requirements must be mapped to indicate the implications of buffer requirements for development planning. In most cases, this will simply entail mapping the maximum of buffers recommended for construction and operational phases. There may however, be instances where a narrower buffer is permissible during the construction phase (for example, to account for sediment risk associated with site clearing) and this should be mapped separately from a larger operational buffer (defining final buffer requirements for actual infrastructure).

In cases where the initial site-based buffer requirement has been refined by identifying additional mitigation measures, it is recommended that both the initial buffer and refined buffer recommendations (with mitigation) are mapped. The process is aided considerably using GIS, which has tools for buffering mapped features based on a specified width (see Practical Guide). Note that the calculated buffer widths are based on horizontal rather than diagonal distance as illustrated in Figure 17.

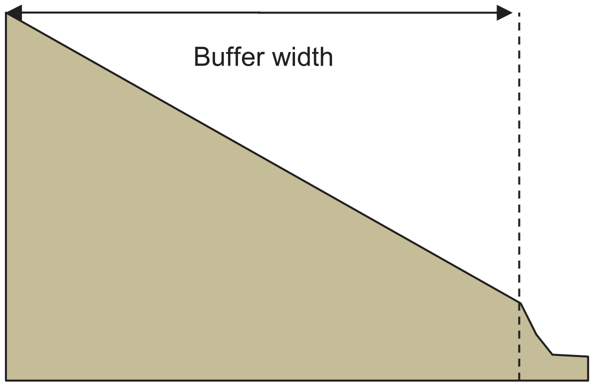

Figure 17 – Cross-section through a slope next to a water resource showing how to measure buffer zone widths

Site-Based Buffer Zone Tools:

- Note whether final aquatic impact buffer zones have been mapped.

9.3 Map Final Buffer Zone Requirements for Water Resource Protection

The final buffer zone requirements are not only dictated by requirements for minimising impacts of pollutants on the water resource. No development is typically permitted within the water resource boundary. Therefore, final buffer zone requirements are effectively determined by the maximum distance of the water resource boundary (including riparian habitat), or the aquatic impact buffer zone required to protect the water resource. There may also be a need for including additional management buffers such as those recommended along the edge of riparian areas. Figure 18 indicates an active channel, riparian zone, recommended aquatic impact buffer zone and final recommended buffer zone for a proposed residential development planned alongside a river system.

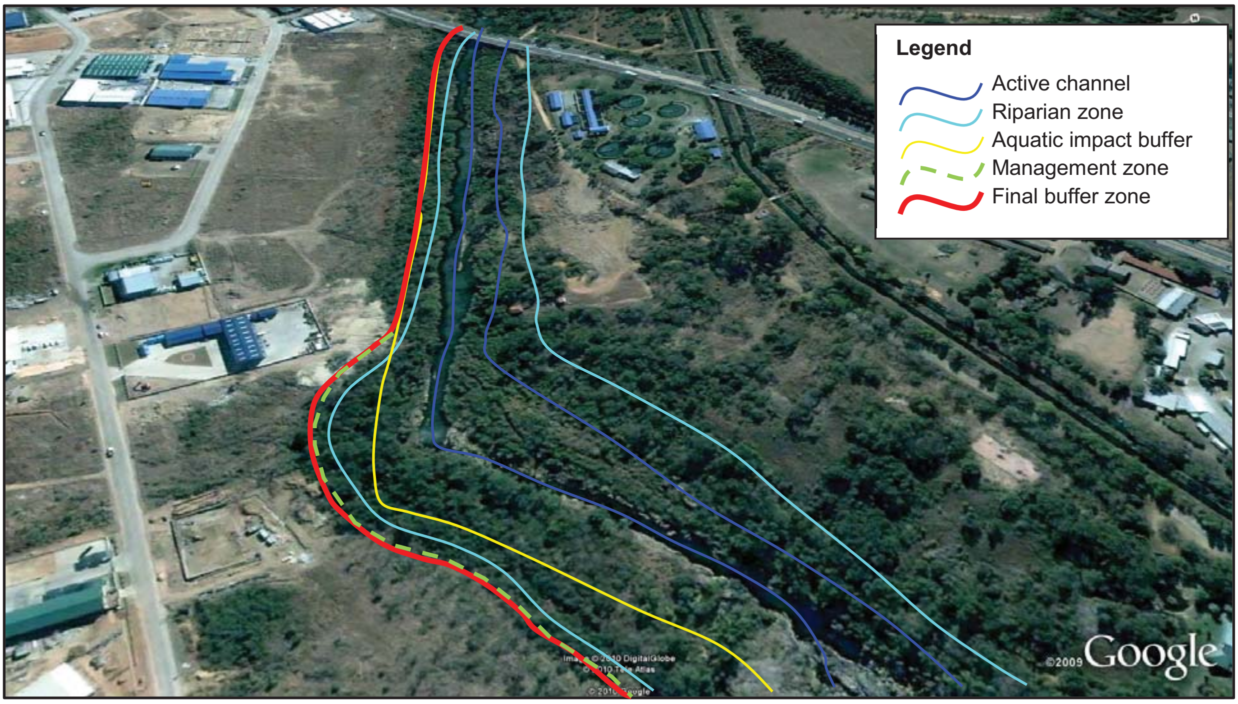

Figure 18 – Example 1 of buffer zone requirements for water resource protection

Figure 19 shows an example of a map indicating the edge of the supratidal zone, estuary boundary (5 m AMSL), recommended aquatic impact buffer zone and final recommended buffer zone requirement for a proposed residential development planned alongside an estuarine system. Note that buffers for any adjoining wetland or river features extending beyond the estuarine boundary would need to be assessed separately and included in the final layout plan.

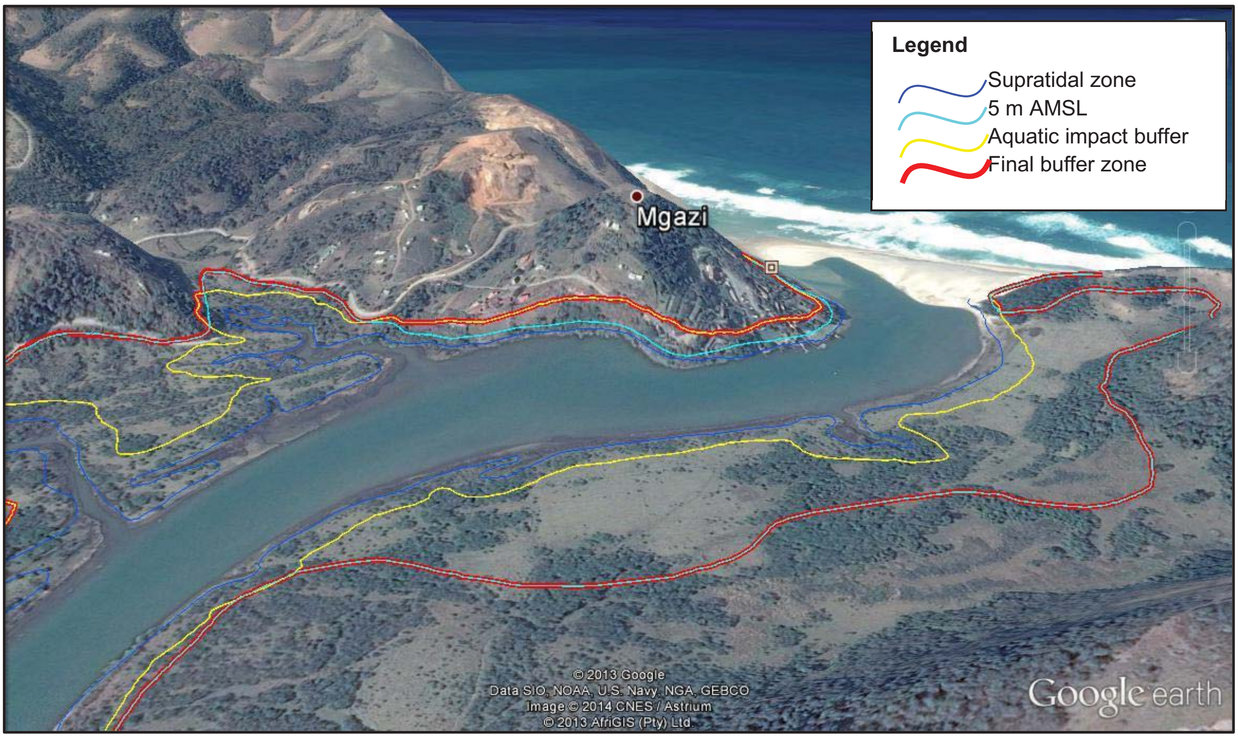

Figure 19 – Example 2 of buffer zone requirements for water resource protection

Site-Based Buffer Zone Tools:

- Note whether final buffer zone requirements for water resource protection have been delineated according to these requirements.

9.4 Map Zones for Biodiversity Protection

Once zones for biodiversity protection have been identified, these and the proposed layout plan must be included on a map. This includes the extent of core areas, proposed biodiversity corridors and biodiversity buffers.

Desktop	Site-based
	✓

Site-Based Buffer Zone Tools:

- Note whether core areas, biodiversity buffers and biodiversity corridors have been mapped.

9.5 Ensure That Additional Factors Have Been Considered Before Finalising Buffer Zone Requirements

There are a range of additional factors that have bearing on where developments may take place around targeted water resources. Considerations will vary from case to case, and the following key factors should be considered:

Desktop	Site-based
	✓

- **Hydrological buffers**: Where there is a risk of planned developments having a negative impact on groundwater, it may be necessary to establish hydrological buffers to reduce the risk of drawdown or pollution of groundwater resources[31]. Guidelines for determining this hydrological buffer or protection zone are included in the Groundwater Resource Directed Measures (Parsons and Wentzel, 2007). Provision is also made for determining protection zones to cater for anticipated impacts from on-site sanitation that can affect water resource quality and cause health impacts to communities (Parsons and Wentzel, 2007; Dennis et al*.,* 2013).
- **Flood risk and climate change**: Local policies may require flood lines to be determined, which may impose restrictions in addition to those required to maintain water resource quality. These restrictions are typically applied to address potential impacts on the welfare, health or safety of human beings or to property in the downstream area. In many instances, the use of the 100-year flood line may be applied, but the effects of climate change will add to the challenges of managing water resources and flood risks to local communities. The development of final buffer areas should therefore ideally also provide "adjustment space" to cater for anticipated future flood risks. Such guidance should ideally be integrated in local policies and by-laws, particularly in urban areas where increased flood peaks are likely to be a significant concern in future (see note).
- **Practical management considerations**: In some instances, it may be necessary to increase the size of the buffer zone to accommodate access (such as a management road or walkway) or to include adequate space for firebreaks to be established. This is particularly relevant in circumstances where the buffer zone habitat is prone to outside disturbance or requires regular fire management to maintain the vigour of indigenous vegetation[32]. There may also be a strong motivation to establish a management buffer to prevent damage to important intact areas including indigenous riparian areas (see Section 7.11). Examples of where this should be considered include:

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[31] Ramsar guidelines suggest that boreholes should not be located close to the wetland where the cone of depression would reduce water levels in the wetland and cause degradation of ecological character (Ramsar Convention Secretariat, 2010).

[32] This is typically the case in forestry areas where buffers need to be wide enough to facilitate burning without such activities placing an unacceptable risk on plantation areas. It is also important in urban areas where risks of burning needs to be appropriately accounted for, to ensure that people and property can be adequately protected.

- **Forestry activities** where felling of trees and other operational activities could damage adjacent habitat[33].
- **Industrial** or similar activities where a physical barrier is required to limit the risk of machinery impacting important conservation areas.
- **Special habitats:** Additional buffer zone guidelines may also be applicable for particular habitats. For example, guidelines for forest buffers are contained within the draft Guidelines for Biodiversity Impact Assessment in KwaZulu-Natal (KZN) (EKZNW, 2011). These guidelines recommend that buffer widths ranging from 20 m to 200 m are established for different forest types (measured from the forest edge). In such instances, the final buffer zone area requirements may need to be adjusted considerably from those initially identified.
- **Aesthetic considerations**: Buffer zones can screen undesirable views and enhance visual quality and appreciation, thereby increasing property values, particularly in urban areas. There may therefore be occasions where the final buffer zone requirements are adjusted for aesthetic purposes.
- **Recreational use**: The availability of open space associated with buffer zones provides opportunities for a range of recreational activities. This is particularly important in urban areas where availability of open space is often lacking.

A note on the use of the 100-year flood line: The 100-year flood line is considered the minimum standard for flood management (Holmes and Dinicola, 2010). It was thought to represent an intermediate flooding level that would alert planners and property owners to the effects of even greater floods (National Academies Keck Centre, 2004). However, the 100-year flood line suffers from many drawbacks that limit its applicability. These include major differences in the flood-height range between locations, lack of consideration of floods that exceed the standard and lack of consideration of over-floodplain flow velocities (Holmes and Dinicola, 2010). In light of these limitations and the expected increase in extreme flooding events under climate change (Loukas et al., 2002; Nicholls, 2004), a call for a higher standard seems to be inevitable. Already, a simulation study has found that the 100-year flood line is likely to be significantly reduced to 10-50 years because of the effects of climate change (Lehner et al., 2006).

A note on mining: Mining is recognised as an activity with potentially high risks to water resources. A number of these risks are not addressed by these buffer zone guidelines, as these guidelines focus primarily on mitigating impacts from diffuse source pollutants in surface run-off. For example, the guidelines do not specifically address impacts of mining on groundwater and hillslope hydrological processes, which may be important aspects to consider when establishing final buffer requirements. It is therefore critical that final buffer requirements for mining activities are informed by supplementary geohydrological and hydropedological studies, where necessary.

It is also important to note that exemption from regulations on the use of water for mining and related activities (published under Government Notice 704 in Government Gazette 20119) will be required for any mining-related activity planned within the 1:100-year flood line or within a horizontal distance of 100 m from any watercourse or estuary.

Site-Based Buffer Zone Tools:

- Note if any of these have been considered when establishing final buffer zone requirements.

[33] The Forestry South Africa Environmental Guidelines (Forestry South Africa, 2002) recommend that a buffer of at least 5 metres should not be planted around the edge of an indigenous forest (including riparian forest). This buffer should be kept free of weeds and the indigenous vegetation which exists or regenerates must be protected. The guidelines further recommend that where there is potential for damage during operational activities, the boundaries should be increased. Once established, the guidelines suggest that no other activities or roads should be established in these buffer zones.

9.6 Finalise Buffer Zone Requirements with Motivations for Any Deviations from These Guidelines

Desktop	Site-based
	✓

There may be instances where there is strong motivation for encroaching on recommended final buffer zone areas. These may be linked to the management objectives of the water resource or directly to aspirations of a development proposal. Any plans of such a nature should be appropriately assessed, motivated and indicated on a revised layout plan. This should include due consideration of the mitigation hierarchy requiring developers to avoid and minimise impacts as far as possible prior to considering options that will impact on water resources and are not aligned with best practice guidelines.

9.7 Map Recommended Final Buffer Zone Requirement Based on the Maximum Width for Water Resource, Biodiversity Protection and Additional Considerations

Desktop	Site-based
	✓

Final recommended buffer zone requirements should be delineated on the layout plan based on the maximum widths required for water resource or biodiversity protection and any other local considerations.

10 STEP 7: DOCUMENT MANAGEMENT MEASURES NECESSARY TO MAINTAIN THE EFFECTIVENESS OF THE FINAL BUFFER ZONE AREAS

Desktop	Site-based
	✓

Once a final buffer zone area has been determined, appropriate management measures need to be documented to ensure that the water quality enhancement and other buffer zone functions, including biodiversity protection, are maintained or enhanced. These measures should ideally be integrated in the environmental management plan[34] (EMP) for the proposed development, as it includes a requirement to assign clear responsibilities for buffer zone management at both the construction and operation phases. Although management measures will be specific to each site, some guidance is provided to ensure that management measures cater adequately for key buffer zone functions.

10.1 Demarcate Designated Buffer Zones

The clear delineation and marking of a buffer zone is a critical first step for ensuring that it is not degraded over time. Therefore, once a project has been approved, and prior to construction, the buffer zone should be measured and clearly marked on the ground. This can take various forms and may be integrated with supplementary mitigation measures, such as the erection of a temporary silt fence to help reduce the volumes of sediment washed into the buffer zone during the construction phase. During the operational phase, it may be desirable to erect a permanent fence, particularly in an urban environment where uncontrolled human access could trample vegetation causing subsequent erosion. Active exclusion may also be appropriate in intensive livestock operations where overuse could lead to a reduction in vegetation condition and stream bank collapse. Where buffer zones are established with a clear emphasis on biodiversity protection, fencing off the boundary may also be important to reduce noise and light intrusion and to limit direct disturbance to wildlife.

Placement of signage along the boundary of the buffer zone should also be considered to help mark the boundary and to educate landowners/stakeholders about the purpose and value of protecting buffer zones (Granger et al., 2005). In areas where there is the potential for human disturbance and degradation of the buffer, more extensive signage explaining the value of the buffer may be necessary to help develop support for its protection. In addition to signage, it may be necessary to engage with stakeholders to explain the reasons why the buffer and the water resource are protected and what human activities are allowed.

Site-Based Buffer Zone Tools:

- Note whether due consideration has been given to the demarcation of buffer zones.

10.2 Document Management Measures to Maintain or Improve the Functional Value of Aquatic Impact Buffers

Desktop	Site-based
	✓

Once an aquatic impact buffer zone has been determined, management measures need to be documented to ensure that water quality functions are maintained or enhanced. In practice, this means that vegetation attributes, soil permeability (and infiltration) and the micro-topography of the buffer zones must be managed appropriately during the construction and operational phases.

Generally, for buffer zones to function effectively, they should be well-vegetated, ideally with indigenous vegetation. The priority here should be to ensure that any rehabilitation requirements are successfully implemented prior to construction (particularly if this was the basis on which smaller buffer zones were

[34] An EMP can be defined as "*an environmental management tool used to ensure that undue or reasonably avoidable adverse impacts of the construction, operation and decommissioning of a project are prevented; and that the positive benefits of the projects are enhanced*". EMPs are important tools for ensuring that the management actions arising from environmental impact assessment processes are clearly defined and implemented through all phases of the project life cycle (Lochner, 2005).

advocated). In other cases, vegetation may be quite well established but there may be opportunities for enhancing key functions through further interventions. These could include:

- Improving the screening and habitat value of the buffer by planting additional trees and shrubs.
- Replacing established vegetation with indigenous vegetation appropriate to the vegetation type for the ecoregion.
- Including zones of dense vegetation, such as vetiver filter strips, to assist sediment trapping and water quality enhancement functions.

The key point is that buffer zone vegetation and soil attributes must be maintained in a reasonable state to remain effective. Management measures should be documented carefully to ensure that buffer zone effectiveness is not undermined by poor management or undesirable activities. Typical threats to buffer zone areas that have to be considered when defining management measures include:

- Access and use by local communities.
- Overgrazing and trampling by livestock.
- Transformation (such as new infrastructure).
- Alien plant encroachment.
- Undesirable burning regimes.

A note on storm water management in urban areas: Storm water management is a critical element of urban planning. Without appropriate planning and management, storm water can have significant impact on water resources. However, carefully designed and managed buffer zones can contribute to a highly effective storm water management system. This requires a shift away from conventional storm water management towards more holistic approaches as advocated in the South African Guidelines for SuDS (Armitage, et al., 2013).

Central to the SuDS approach is that storm water should be managed through several unit processes that together form a treatment train for storm water run-off. Buffer zones (often referred to as filter strips) are recognised as one of several local controls and should ideally be integrated into the storm water management system.

There are, however, situations where the integration of buffer zones into the storm water management plan may prove difficult, for example, large industrial sites where elevated platforms are created alongside water resources. In such a situation, any run-off is typically deflected away from the platform edge (to reduce erosion risk) and directed into a centralised storm water management system. Water then typically flows through storm water pipes to the edge of the platform where it discharges into the receiving environment (Figure 20).

Given that discharge is typically concentrated, this provides little opportunity for buffer zones to address water quality risks prior to entering the receiving environment. Therefore, greater reliance should be placed on supplementary mitigation measures including source controls on the platform such as the use of grit/oil separators, sand filter traps and bioretention areas to reduce pollutant loadings prior to storm water being discharged from the site. This is typically desirable and may allow minimum buffer zone widths to be applied. Although buffer zones may provide a range of ancillary benefits, their role in addressing pollutants in such storm water run-off will be very limited. Some enhancement may be possible by encouraging storm water to discharge over a broad area with appropriate stabilisation measures to prevent erosion, but overall treatment effectiveness of the buffer zone is likely to be limited.

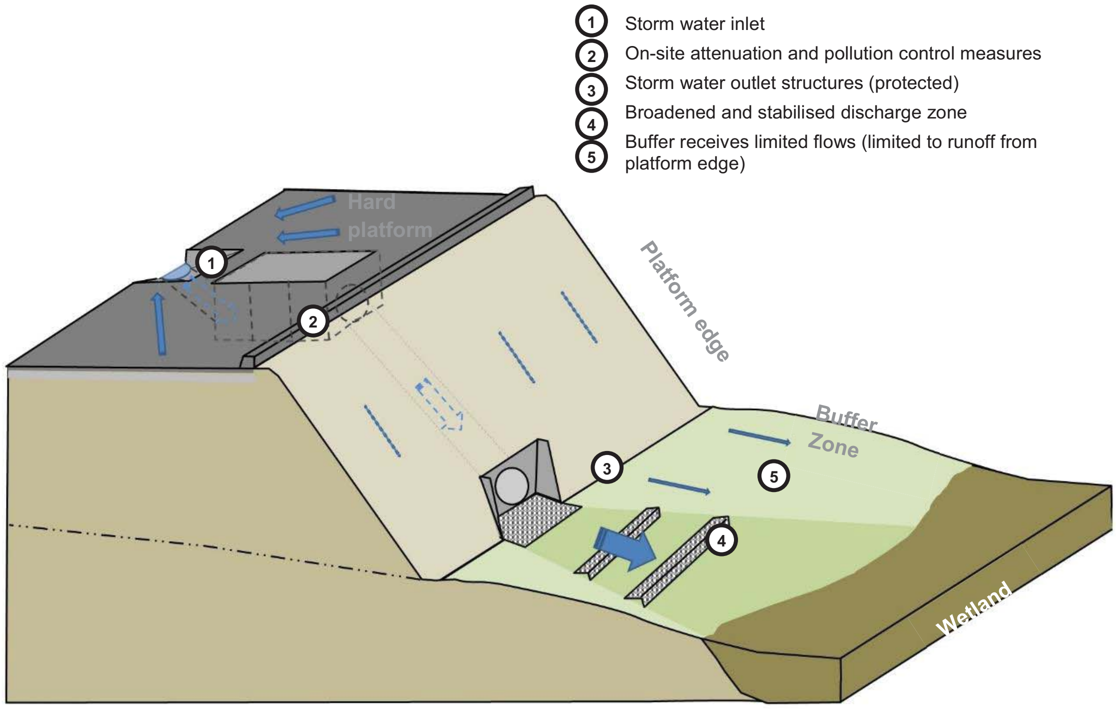

Figure 20 – Example 1: Typical storm water discharge scenario

There may, however, be opportunities for enhancing the effectiveness of buffer zones as part of the storm water treatment train, particularly for relatively small platforms. Although on-site attenuation will still be required, directing water off the platform through a series of small outlets and introducing a distribution structure below the foot of the platform edge, can greatly improve buffer zone effectiveness (Figure 21).

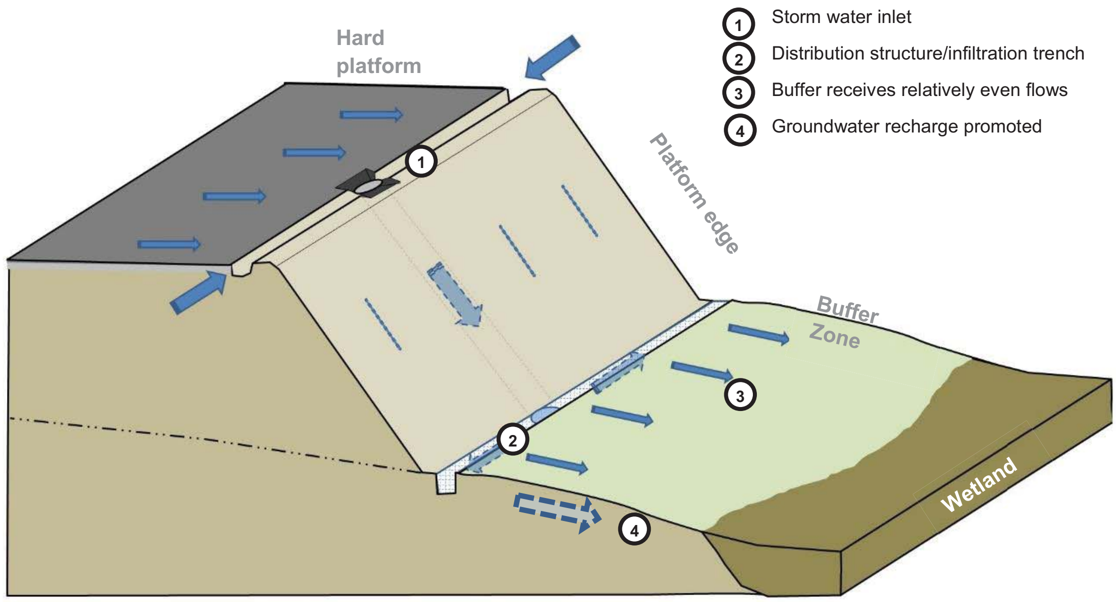

Figure 21 – Example 2: Alternative discharge scenario where a distribution structure is used to spread flows more evenly across the buffer zone

Careful design of distribution structures is necessary to ensure that flows are distributed effectively, including mechanisms to promote infiltration, which is important for wetland systems. Additional options could include constructing enhanced bioretention areas below storm water outlets as part of the storm water treatment process. **It should be noted that primary storm water treatment structures should generally be located outside of buffer zones, with buffer zones then providing a post-attenuation treatment function**. These examples highlight the importance of cross-disciplinary teams in the design and implementation of effective storm water management solutions that also address water quality concerns.

Site-Based Buffer Zone Tools:

- Note whether any management measures necessary to maintain or improve the functioning of final buffer zone areas have been defined.

10.3 Tailor Management for Biodiversity Protection

Desktop	Site-based
	✓

If buffer zones and any supporting habitat have been set aside for biodiversity protection, it is important that specific management measures are incorporated into the management plan. Assessors should refer to information sheets for specific biodiversity features (examples are included in Annexure 17) or obtain specialist input to ensure that management activities cater for habitat and species requirements adequately. Some key aspects when determining management measures for core habitats and corridors include:

- Species habitat preferences and BMPs.
- The need to screen infrastructure to reduce noise and light pollution.
- Control and maintenance of alien and invasive species.
- Fencing requirements, including the need to manage access and use of sensitive areas.
- Fire and livestock management.
- The management of soil erosion and physical disturbances.

Site-Based Buffer Zone Tools:

- Note whether any activities that should not be permitted in the final buffer zone have been stipulated.

10.4 Integrate Protection Requirements with Social and Development Imperatives

Desktop	Site-based
	✓

Historical approaches have often sought to protect key environmental attributes by excluding communities and so limiting any negative impacts that can result from human use. All too often such areas become the back-end of development and high security risk areas, and are ultimately seen as a burden to society rather than an asset. There is growing recognition, however, that long-term protection of natural ecosystems is contingent on these areas delivering positive benefits to local communities, and vice versa, with local communities contributing positively to natural ecosystems (Royden-Turner et al., 2015). It is therefore necessary to integrate appropriate use into open space management. This means actively encouraging reasonable levels of use, creating aesthetically pleasing landscapes and bringing the eyes and ears of the public into these areas to provide passive surveillance and reduce security risks. A change in mindset at both local and regional level will be needed so that buffer zones are seen as an opportunity to integrate conservation and social value objectives in the urban landscape effectively (Figure 22).

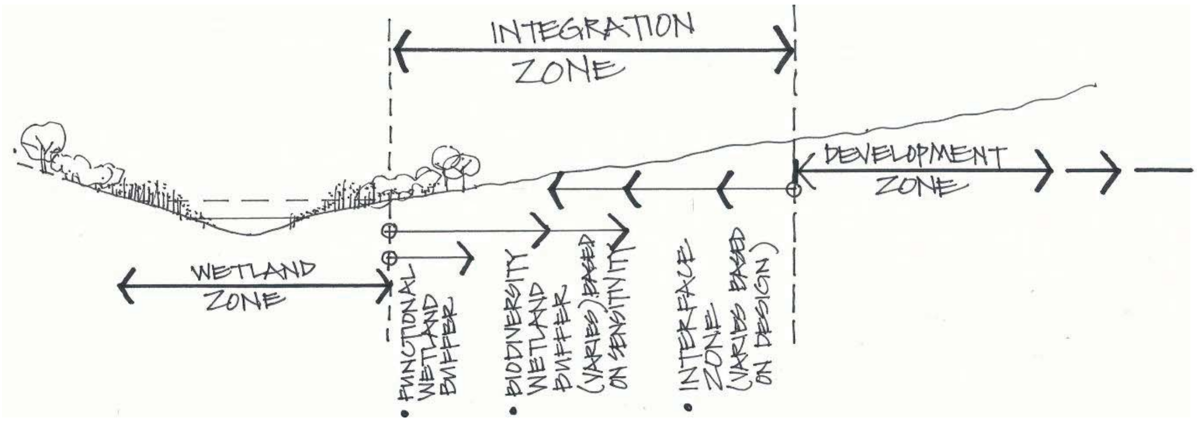

Figure 22 – Schematic drawing illustrating the need for integrating wetland and biodiversity management considerations with social and development imperatives (Royden-Turner et al., 2015)

Developments alongside open spaces can be tailored to reduce impacts on the natural environment by scaling the intensity and planned uses of land to create a softer interface between urban development and adjacent open spaces. The concept of an integration zone is developed further in Figure 23.

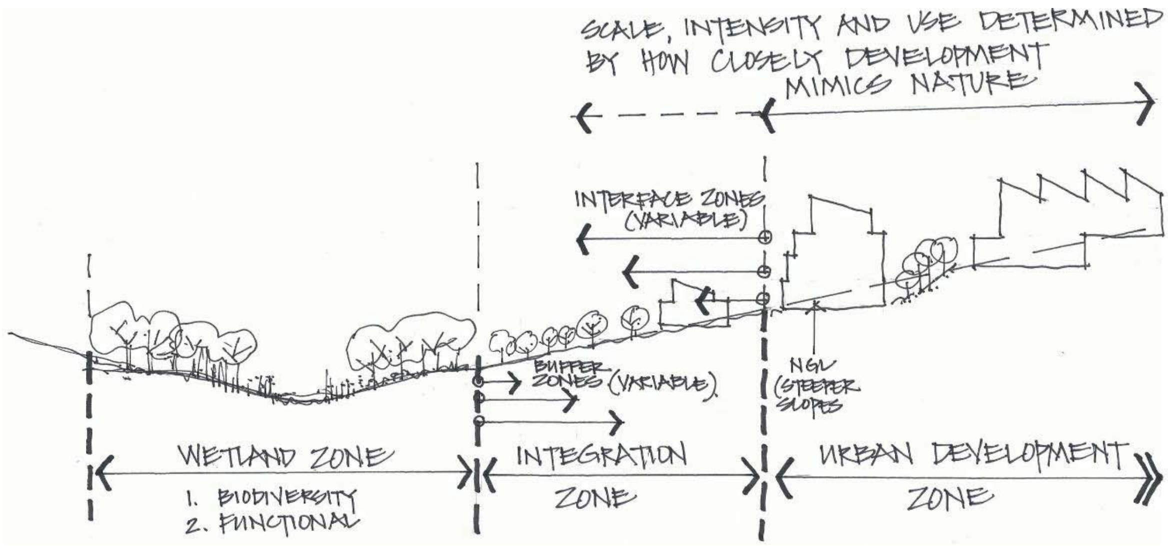

Figure 23 – Schematic drawing illustrating the need to tailor urban design to facilitate better integration with open space networks (Royden-Turner et al., 2015)

Site-Based Buffer Zone Tools:

- Note whether specific consideration has been given to integration of social imperatives including access and use of buffer zones and how such use will be managed.

10.5 Maintain Supporting Mitigation Measures

In many instances, the width of aquatic impact buffer zones may be reduced based on a commitment to implement supplementary mitigation measures. It is therefore essential that these additional mitigation measures are managed effectively to ensure that contaminant risk is minimised and that the buffer zone habitat is not eroded or smothered. Specific requirements necessary to ensure the ongoing functioning of these measures must therefore also be clearly documented in EMPs and be enforced through regular monitoring.

Site-Based Buffer Zone Tools:

- Note specifically whether any management measures to ensure the continued functioning of additional mitigation measures have been defined.

11 STEP 8: MONITOR IMPLEMENTATION OF BUFFER ZONES

It is vital to monitor the effectiveness of the final buffer zone area and the associated recommended management practices. In keeping with the approach for determining and documenting management measures, monitoring implementation should include:

- Determining monitoring objectives and indicators of buffer zone effectiveness.
- Designing a monitoring programme (such as timing and methods) to achieve monitoring objectives.

The implementation and management of the final buffer area areas should be monitored throughout the duration of construction activities to ensure that the effectiveness of the final buffer zone areas is maintained, and that management measures are implemented appropriately. Regular inspections during the operational phase should also be undertaken to ensure that functions are not undermined by inappropriate activities. Where relevant, inspections may also be required during the closure phase.

In compliance with the requirements of an EMP, the environmental officer and/or the environmental control officer should check that:

- The final buffer zone area has been demarcated clearly.
- Disturbances are managed effectively.
- Rehabilitation requirements are successfully implemented.
- Required management measures are implemented effectively.

Where concerns are noted, appropriate actions must be taken to ensure that the functions of the final buffer/buffer areas are not undermined. Key management aspects typically considered include:

- Use of final buffer areas and whether they are controlled appropriately to ensure that buffer zone functions are not undermined.
- Maintenance of good vegetation cover through appropriate management measures (such as burning, grazing and alien plant control).
- Prevention of erosion and associated concentrated flows that may undermine buffer functions.
- Implementation of management controls necessary to ensure that corridors and core habitats established for biodiversity are maintained.

In addition, where rehabilitation or some form of enhancement of a buffer is required, the maintenance of the buffer zone must be monitored. A monitoring/maintenance programme should include evaluating the rehabilitation measures and providing for alternative mitigation measures to aid the buffer in achieving its required function. The developer or landowner should be responsible for any maintenance or monitoring. It is also important to monitor buffer zones when human use is allowed or anticipated (Granger et al., 2005). If monitored, adverse effects of human access, such as vegetation trampling, littering and soil compaction or erosion, can be addressed before it affects the water resource. In some scenarios, it may be appropriate to implement an ecological monitoring programme to ensure mitigation measures are effective in addressing potential impact to water resources. This is particularly important in high risk situations and should be based on specialist input and input from regulating authorities.

Simply designating and marking the boundaries of buffer areas is not sufficient to protect buffers in all cases. Regular observation of buffer areas is critical to determine whether vegetation and soils are being damaged and to ensure that adjacent development does not encroach on the buffer over time. Where illegal activities occur, enforcement actions to restore the buffer may be necessary.

The final step in the approach to determining appropriate buffer zones focuses on providing guidance on monitoring implementation and management of buffer zones once established, to ensure that desired buffer functions are achieved. In some instances, it may also be necessary to review the effectiveness of mitigation measures and apply adaptive management where appropriate.

Site-Based Buffer Zone Tools:

- Note whether any construction or operational phase monitoring requirements have been defined for buffer zones.

12 CONCLUSIONS AND RECOMMENDATIONS

The development of a guideline for determining buffer zones commenced in 2009 and has extended over two WRC projects. During the first phase, the preliminary guideline for buffer zone determination was developed. This was informed by a comprehensive literature review that provided the platform for developing the initial conceptual framework. Thereafter, the step-wise approach for determining buffer zones, models and preliminary tools for buffer zone determination were developed.

The second project provided an opportunity for testing the preliminary guideline further at a series of national training and development workshops. This input was used to update and improve guidelines and accompanying tools, which culminated in the Technical Manual, the accompanying Practical Guide and a refined suite of Buffer Zone Tools. These have to be used and applied as part of a broader suite of tools to ensure that water resource management is integrated appropriately into development planning and land use management. Although a sound scientific approach was adopted to develop these guidelines, many assumptions and limitations were identified and need to be noted by users:

- Mining is recognised as an activity with potentially high risks to water resources. Some of these risks are not addressed adequately by these buffer zone guidelines as they focus primarily on mitigating impacts from diffuse source pollutants in surface run-off. It is therefore critical that any buffer recommendations for mining activities are informed by an appropriate risk assessment and supplementary geohydrological and hydropedological studies, where necessary.
- The desktop threat assessment was informed by readily available scientific literature, but there was limited information for some sub-sectors. As such, threat ratings should be seen as preliminary and subject to further verification. The Buffer Zone Tools make provision for specialists to review and refine the preliminary threat ratings with appropriate justification.
- Rule curves used to define buffer requirements were developed based on an interpretation of best available science at the time of the assessment. It is important to note that there was high variability in reported buffer efficiencies for different contaminants, and therefore these rule curves should be seen as an initial approximation. These should be reviewed and refined in time to cater for more up-to-date information.
- Although applying these guidelines will help to address key risks from diffuse run-off, it is essential that such buffer zones are managed appropriately to maintain their effectiveness. If this is not done, there is a real risk that buffer zones will not perform functions in line with expectations. Integration of supplementary mitigation measures, including appropriate storm water management and management of point-source discharges, also need to be managed to ensure that risks to water resources are appropriately addressed.
- The Buffer Zone Tools were tested as part of this project, but the tools have subsequently been updated following feedback from stakeholders and steering committee members. There is therefore a risk that there may be some errors in the Buffer Zone Tools. It is envisaged that some changes to these tools will be needed over time, and these will be updated on the website for this project.
- It is recognised that biodiversity considerations depend largely on expert input. Species information sheets need to be developed to improve and standardise recommendations for biodiversity protection. While some examples have been compiled, these should be viewed as preliminary and subject to further specialist input. It is hoped that conservation agencies will take up the challenge to develop information sheets for priority species to better inform protection requirements.

Despite these limitations, we believe that developing these guidelines is crucial in developing practical tools to improve water resource management. It is hoped that legislation and policy will integrate these guidelines, and they become entrenched in land use planning and decision-making processes. We encourage government authorities and the business sector to apply these guidelines actively, and to initiate processes to address conflicts with other guidance that may exist from local to national scale. Training and capacity building is critical for effective uptake of these guidelines. Government is therefore encouraged to provide focused training on these guidelines and to support learning institutions in developing and running suitable training courses.

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GLOSSARY[35]

Acidic:	Where the pH of water is less than 6.
Active channel:	The portion of river that conveys flowing water at sufficiently regular intervals to maintain channel form (the presence of distinct bed and banks) and keep the channel free of established terrestrial vegetation.
Alkaline:	Where the pH of water is greater than 8.
Anthropogenic:	Of, relating to, or resulting from, the influence of human beings on nature.
Aquatic impact buffer zone:	A buffer zone acting as a barrier between human activities and sensitive water resources thereby protecting resource from adverse negative impact.
Bedrock:	Solid rock under unconsolidated material such as soil, sand, clay or gravel.
Biodiversity buffer zone:	A buffer zone designed to adequately mitigate adverse effects of adjacent land use activities on important biodiversity features.
Biodiversity corridor:	Typically, linear habitats that differ from a more extensive surrounding matrix, designed to link one or more patches of habitat to improve species movement and dispersal.
Braided river:	A stream with multiple channels that interweave as a result of division and rejoining of flow around interchannel bars, resembling (in plain view) the strands of a complex braid.
Buffer zone:	A strip of land with a use, function or zoning specifically designed to protect one area of land against impacts from another.
Catchment:	The land area from which water runs off into a specific wetland or aquatic ecosystem; a drainage basin.
Channel:	The part of a river bed containing its main current, naturally shaped by the force of water flowing within it.
Channelled valley bottom wetland:	A valley bottom wetland with a river channel running through it. Channelled valley bottom wetlands are characterised by their position on valley floors and the absence of characteristic floodplain features. Dominant water inputs to these wetlands are from the river channel flowing through the wetland, either as surface flow resulting from flooding or as sub-surface flow, and/or from adjacent valley-side slopes (as overland flow or interflow).
Concentrated flow:	A flow of water contained within a distinct channel. Rivers are characterised by concentrated flow, either permanently or periodically.
Core habitat:	The area of natural habitat essential for long-term persistence of a species in its current distribution range.
Deposition:	The laying down of material transported by running water (or wind).
Depression:	An inland aquatic ecosystem with closed (or near closed) elevation contours, which increases in depth from the perimeter to a central area of greatest depth, and within which water usually accumulates. Dominant water sources are groundwater, precipitation, interflow and diffuse or concentrated overland flow.

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Diffuse (surface or sub-surface) flow:	When water flow is not concentrated.
Ecosystem:	An ecological system in which there is constant interaction between biotic and abiotic components and in which nutrients are cycled.
Endorheic:	Basin or region from which there is little or no outflow of water (either on the surface as rivers, or underground by flow or diffusion through rock or permeable material).
Ephemeral (wetland or river):	Wetland or river or portion thereof with markedly short-lived inundation. Rivers that flow or flood for short periods of most years in a five-year period in response to unpredictable high rainfall events.
Episodic:	Highly flashy systems that flow or flood only in response to extreme rainfall events, usually high in their catchments. May not flow in a five-year period, or may flow only once in several years.
Erosion:	Physical and chemical processes that remove and transport soil and weathered rock.
Estuarine system:	A body of surface water (a) that is part of a watercourse that is permanently or periodically open to the sea (b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the watercourse is open to the sea, or (c) in respect of which the salinity is measurably higher as a result of the influence of the sea. The upstream boundary of an estuary is taken to be the extent of tidal influence (the point up to where tidal variation in water levels can still be detected), or the extent of saline intrusion, or the extent of back-flooding during the closed mouth state, whichever is furthest upstream.
Event mean concentration:	Pollutant concentrations in run-off water reported as a mass of pollutant per unit volume of water (usually mg/ℓ), which allowed these values to be compared against wastewater limit values.
Exorheic:	A basin region characterised by outflow of water, usually involving drainage to the ocean.
Floodplain:	Valley bottom areas with a well-defined stream channel, gently sloped and characterised by floodplain features such as oxbow depressions and natural levees and the alluvial transport and deposition of sediment, usually leading to a net accumulation of sediment. Water inputs from main channel (when channel banks overspill) and from adjacent slopes.
Groundwater:	Sub-surface water in the zone of saturation above an impermeable layer.
Hydrogeomorphic (HGM) type:	One of the seven primary HGM units of the classification system, as categorised at level 4A (namely, river or the following wetlands: floodplain, channelled valley bottom, unchannelled valley bottom, depression, seep or flat).
Hydrology:	The study of the properties, distribution and circulation of water on the earth.
Infiltration:	Downward permeation of water below the ground surface, either into the soil or into the groundwater.
Macro channel:	With respect to river or stream channels, a 'macro channel' refers to a compound channel form that typically develops as the result of incision by the active channel into former alluvial terraces, resulting in the active channel being generally confined within macro channel banks, which may or may not be vegetated (Dallas, 2000).
Mineral soil:	Non-organic soil (with an average organic carbon content of less than 10% throughout a vertical distance of 200 mm) consisting primarily of rock and/ or mineral particles smaller than 2 mm in diameter. Mineral soils include sandy soil, silt (mud), clayey soil and loamy soil.

Organic soil:	Topsoil with an average organic carbon content of at least 10% throughout a vertical distance of 200 mm (after Soil Classification Working Group, 1991).
Peat:	A sedentarily accumulated material comprising of 30% (dry mass) of dead organic matter (after Joosten and Clark, 2002) generally formed under permanently saturated conditions.
Perennial:	Flows continuously throughout the year, in most years.
Precipitation:	The deposition of moisture on the earth's surface from the atmosphere, including dew, hail, rain, sleet and snow.
Rehabilitation:	Restoring processes and characteristics that are sympathetic to, and not conflicting with, the natural dynamic of an ecological or physical system.
Riparian zone/ habitat:	Area of land directly adjacent to the active channel of a river, which is influenced by the river-induced or river-related processes. The South African NWA (Act No. 36 of 1998) defines 'riparian habitat' to include "… the physical structure and associated vegetation of areas associated with a water course which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas".
Salinity:	Saltiness; the concentration of dissolved inorganic solids in water. Salinity and total dissolved solids concentration are virtually identical in waters with small quantities of dissolved organic matter relative to the amount of inorganic matter (as is the case for waters with a high salinity, close to that of seawater at 35 g/ℓ). Conductivity can be used as a surrogate measure of salinity.
Saturated:	A condition in which the spaces between the soil particles are filled with water but surface water is not necessarily present.
Seasonal (as relates to non-perennial flow regime):	With water flowing for extended periods during the wet season/s (generally between a duration of three and nine months) but not during the rest of the year.
Seep:	A wetland area located on gently to steeply sloping land and dominated by the colluvial (gravity-driven) unidirectional movement of water and material down-slope. Seeps are often located on the side slopes of a valley but they do not, typically, extend onto a valley floor. Water inputs are primarily via sub-surface flows from an upslope direction. Note 1: Seeps are often associated with diffuse overland flow ('sheetwash') during and after rainfall events. Note 2: For purposes of the classification system, the drainage of a seep is classified (at Level 4C) according to whether water from the seepage area concentrates towards a point where it exits via channelized surface flow ('with channelled outflow') or whether water from the seepage area exits via diffuse surface or sub-surface flow ('without channelled outflow'). It is important to note that a seep abutting a distinct river channel and feeding into the channel via diffuse surface flow or sub-surface flow, but not having a channelized outlet from the seepage area to the adjacent channel, would be classified as a 'seep without channelled outflow' even though it feeds into a channel. Note 3: Seeps can occur in relatively flat or very gently sloping landscapes where there is a unidirectional sub-surface flow of water.
Submerged macrophytes:	Non-microscopic aquatic plants that are rooted in the underlying substratum of a wetland or aquatic ecosystem, with their foliage below the water surface. Submerged aquatic plants only produce reproductive organs (such as flowers) above the water surface. The rest of the plant generally remains under water.

Supratidal zone:	The area that is periodically inundated by tidal or flood waters and within which the sub-surface-surface water is saline and is generally between 2.0 m and 3.5 m AMSL (SANBI, 2009).
Unchannelled valley bottom:	A valley bottom wetland without a river channel running through it. These wetlands are characterised by their location on valley floors, an absence of distinct channel banks, and the prevalence of diffuse flows. Water inputs are typically from an upstream channel and seepage from adjacent valley-side slopes, if present. Note 1: These areas are usually characterised by alluvial sediment deposition, generally leading to a nett accumulation of sediment and the presence of vegetation. Note 2: Preferential flow paths (minor channels) are often present, particularly towards the lower end of the wetland where flow often begins to concentrate.
Wetland:	"Land which is transitional between a terrestrial and aquatic system 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." (NWA Act No. 36 of 1998).

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ANNEXURES

Annexure 1 – Range of Management Measures Available to Address Threats Posed to Water Resources

Note: Areas where buffer zones may play a meaningful role in addressing potential threats are highlighted in blue.

Threat	Location of Threat	Source of Threat	Primary Management Measures
Changing the amount of water (increasing or decreasing the amount)	Upstream catchment	• Direct abstraction • Abstraction from groundwater • Impoundments and associated increased evaporation losses • SFR activities • Invasion by woody alien invasive plants • Inter-basin transfers	• Licensing of water use (including groundwater abstraction) • Protection of groundwater reserves • Reserve determination • Water resource classification • Setting and monitoring of RQOs • Alien plant control activities
	Adjacent land use	• Abstraction from groundwater lowering water levels • SFR activities • Invasion by woody alien invasive plants • Discharge of water from outside catchment (for example, grey water from municipal supply) • Diversion of water away from water resource (such as irrigation)	• Limiting impacts to preferential recharge areas • Restriction of SFR activities (**including maintenance of buffer zones**) • Alien plant control activities • Preventing diversion of water
	Within water resource	• Direct abstraction from water resource • SFR activities in the water resource • Invasion by woody alien invasive plants • Extra water into the water resource	• Management of abstraction • Restriction/removal of SFR activities • Alien plant control activities • Management of point discharges
Changing the fluctuation of water levels (frequency, amplitude, direction of flow)	Upstream catchment	• Impoundments upstream of water resource • Inter-basin transfers • Development leading to hardened surfaces in catchment • Poor land management reducing basal cover	• Management of releases from impoundments (allowance for natural floods) • Storm water detention and treatment • Sound land management practices
	Adjacent land use	• Hardened surfaces leading to increased run-off intensity • Storm water drains and associated discharge	• Storm water detention and treatment • Prevention of canalised flows • **Buffer zones to mitigate diffuse flows**
	Within water resource	• Development within water resources • Drainage to minimise flooding • Impeding features redirecting flows • Alteration of surface characteristics (roughness) • Direct water losses • Impoundments causing flooding	• Control of activities directly impacting on water resources • Blockage of drainage channels • Demolition of impeding features • Rehabilitation/restoration of vegetative cover • Management of on-site water use • Decommissioning of impoundments

Threat	Location of Threat	Source of Threat	Primary Management Measures
Changing the amount of sediment entering water resource and associated change in turbidity (increasing or decreasing the amount)	Upstream catchment	• Impoundments upstream of water resource (sediment trapping) • Breaching of dams (scouring) • Poor land use management (increased sediment supply) • Changes in water inputs resulting in elevated flows and associated erosion • Road infrastructure (density and management) • Mining operations (such as coal and gold mines)	• Sound land management practices • Management of road infrastructure • Dam construction techniques (dam safety) • **Implementation of buffers at a catchment scale to reduce sediment inputs**
	Adjacent land use	• Bulk earthwork activities • Disturbance of soil surface • Disturbance of slopes by creating roads and tracks • Poor land management • Inappropriate burning • Changes in run-off characteristics	• Implementation of BMPs ○ Roads and associated drainage ○ Earthwork activities ○ Fire and livestock management ○ Agricultural activities • Source-directed controls • **Buffer zones for trapping sediments**
	Within water resource (geomorphology)	• Channel straightening (reducing flooding) • Artificial infilling (affecting water distribution) • Erosion (such as gully formation, bank collapse) • Peat extraction • Sand winning • Dredging • Clearing of natural vegetation up to stream banks • Stock trampling and overgrazing	• Active rehabilitation • Management of sediment removal activities (permits)

Threat	Location of Threat	Source of Threat	Primary Management Measures
Alteration of water quality – increasing the amounts of nutrients (phosphate, nitrite, nitrate)	Upstream catchment	• Disposal or discharge of human (including partially treated and untreated) sewage, animal debris and excrement into water resources • Run-off from agricultural activities such as the large-scale concentration of livestock (feedlots) • Overuse of nitrate-based fertiliser such as limestone ammonium nitrate • Orthophosphates applied to agricultural/residential lands as fertiliser and carried into surface water during storm events • Activities influencing oxidising or reducing circumstances in the nitrogen cycle, such as aeration or acidification • Activities, such as excavation, ploughing, building and mining, disturbing bedrock high in elemental nitrogen[36] • Run-off from land areas mined for phosphate deposits • Industrial discharges (sugar and dairy industries) • Elevated phosphorus levels in urban sewage from household products, such as toothpaste, detergents, pharmaceuticals, and food-treating compounds • Run-off/leachate from solid waste disposal sites	• Licensing of water use (including point-source discharges) • Provision of sanitation facilities • Management of waste water facilities • Source-directed controls for agricultural activities • Management of mining activities • **Implementation of buffers at a catchment scale to reduce water quality impacts**
	Adjacent land use	As above	• **Rehabilitation/maintenance of riparian zone** • **Establishment of buffer zones to reduce nutrient inputs in diffuse flow** • Implementation of appropriate storm water management around the excavation to prevent the ingress of run-off into the excavation. This will reduce the volume of pit water that is contaminated with nitrate, which would reduce the costs associated with the management of this water • Implementation of appropriate storm water management around rock dumps through the establishment of a clean and dirty water system, which would reduce the volume of run-off contaminated with nitrate from the rock dumps • Implementation of appropriate containment measures for all impoundments used to store contaminated water, such as pollution control dams, return water dams and tailings dams, which have clay and/or plastic linings

[36] Bossman, B.P., Nyman, A.J. and Klerks, P.L. (2009). Relationship between hydrocarbon measurements and toxicity to a chironomid, fish larvae, and daphnid for oils and oil spill chemical treatments in laboratory freshwater marsh microcosms. *Environmental Pollution* 129, 345-353.

Threat	Location of Threat	Source of Threat	Primary Management Measures
	Within water resource	• Defecation by livestock • Point-source discharges of waste water	• Management of livestock • Source-directed controls
Alteration of water quality – toxic contaminants (including toxic metal ions (such as copper, lead, zinc), toxic organic substances (reduces oxygen), hydrocarbons and pesticides)	Upstream catchment	Toxic metal ions: • Mining operations, leading to the release of toxic metal ions • Purification of metals, such as smelting of copper and preparation of nuclear fuels • Industrial discharge (such as electro-plating, tanning, smelting activities) • Urban run-off containing lead from road surfaces Toxic organic substances: • Spray drift from pesticides • Run-off of pesticides from agricultural lands • Careless disposal of pesticide containers • Release of household pesticides • Discharge of solvents, and other industrial chemicals • Discharge of pharmaceuticals and personal care products through excretion or disposal by flushing	Toxic metal ions: • Mining: Implementation of appropriate containment measures for all impoundments used to store contaminated water, such as pollution control dams, return water dams and tailings dams, such as clay and plastic linings • Control of waste discharges • Guidelines for implementing clean technologies • Environmental management systems (such as ISO 14001), which seek continuous improvement in environmental management. Toxic organic substances: • Control of pesticide application, particularly in proximity to water resources
	Adjacent land use	As above	• As above • **Maintenance of riparian zones** • **Establishment of buffer zones (especially wooded areas) to catch spray drift and trap sediments with associated toxics**
Alteration of water quality – acidity (pH)	Upstream catchment	• Acid mine drainage (AMD), or acid rock drainage (ARD), from abandoned and active **metal** mines or coal mines • Run-off from coal stocks, coal handling facilities, coal washers, and coal waste tips	• Controlled placement of overburden or management of water to prevent AMD (involves methods to minimise or neutralise the formation of AMD. According to the generally accepted chemical equations for pyrite oxidation, oxygen and water are necessary to initiate acid formation. Exclusion of either reactant should preclude or inhibit acid production) • Limestone chips may be introduced into sites to have a neutralising effect • Constructed wetlands to filter out heavy metals and raise pH
	Adjacent land use	As above	As above

Threat	Location of Threat	Source of Threat	Primary Management Measures
Alteration of water quality – concentration of salts (salinization)	Upstream catchment	• Return flows from irrigated croplands • Fertilisers and biocides applied to agricultural croplands • Mine drainage (for example, coal and gold mines) • Point-source releases of salts from industrial plants (such as tanneries)	• Control of water use and point-source discharges
Alteration of water quality – **temperature**	Upstream catchment	• Overflow or release from impoundments • Release/discharge from industries	• Design of overflow structures • Control of point-source discharges
	Adjacent land use	• Removal/damage to riparian zone, important for shading • Release/discharge from industries • Run-off from hardened surfaces	• **Protection/re-establishment of riparian zone to shade water resource** • Establishment of buffer zones to allow cooling of water before entering water resources
Alteration of water quality – pathogens (i.e. disease-causing organisms)	Upstream catchment	• Wash from animal feeding operations • Release from municipal waste water treatment plant effluents • Discharge of partially treated sewage from malfunctioning on-site systems (such as septic tanks) • Treated sewage sludge (bio-solids) for crop and landscape irrigation. • Application of untreated manure as fertiliser on agricultural lands	• Placement and management of animal feeding areas • Implementation of microbial standards for reclaimed waste water • Implementation of best practice guidelines for construction of waste water systems • Composting of manure to effectively eliminate pathogens
	Adjacent land use	• Wash from animal feeding operations • Discharge of partially treated sewage from malfunctioning on-site systems (such as septic tanks) • Treated sewage sludge (bio-solids) for crop and landscape irrigation. • Application of untreated manure as fertiliser on agricultural lands	• **Placement and management of animal feeding areas** • Implementation of microbial standards for reclaimed waste water • Implementation of best practice guidelines for construction of waste water systems • Composting of manure to effectively eliminate pathogens • **Establishment of buffer zones to help trap pathogens before reaching water resource**
	Within water resource		• Drainage inflows eliminated or managed

Threat	Location of Threat	Source of Threat	Primary Management Measures
Changing the physical structure within a water resource (habitat)	Upstream catchment	• Alteration of hydrological regime • Alteration in sediment regime • Alteration of water quality	• See relevant sections
	Adjacent land use	• Encroachment to achieve maximum commercial returns • Loss of fringing vegetation and erosion from stock trampling • Loss of fringing vegetation to provide aesthetic views • Alteration in natural fire regimes • Shading of natural vegetation	• Delineation and protection of water resource • **Establishment of buffer zones to limit disturbance** • Weed control in buffer zone • Barriers to prevent trampling/damage to buffer zone • Introduction of fire break and appropriate burning regime
	Within water resource	• Infrastructure development (such as housing, bridges) • Canalisation or diversion of watercourses • Mining within water resources • Inundation by impoundments • Cropping and pastures • Encroachment by alien invasive plants • Overgrazing and trampling by livestock • Sports fields and gardens • Seepage below dams • Alteration in natural fire regimes	• Restricting developments with direct impact on water resources • Removing of crops and pastures and associated re-vegetation • Alien invasive plant control within water resource • Control of livestock numbers • Introduction of fire breaks and appropriate burning regime
Other disturbances	Adjacent land use	• Noise from urban areas and transportation networks • Light pollution from residential/industrial developments • Physical disturbance from hunting or recreational activities • Dust pollution from exposed areas, active earthworks and dirt roads	• Restrict development away from water resources with threatened species sensitive to disturbance • **Construction of barriers (including buffers) to reduce disturbance** • Use fencing or other means to control access • Use BMPs to control dust
	Within water resource	• Physical disturbance through direct human presence	• Restrict access, particularly where sensitive species occur

Annexure 2 – National and/or Sub-national (Cape) Priority Estuaries

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

Annexure 3 – Estuary Importance Scores for all South African Estuaries

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

Annexure 4 – Description of Sectors and Sub-sectors Included in the Threat Assessment

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
Agriculture	Agricultural-based land use activities that range from the large-scale commercial production of crops and timber to small-scale subsistence crop farming and livestock rearing. May be associated with rural and/or urban contexts.	**Forestry/timber**	Includes the planting and harvesting of various species of non-indigenous trees (pine, wattle, gum) but also includes intensive planting and harvesting of indigenous species.
		Nurseries and tunnel farming operations	Intensive agricultural activities, associated with the production of flowers, vegetables or other plant materials (such as flower farms and crops in tunnels).
		Dryland commercial cropland – annual rotation	The agricultural production of produce including crops, vegetables or other plant material using conventional tillage cultivation with no irrigation and requiring annual re-establishment.
		Dryland commercial cropland – infrequent rotation	The agricultural production of produce including crops, trees, seeds, fruit, or other plant material using conventional tillage cultivation with no irrigation. Re-establishment takes place on a bi-annual or more infrequent basis.
		Irrigated commercial cropland	The agricultural production of produce including crops, trees, seeds, fruit, vegetables or other plant material using conventional means of irrigation.
		Subsistence cultivation	Communal land used for the cultivation of crops and for livestock grazing activities. Typically involves less intensive use of machinery, with lower nutrient and fertiliser inputs than commercial operations.
		Extensive livestock grazing operations	Includes the rearing and husbandry of a range of domestic livestock (such as cattle, sheep, horses, goats) on areas of natural or largely natural pastures without irrigation.
		Intensive livestock grazing operations	Includes the rearing and husbandry of a range of domesticated livestock (such as cattle, sheep, horses, goats) on enhanced pastures, typically supplemented with irrigation.
		Concentrated livestock operations	Livestock intensive operations associated with areas of concentrated animal activities including (1) dairies; (2) piggeries; (3) poultry facilities; (4) stables, (5) sale yards (6) feedlots and (7) zoos.

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
		Sludge dams associated with concentrated livestock operations	Sludge dams containing waste water from intensive livestock operations.
		Aquaculture or marine culture	Commercial production including the breeding, hatching, rearing or cultivation of marine, estuarine or freshwater organisms, including aquatic plants or animals (such as fin fish, crustaceans, molluscs or other aquatic invertebrates but not including oysters).
Industry	Includes a range of industrial activities from light industrial with limited impacts on surrounding land use, to hazardous or noxious industry with high impact on surrounding land use. Includes activities such as the processing of resources and storage of manufactured materials and products.	**High risk chemical industries**	Industries that produce/manufacture batteries (acid and alkaline), paint solvents, petrochemicals, explosives, radioactive materials, pharmaceuticals, pesticides, herbicides, fungicides, rodenticides, nematocides, miticides, fumigants and related products.
		Chemical storage facilities	Includes facilities to store or package chemical substances in containers, bulk storage facilities, stockpiles or dumps.
		Drum/container reconditioning	Industries that recondition and package containers (including metal, plastic or glass drums, bottles or cylinders) previously used for the transport of storage or substances classified as poisonous or radioactive.
		Paper, pulp or pulp products industries	Industries that manufacture paper, pulp or pulp-related products.
		Petroleum works	Industries that: (1) refine crude petroleum, shale oil or natural gas; (2) manufacture petroleum products (including aviation fuel, petrol, kerosene, mineral turpentine, fuel oils, lubricants, wax, bitumen, liquefied gas and the precursors to petrochemicals, such as acetylene, ethylene, toluene and xylene); or (3) dispose of oil waste or petroleum waste or process or recover oil waste or petroleum.
		Breweries/distilleries	Industries responsible for producing alcohol-based products such as ethanol and beer.
		Cement/concrete works	Industries involved in the production of quicklime including the use of argillaceous and calcareous materials in the production of cement clinker. Includes the production of pre-mixed concrete or concrete products.

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
		Ceramic works	Industries responsible for producing products such as bricks, tiles, pipes, pottery goods, refractories or glass manufactured through a firing process.
		Medium-risk chemical industries	Including the production of (1) agricultural fertiliser; (2) carbon black industries; (3) explosive or pyrotechnics (for purposes including extractive industries and mining uses, ammunition, fireworks or fuel propellants); (4) paints, pigments, dyes, printing inks, industrial polishes, adhesives or sealants; (5) soap or detergent industries (including domestic, institutional or industrial soaps or detergents); (6) plastics; and (7) rubber products.
		Dredging works	Storage and processing of materials obtained from the bed, banks or foreshores of many waters.
		Electricity generation works	Facilities that supply electrical power from energy sources (including coal, gas, bio-material or hydro-electric stations), but not including solar powered generators.
		Timber milling or processing works	Other than a joinery, builders' supply yard or home improvement centre that saws, machines mills, chips, pulps or compresses timber or wood
		Livestock processing operations	Processing of livestock including: slaughter animals (including poultry, piggeries, cattle and sheep)
		Industries processing livestock derived products	Industries involved with secondary processing of products derived from the slaughter of animals (including tanneries, fellmongeries, rendering or fat extraction plants, wool or fleeces with an intended production capacity).
		Composting facilities	Facilities for producing compost/manure originating from livestock waste.
Mixed use/ commercial/ retail/business	Land use activities including retail, commercial and business, with varying degrees of mix.	**Core mixed use**	Intended for the development of the major activity focus or foci of urban areas and provides for land and buildings where the full range of residential, businesses, offices, service and light industry, civic and social, educational and environmental uses are freely permitted and under certain conditions general industry is permitted, but excludes extractive or noxious industry.
		Medium impact mixed use	A mixed-use area where the full range of residential, businesses, offices, service and light industries, civic and social, educational and environmental uses are freely permitted, but excludes other forms of industry.

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
		Low impact mixed use	Includes areas where a full range of residential, businesses, offices, civic and social, educational and environmental uses are freely permitted, and under certain conditions light industry might be permitted, but excludes other industrial uses, and which can act as an interface between residential and higher impact non-residential uses or major traffic routes. The general level of amenity is intended to be good.
		Multi-purpose retail and office	Land use that provides for the development of a full range of shopping centre types and can comprise a mix of retail, office, residential and entertainment uses. Examples include: commercial/business; hawking/informal trading; laundrette; parking garage; restaurant; shop; spaza; take away/fast food; tavern/bar.
		Petrol station/fuel depot	Land designated for buildings used for the sale of motor fuels, lubricants, motor spares and motor accessories.
		Maintenance and repair facilities	Facilities for the repair and maintenance of vessels, vehicles or other machinery. Includes workshops, service yards, etc.
		Offices	This includes all office development as the primary developmental focus in suburban and peripheral locations, adjacent to shopping centres or a mixed-use core, or as independent zones. Forms of office development may include: doctor's consulting rooms; home business; office building; private clinic; professional office.
Civic and Social	This category includes buildings and land associated with public and private service providers and administrative or government functions including education, health, pension offices, museums, libraries, correctional facilities and community halls.	**Government and municipal**	Buildings to be used for national, provincial and municipal administration and services.
		Place of worship	Buildings or portion of a building to be used as a church, chapel, oratory, synagogue, mosque, and temple.
		Education	Educational facilities, including infants, pre-primary, primary, secondary, tertiary and adult education and training, with associated buildings.
		Cemetery	Land used for public and private cemeteries, memorial parks, funeral chapel and crematoria.
		Health and welfare	Buildings for public and private hospital, medical centres, clinics, sanatoria, community care, welfare and social requirements.

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
Residential	Provides for land and buildings for a variety of housing types, ranging from areas that are almost entirely residential to those areas having a mix of other compatible land uses, where the predominant land use is residential.	**Residential low impact/ residential only**	Includes buildings for a variety of housing types with a limited number of compatible ancillary land uses permissible to cater for every day needs of the residents. The building density is likely to be low (<1 unit/acre[37]) and the amenity high, and generally in harmony with the natural environment.
		Residential medium impact	Buildings for primary residential land uses with an increasing number of appropriate ancillary land uses to satisfy local demands and convenience. The residential density may also increase, which will increase the impact of the residential land use on the area. Housing density of <1 unit/acre: Includes tourism cottage settlements, smaller cluster complexes, family hotels, B&B and lodges.
		High density urban – **residential high impact**	Comprises the full range of residential accommodation and a wide variety of services and activity mix to cater for broader community needs. The residential density is likely to be higher (>1 unit/acre) thus increasing the impact of the residential use on the area and requiring additional retail, civic and social and service activity to serve the needs of the community.
		Resort	Accommodation in the form of lodges, bush camps, cultural villages and bed and breakfast establishments within a rural setting.
		Hotel	The development of a licensed hotel. Accommodation and public lounge and bar areas may be provided as well as other recreational facilities and parking.
		Informal settlements	Housing density of >1 unit/acre: intensive rural housing development such as formal/informal settlements.

[37] Note: 1 acre = approximately 4046 m^2.

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
Open space	Areas defined as open space include a range of land uses with minimal infrastructural development, such as parks, gardens and off-road trails. Includes areas set aside for preservation and conservation because they provide ecosystem services, are unique natural landscapes, viewpoints, areas of ecological, historical and/or cultural importance, biodiversity, and/or have unique, rare or endangered habitats or species.	**Parks and gardens**	Land that is either publicly or privately owned/managed as part of the sustainable open space system and the local authority's environmental services. It includes independent or linked open space areas and green lung areas such as parks, lawns and gardens for sporting and recreational activities.
		Sports fields	Land that is typically grassed and regularly maintained for sporting activities.
		Golf courses – fairways	The part of a golf course covered with short grass and extending from the tee to the putting green and maintained through regular mowing.
		Golf courses – tee boxes and putting greens	Small areas of a golf course with very short grass that are heavily manicured to maintain the condition of the grass surface.
		Maintained lawns and gardens	Areas of lawn and gardens of introduced species, typically requiring maintenance (fertilisation, and/or irrigation).
Transportation infrastructure	Land used to provide for developments and buildings associated with public and private transportation in all its forms.	**Paved roads**	Land that has been provided for the full range of road infrastructures within rural and urban areas. Roads that have been paved/asphalted (includes major roads and freeways, as well as bridges over waterways).
		Unpaved roads	Land that has been provided for the full range of road infrastructures mainly within rural areas. Including dirt tracks and gravel roads that have not been formerly paved/asphalted.
		Paved trails	Small trails that have been constructed by paving/asphalting.
		Unpaved tracks and trails	Unpaved tracks and trails used for recreational purposes (such as biking/jogging)
		Parking lots	Extensively asphalted/paved areas used for the parking of vehicles.
		Airport – runways and taxiways	Tarred runways and taxiways associated with private and commercial airports used by various forms of commercial and private aircraft.

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
		Railway	Commuter, passenger and goods railway infrastructure within the rural and urban context. Activities include one or more of the following: installation of track; on-site repair of track; on-site maintenance of track; on-site upgrading of track; construction or significant alterations; operation of rolling stock on track.
Service infrastructure	Land use relating to the provision of all necessary utility services such as communication, municipal waste handling facilities and associated transfer pipeline infrastructure for fuels and water.	**Above-ground communication/power (electricity) infrastructure**	Above-ground infrastructure designed for the transfer of power (electricity cables) or data (telephone lines).
		Below-ground communication/power (electricity) infrastructure	Below-ground infrastructure designed for the transfer of power (electricity cables) or data (underground data cables).
		Hazardous waste disposal facility	Facilities for the disposal of hazardous waste, as analysed and characterised according to SABS Code 0228, the Basel Convention and Appendix 9.2 “Hazardous Waste Classification Tables”, of the Department of Water Affairs and Forestry’s Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste. Material with a Hazard Rating 1 (extreme risk) or Hazard Rating 2 (high risk) can only be disposed of at a permitted landfill with an H:H classification.
		General solid waste disposal facility	Facilities such as landfills for the disposal of household waste, builder’s rubble and industrial waste that is not classified as hazardous.
		Sewage treatment works	Treatment works and associated infrastructure including pumping stations, sewage overflow structures and the reticulation system.
		Septic tanks and French drains	Septic tank and French drains used in residential areas for the bacterial treatment and distribution of waste water.
		Sludge dams associated with concentrated livestock operations	Sludge dams containing waste water from intensive livestock operations.
		Pipelines for transportation of hazardous substances	Pipelines (above or underground) for the transportation of fuels and related chemicals.

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
		Pipelines for the transportation of waste water	Pipelines for the transportation of waste water (such as sewage) to treatment facilities.
Mining	This class comprises all mining-related activities including surface and sub-surface mining, quarrying and dredging for the extraction of minerals or materials, including sand and stone.	**Prospecting (all materials)**	Prospecting activities including excavation of test-pits.
		High risk mining operations	Mining operations (including mine and mine waste) posing a high water quality risk to water resources including mining of the following substances: antimony (large mines), asbestos, base metals (copper, cadmium, cobalt, iron ore, molybdenum, nickel, tin, vanadium) – sulphide ore, coal, gold, silver, uranium.
		Moderate risk mining operations	Mining operations (including mine and mine waste) posing a high moderate risk to water resources. Includes underground mining of the following substances: antimony (small mines), base metals (copper, cadmium, cobalt, iron ore, molybdenum, nickel, tin, vanadium) – oxide ore, chrome, diamonds and precious stones, phosphate, platinum, magnesium, manganese, mineral sands (ilmenite, titanium, rutile, zircon), zinc and lead, industrial minerals (andalusite, barite, bauxite, cryolite, fluorspar).
		Low risk mining operations	Mining operations (including mine and mine waste but excluding underground mining operations) posing a low water quality risk to water resources including mining of the following substances: antimony (small mines), base metals (copper, cadmium, cobalt, iron ore, molybdenum, nickel, tin, vanadium) – oxide ore, chrome, diamonds and precious stones, phosphate, platinum, magnesium, manganese, mineral sands (ilmenite, titanium, rutile, zircon), zinc and lead, industrial minerals (andalusite, barite, bauxite, cryolite, fluorspar).
		Plant and plant waste from mining operations – high risk activities	Waste generated from plant and plant waste from processing of minerals and metals extracted from the ground, which pose a high water quality risk to water resources. These include: antimony (large mines), asbestos, base metals (copper, cadmium, cobalt, iron ore, molybdenum, nickel, tin, vanadium), chrome (large mines), coal, gold, silver, uranium, zinc and lead.
		Plant and plant waste from mining operations – moderate risk activities	Waste generated from plant and plant waste from processing of minerals and metals extracted from the ground, which pose a moderate water quality risk to water resources. These include: diamonds and precious stones (large mines), phosphate (large mines), platinum, magnesium (large mines), manganese (large mines), mineral sands (ilmenite, titanium, rutile, zircon) – (large mines).

Sector	Sector Description	Land Use/Activity	Description of Land Use/Activity
		Plant and plant waste from mining operations – low risk activities	Waste generated from plant and plant waste from processing of minerals and metals extracted from the ground, which pose a low water quality risk to water resources. These include: diamonds and precious stones (small mines), phosphate (small mines), magnesium (small mines), manganese (small mines), mineral sands (ilmenite, titanium, rutile, zircon) – (small mines), industrial minerals (andalusite, barite, bauxite, cryolite, fluorspar).
		Moderate risk quarrying operations	Quarrying operations of minerals with a moderate water quality risk to water resources. These include: granite, cement limestone, limestone, slate.
		Low risk quarrying operations	Quarrying operations of minerals with a low water quality risk to water resources. These include: attapulgite (special clays), calcrete, clays, dolerite, kyanite, mica, norite (dimension stone), pyrophyllite, quartzite (dimension stone and abrasive), sand and gravel, siltstone fines, soil, bentonite (special clays), $CaCO_3$, diatomaceous earth, feldspar, graphite, lime (produced from limestone), mineral aggregates, phosphate rock, quartz, rare earths, shale, silica, talc, calcite, dolomite, fullers earth, kaolin, montmorillonite, pumice, quartzite, salt, siltstone (dimension stone), vermiculite.
		Exploratory drilling	Drilling for mineral/fuel exploration.

Annexure 5 – Specific Limits set for Evaluating Different Threat Types Assessed

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

Annexure 6 – Summary of Average EMCs for Sectors and Sub-sectors

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

Annexure 7 – EMCs for Sectors and Sub-sectors Obtained from International Literature

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

Annexure 8 – Initial Desktop Threat Ratings Based on Expert Workshops

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

Annexure 9 – Hydrological Sensitivity Analysis

A hydrological sensitivity analysis was undertaken by Hydrogeomorphic Systems, based at the University of KwaZulu-Natal (UKZN)[38], to understand how a suite of climatic and site-based attributes affect peak discharge (when surface flows are most likely to take place).

Understanding such relationships is important because buffer zones are typically designed to assimilate contaminants in surface overland flows. The effect of climatic conditions on overland flow is therefore likely to affect the risk of contaminants being washed from land uses upstream of the buffer zone, while site-based characteristics may affect the ability of the buffer zone to slow flows and promote pollutant assimilation.

1. Methodology Applied

The Agricultural Catchment Research Unit (ACRU) agrohydrological model (version 3) (Schulze, 1995) model was used to simulate a hypothetical catchment of 1 km^2 (1 km × 1 km) that included a 30 m buffer zone along the edge of a river\stream, with an area of 0.03 km^2. Above this buffer is the land use "section" of this catchment, comprising an area of 0.97 km^2. A schematic of this hypothetical catchment is illustrated in Figure 24.

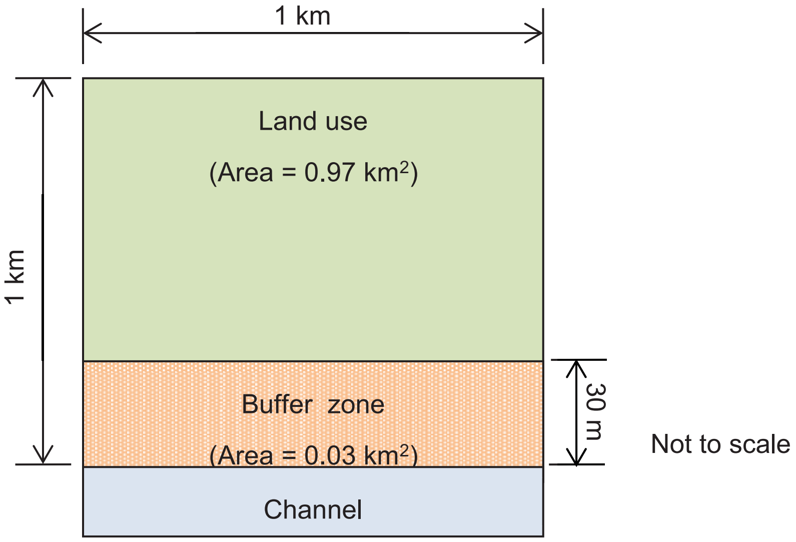

Figure 24 – Schematic of the hypothetical 1 km^2 catchment used for hydrological simulations

Various simulations represented changes in slope, soil texture, land cover, MAP[39] and rainfall intensity. The input climate data was from the quinary catchment database and for the 50-year period from 1950 to 1999. Five scenarios were simulated to establish the sensitivity of: changing the catchment land use, rainfall intensity, slope, change in the buffer zone vegetation, and change in the soil texture. For the rainfall intensity simulations, the Schmidt–Schulze equation (Schmidt and Schulze, 1984) was used for peak discharge, as it considers the 30-minute rainfall intensity ($mm \cdot h^{-1}$) for the two-year return period. The other peak discharge simulations used the Soil Conservation Service (SCS-SA) equation, which considers the impact of land use and soil on peak discharge. The land uses considered included

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[38] Authors included Mr Nicholas Davis (MSc Hydrology), Dr Hartley Bulcock (PhD Hydrology) and Mrs Lauren Bulcock (MSc Bioresource Systems).

[39] Rainfall data for a suite of test-catchments reflecting the variability in MAR across the country was selected. MARs in these catchments were 192 mm, 666 mm, 1117 mm and 1281 mm for very low to very high MAR classes respectively, and reflected approximate mid-points for the MAR classes used in simulations.

grassland, maize cultivation, commercial forestry, urban residential and industrial. In the buffer zone, the vegetation cover included grassland in good condition, degraded grassland and bare soil. Four rainfall intensity scenarios of 90 mm·h^{-1}, 70 mm·h^{-1}, 50 mm·h^{-1} and 30 mm·h^{-1} were considered to simulate peak discharge. Slope was varied from 0-45°. Eight soil textural classes were also considered.

As the Buffer Zone Model was developed by applying a series of modifiers to a given "reference" scenario, it was important to set reference parameters against which changes in site characteristics could be evaluated. For this exercise, the baseline simulation considered the land use to be grassland, slope to be between 5-10°, the buffer zone vegetation to be grass in good condition, and the soil texture to be clay loam. These variables were kept constant for all simulations unless the scenarios required them to be changed (for example, the land use was grassland for all scenarios unless the scenario was specifically considering a change of land use). The parameters that were kept constant are highlighted in grey in the results tables that follow. The rainfall intensity zones were not kept constant for all simulations because they were only required in the calculation of peak discharge using the Schmidt–Schulze equation. Thereafter, the model did not require rainfall intensity for the other simulations. Table 29 details the input parameters used for each simulation.

Table 29 – Input variables used

Simulation	***Variable Changed***	***Full Variable Name***	***Value***
XI30_Z1	MAP\XI30	Mean Annual Precipitation (mm)\ 30 min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [90 mm·h^{-1}]
XI30_Z2	MAP\XI30	Mean Annual Precipitation (mm)\ 30 min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [70 mm·h^{-1}]
XI30_Z3	MAP\XI30	Mean Annual Precipitation (mm)\ 30 min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [50 mm·h^{-1}]
XI30_Z4	MAP\XI30	Mean Annual Precipitation (mm)\ 30 min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [30 mm·h^{-1}]
LU_GRASS	CROPNO	Land cover type	Southern tall grassveld
LU_FORESTRY	CROPNO	Land cover type	Eucalyptus general
LU_INDUSTRIAL	CROPNO	Land cover type	Industrial
LU_MAIZE	CROPNO	Land cover type	Maize October planting date
LU_RESIDENTIAL	CROPNO	Land cover type	Residential (formal, medium density)
LUS_GRASS (1)	SLOPE	Slope (%)	2.2
LUS_GRASS (5)	SLOPE	Slope (%)	5
LUS_GRASS(10)	SLOPE	Slope (%)	16.5
LUS_GRASS(15)	SLOPE	Slope (%)	27.5
LUS_GRASS(30)	SLOPE	Slope (%)	49.5
LUS_GRASS(45)	SLOPE	Slope (%)	82.5
BZ_GRASS_GOOD	CROPNO	Buffer zone land cover type	Veld in good condition – general
BZ_GRASS_DEG	CROPNO	Buffer zone land cover type	Veld in poor condition – general

Simulation	Variable Changed	Full Variable Name	Value
BZ_GRASS_BARE_SOIL	CROPNO	Buffer zone land cover type	Bare rock\soil
BZ_GRASS_SLOPE(1)	SLOPE	Slope of only buffer zone (%)	2.2
BZ_GRASS_SLOPE(5)	SLOPE	Slope of only buffer zone (%)	5
BZ_GRASS_SLOPE(10)	SLOPE	Slope of only buffer zone (%)	16.5
BZ_GRASS_SLOPE(15)	SLOPE	Slope of only buffer zone (%)	27.5
BZ_GRASS_SLOPE(30)	SLOPE	Slope of only buffer zone (%)	49.5
BZ_GRASS_SLOPE(45)	SLOPE	Slope of only buffer zone (%)	82.5
BZ_SOIL_TEXT1	ITEXT	Soil texture	1 (Clay)
BZ_SOIL_TEXT2	ITEXT	Soil texture	2 (Loam)
BZ_SOIL_TEXT3	ITEXT	Soil texture	3 (Sand)
BZ_SOIL_TEXT4	ITEXT	Soil texture	4 (Loamy sand)
BZ_SOIL_TEXT5	ITEXT	Soil texture	5 (Sandy loam)
BZ_SOIL_TEXT7	ITEXT	Soil texture	7 (Sandy clay loam)
BZ_SOIL_TEXT8	ITEXT	Soil texture	8 (Clay loam)
BZ_SOIL_TEXT10	ITEXT	Soil texture	10 (Sandy clay)

2. Results of the Hydrological Sensitivity Assessment

The results presented in the tables that follow are for the outputs of total streamflow from the sub-catchment and include the upstream contributions (Celrun) and peak discharge (Qpeak). Peak discharge is the variable of interest to this study. The simulations were for four climatic zones with different MAPs ranging from 0-400 mm to >1200 mm. The Qpeak values were summed for the 50-year period to make a relative comparison of the impact of each scenario. It was decided to use the Qpeak value for this study as it accounts for rainfall intensity, which was a required outcome (y) and provides a useful surrogate measure for surface overland flow (flows carrying diffuse pollutants through the buffer zone).

a. Land use impacts

The comparison shows that land use has a clear impact on run-off characteristics (Table 30), with land uses dominated by high levels of hardened surfaces/bare ground leading to increased peak discharge (Table 31). When compared to reference conditions, this shows that maize lands and industrial land uses can result in peak discharges that are more than double those simulated under natural (grassland) conditions (Table 32). The importance of climate is also clearly demonstrated here, with a dramatic reduction in simulated peak discharge occurring in drier climatic conditions. Table 33 shows that peak discharge responds consistently with land use changes across all climatic ranges.

These changes in peak discharge, together with potential presence of pollutants, contribute to the risk of land use activities delivering pollutants into adjacent water resources. These variations have already been subjectively accounted for in the land use risk assessment process but reinforce the importance of land use adjacent to water resources in contributing to storm water run-off into buffer zones and the associated risk of pollutants being transported into adjacent water resources.

Table 30 – Impacts of changes in land use on run-off from test catchment

	Land use	MAP (mm) 0-400	401-800	801-1200	>1200
Celrun (mm)	Grassland	0.86	69.26	355.7	489.34
	Maize	1.1	81.92	479.28	639.14
	Forestry	0.56	58.1	265.14	319.36
	Residential	0.7	67.56	317.98	418.02
	Industrial	0.78	71.44	351.8	483.3

Table 31 – Impacts of changes in land use on peak quick flows from test catchment

	Land use	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Grassland	5.93	388.77	1694.20	2187.84
	Maize	15.01	831.47	3633.90	4670.81
	Forestry	3.94	383.83	1693.58	2124.39
	Residential	7.34	625.95	2614.43	3337.37
	Industrial	13.41	1003.01	4254.32	5468.79

Table 32 – Variation in peak discharge relation to "reference" conditions

	Land use	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Grassland	0.00	0.23	1.00	1.29
	Maize	0.01	0.49	2.14	2.76
	Forestry	0.00	0.23	1.00	1.25
	Residential	0.00	0.37	1.54	1.97
	Industrial	0.01	0.59	2.51	3.23

Table 33 – Consistency of peak discharge responses to rainfall intensity zones across different MAP zones

	Land use	MAP (mm) 0-400	401-800	801-1200	>1200	Avg.
Qpeak ($m^3 \cdot s^{-1}$)	Grassland	1.00	1.00	1.00	1.00	1.00
	Maize	2.53	2.14	2.14	2.13	2.24
	Forestry	0.66	0.99	1.00	0.97	0.91
	Residential	1.24	1.61	1.54	1.53	1.48
	Industrial	2.26	2.58	2.51	2.50	2.46

b. Rainfall intensity

The simulation outcomes show that the rainfall intensity zone has a moderate effect on peak discharge across all ranges of MAP considered (Table 34). In high rainfall intensity zones, a 24% increase in peak discharge can be expected over "Reference" whereas a reduction of 25% and 51% can be expected in rainfall zones 3 and 4, respectively (Table 36). This relationship is consistent across different MAP zones (Table 37) and a suite of adjustment factors have therefore been included relative to the "Reference" to account for variations in rainfall intensity zone in the Buffer Zone Model (Table 38).

Table 34 – Impacts of changes in rainfall intensity on run-off from the test catchment

	Rainfall zone	MAP (mm) 0-400	401-800	801-1200	>1200
Celrun (mm)	Zone 4	0.86	69.26	355.7	489.34
	Zone 3	0.86	69.26	355.7	489.34
	Zone 2	0.86	69.26	355.7	489.34
	Zone 1	0.86	69.26	355.7	489.34

Table 35 – Effect of rainfall intensity on peak discharge from the test catchment

	Rainfall zone	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Zone 4	5.00	84.00	204.00	225.00
	Zone 3	4.00	67.00	164.00	182.00
	Zone 2	3.00	50.00	123.00	137.00
	Zone 1	2.00	32.00	80.00	89.00

Table 36 – Variation in peak discharge relation to "reference" conditions

	Rainfall zone	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Zone 4	0.03	0.51	1.24	1.37
	Zone 3	0.02	0.41	1.00	1.11
	Zone 2	0.02	0.30	0.75	0.84
	Zone 1	0.01	0.20	0.49	0.54

Table 37 – Consistency of peak discharge responses to rainfall intensity zones across different MAP zones

	Rainfall zone	MAP (mm) 0-400	401-800	801-1200	>1200	Avg.
Qpeak ($m^3 \cdot s^{-1}$)	Zone 4	1.25	1.25	1.24	1.24	1.25
	Zone 3	1.00	1.00	1.00	1.00	1.00
	Zone 2	0.75	0.75	0.75	0.75	0.75
	Zone 1	0.50	0.48	0.49	0.49	0.49

Table 38 – Simulated adjustment factors for buffer zones to account for rainfall intensity

Rainfall intensity zone	Category	Zone 4	Zone 3	Zone 2	Zone 1
	Modifier	1.25	1.00	0.75	0.49

c. Slope of the buffer zone

As expected, simulation outcomes show that the slope angle across the buffer zone has a clear impact on peak discharges across all ranges of MAP considered (Table 40). In situations where slopes are steep, an increase of 66% above reference was simulated while this declined to only 56% of reference where buffer zones were very gently sloping (Table 41). This relationship is consistent across different MAP zones (Table 42) and a suite of adjustment factors have therefore been included relative to the "reference" to account for variations in rainfall intensity zone in the Buffer Zone Model (Table 43).

Table 39 – Impacts of changes in the slope of the buffer zone on run-off from the test catchment

	Degrees	MAP (mm) 0-400	401-800	801-1200	>1200
Celrun (mm)	0-1	0.86	69.26	355.7	489.34
	0-5	0.86	69.26	355.7	489.34
	5-10	0.86	69.26	355.7	489.34
	10-15	0.86	69.26	355.7	489.34
	15-30	0.86	69.26	355.7	489.34
	30-45	0.86	69.26	355.7	489.34

Table 40 – Effect of slope (degrees) on peak discharge from the test catchment

	Degrees	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	0-1	3	51	125	139
	0-5	4	65	160	177
	5-10	5	93	227	251
	10-15	7	109	265	292
	15-30	8	130	315	348
	30-45	9	151	367	405

Table 41 – Variation in peak discharge relation to "Reference" conditions

	Degrees	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	0-1	0.01	0.22	0.55	0.61
	0-5	0.02	0.29	0.70	0.78
	5-10	0.02	0.41	1.00	1.11
	10-15	0.03	0.48	1.17	1.29
	15-30	0.04	0.57	1.39	1.53
	30-45	0.04	0.67	1.62	1.78

Table 42 – Consistency of peak discharge responses to slope variation across different MAP zones

	Degrees	MAP (mm) 0-400	401-800	801-1200	>1200	Average
Qpeak ($m^3 \cdot s^{-1}$)	0-1	0.60	0.55	0.55	0.55	0.56
	0-5	0.80	0.70	0.70	0.71	0.73
	5-10	1.00	1.00	1.00	1.00	1.00
	10-15	1.40	1.17	1.17	1.16	1.23
	15-30	1.60	1.40	1.39	1.39	1.44
	30-45	1.80	1.62	1.62	1.61	1.66

Table 43 – Simulated adjustment factors for buffer zones to account for variations in buffer zone slope

Slope of buffer zone	Category	0-1	0-5	5-10	10-15	15-30	30-45
	Modifier	0.56	0.73	1.00	1.23	1.44	1.66

d. Vegetation characteristics of the buffer zone

Simulated results show that buffer zone vegetation has a clear impact on peak discharge with higher simulated peak discharge volumes occurring in situations where the buffer zone is degraded (lower basal cover) under natural grassland reference conditions (Table 45). Where vegetation is lacking (bare soil), peak discharge is likely to be more than double that observed under reference conditions (good condition grassland) (Table 46). This emphasises the importance of buffer zone management in slowing surface overland flow, promoting infiltration and allowing pollutants to be deposited in the buffer zone. A range of preliminary adjustment factors have been calculated relative to the "reference" to account for variations in buffer zone vegetation characteristics in the Buffer Zone Model.

Table 44 – Impacts of changes in buffer zone vegetation characteristics on run-off from the test catchment

	Buffer vegetation	MAP (mm) 0-400	401-800	801-1200	>1200
Celrun	Good grass	0.86	69.26	355.7	489.34
	Degraded grass	0.92	69.76	358.08	492.84
	Bare soil	0.9	70.32	359.62	494.54

Table 45 – Effect of changes in buffer zone vegetation characteristics on peak discharge from test catchment

	Buffer vegetation	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak	Good grass	0.2	12.4	53	69
	Degraded grass	1.3	28.5	114	149
	Bare soil	1.4	33	129	168

Table 46 – Variation in peak discharge relation to "Reference" conditions

	Buffer vegetation	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak	Good grass	0.00	0.23	1.00	1.30
	Degraded grass	0.02	0.54	2.15	2.81
	Bare soil	0.03	0.62	2.43	3.17

Table 47 – Consistency of peak discharge responses to variation in buffer vegetation characteristics across different MAP zones

	Buffer vegetation	MAP (mm) 0-400	401-800	801-1200	>1200	Avg.*
Qpeak	Good grass	1.00	1.00	1.00	1.00	1.00
	Degraded grass	6.50	2.30	2.15	2.16	2.20
	Bare soil	7.00	2.66	2.43	2.43	2.51

* In this case, the average excludes very low MAR values, which show inconsistencies in typical relationships

Table 48 – Simulated adjustment factors for buffer zones to account for variations in buffer vegetation characteristics

Condition of buffer zone vegetation	Category	Good grass	Degraded grass	Bare soil
	Modifier	1.00	2.20	2.51

e. Soil texture in the buffer zone

This simulation shows a reduction in peak discharge where soil characteristics of the buffer zone are more coarsely textured (Table 50). When compared with reference (clay loam soils), there is approximately a 25% reduction in peak discharge for sandy soils, while clay soils result in a considerable increase in discharge (Table 51). This is in line with expectations as such soils have a higher infiltration capacity than fine textured soils. A range of preliminary adjustment factors have therefore been calculated relative to the "reference" to account for variations in variations in soil texture in the buffer zone.

Table 49 – Impacts of changes in the soil textural characteristics in the buffer zone on run-off from the test catchment

	Soil texture	MAP (mm) 0-400	401-800	801-1200	>1200
Celrun (mm)	Sand	0.78	69.74	358.16	491.42
	Loamy sand	0.8	69.42	356.76	490.08
	Clay loam	0.86	69.26	355.7	489.34
	Sandy loam	0.84	69.34	356.26	489.62
	Loam	0.84	69.28	355.98	489.44
	Sandy clay loam	0.84	69.28	355.98	489.44
	Sandy clay	0.78	69.6	357.76	490.92
	Clay	3.64	108.84	396.18	529

Table 50 – Effect of changes in soil texture in the buffer zone on peak discharge from the test catchment

	Soil texture	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Sand	0.13	8.9	39	51
	Loamy sand	0.13	9	39	50
	Clay loam	0.19	12.1	53	68
	Sandy loam	0.23	15.5	67	86
	Sandy loam	0.23	15.5	67	86
	Loam	0.24	15.5	67	86
	Sandy clay loam	0.28	18.5	80	102
	Clay	0.83	24.7	85	112

Table 51 – Variation in peak discharge relation to "Reference" conditions

	Soil texture	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Sand	0.00	0.17	0.74	0.96
	Loamy sand	0.00	0.17	0.74	0.94
	Clay loam	0.00	0.23	1.00	1.28
	Sandy loam	0.00	0.29	1.26	1.62
	Sandy loam	0.00	0.29	1.26	1.62
	Loam	0.00	0.29	1.26	1.62
	Sandy clay loam	0.01	0.35	1.51	1.92
	Clay	0.02	0.47	1.60	2.11

Table 52 – Consistency of peak discharge responses to variation in soil textural characteristics of the buffer zone across different MAP zones

	Soil texture	MAP (mm)				
		0-400	401-800	801-1200	>1200	Average*
Celrun (mm)	Sand	0.68	0.74	0.74	0.75	0.74
	Loamy sand	0.68	0.74	0.74	0.74	0.74
	Clay loam	1.00	1.00	1.00	1.00	1.00
	Sandy loam	1.21	1.28	1.26	1.26	1.27
	Sandy loam	1.21	1.28	1.26	1.26	1.27
	Loam	1.26	1.28	1.26	1.26	1.27
	Sandy clay loam	1.47	1.53	1.51	1.50	1.51
	Clay	4.37	2.04	1.60	1.65	1.76

* In this case, the average excludes very low MAR values, which show inconsistencies in typical relationships

Table 53 – Simulated buffer zones adjustment factors for variations in buffer zone soil characteristics

Soil texture of buffer zone	Category	Sand	Loamy sand	Clay loam	Sandy loam	Sandy loam	Loam	Sandy clay loam	Clay
	Modifier	0.74	0.74	1.00	1.27	1.27	1.27	1.51	1.76

f. MAP

This simulation shows that MAP has a significant and consistent effect on peak discharge with dramatic reductions in discharge expected in drier parts of the country (Table 54 to Table 59). Indeed, in very low rainfall areas, even peak discharge is likely to be very low due to typically small rainfall events. This suggests that the risk of contaminated surface flows emanating from land use activities adjacent water resources is likely to be negligible in very dry areas, and significantly lower in moderate rainfall areas (MAP = 401-800 mm) than in high rainfall areas (MAP = 801-1200 mm). A range of preliminary adjustment factors have therefore been calculated relative to the "reference" to account for variations in MAP in the Buffer Zone Model.

Table 54 – Consistency of the effect of MAP on peak discharge across changes in land use types

	Land use	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Grassland	0.00	0.23	1.00	1.29
	Maize	0.00	0.23	1.00	1.29
	Forestry	0.00	0.23	1.00	1.25
	Residential	0.00	0.24	1.00	1.28
	Industrial	0.00	0.24	1.00	1.29
	Average	0.00	0.23	1.00	1.28

Table 55 – Consistency of the effect of MAP on peak discharge across different rainfall intensity zones

	Rainfall zone	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Zone 4	0.02	0.41	1.00	1.10
	Zone 3	0.02	0.41	1.00	1.11
	Zone 2	0.02	0.41	1.00	1.11
	Zone 1	0.03	0.40	1.00	1.11
	Average	0.02	0.41	1.00	1.11

Table 56 – Consistency of MAP effect on peak discharge in relation to changes in buffer zone slope classes

	Degrees	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	0-1	0.02	0.41	1.00	1.11
	0-5	0.03	0.41	1.00	1.11
	5-10	0.02	0.41	1.00	1.11
	10-15	0.03	0.41	1.00	1.10
	15-30	0.03	0.41	1.00	1.10
	30-45	0.02	0.41	1.00	1.10
	Average	0.02	0.41	1.00	1.11

Table 57 – Consistency of MAP effect on peak discharge in relation to changes in buffer zone vegetation characteristics

	Buffer vegetation	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Good grass	0.00	0.23	1.00	1.30
	Degraded grass	0.01	0.25	1.00	1.31
	Bare soil	0.01	0.26	1.00	1.30
	Average	0.01	0.25	1.00	1.30

Table 58 – Consistency of MAP effect on peak discharge in relation to changes in buffer zone textural characteristics

	Soil texture	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Sand	0.00	0.23	1.00	1.31
	Loamy sand	0.00	0.23	1.00	1.28
	Clay loam	0.00	0.23	1.00	1.28
	Sandy loam	0.00	0.23	1.00	1.28
	Loam	0.00	0.23	1.00	1.28
	Sandy clay loam	0.00	0.23	1.00	1.28
	Sandy clay	0.00	0.23	1.00	1.28
	Clay	0.01	0.29	1.00	1.32
	Average	0.00	0.24	1.00	1.29

Table 59 – Consistency of MAP effect on peak discharge across different criteria considered during the simulation

	Criteria	MAP (mm) 0-400	401-800	801-1200	>1200
Qpeak ($m^3 \cdot s^{-1}$)	Land use	0.00	0.23	1.00	1.28
	Rainfall Zone	0.02	0.41	1.00	1.11
	Slope	0.02	0.41	1.00	1.11
	Buffer vegetation	0.01	0.25	1.00	1.30
	Soil texture	0.00	0.24	1.00	1.29
	Overall Average	0.01	0.31	1.00	1.22

Table 60 – Simulated adjustment factors for buffer zones to account for variations in MAP

MAP	Category	0-400	401-800	801-1200	>1200
	Modifier	0.01	0.31	1.00	1.22

3. References

Schmidt, E.T. and Schulze, R.E. (1984). Improved estimation of peak flow rates using modified SCS lag equations. WRC Report No. 63/1/84. Water Research Commission, Pretoria.

Schulze, R.E. (1995). Hydrology and agrohydrology: A text to accompany the ACRU 3.00 agrohydrological modelling system. Department of Agricultural Engineering, University of Natal, Pietermaritzburg.

Annexure 10 – Guidelines for Determining Sensitivity of Wetlands to Lateral Inputs

The focus of this assessment is on the sensitivity of wetlands to lateral impacts rather than broader catchment impacts. The sensitivity of the wetland itself, rather than the sensitivity of important biota is assessed here. Where there are important biodiversity elements, additional protection measures need to be identified in line with the sensitivity of focus species to threats identified. Users should refer to the Technical Manual, which details the additional protection measures for important biodiversity elements.

Criteria have been defined to assess the sensitivity of wetlands to common threats posed by lateral land use impacts (Table 61). The criteria were scored relative to a typical "reference" wetland of intermediate sensitivity and are used to calculate a sensitivity score and associated class for each threat type under consideration.

> ***Note:*** *Sensitivity criteria have a moderate bearing on the final buffer recommendation. Therefore, slight variations in rating of criteria amongst users, although important, should not result in major variations to buffer zone recommendations.*

Table 61 – List of criteria and their relevance for determining the sensitivity of wetlands to common threats posed by lateral land use impacts

Criteria		Wetland Sensitivities from Lateral Inputs								
		Changes in water quantity	Changes in patterns of flow	Changes in sediment inputs and turbidity	Increased inputs of nutrients	Increases in toxic contaminants	Changes in acidity (pH)	Changes in concentration of salts	Changes in water temperature	Changes in pathogens
Desktop Assessment	Overall size	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Size of the wetland relative to its catchment	✓	✓							
	Average slope of the wetland's catchment		✓							
	The inherent run-off potential of catchment soils		✓							
	The extent to which the HGM setting is characterised by sub-surface water input	✓	✓							
	Perimeter-to-area ratio			✓	✓	✓	✓	✓	✓	✓
	Vulnerability of the HGM type to sediment accumulation			✓						
	Vulnerability of the site to erosion given the wetland's slope and size			✓						
	Inherent level of nutrients in the landscape				✓					
	Mean annual temperature	✓		✓	✓	✓	✓	✓		✓
	Natural salinity levels							✓		

Criteria		Wetland Sensitivities from Lateral Inputs								
		Changes in water quantity	Changes in patterns of flow	Changes in sediment inputs and turbidity	Increased inputs of nutrients	Increases in toxic contaminants	Changes in acidity (pH)	Changes in concentration of salts	Changes in water temperature	Changes in pathogens
In-field Assessment Required	Extent of open water, in relation to the extent of the HGM unit			✓					✓	
	Peat/high organic content versus mineral soils			✓						
	Sensitivity of the vegetation to burial under sediment			✓						
	Sensitivity of the vegetation to increased availability of nutrients				✓					
	Sensitivity of the vegetation to toxic inputs, changes in acidity and salinity					✓	✓	✓		
	Natural wetness regimes						✓			
	Level of domestic, livestock and contact recreational use									✓

1. Sensitivity to Changes in Water Quantity (Volumes of Flow) from Lateral Inputs

Table 62 – Wetland characteristics affecting the sensitivity of water resource to changes in the volumes of inputs from lateral inputs

Criteria	Sensitivity Classes				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Size of the wetland relative to (as a percentage of) its catchment	Large (>20%)	10-20	*Intermediate (6-10%)*	2-5%	Small (<2%)
The extent to which the wetland (HGM) setting is generally characterised by sub-surface water input	High (hillslope seepage)	Moderately high	*Intermediate (remaining HGM types)*	Moderately low	Low (Floodplain)

a. Overall size

Rationale: Wetland size provides a broad surrogate for sensitivity to changes in water inputs. Large wetlands have a greater inherent buffering capacity and are less likely to be affected by changes in lateral water inputs than small wetlands where moderate changes in water inputs could have a substantial impact by affecting hydrologic functions and reducing water available to support wetland biota.

Method: Refer to Practical Guide.

b. *Size of the wetland relative to its catchment*

Rationale: Reinelt and Taylor (2001) observed that wetlands that were small in relation to their contributing watersheds had greater water level fluctuations and were dominated by surface inflow. Wetlands that were larger than their contributing watersheds had smaller water level fluctuations and more groundwater interface. By implication then, the larger the wetland relative to its catchment, the greater the extent to which a wetland is fed hydrologically by lateral inputs from its immediate catchment as opposed to from an upstream area, and the more sensitive it will be to changes in water quantity from lateral inputs. At the one extreme, a wetland fed almost entirely by lateral inputs would be the most sensitive, whereas a wetland fed almost entirely from an upstream area would be the least sensitive (Figure 25).

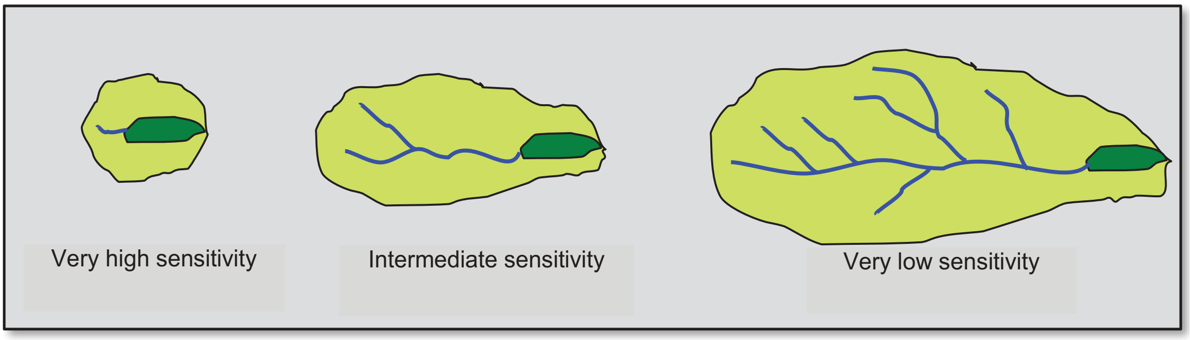

Figure 25 – Illustration of HGM unit's sensitivity in terms of size relative to the catchment

Method: Refer to Practical Guide.

c. *The extent to which the HGM setting is characterised by sub-surface water input*

Rationale: Generally, hillslope seepages are fed primarily from lateral inputs from their immediate catchment, and are typically located in steep settings. These wetlands are therefore likely to be most sensitive to changes in run-off characteristics. Floodplains are however characterised by highly variable flows and fed primarily from an upstream area (although some floodplains, particularly those in higher rainfall areas, may be fed by extensive lateral inputs) and are likely to be considerable less sensitive. Other HGM types tend to be intermediate.

Method: Refer to Practical Guide.

2. Sensitivity to Changes in Patterns of Flow (Frequency, Amplitude, Direction of Flow) from Lateral Inputs

Table 63 – Wetland characteristics affecting the sensitivity of the water resource to changes in the patterns of flow from lateral inputs

Criteria	Sensitivity Classes				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Size of the wetland relative to (as a percentage of) its catchment	Large (>20%)	10-20%	*Intermediate (6-10%)*	2-5%	Small (<2%)
Average slope of the wetland's catchment	<3%	3-5%	*6-8%*	9-11%	>11%

Criteria	Sensitivity Classes				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Inherent run-off potential of catchment soils	Low (A and A/B)	Moderately low (B)	*Moderate* *(B/C)*	Moderately high (C)	High (C/D)
The extent to which the wetland (HGM) setting is generally characterised by sub-surface water input	High (Hillslope seepage)	Moderately high	*Intermediate (remaining HGM types)*	Moderately low	Low (Floodplain)

a. Overall size

Rationale: Wetland size provides a broad surrogate for sensitivity to changes in water inputs. Large wetlands have a greater inherent buffer capacity and are therefore less likely to be affected by increased flood peaks than small wetlands where moderate changes in water inputs could have a substantial impact by affecting water levels and potentially accelerating erosive processes.

***Method**:* Refer to Practical Guide.

b. Size of the wetland relative to its catchment

Rationale: The larger the wetland relative to its catchment, the greater the extent to which a wetland is fed hydrologically by lateral inputs from its immediate catchment as opposed to from an upstream area, and the more sensitive it will be to changes in changes in timing from lateral inputs. At the one extreme, a wetland fed almost entirely by lateral inputs would be the most sensitive, whereas a wetland fed almost entirely from an upstream area would be the least sensitive.

Method: Refer to Practical Guide.

c. Average slope of the wetland's catchment

Rationale: The steeper the slope and the greater the inherent run-off potential of the soils, the lower the infiltration will be and, in turn, the higher flood peaks are likely to be. Wetland systems located at the base of steep catchments with poor infiltration rates are therefore likely to be characterised by naturally flashy flow. Wetlands located below catchments with gentle slopes and high permeability are, however, likely to be characterised more by higher base flows and less flashy flows. These systems are therefore likely to be more sensitive to changes in flow patterns than those that are subject to naturally high variations in flows.

Method: Refer to Practical Guide.

d. The inherent run-off potential of catchment soils

Rationale: The ability of a catchment to partition run-off into surface and sub-surface flow components depends largely on prevailing catchment conditions, which may be the result of both natural and anthropogenic processes. Soils are a key natural regulator of catchment hydrological response due the capacity that soils have for absorbing, retaining and releasing/redistributing water (Schulze, 1989). Catchments dominated with deep, well-drained soils generally have high rates of permeability and lower run-off potential compared to soils with a low permeability (such as clay soils). As such, wetlands fed by catchments characterised by higher permeability are characterised by less flashy flows than those fed by catchments characterised by low permeability. Wetlands fed by catchment inputs, which are naturally flashy, are therefore regarded as less sensitive to changes in the pattern of lateral water inputs (such as increased run-off during heavy rains) than those characterised by less variable flow regimes.

Method: Refer to Practical Guide.

e. The extent to which the HGM setting is characterised by sub-surface water input

Rationale: Generally, hillslope seepages are fed primarily from lateral inputs from their immediate catchment, and are typically located in steep settings. These wetlands are therefore likely to be most sensitive to changes in run-off characteristics. Floodplains on the other hand, are characterised by highly variable flows and fed primarily from an upstream area (although some floodplains, particularly those in higher rainfall areas, may be fed by extensive lateral inputs) and are likely to be considerably less sensitive. Other HGM types tend to be intermediate.

Method: Refer to Practical Guide.

3. Sensitivity to Changes in Sediment Inputs and Turbidity from Lateral Inputs

Table 64 – Wetland characteristics affecting the sensitivity of the water resource to changes in sediment inputs and turbidity from lateral inputs

Criteria	Sensitivity Classes				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Perimeter-to-area ratio	High (>1600 m/ha)	Moderately high (1600-1201 m/ha)	*Moderate (1200-801 m/ha)*	Moderately low (800-401 m/ha)	Low (<400 m/ha)
Vulnerability of the HGM type to sediment accumulation	Depression – endorheic, flat	Depression – exorheic	*Hillslope seep, valley head seep, unchannelled valley bottom*	Channelled valley bottom	Floodplain wetland
Vulnerability of the site to erosion given the site's slope and size	High (vulnerability score 10)	Moderately high (vulnerability score: 8)	*Moderate (vulnerability score: 5)*	Moderately low (vulnerability score: 2)	Low (vulnerability score 0)
Extent of open water, in relation to the extent of the HGM unit	High (>9%)	Moderately high (7-9%)	*Moderate (4-6%)*	Low (0.5-3%)	Very low (<0.5%)
Peat versus mineral soils	Peat/ Champagne/ high organic content	–	Mixed	–	Mineral

Criteria	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Sensitivity of the vegetation to burial under sediment	High (short growing and slow colonising)	Moderately high	*Intermediate (moderate height and robustness OR plants typically fast colonising)*	Moderately low	Low (tall growing and fast colonising)

a. Overall size

***Rationale**:* Wetland size provides a broad surrogate for sensitivity to sediment inputs. Large wetlands have a greater inherent buffer capacity and are therefore less likely to be affected by changes in lateral sediment inputs than small wetlands where moderate changes in sediment inputs could have a substantial impact by reducing storage capacity and affecting hydrologic functions.

Method: Refer to Practical Guide.

b. Perimeter-to-area ratio

Rationale: The greater the perimeter-to-area ratio, the greater the likelihood that much of the wetland could potentially be impinged upon by lateral inputs of sediment. Long, thin wetlands are therefore regarded as more susceptible than round or oval systems that would be less affected by edge impacts.

Method: Refer to Practical Guide.

c. Vulnerability of the HGM type to sediment accumulation

Rationale: Wetland systems that are well connected to the drainage network, characterised by naturally high sediment inputs and subject to regular flushing, are likely to be significantly less susceptible to long-term impacts of sedimentation than wetlands that have not formed under these processes. Floodplains are therefore likely to be least sensitive to increased sediment inputs, with sediment deposition characteristic of these systems, together with high flows that may cause considerable scouring of sediments. Pans, particularly those with a closed drainage system, however, are likely to be highly susceptible to increases in sediment inputs, as are flats, where any accumulation of sediment is likely to remain. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 64.

Method: Refer to Practical Guide.

d. Vulnerability of the wetland to erosion given the wetland's slope and size

Rationale: Deposition of sediment within a wetland steepens the wetland's gradient on the downstream side of the deposition, which potentially increases the threat of erosion taking place in this part of the wetland (Ellery et al., 2008). If the wetland is inherently vulnerable to erosion, then this threat is much more likely to be realised than if the vulnerability of the wetland is low. The vulnerability of the wetland is assessed by establishing the controls on the distribution and occurrence of each HGM, and then assessing vulnerability through an analysis of longitudinal slope in relation to wetland size.

Method: Refer to Practical Guide.

e. Extent of open water, in relation to the extent of the HGM unit

Rationale: Increased water turbidity from suspended sediment reduces light penetration and thus the light available for aquatic plant growth. Open water areas generally support a greater diversity of submerged aquatic plants and/or aquatic fauna than what occurs in dense stands of emergent vegetation, particularly those with very shallow water. In addition, increased turbidity can reduce the visual clarity for sighted organisms (such as fish) that typically use open water areas.

***Method**:* Refer to Practical Guide.

f. Peat/high organic content versus mineral soils

Rationale: In wetlands, peat soils typically form under conditions of limited clastic sediment input, whereas mineral soils typically (although not always) form under conditions of clastic sediment input (Ellery et al., 2008). Sheldon et al. (2003) further report that seeds, seedlings and plants that have evolved in wetland types where sedimentation is rare, are highly sensitive to burial. Therefore, anthropogenic-driven lateral inputs of clastic sediment would generally alter the sediment regime more profoundly in a wetland area with peat soil than in a wetland area with mineral soil.

***Method**:* Refer to Practical Guide.

g. Sensitivity of the vegetation to burial under sediment

Rationale: Sedimentation may lead to burying of established seed banks and natural vegetation. This may lead to a reduction in germination and survival rates of natural species, favouring plant species tolerant to sediment inputs. The sensitivity of vegetation to increased sediment inputs is therefore a useful indicator of sensitivity. In this regard, many mature plants, and especially woody species, apparently are not harmed by a small amount of sediment (Wang et al., 1994). Growth of species such as the reed *Phragmites australis* reportedly also typically keeps pace with moderate levels of sedimentation (Pyke and Havens, 1999). Typically, short growing, slow growing and/or species with limited capacity to colonise new areas are, however, likely to be most sensitive to burial under sediment.

***Method**:* Refer to Practical Guide.

4. Sensitivity to Increased Inputs of Nutrients (Phosphates, Nitrite, Nitrate) from Lateral Inputs

Table 65 – Wetland characteristics affecting the sensitivity of the water resource to increase nutrient inputs from lateral sources

Criterion	**Sensitivity Classes**				
	1.15	1.075	1	0.925	0.85
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Perimeter-to-area ratio	High (>1600 m/ha)	Moderately high (1600-1201 m/ha)	*Moderate (1200-801 m/ha)*	Moderately low (800-401 m/ha)	Low (<400 m/ha)
Inherent level of nutrients in the landscape	Very low base status	Low base status	*Low to moderate base status*	Moderate base status	High base status
Vulnerability of the HGM type to nutrient enrichment	Depression – endorheic, flat	Depression – exorheic	*Hillslope seep, valley head seep, unchannelled valley bottom*	Channelled valley bottom	Floodplain wetland

Criterion	Sensitivity Classes				
	1.15	1.075	1	0.925	0.85
Extent of open water	High (>9%)	Moderately high (7-9%)	*Moderate (4-6%)*	Low (0.5-3%)	Very low (<0.5%)
Sensitivity of the vegetation to increased availability of nutrients	High (short and/or sparse vegetation cover with high natural diversity)	Moderately high	*Intermediate (short vegetation with moderate natural plant diversity)*	Moderately low	Low (tall and dense vegetation with low natural diversity)

a. Overall size

***Rationale**:* Wetland size provides a broad surrogate for sensitivity to nutrient inputs. Large wetlands have a greater inherent buffer capacity and are therefore less likely to be affected by changes in lateral nutrient inputs than small wetlands where moderate changes in nutrient inputs could have a substantial impact on natural nutrient dynamics.

***Method**:* Refer to Practical Guide.

b. Perimeter-to-area ratio

Rationale: The greater the perimeter-to-area ratio, the greater the likelihood that much of the wetland could potentially be impinged upon by lateral inputs of sediment. Long, thin wetlands are therefore regarded as more susceptible than round or oval systems that would be less affected by edge impacts (Figure 2).

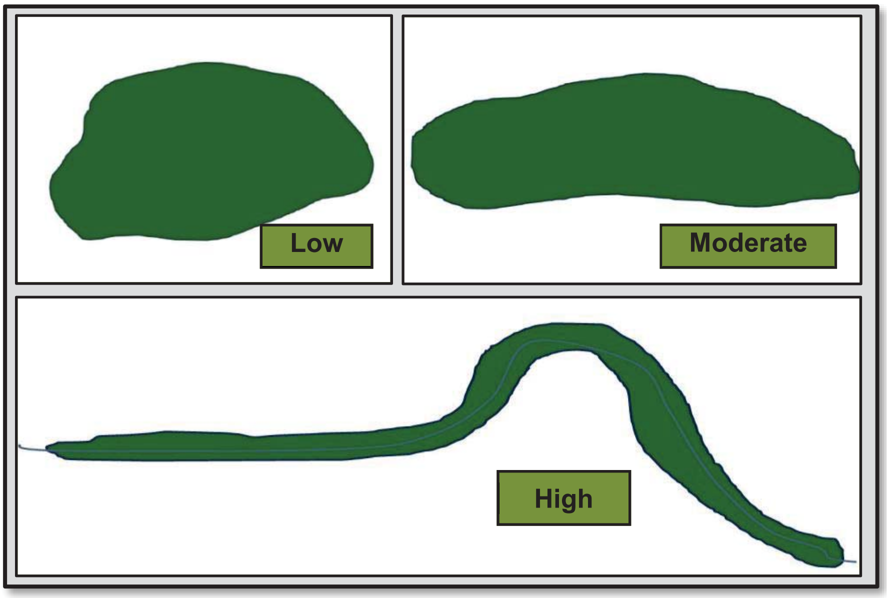

Figure 26 – Illustration of different shaped wetlands and the associated perimeter-to-area ratio sensitivity

Method: Refer to Practical Guide.

c. *Inherent level of nutrients in the landscape*

Rationale: Increased nutrient availability in naturally nutrient-poor systems allows grasses and common opportunistic plants to outcompete rare plants adapted to nutrient-poor conditions (Sheldon et al*.,* 2003). Wetlands or rivers located in landscapes that are inherently low in nutrients are likely to have evolved under low nutrient inputs, and are therefore considered to be more sensitive to increased nutrient inputs than wetlands/streams/rivers in landscapes faced with less severe nutrient limits.

Method: Refer to Practical Guide.

d. *Vulnerability of the HGM type to nutrient enrichment*

Rationale: The less open (the more closed) the drainage system of a wetland (for example, in the case of an endorheic pan) and the less common natural flushing events are, the more readily nutrients will be able to accumulate within the system. Wetland systems with open drainage systems characterised by regular flushing are therefore likely to be significantly less susceptible to nutrient inputs. Floodplains are likely to be least sensitive while pans, particularly those with a closed drainage system, are likely to be most susceptible. Other HGM types are likely to be of intermediate sensitivity (Table 65).

Method*:* Refer to Practical Guide.

e. *Extent of open water, particularly where the substrate is non-muddy*

Rationale: Nutrient enrichment stimulates plant growth, potentially changing the composition of naturally occurring vegetation. Areas of open water, which generally support a higher diversity of submerged aquatic plants and fauna, are regarded as more sensitive than wetland areas with very shallow water. In addition, submerged aquatic plants and aquatic fauna are generally severely affected by increased nutrients.

Method*:* Refer to Practical Guide.

f. *Sensitivity of the vegetation to increased availability of nutrients*

Rationale: An area that is already dominated by tall, dense vegetation has a low sensitivity because it is much less likely to be overgrown by species, such as *Typha capensis*, which are well-suited to responding to increased nutrients. In contrast, short and/or sparse vegetation may easily be overgrown by such species. Naturally high plant species richness may further add to the sensitivity of the vegetation to compositional and structural change because of the increased availability of nutrients, which stimulates plant growth of specific species.

Method*:* Refer to Practical Guide.

5. Sensitivity to Increases in Toxic Contaminants [Including Toxic Metal Ions Such as Copper, Lead, Zinc, Toxic Organic Substances (Reduces Oxygen), Hydrocarbons and Pesticides] from Lateral Inputs

Table 66 – Wetland characteristics affecting the sensitivity of the water resource to increase inputs of toxic substances from lateral sources

Criterion	**Sensitivity Classes**				
	1.15	**1.075**	**1**	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate* *(6-50 ha)*	(51-300 ha)	Large (>300 ha)

Criterion	Sensitivity Classes				
	1.15	1.075	1	0.925	0.85
Perimeter-to-area ratio	High (>1600 m/ha)	Moderately high (1600-1201 m/ha)	*Moderate (1200-801 m/ha)*	Moderately low (800-401 m per ha)	Low (<400 m/ha)
Vulnerability of the HGM type to toxic inputs	Depression – endorheic, flat	Depression – exorheic	*Hillslope seep, valley head seep, unchannelled valley bottom*	Channelled valley bottom	Floodplain wetland
Sensitivity of the vegetation to increased toxic inputs	High (high natural diversity)	Moderately high	*Intermediate (moderate natural plant diversity)*	Moderately low	Low (low natural diversity)

a. Overall size

***Rationale**:* Wetland size provides a broad surrogate for sensitivity to toxic inputs. Large wetlands have a greater inherent buffer capacity and are therefore less likely to be affected by changes in lateral toxic inputs than small wetlands, where moderate changes in toxic inputs could have a substantial impact on wetland biota.

***Method**:* Refer to Practical Guide.

b. Perimeter-to-area ratio

***Rationale**:* The greater the perimeter-to-area ratio, the greater the likelihood that much of the wetland could potentially be impinged upon by lateral toxic inputs. Long, thin wetlands are therefore regarded as more susceptible than round or oval systems that would be less affected by edge impacts, which are likely to be felt most notably on the periphery where toxins enter the wetland.

***Method**:* Refer to Practical Guide.

c. Vulnerability of the HGM type to toxic inputs

Rationale: The less open (the more closed) the drainage system of a wetland (for example, in the case of an endorheic pan), and the less common natural flushing events are, the more readily toxins will be able to accumulate within the system. Wetland systems with open drainage systems that are characterised by regular flushing are therefore likely to be significantly less susceptible to toxic inputs. Floodplains are therefore likely to be least sensitive while pans, particularly those with a closed drainage system, are likely to be most susceptible. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 66.

***Method**:* Refer to Practical Guide.

d. Sensitivity of the vegetation to toxic inputs

***Rationale**:* Most plant species are relatively tolerant to toxic contaminants, with shifts in the composition of the plant community in response to toxic contaminants not widely documented (Sheldon et al*.*, 2003). Despite the lack of reported responses of plants to toxic contaminants, the potential of impacts occurring is likely to be higher in naturally diverse (typically un-impacted) systems. The diversity of wetland vegetation is therefore used as a surrogate for the sensitivity of wetland vegetation to toxic inputs.

***Method**:* Refer to Practical Guide.

6. Sensitivity to Changes in Acidity (pH) from Lateral Inputs

Table 67 – Wetland characteristics affecting the sensitivity of the water resource to changes in acidity from lateral sources

Criterion	Sensitivity Classes				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Perimeter-to-area ratio	High (>1600 m/ha)	Moderately high (1600-1201 m/ha)	*Moderate (1200-801 m/ha)*	Moderately low (800-401 m/ha)	Low (<400 m/ha)
Vulnerability of the HGM type to changes in pH	Depression – endorheic, flat	Depression – exorheic	*Hillslope seep, valley head seep, unchannelled valley bottom*	Channelled valley bottom	Floodplain wetland
Sensitivity of the vegetation to changes in acidity	High (high natural diversity)	Moderately high	*Intermediate (moderate natural plant diversity)*	Moderately low	Low (low natural diversity)
Natural wetness regimes	Dominated by temporarily saturated soils	Mix of seasonal and temporarily saturated soils	*Dominated by seasonally saturated soils*	Mix of permanently and seasonally saturated soils	Dominated by permanently saturated soils

a. Overall size

***Rationale**:* Wetland size provides a broad surrogate for sensitivity to acidity. Large wetlands have a greater inherent buffer capacity and are therefore less likely to be affected by changes in pH in influent water than small wetlands where moderate changes in acidity could have a substantial impact on wetland biota.

***Method**:* Refer to Practical Guide.

b. Perimeter-to-area ratio

***Rationale**:* The greater the perimeter-to-area ratio, the greater the likelihood that much of the wetland could potentially be impinged upon by lateral inputs. Long, thin wetlands are therefore regarded as more susceptible than round or oval systems that would be less affected by edge impacts that are likely to be felt most notably on the periphery of the wetland.

***Method**:* Refer to Practical Guide.

c. Vulnerability of the HGM type to changes in pH

Rationale: The less open (the more closed) the drainage system of a wetland (for example, in the case of an endorheic pan) and the less common natural flushing events are, the more likely that pH levels will change in response to lateral impacts. Wetland systems with open drainage systems characterised by regular flushing are therefore likely to be significantly less susceptible. Floodplains are likely to be least sensitive while pans, particularly those with a closed drainage system, are likely to be most susceptible. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 7.

***Method**:* Refer to Practical Guide.

d. Sensitivity of the vegetation to changes in salinity

***Rationale**:* pH is reportedly critical in determining the distribution of plants in wetlands, by altering the availability of some inorganic nutrients and carbon, and increasing the toxicity of heavy metals such as aluminium and manganese (Sheldon et al., 2003). Changes in acidity are likely to affect wetland plants differently, depending on the sensitivity of specific species. The diversity of indigenous wetland vegetation is likely to provide a useful surrogate for the sensitivity of wetland vegetation to changes in acidity.

***Method**:* Refer to Practical Guide.

e. Natural wetness regimes

***Rationale**:* Generally, permanently saturated/flooded areas, which would support anaerobic soil conditions, are better buffered than temporarily saturated soils. Seasonally saturated areas are probably intermediate.

***Method**:* Refer to Practical Guide.

7. Sensitivity to Changes in Concentration of Salts (Salinization) from Lateral Inputs.

Table 68 – Wetland characteristics affecting the sensitivity of the water resource to changes in salinity from lateral sources

Criterion	Sensitivity Classes				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Perimeter-to-area ratio	High (>1600 m/ha)	Moderately high (1600-1201 m/ha)	*Moderate (1200-801 m/ha)*	Moderately low (800-401 m/ha)	Low (<400 m/ha)
Vulnerability of the HGM type to changes in salinity	Depression – endorheic, flat	Depression – exorheic	*Hillslope seep, valley head seep, unchannelled valley bottom*	Channelled valley bottom	Floodplain wetland
Natural salinity levels	–	–	*Non-saline (<200 mS/m)*	Slightly saline (200-400 mS/m)	Saline and/or sodic (>400 mS/m)
Sensitivity of the vegetation to changes in salinity	High (high natural diversity)	Moderately high	*Intermediate (moderate natural plant diversity)*	Moderately low	Low (low natural diversity)

a. Overall size

***Rationale**:* Wetland size provides a broad surrogate for sensitivity to lateral inputs. Large wetlands have a greater inherent buffer capacity and are therefore less likely to be affected by increases in salt concentrations in influent water than small wetlands where moderate changes in salinity could have a substantial impact on wetland biota.

***Method**:* Refer to Practical Guide.

b. Perimeter-to-area ratio

***Rationale**:* The greater the perimeter-to-area ratio, the greater the likelihood that much of the wetland could potentially be impinged upon by lateral inputs. Long, thin wetlands are therefore regarded as more susceptible than round or oval systems that would be less affected by edge impacts which are likely to be felt most notably on the periphery where salts enter the wetland.

***Method**:* Refer to Practical Guide.

c. Vulnerability of the HGM type to changes in salinity

Rationale: The less open (the more closed) the drainage system of a wetland (for example, in the case of an endorheic pan) and the less common natural flushing events are, the more likely that salinity levels will change in response to lateral impacts. Wetland systems with open drainage systems characterised by regular flushing are therefore likely to be significantly less susceptible. Floodplains are likely to be least sensitive while pans, particularly those with a closed drainage system, are likely to be most susceptible. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 68.

***Method**:* Refer to Practical Guide.

d. Natural salinity levels

Rationale: Biota that inhabit naturally saline wetlands (for example, those associated with estuaries or pans with naturally high salt levels) are adapted to tolerating salt levels that would kill most other wetland species. Inland wetlands characterised by naturally low saline concentrations are, however, expected to be far more susceptible.

***Method**:* Refer to Practical Guide.

e. Sensitivity of the vegetation to changes in salinity

Rationale: In general, high concentrations of soluble salts are lethal to freshwater plants, and lower concentrations may impair growth (Rending and Taylor, 1989, cited in Sheldon et al., 2003). Woody plants also tend to be less tolerant than herbaceous plants because they do not have mechanisms for removing salt other than accumulating salts in leaves and subsequently dropping them (Adamus et al., 2001). It can be expected that the plant community in a wetland will therefore change to one dominated by salt-tolerant plants when additional salts are introduced. The diversity of wetland vegetation is likely to provide a useful surrogate for the sensitivity of wetland vegetation to changes in acidity.

***Method**:* Refer to Practical Guide.

8. Sensitivity to Changes in Water Temperature from Lateral Inputs

Table 69 – Wetland characteristics affecting the sensitivity of the water resource to changes in water temperature from lateral sources

Criterion	Sensitivity Classes				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Perimeter-to-area ratio	High (>1600 m/ha)	Moderately high (1600-1201 m/ha)	*Moderate (1200-801 m/ha)*	Moderately low (800-401 m/ha)	Low (<400 m/ha)
Extent of open water	High (>9%)	Moderately high (7-9%)	*Moderate (4-6%)*	Low (0.5-3%)	Very low (<0.5%)
Mean annual temperature	Zone 1 (6.3-15.5°C)	Zone 2 (15.5-16.9°C)	*Zone 3 (16.9-18.2°C)*	Zone 4 (18.2-19.5°C)	Zone 5 (19.5-24.2°C)

a. Overall size

Rationale: Wetland size provides a broad surrogate for sensitivity to lateral inputs. Large wetlands have a greater inherent buffer capacity and are therefore less likely to be affected by changes in temperature in influent water than small wetlands where moderate changes in water temperature could have a substantial impact on wetland biota.

Method*:* Refer to Practical Guide.

9. Perimeter-to-area Ratio

Rationale: The greater the perimeter-to-area ratio, the greater the likelihood that much of the wetland could potentially be impinged upon by lateral inputs. Long, thin wetlands are therefore regarded as more susceptible than round or oval systems that would be less affected by edge impacts that are likely to be felt most notably on the periphery where warm water enters the wetland.

Method*:* Refer to Practical Guide.

b. Extent of open water

Rationale: Submerged aquatic plants and aquatic fauna are generally more severely affected by changes in water temperature, given the fact that they are contained entirely within the water column. Therefore, open water areas are considered more sensitive to changes in water temperature from lateral inputs than emergent vegetation areas.

Method*:* Refer to Practical Guide.

c. Mean annual temperature

Rationale: Water resources characterised by cooler water are more sensitive to thermal pollution than those with higher temperatures. Wetland or rivers situated in cooler regions are likely to be more sensitive to changes in water temperature (Figure 27). Mean annual temperature is considered when assessing sensitivity to changes in water temperature from lateral inputs.

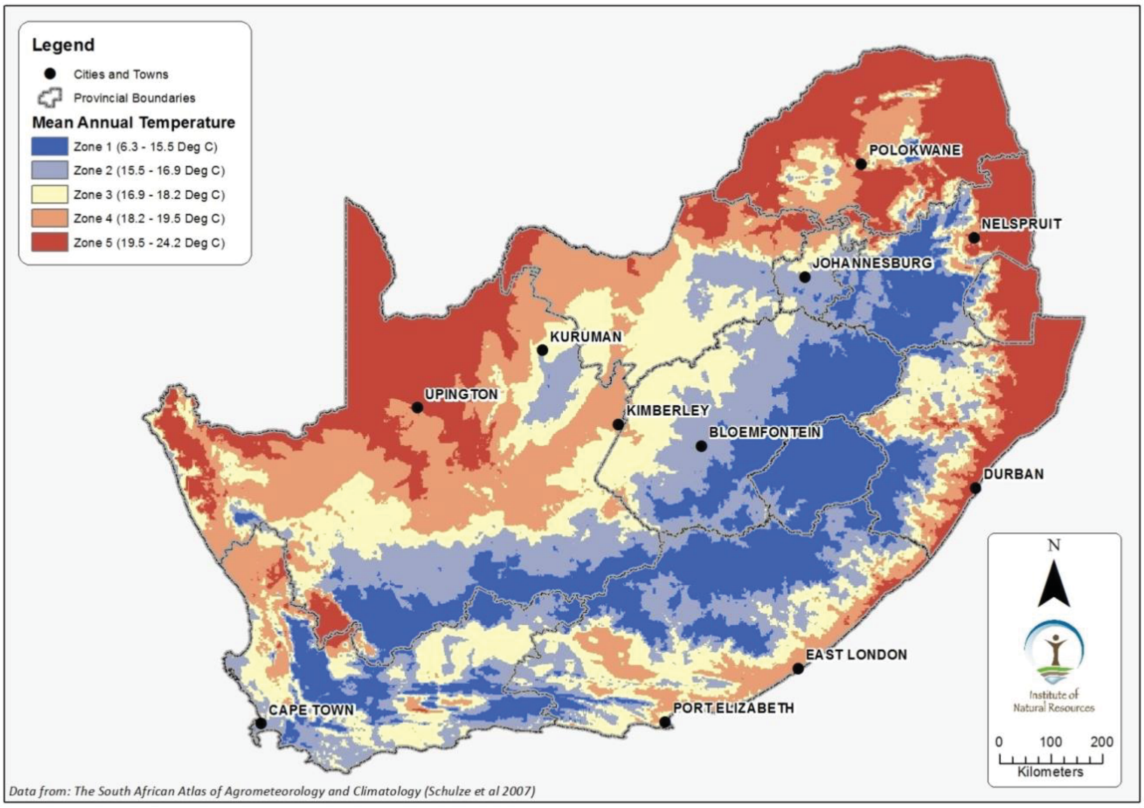

Figure 27 – Mean annual temperature separated into five temperature zones, based on five equal quantiles) (Data from Schulze, 2007)

Method: Refer to Practical Guide.

10. Sensitivity to Changes in Pathogens from Lateral Inputs

Table 70 – Wetland characteristics affecting the sensitivity of the water resource to increased pathogen inputs from lateral sources

Criterion	**Sensitivity Classes**				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*Intermediate (6-50 ha)*	(51-300 ha)	Large (>300 ha)
Perimeter-to-area ratio	High (>1600 m/ha)	Moderately high (1600-1201 m/ha)	*Moderate (1200-801 m/ha)*	Moderately low (800-401 m/ha)	Low (<400 m/ha)
Level of domestic and contact recreational use	High	Moderately high	*Moderate*	Moderately low	Low

a. Overall size

Rationale: Wetland size provides a broad surrogate for sensitivity to lateral inputs. Large wetlands have a greater inherent buffer capacity and are therefore likely to be affected by increases in pathogen inputs to a lesser degree than small wetlands where moderate increases in pathogen inputs could lead to rapid increases in pathogen levels.

Method*:* Refer to Practical Guide.

b. Perimeter-to-area ratio

Rationale: The greater the perimeter-to-area ratio, the greater the likelihood that much of the wetland could potentially be impinged upon by lateral inputs. Long, thin wetlands are therefore regarded as more susceptible than round or oval systems that would be less affected by edge impacts that are likely to be felt most notably on the periphery where pathogens enter the wetland.

Method*:* Refer to Practical Guide.

c. Level of domestic, livestock and contact recreational use

Rationale: The higher the level of domestic, and contact recreational water use, the higher the threat of increasing pathogen levels to water users. Higher levels of use by domestic animals and livestock have also been found to increase pathogen loads and faecal coliforms. Level of domestic use is taken into consideration when assessing sensitivity to changes in pathogens from lateral inputs.

Method*:* Refer to Practical Guide.

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Annexure 11 – Guidelines for Determining Sensitivity of Rivers and Streams to Impacts from Lateral Land Use Inputs

The focus of this assessment is on the sensitivity of streams and rivers to lateral impacts rather than broader catchment impacts. The sensitivity of the river as an integrated ecosystem, rather than the sensitivity of important biota is assessed here. Where there are important biodiversity elements, additional protection measures need to be identified in line with the sensitivity of focus species to threats identified.

Indicators have been defined to assess the sensitivity of rivers to common threats posed by lateral land use impacts. The indicators were scored relative to a typical “reference” river of intermediate sensitivity and are used to calculate a sensitivity score (Table 71) and associated class for each threat type under consideration. Sensitivity criteria have a moderate bearing on the final buffer recommendation. Therefore, slight variations in rating of criteria amongst users, although important, should not result in major variations to buffer zone recommendations.

Table 71 – List of criteria and their relevance for determining the sensitivity of rivers to common threats posed by lateral land use impacts

Criteria		Rivers Sensitivities from Lateral Inputs								
		Changes in water quantity	Changes in patterns of flow	Changes in sediment inputs and turbidity	Increased inputs of nutrients	Increases in toxic contaminants	Changes in acidity (pH)	Changes in concentration of salts	Changes in water temperature	Changes in pathogens
Desktop Assessment	Stream order	✓	✓		✓	✓	✓	✓	✓	
	Average catchment slope		✓	✓						
	Inherent run-off potential of catchment soils		✓	✓		✓				
	Longitudinal river zonation			✓					✓	
	Inherent erosion potential (K-factor) of catchment soils			✓	✓	✓				
	Inherent levels of nutrients in catchment soils				✓					
	Inherent buffering capacity						✓			
	Natural salinity levels							✓		
	Mean annual temperature									✓
In-field Assessment	Channel width	✓		✓	✓	✓	✓	✓		✓
	Perenniality	✓								
	Retention time				✓					
	River depth-to-width ratio								✓	✓
	Level of domestic, livestock and contact recreational use									✓

1. Sensitivity to Changes in Water Quantity (Volumes of Flow) from Lateral Inputs

Table 72 – Stream/river characteristics affecting the sensitivity of the water resource to changes in the volumes of flow from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Stream order	1st order	2nd order	*3rd order*	4th order	>5th order
Channel width	<1 m	1-5 m	*5-10 m*	10-20 m	>20 m
Perenniality		Perennial systems (>9 months)	*Seasonal systems (3-9 months)*	Intermittent systems (<3 months)	

a. Stream order

Rationale: Small streams are likely to be more sensitive to changes in quantity of water generated within the catchment than larger systems. As a result, small contributions of water from lateral inputs will have a much greater effect on streams and rivers fed by small catchments as opposed to those fed by large catchments. Stream ordering is a useful surrogate for determining the relative size of catchments and is used here as a method for estimating catchment size for a particular section of river.

***Method**:* Refer to Practical Guide.

b. Channel width

Rationale: River width is a useful measure of the size of a river and therefore provides an indication of a river's sensitivity to changes in flow volumes from lateral inputs. River widths are based on site-specific measurements and therefore account for any possible variations of the size of rivers that may have the same stream order (as determined in the previous step).

***Method**:* Refer to Practical Guide.

c. Perenniality

Rationale: The perenniality of a river affects how sensitive the water resource will be to changes in water inputs. In this regard, perennial systems (particularly small streams) are regarded as most sensitive as habitat and biota is adapted to constant flow regimes. Seasonal systems are regarded as moderately sensitive as organisms are adapted to periods of no flow. Intermittent streams are naturally highly variable and usually associated with low MAR and are therefore adapted to no-flow conditions. Additional reductions in flow will simply increase the variability or duration of no-flow conditions.

***Method**:* Refer to Practical Guide.

2. Sensitivity to Changes in Patterns of Flow (Frequency, Amplitude, Direction of Flow) from Lateral Inputs

Table 73 – Stream/river characteristics affecting the sensitivity of the water resource to changes in the patterns of flow from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Stream order	1st order	2nd order	*3rd order*	4th order	>5th order
Average catchment slope	<3%	3-5%	*6-8%*	9-11%	>11%
Inherent run-off potential of catchment soils	Low (A and A/B)	Moderately low (B)	*Moderate (B/C)*	Moderately high (C)	High (C/D and D)

a. Stream order

Rationale: Streams with small catchments are generally more sensitive to changes in patterns of flow than they are to changes in quantity of water generated within the catchment. As a result, small contributions of water from lateral inputs will have a much greater effect on small streams as opposed to those associated with larger catchments. For example, a volume of stormflow generated from an impervious area (such as parking areas and roofs) adjacent to a river of a small catchment will have a more dramatic effect on the natural hydrograph than a river draining a large catchment. Figure 1 illustrates this example of the relative sensitivity of small and large catchments to a similar volume of effluent water (note the scale of river discharge is not in proportion).

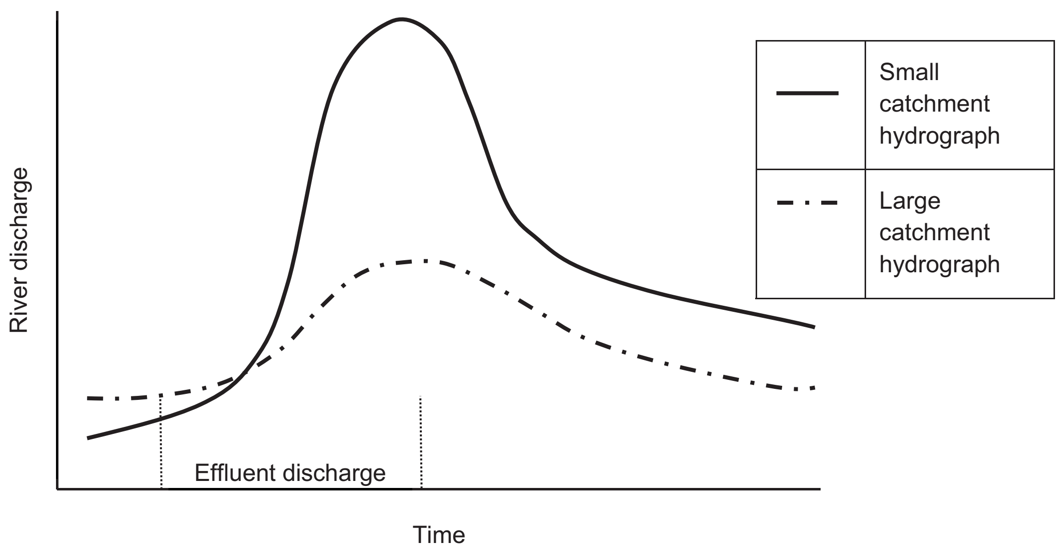

Figure 28 – Illustration of sensitivity of small and large catchments to a similar volume of effluent water

***Method**:* Refer to Practical Guide.

b. Average catchment slope

Rationale: Catchment topography is a key driver of hydrological responses in the landscape. Slope is therefore particularly important in terms of encouraging surface run-off in response to rainfall events where steeper slopes generally produce higher surface run-off compared to flat/moderate slopes. The result of higher surface run-off is a natural tendency for 'flashy' flow properties in rivers. Rivers that are naturally 'flashy' are likely to be less sensitive to impacts on patterns of flow from lateral inputs.

***Method**:* Refer to Practical Guide.

c. The inherent run-off potential of catchment soils

The ability of a catchment to partition run-off into surface and sub-surface flow components depends largely on prevailing catchment conditions, which may be the result of both natural and anthropogenic processes. Soils are a key natural regulator of catchment hydrological response because of the capacity that soils have for absorbing, retaining and releasing/redistributing water (Schulze, 1989). Catchments dominated with deep, well-drained soils generally have high rates of permeability and lower run-off potential compared to soils with a low permeability (such as clay soils). As such, wetlands fed by catchments characterised by higher permeability have less flashy flows than those fed by catchments characterised by low permeability. Wetlands fed by catchment inputs that are naturally flashy are therefore regarded as less sensitive to changes in the pattern of lateral water inputs (for example, increased run-off during heavy rains) than those characterised by less variable flow regimes.

***Method**:* Refer to Practical Guide.

3. Sensitivity to Changes in Sediment Inputs and Turbidity from Lateral Inputs

Table 74 – Stream/river characteristics affecting the sensitivity of the water resource to changes in sediment inputs and turbidity from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Channel width	<1 m	1-5 m	*5-10 m*	10-20 m	>20 m
Longitudinal river zonation	Upper foothill river	Transitional river	*Mountain stream*	Lower foothill river	Lowland river
Inherent erosion potential (K-factor) of catchment soils	<0.13	0.13-0.25	*0.25-0.50*	0.50-0.70	>0.70
Average catchment slope	<3%	3-5%	*6-8%*	9-11%	>11%
Inherent run-off potential of catchment soils	Low (A and A/B)	Moderately low (B)	*Moderate (B/C)*	Moderately high (C)	High (C/D and D)

a. Channel width

Rationale: Stream size provides a broad surrogate for sensitivity to sediment inputs. Large rivers have a greater inherent buffer capacity and are therefore less likely to be affected by changes in lateral sediment inputs than small streams where moderate changes in sediment inputs could have a substantial impact on turbidity levels.

***Method**:* Refer to Practical Guide.

b. Longitudinal river zonation

Rationale: Whether a river is characterised as an upland or lowland river depends on various geomorphological characteristics driven by factors such as topography and hydrology. These characteristics in turn affect the rates of sediment transport and deposition taking place within a river along its longitudinal length. Rivers situated in the upper reaches of catchments tend to be 'sediment-free' because of effective removal mechanisms resulting from river flow rates while rivers situated in the lower reaches are naturally driven by sediment deposition (notable of river floodplains). Intermediate river sections, however, are arguably more sensitive to sediment inputs than headwater and lowland sections because of limited abilities for sediment removal as well as reasonably high potential for deposition.

Method*:* Refer to Practical Guide.

c. Inherent erosion potential of catchment soils

Rationale: Soils vary in terms of processes such as soil particle detachment and transport caused by raindrop impact and surface run-off. Different soils also have different rates of infiltration into the soil profile. Soil characteristics such as these therefore determine the erosive potential of different soils. Rivers driven by soils with characteristically high erodibility potential, are characterised by naturally higher sediment inputs and are therefore considered less sensitive to additional sediment inputs than river catchment systems dominated by soils with a low erodibility potential (Figure 29).

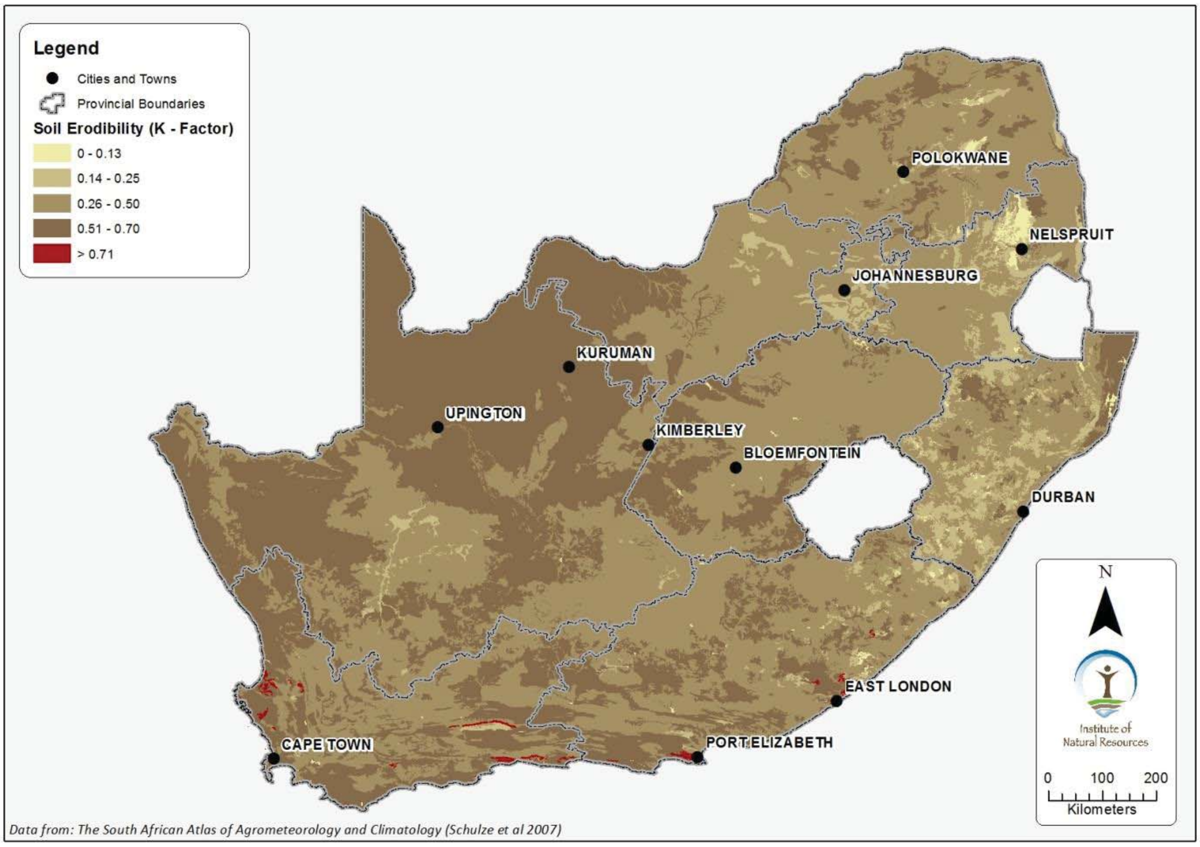

Figure 29 – Soil erodibility (K-Factor) (Schulze et al., 2007)

d. Average catchment slope

***Rationale**:* As slope is a key driver of catchment hydrological response (see *Rationale 3d*), it also has a significant influence on secondary factors such as soil erosion. Catchments affected by heavy soil erosion are expected to have high rates of sedimentation within the rivers. Therefore, rivers draining catchments characterised by steep topography are likely to experience higher levels of sedimentation resulting from greater erosion.

***Method**:* Refer to Practical Guide.

e. The inherent run-off potential of catchment soils

The ability of a catchment to partition run-off into surface and sub-surface flow components depends largely on prevailing catchment conditions, which may be the result of both natural and anthropogenic processes. Soils are a key natural regulator of catchment hydrological response because of their capacity for absorbing, retaining and releasing/redistributing water (Schulze, 1989). Catchments dominated with deep, well-drained soils generally have high rates of permeability and lower run-off potential compared to soils with a low permeability (such as clay soils). As such, wetlands fed by catchments characterised by higher permeability have less flashy flows than those fed by catchments characterised by low permeability. Wetlands fed by catchment inputs that are naturally flashy are therefore regarded as less sensitive to changes in the pattern of lateral water inputs (for example, increased run-off during heavy rains) than those characterised by less variable flow regimes.

***Method**:* Refer to Practical Guide.

4. Sensitivity to Increased Inputs of Nutrients (Phosphate, Nitrite, Nitrate) from Lateral Inputs

Table 75 – Stream/river characteristics affecting the sensitivity of the water resource to increased inputs of nutrients (phosphate, nitrite, nitrate) from lateral inputs)

Criterion	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Channel width	<1 m	1-5 m	*5-10 m*	10-20 m	>20 m
Stream order	1st order	2nd order	*3rd order*	4th order	>5th order
Retention time		Generally free-flowing		Generally slow moving	
Inherent level of nutrients in the landscape	Very low base status	Low base status	*Low to moderate base status*	Moderate base status	High base status
Inherent erosion potential (K-factor) of catchment soils	<0.13	0.13-0.25	*0.25-0.50*	0.50-0.70	>0.70

a. Channel width

***Rationale**:* Stream size provides a broad surrogate for sensitivity to inputs of various nutrient pollutants. Large rivers have a greater inherent buffer capacity and are therefore less likely to be affected by changes in lateral nutrient pollutant inputs than small streams where moderate changes in nutrient pollutant inputs could have a substantial impact on water quality.

***Method**:* Refer to Practical Guide.

b. Stream order

Rationale: Small catchments are generally more sensitive to nutrient pollutant loading than larger systems as smaller systems have a much smaller inherent potential to dilute sources of nutrient pollutants. As a result, a source of nutrient pollution from lateral inputs will have a much greater effect on a small catchment than on a large catchment. For example, a 2 Ml discharge of effluent water from a waste water treatment works into a small catchment will have a much greater impact in terms of nutrient pollution than a large catchment system.

***Method**:* Refer to Practical Guide.

c. Retention time

Rationale: Rivers dominated by pools and slow flowing sections have a greater tendency for nutrients to accumulate and thus for higher impacts to occur (such as increased algal growth) because of higher retention times. Hence rivers characterised by higher retention times are more sensitive to nutrient loads received from lateral inputs.

***Method**:* Refer to Practical Guide.

d. Inherent level of nutrients in the landscape

Rationale: Increased nutrient availability in naturally nutrient-poor systems allows grasses and common opportunistic plants to outcompete rare plants that are adapted to nutrient-poor conditions (Sheldon et al*.,* 2003). Rivers located in landscapes which are inherently low in nutrients are likely to have evolved under low nutrient inputs, and are therefore considered to be more sensitive to increased nutrient inputs than streams or rivers in landscapes faced with less severe nutrient limits.

***Method**:* Refer to Practical Guide.

e. Inherent erosion potential of catchment soils (K-factor)

Rationale: Soil erosion is regarded as a major contributor to phosphorus levels in streams. As such, streams fed by catchments with high erodibility are likely to have higher inherent phosphate loadings than where the catchments are characterised by low soil erodibility.

***Method**:* Refer to Practical Guide.

5. Sensitivity to Increases in Toxic Contaminants [Including Toxic Metal Ions such as Copper, Lead, Zinc, Toxic Organic Substances (Reduces Oxygen), Hydrocarbons and Pesticides] from Lateral Inputs

Table 76 – Stream/river characteristics affecting the sensitivity of the water resource to increases in toxic contaminants from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Channel width	<1 m	1-5 m	*5-10 m*	10-20 m	>20 m
Stream order	1st order	2nd order	*3rd order*	4th order	>5th order
Inherent erosion potential (K-factor) of catchment soils	<0.13	0.13-0.25	*0.25-0.50*	0.50-0.70	>0.70
Inherent run-off potential of catchment soils	Low (A and A/B)	Moderately low (B)	*Moderate (B/C)*	Moderately high (C)	High (C/D and D)

a. Channel width

***Rationale**: See Rationale 4a.*

***Method**: Refer to Practical Guide.*

b. Stream order

Rationale: See *Rationale 4b.*

***Method**: Refer to Practical Guide.*

c. Inherent erosion potential of catchment soils (heavy metals only)

Rationale: Concentrations of heavy metals in rivers are derived naturally by the weathering of underlying geological formations resulting in a natural enrichment of heavy metals contained in weathered sediments. Therefore, catchments with a high erodibility potential are likely to experience high levels of heavy metal enrichment through geological weathering. Catchments driven naturally by heavy metal enrichments are considered less sensitive than catchments with low weathering (and thus low enrichment).

***Method**: Refer to Practical Guide.*

d. Inherent run-off potential of catchment soils

Rationale: Toxic contamination in rivers is driven naturally by processes such as surface run-off, a key factor resulting in the transport of various toxic contaminants from the land and into rivers. Based on the prevailing soils, catchments with a high run-off potential are more susceptible to toxic contamination in the rivers than catchments with low run-off potential.

***Method**: Refer to Practical Guide.*

6. Sensitivity to Changes in Acidity (pH) from Lateral Inputs

Table 77 – Stream/river characteristics affecting the sensitivity of the water resource to changes in acidity (pH) from lateral inputs

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Channel width	<1 m	1-5 m	*5-10 m*	10-20 m	>20 m
Stream order	1st order	2nd order	*3rd order*	4th order	>5th order
Inherent buffering capacity	Pure waters with poor pH buffering		*Neutral pH*		'Hard' water rich in bicarbonate and carbonate ions or naturally acid waters high in organic acids[40]

a. Channel width

***Rationale**: See Rationale 4a.*

***Method**: Refer to Practical Guide.*

[40]http://yosemite.epa.gov/r10/ecocomm.nsf/c6b2f012f2fd7f158825738b0067d20b/9a6226e464ecdb3f88256b5d0067de0d/$FILE/chapter3.pdf

b. Stream order

Rationale: See *Rationale 4b.*

Method: Refer to Practical Guide.

c. Inherent buffering capacity

Rationale: The pH of a substance is determined by the concentration of hydrogen ions (H^+). Buffering capacity is defined by the ability of a solution to resist changes to the pH. Waters with a low buffering capacity (for example, pure waters which contain no solutes) have a high rate of pH change when exposed to acidic or basic substances, whereas waters with a high buffering capacity are considered more stable because they can absorb the impact of added substances and have a low rate of pH change. In freshwater systems, most of the buffering capacity results from the concentrations of carbonate and bicarbonate ions in the water. Consequently, pH in river water is, to some degree, driven naturally by the dominance of bicarbonate and carbonate ions present in the mineral composition of the geological substratum. At the opposite end of this scale, acidic rivers dominated by organic acids have an entirely different buffering system based on the presence of organic acids. However, these systems are not well understood.

Method: Refer to Practical Guide.

7. Sensitivity to Changes in Concentration of Salts (Salinization) from Lateral Inputs

Table 78 – Stream/river characteristics affecting the sensitivity of the water resource to changes in concentration of salts from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Channel width	<1 m	1-5 m	*5-10 m*	10-20 m	>20 m
Stream order	1st order	2nd order	*3rd order*	4th order	>5th order
Natural salinity levels			*Non-saline (<200 mS/m)*	Slightly saline (200-400 mS/m)	Saline and/or sodic (>400 mS/m)

a. Channel width

Rationale: See *Rationale 4a.*

Method: Refer to Practical Guide.

b. Stream order

Rationale: Salts tend to accumulate with downstream distance as salts are continually added through natural and anthropogenic sources and very little is removed through natural processes.

Method: Refer to Practical Guide.

c. Natural salinity levels

Rationale: River water has natural salt concentrations that result from the dissolving of minerals in rocks and soils. Salinity is a very important attribute of rivers because it has a major influence on the chemical and biological make-up and functioning of an inland aquatic ecosystem (Ollis et al., 2013). Non-saline river systems are likely to be more sensitive to increased salt concentrations in comparison to saline river systems. Conductivity, which is measured in milli-Siemens per metre (mS/m), can be used as a surrogate measure of salinity. Nell (2009) produced a map of salt-affected soils through South

Africa, which can be used at a broad level to estimate whether an area of concern is located within a non-saline, slightly saline or saline region within the country.

***Method**:* Refer to Practical Guide.

8. Sensitivity to Changes in Water Temperature from Lateral Inputs

Table 79 – Stream/river characteristics affecting the sensitivity of the water resource to changes in water temperature from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Stream order	1st order	2nd order	*3rd order*	4th order	>5th order
River depth-to-width ratio	<0.25		*0.25-0.75*		>0.75
Mean annual temperature	Zone 1 (6.3-15.5°C)	Zone 2 (15.5-16.9°C)	*Zone 3 (16.9-18.2°C)*	Zone 4 (18.2-19.5°C)	Zone 5 (19.5-24.2°C)
Longitudinal river zonation	Mountain stream and headwaters		*Transitional and upper foothill rivers*		Lower foothill and lowland rivers

a. Stream order

Rationale: See *Rationale 4b.*

***Method**:* Refer to Practical Guide.

b. River depth-to-width ratio

***Rationale**:* Rivers with a large depth-to-width ratio have a low thermal inertia and hence a lower capacity to absorb solar radiation than shallow systems. Systems with a low thermal inertia are therefore more sensitive to changes in water temperature from lateral inputs, such as heated industrial effluents. The following categories are used to represent the sensitivity of a river to changes in water temperature based on the river's thermal capacity:

- Large depth-to-width ratio: >0.75.
- Medium depth-to-width ratio: 0.25-0.75.
- Small depth-to-width ratio: <0.25.

***Method**:* Refer to Practical Guide.

c. Mean annual temperature

Rationale: Rivers characterised by cooler water are more sensitive to thermal pollution than rivers with higher temperatures. Rivers situated in cooler regions are likely to be more sensitive to changes in water temperature (Figure 30).

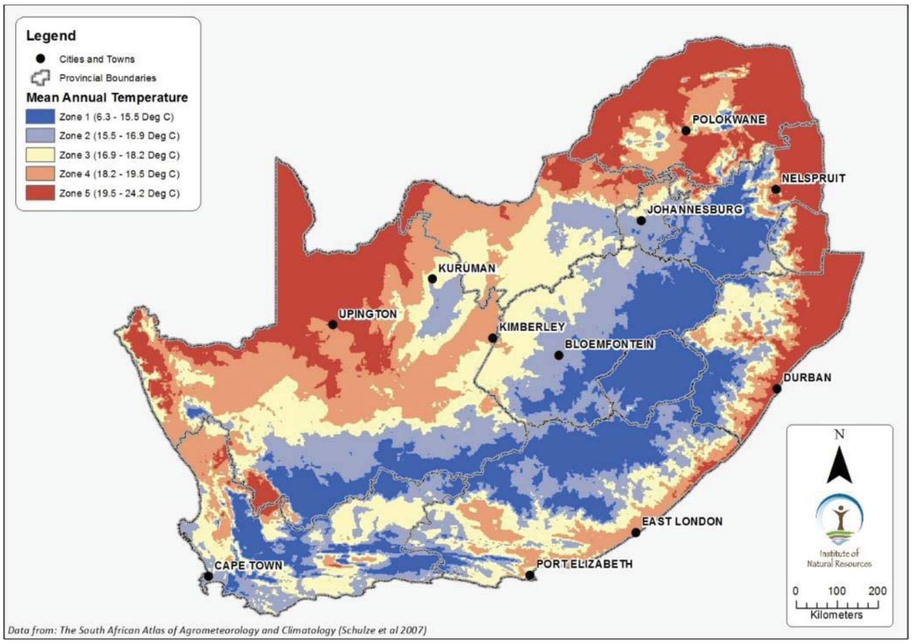

Figure 30 – Mean annual temperature separated into five temperature zones, based on five equal quantiles (Data from Schulze, 2007)

Method: Refer to Practical Guide.

d. Longitudinal river zonation

Rationale: The position of a river relative to the landscape and its catchment affects the hydrological processes that drive the river system. Hydrology, particularly flow rate, in turn affects the river's thermal regime because of influences on residence time which affects the amount of solar radiation that can be absorbed. Therefore, headwater and mountain systems are likely to vary more in temperature than slower flowing lowland rivers.

Geomorphological status also defines, to some extent, the concentration of suspended sediments contained within the river which further influences river water temperature. Lowland rivers, because of the accumulation of sediments and fines with downstream distance, tend to be more turbid than rivers situated in the upper catchment reaches. Rivers with a high turbidity have a low albedo[41] and thus have a greater ability to absorb solar radiation rather than reflecting incoming solar rays. Therefore, rivers that are naturally turbid are generally warmer and less sensitive to changes in river water temperature caused by thermal pollution from lateral inputs.

Method: Refer to Practical Guide.

9. Sensitivity to Changes in Pathogens from Lateral Inputs

Table 80 – Stream/river characteristics affecting the sensitivity of the water resource to changes in pathogens from lateral inputs

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Channel width	<1 m	1-5 m	*510 m*	10-20 m	>20 m

[41] Albedo is a measure of how strongly an object reflects light from light sources such as the sun.

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
River depth-to-width ratio	<0.25		0.25-0.75		<0.75
Level of domestic and contact recreational use	High	Moderately high	*Moderate*	Moderately low	Low

a. Channel width

Rationale: See *Rationale 4a.*

Method: Refer to Practical Guide.

b. River depth-to-width ratio

Rationale: Increased exposure of pathogens to solar radiation results in higher inactivation rates resulting from processes such as photo oxidative damage (Sinton et al*.,* 2007). Thus, rivers with higher surface area to volume ratios have a greater potential for exposing pathogens to solar radiation, and hence the greater amount of pathogenic inactivation. Rivers with small surface area to volume ratios are considered to have a high sensitivity to pathogen influxes because of limited breakdown and inactivation from sunlight exposure.

Method: Refer to Practical Guide.

c. Level of domestic, livestock and contact recreational use

Rationale: The higher the level of domestic and contact recreational water use, the higher the threat of increased pathogen levels to water users. Higher levels of use by domestic animals and livestock have also been found to increase pathogen loads and faecal coliforms. Level of domestic use is considered when assessing sensitivity to changes in pathogens from lateral inputs.

Method: Refer to Practical Guide.

10. References

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Annexure 12 – Guidelines for Determining the Sensitivity of Estuaries to Lateral Inputs

The focus of this assessment is on the sensitivity of estuaries to lateral impacts rather than broader catchment impacts. The sensitivity of the overall estuary, rather than the sensitivity of important biota is assessed. Where there are important biodiversity elements, additional protection measures need to be identified in line with the sensitivity of focus species to threats identified.

Indicators have been defined to assess the sensitivity of estuaries to common threats posed by lateral land use impacts. These impacts include volume and timing of lateral water inputs, sediment, nutrients and toxins, and pathogen inputs from lateral inputs as well as changes in salt input and temperature. The indicators were scored relative to a typical "reference" estuary of intermediate sensitivity and are used to calculate a sensitivity score and associated class for each threat type under consideration. It is important to note that the sensitivity criteria (Table 81) have a moderate bearing on the final buffer recommendation. Slight variations in rating of criteria amongst users, even though important, should not result in major variations to buffer zone recommendations.

Table 81 – List of criteria and their relevance for determining the sensitivity of estuaries to common threats posed by lateral land use impacts

Criteria		Sensitivities from lateral inputs								
		Changes in water quantity	Changes in patterns of flow	Changes in sediment inputs and turbidity	Increased inputs of nutrients	Increases in toxic contaminants	Changes in acidity (pH)	Changes in concentration of salts	Changes in water temperature	Changes in pathogens
Desktop Assessment	Estuary size	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Estuary length	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Inherent run-off potential of catchment soils		✓							
	Mouth closure as a measure of water exchange		✓	✓	✓	✓	✓	✓		
	Water clarity			✓	✓					
	Biogeographic zone								✓	
Some In-field Assessment	Perenniality of river inflows	✓								
	Presence of submerged macrophytes			✓	✓					
	Level of domestic, livestock and contact recreational use									✓

1. Sensitivity to Changes in Water Quantity (Volumes of Flow) from Lateral Inputs

Table 82 – Estuary characteristics affecting the sensitivity of the water resource to changes in the volumes of inputs from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Perenniality of river inflows		Intermittent	*Seasonal*	Perennial	

a. Estuary size

Rationale: Estuary size provides a broad surrogate for sensitivity to lateral flow inputs. Large estuaries are typically fed by large catchments and lateral inputs can have localised effects. For example, run-off can decrease salinity encouraging reed encroachment. In small estuaries, lateral flow inputs would have a greater impact relative to overall size of the system. The size categories from the National Biodiversity Assessment (NBA) document (Van Niekerk and Turpie, 2012) have been used (large >1000 ha, medium 100-1000 ha, small 10-100 ha, very small <10 ha). About 50% (144 estuaries) of South Africa's estuaries are between 10 ha and 100 ha, while 32% (94 estuaries) are less than 10 ha.

> ***Note:*** *Ensure wetland boundaries are also mapped and assessed as opposed to relying on the outer edge of the supratidal zone. This is important as the wetland fringe can often extend further that the supratidal habitat.*

Method*:* Refer to Practical Guide.

b. Estuary length

Rationale: Longer estuaries are more sensitive to lateral inputs than shorter systems with a smaller perimeter. Medium-sized estuaries are between 10 km and 20 km in length whereas small systems are less than 5 km in length. Systems smaller than 500 m have not been included in the national estuary list of the NBA until it can be established that they are of functional importance.

Method*:* Refer to Practical Guide.

c. Perenniality of river inflows

Rationale: The perenniality of river inflow to an estuary affects how sensitive the estuary will be to changes in water quantity, and thus to impacts from adjoining land use. In this regard, estuaries fed by non-perennial rivers are likely to be more affected by increases or decreases in water quantity from lateral inputs than those fed by perennial inflow. The following classes are used to define perenniality of rivers feeding the estuary being assessed, namely, perennial, non-perennial (seasonal), and non-perennial (intermittent).

Seasonal: *river systems that flow for extended periods during the wet seasons/s (generally between three and nine months), at intervals varying from less than a year to several years (Ollis et al., 2013).*

Intermittent: *systems that flow for a relatively short time of less than one season's duration (less than approximately three months) at intervals varying from less than a year to several years (Ollis et al., 2013).*

***Method**:* Refer to Practical Guide.

2. Sensitivity to Changes in Patterns of Flow (Frequency, Amplitude, Direction of Flow) from Lateral Inputs

Table 83 – Estuary characteristics affecting the sensitivity of the water resource to changes in the patterns of flow from lateral inputs

Criterion	Sensitivity Classes				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	*5-10 km*	*10-20* km	>20 km
Inherent run-off potential of catchment soils	Low (A and A/B)	Moderately low (B)	*Moderate (B/C)*	Moderately high (C)	High (C/D and D)
Mouth closure	>81%	61-80%	*41-60%*	21-40%	<20%

a. Estuary size

Rationale: Estuary size provides a broad surrogate for sensitivity to lateral flow inputs. In large estuaries, lateral inputs can have localised effects changing the frequency, amplitude and direction of flow. For example, run-off could add water to the system during a natural low flow period. This would change salinity conditions and influence the biota at the specific sites of input. In small estuaries, lateral flow inputs would have a greater impact relative to the overall size of the system. The size categories from the NBA document (Van Niekerk and Turpie, 2012) have been used (large >1000 ha, medium 100-1000 ha, small 10-100 ha, very small <10 ha). About 50% (144 estuaries) of South Africa's estuaries are between 10 and 100 ha, while 32% (94 estuaries) are less than 10 ha in size.

***Method**:* Refer to Practical Guide.

b. Estuary length

Rationale: Longer estuaries will be more sensitive to changes in patterns of lateral inputs than shorter systems with a smaller perimeter. Medium-sized estuaries are between 10 km and 20 km in length whereas small systems are less than 5 km in length. Systems smaller than 500 m have not been included in the national estuary list of the NBA until it can be established that they are of functional importance.

***Method**:* Refer to Practical Guide.

c. *Inherent run-off potential of catchment soils*

Rationale: The ability of a catchment to partition run-off into surface and sub-surface flow components depends largely on prevailing catchment conditions, which may be the result of both natural and anthropogenic processes. Soils are a key natural regulator of catchment hydrological response as they have the capacity for absorbing, retaining and releasing/redistributing water (Schulze, 1989). Catchments dominated with deep, well-drained soils generally have high rates of permeability and therefore a greater proportion of rainfall can infiltrate into the soil profile. Consequently, catchments with highly permeable soils have a much lower run-off potential than soils with a low permeability (such as clay soils). As such, estuaries fed by catchments characterised by higher permeability have less flashy flows than those fed by catchments characterised by low permeability. Estuaries fed by catchment inputs that are naturally flashy are therefore regarded as less sensitive to changes in the pattern of lateral water inputs (for example, increased run-off during heavy rains), than those characterised by less variable flow regimes.

Method*:* Refer to Practical Guide.

d. *Mouth closure as a measure of water exchange*

Rationale: The duration of mouth closure can be used as a surrogate for tidal exchange. Those estuaries closed to the sea are less influenced by tidal exchange. They will be more sensitive to changes in the patterns of flow from lateral inputs. The duration of mouth closure is used to indicate water retention. Open estuaries are usually characterised by higher freshwater inflow. Temporarily open/closed estuaries will be more sensitive to lateral inputs than permanently open estuaries or river mouths where these effects would be reduced by dilution from sea and river inputs.

Method*:* Refer to Practical Guide.

3. Sensitivity to Changes in Sediment Inputs and Turbidity from Lateral Inputs

Table 84 – Estuary characteristics affecting the sensitivity of the water resource to increased sediment inputs from lateral sources

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Water clarity		Clear	*Blackwater*	Turbid	–
Submerged macrophytes present (adjacent planned development)		Yes		No	

a. *Estuary size*

Rationale: Estuary size provides a broad surrogate for sensitivity to sediment inputs. Large estuaries have a greater inherent buffer capacity and are therefore less likely to be affected by changes in lateral sediment inputs than small estuaries where moderate changes in sediment inputs could have a substantial impact by reducing water depth and affecting hydrodynamic functions. The size categories from the NBA document (Van Niekerk and Turpie, 2012) have been used (large >1000 ha, medium 100-1000 ha, small 10-100 ha, very small <10 ha). About 50% (144 estuaries) of South Africa's estuaries are between 10 and 100 ha, while 32% (94 estuaries) are less than 10 ha in size.

Method*:* Refer to Practical Guide.

b. Estuary length

Rationale: Longer estuaries will be more sensitive to lateral inputs than shorter systems that have a smaller perimeter. Medium-sized estuaries are between 10 km and 20 km in length whereas small systems are less than 5 km in length. Systems smaller than 500 m have not been included in the national estuary list of the NBA until it can be established that they are of functional importance.

Method*:* Refer to Practical Guide.

c. Water clarity

Rationale: The NBA has classified all estuaries as "clear", "blackwater", or "turbid" based on the quality of the freshwater inflow to the system. Clear estuaries will be more sensitive to lateral inputs than naturally turbid systems. Turbid systems have a MAR >30 × 10^6, and blackwater systems are those that are rich in tannins.

Method*:* Refer to Practical Guide.

d. Presence of submerged macrophytes

Rationale: Submerged macrophytes are sensitive to changes in the light environment caused by sediment input and changes in turbidity. The distribution of submerged macrophytes is limited in South African estuaries due to a variety of pressures and therefore they are sensitive to further disturbances. Dominant species in South African estuaries are *Zostera capensis,* which grows in the intertidal zone, and *Ruppia cirrhosa* and *Potamogeton pectinatus* that grow in closed estuaries or in the upper more freshwater rich areas of estuaries.

Method*:* Refer to Practical Guide.

4. Sensitivity to Increased Inputs of Nutrients (Phosphates, Nitrite, Nitrate) from Lateral Inputs

Table 85 – Estuary characteristics affecting the sensitivity of the water resource to increase nutrient inputs from lateral sources

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Water clarity		clear	*blackwater*	turbid	–
Mouth closure	>81%	61-80%	*41-60%*	21-40%	<20%
Submerged macrophytes present (adjacent planned development)		Yes		No	

a. Estuary size

Rationale: Estuary size provides a surrogate for sensitivity to nutrient inputs. Large estuaries have a greater inherent buffering capacity and are therefore less likely to be affected by changes in lateral nutrient inputs than small estuaries where moderate changes in nutrient inputs could have an impact on natural nutrient dynamics. The size categories from the NBA document (Van Niekerk and Turpie, 2012) have been used (large >1000 ha, medium 100-1000 ha, small 10-100 ha, very small <10 ha).

Method*:* Refer to Practical Guide.

b. Estuary length

Rationale: See *Rationale 3b.*

Method*:* Refer to Practical Guide.

c. Water clarity

Rationale: Typically, clear estuaries will be more sensitive to lateral inputs than naturally turbid systems. Blackwater systems are those which are rich in tannins.

Method*:* Refer to Practical Guide.

d. Mouth closure as a measure of flushing/residence time

Rationale: Flushing time is the time required to replace the existing water in the estuary at a rate equal to river inflow. Reduced flushing will result in greater accumulation of nutrients. An ongoing study on the desktop assessment of estuary water quality is developing a flushing rate index for all South African estuaries (Taljaard, pers. comm.). This measure is based on the estuary volume relative to the daily inflow volume and the percentage of time that the mouth of the estuary is open in a year. In the absence of this data, the duration of mouth closure can be used to indicate retention of nutrients. Temporarily open/closed estuaries will be more sensitive to nutrient inputs than permanently open estuaries or river mouths where these effects would be reduced by dilution from sea and river inputs.

Method*:* Refer to Practical Guide.

e. Presence of submerged macrophytes

Rationale: Submerged macrophytes are outcompeted by the faster growing macroalgae, particularly filamentous greens under nutrient rich conditions. The distribution of submerged macrophytes is limited in South African estuaries due to a variety of pressures and therefore they are sensitive to further disturbances such as nutrient inputs.

Method*:* Refer to Practical Guide.

5. Sensitivity to Increases in Toxic Contaminants [Including Toxic Metal Ions Such as Copper, Lead, Zinc, Toxic Organic Substances (Reduces Oxygen), Hydrocarbons and Pesticides] from Lateral Inputs

Table 86 – Estuary characteristics affecting the sensitivity of the water resource to changes in contaminants from lateral inputs

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Mouth closure	>81%	61-80%	*41-60%*	21-40%	<20%

a. Estuary size

Rationale: See *Rationale 4a.*

Method*:* Refer to Practical Guide.

b. Estuary length

Rationale: See *Rationale 3b*.

***Method**:* Refer to Practical Guide.

c. Mouth closure

Rationale: See *Rationale 4d*.

***Method**:* Refer to Practical Guide.

6. Sensitivity to Changes in Acidity (pH) from Lateral Inputs

Table 87 – Estuary characteristics affecting the sensitivity of the water resource to changes in acidity (pH) from lateral inputs

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Mouth closure	>81%	61-80%	*41-60%*	21-40%	<20%

a. Estuary size

Rationale: See *Rationale 4a*.

***Method**:* Refer to Practical Guide.

b. Estuary length

Rationale: See *Rationale 3b*.

***Method**:* Refer to Practical Guide.

c. Mouth closure

Rationale: See *Rationale 4d*.

***Method**:* Refer to Practical Guide.

7. Sensitivity to Changes in Salinity from Lateral Inputs

Table 88 – Estuary characteristics affecting the sensitivity of the water resource to changes in salinity from lateral inputs

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Mouth closure	>81%	61-80%	*41-60%*	21-40%	<20%

Inputs from lateral flow can have a localised effect in estuaries. For example, development and run-off often freshens the system leading to a loss of salt marsh and expansion of reeds at the estuary boundary. Similarly, run-off from some sources such as salt works/salt pans can increase salinity causing die-back of estuarine vegetation such as reeds, sedges and salt marsh. All natural plant communities in estuaries would have a high sensitivity to salinity changes caused by lateral flow inputs.

Naturally saline estuaries (which are more open to sea), are characterised by highly variable salinity and likely to be less sensitive than estuaries that are naturally characterised by lower and less variable salinity levels. Estuaries in the warm temperate zone are characterised by low rainfall and run-off which results in elevated salinity (Harrison, 2004) and sensitivity to lateral inflows.

a. Estuary size

Rationale: See *Rationale 4a*.

Method*:* Refer to Practical Guide.

b. Estuary length

Rationale: See *Rationale 3b*.

Method*:* Refer to Practical Guide.

c. Mouth closure

Rationale: See *Rationale 4d*.

Method*:* Refer to Practical Guide.

8. Sensitivity to Changes in Water Temperature from Lateral Inputs

Table 89 – Estuary characteristics affecting the sensitivity of the water resource to changes in water temperature from lateral sources

Criterion	**Sensitivity Classes**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-100 ha*	100-1000 ha	>1000 ha
Estuary length		<5 km	5-10 km	*10-20 km*	>20 km
Biogeographic zone	Low latitude subtropical		*Moderate latitude warm temperate*		High latitude cool temperate

Inputs from lateral flow could have a localised temperature effect in estuaries. Industries can discharge warm or cool waters. Temperature in estuaries follows the trend for marine coastal waters, decreasing from the subtropical east coast, along the warm temperate south coast and up the cool temperate west coast. Naturally cooler systems are likely to be more susceptible to increased water temperatures from lateral inputs than are warmer estuaries.

a. Estuary size

Rationale: See *Rationale 4a*.

Method*:* Refer to Practical Guide.

b. Estuary length

Rationale: See *Rationale 3b*.

Method*:* Refer to Practical Guide.

c. Biogeographic zone

Rationale: Estuaries characterised by cooler water are more sensitive to thermal pollution than those with higher temperatures. Estuaries situated on the west coast are generally cooler and therefore more sensitive to increases in water temperature.

***Method**:* Refer to Practical Guide.

9. References

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Annexure 13 – Development of Rule Curves to Link Buffer Efficiency to Buffer Width

This annexure includes a summary of the available scientific literature used to inform the development of rule curves that link buffer efficiency to buffer width for selected buffer functions. These rule curves form the basis for buffer zone determination in the Buffer Zone Models but are refined to cater for climatic variability, the sensitivity of the receiving environment and buffer zone attributes for the site-based assessment.

1. Increased Sedimentation and Turbidity

Yuan et al. (2009) undertook a thorough review of the effectiveness of vegetative buffers on sediment trapping in agricultural areas. In this review of many quantitative studies, there was clear evidence that, although sediment trapping capacities are site- and vegetation-specific, and many factors influence the sediment trapping efficiency, the width of a buffer is important in filtering agricultural run-off, and wider buffers tended to trap more sediment. Despite some variability between studies, results indicated that the first 3-6 m of a buffer plays a dominant role in sediment removal. This finding is backed up by Sheldon et al. (2003) who showed that the relationship between the length covered by the run-off (buffer width) and sediment removal is not linear, as most sediment is deposited in outer portions of the buffer.

A study undertaken on forested buffers by Barling and Moore (1994) found that most (91%) sediment deposition took place within the first 0.25 m to 0.6 m of the outer edge of the buffer. Robinson et al. (1996) observed that sediment was reduced by 70% and 80% from the 7% and 12% slope plots, respectively, within the first 3 m of the buffer. Dillaha et al. (1989) and Magette et al. (1989) reported sediment trapping efficiencies of 70-80% for 4.6 m and 84-91% for 9.1 m wide grass filter strips. Yuan et al. (2009) concluded that generally buffers of 4-6 m can reduce sediment loading by more than 50%.

Yuan et al. (2009) further reported that buffers greater than 6 m are effective and reliable in removing sediment from any situation. They referred, for example, to Hook (2003) who reported that more than 97% of sediment was trapped in the rangeland riparian buffer area with a 6 m buffer in any of the experimental conditions studied. Sheridan et al. (1999) recorded sediment trapping efficiencies of 77-90% across three different management schemes (clear cut, thinned, and untouched) when studying the impact of forest management practices within the riparian zone. Cooper et al. (1992) estimated that 90% of the sediment leaving fields was retained in the wooded riparian zone.

Yuan et al. (2009) indicated that overall the sediment trapping efficiency to buffer width relationship can be best fitted with logarithm models (Figure 1). This is similar to the relationship previously developed by Gilliam (1994) and to that modelled by Zhang et al. (2009).

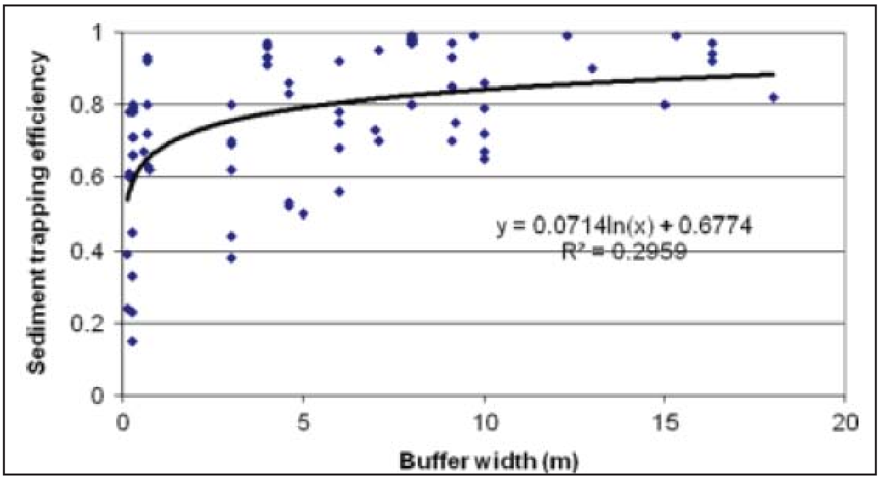


Figure 31 – Buffer width and sediment trapping efficiency (Yuan et al., 2009)

According to this relationship, a 5 m buffer can trap about 80% of incoming sediment. Yuan et al. (2009) further observed that effectiveness differed amongst buffer width categories (Figure 2). Buffers of 3-6 m wide have greater sediment trapping efficiency than buffers of 0-3 m wide, and buffers of greater than 6 m wide have greater sediment trapping efficiency than buffers of 3-6 m wide. Thus, wider buffers are likely to be more efficient in trapping sediment than narrower buffers.

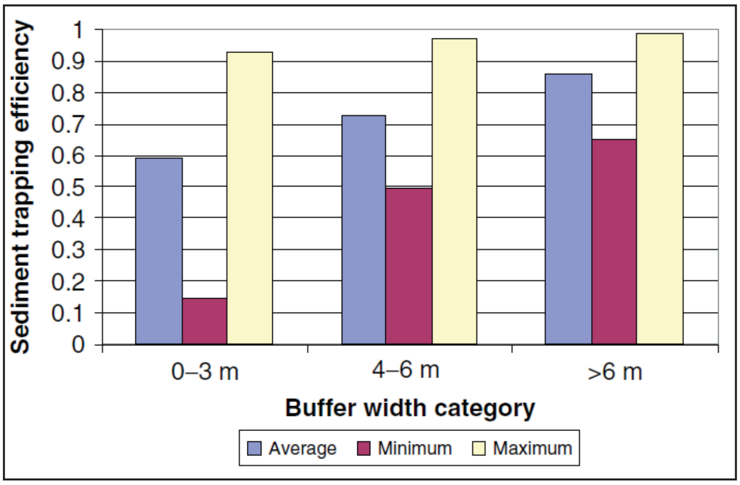
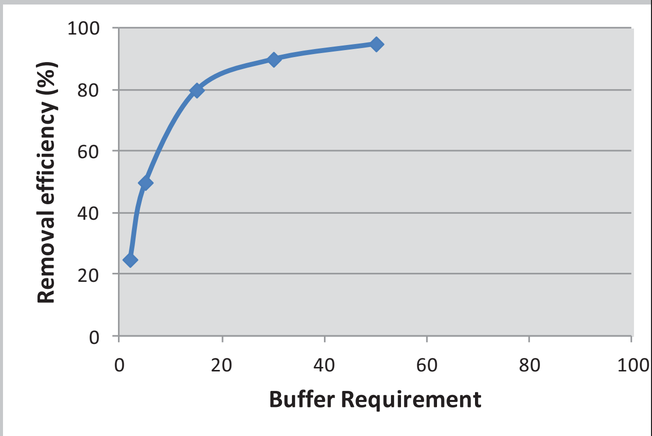


Figure 32 – Average, minimum, and maximum sediment trapping efficiency for different buffer width category (Yuan et al., 2009)

Based on this information, a curvilinear relationship between sediment removal efficiency and buffer width is assumed. Details of starting buffer widths proposed based on risk and associated buffer effectiveness scores are provided in Table 90.

Table 90 – Starting buffer widths based on risk and associated buffer effectiveness

Risk Class	Effectiveness (%)	Buffer Width
Very low	25	2
Low	50	5
Moderate	80	15
High	90	30
Very high	95	50



It is important to note that these results reflect buffer effectiveness in situations where the buffer is designed to trap sediment (good vegetative cover) and concentrated flows are avoided. High levels of variability are reported for different size particles, with fine particles requiring a far larger buffer width.

2. Increased Nutrient Inputs from Lateral Inputs

Many studies have shown greater than 90% reductions in nitrate concentrations in sub-surface flows as water passes through riparian areas or wetlands (Gilliam, 1994; Fennesy and Cronk, 1997). Buffers are consistently reported to reduce nitrate to below 2 mg/ℓ (in line with SLV limits), often throughout the year and even when nitrate inputs are extremely high (Muscutt et al., 1993). As such, establishing buffer zones is regarded as an effective and appropriate mitigation measure for removing nitrogen from diffuse lateral inputs.

In a meta-analysis of 73 studies undertaken by Zhang et al. (2009), theoretical models were developed to quantify the relationship between pollutant removal efficiency and buffer width. Models developed suggested that buffer width was a primary factor affecting nutrient removal efficiency, with about 50% of the variation in nitrogen removal efficiency and 48% of the variation in phosphorous removal efficiency explained by buffer width and vegetation. This highlights the usefulness of buffer width as a primary discriminator for assessing nutrient removal efficiency.

Another comprehensive meta-analysis of nitrogen removal in riparian buffers was undertaken by Mayer et al. (2007). This included analysing data from 89 individual riparian buffers from 45 published studies. Although nitrogen removal effectiveness varied widely amongst studies, there was a clear relationship between buffer width and buffer effectiveness. This review showed that nitrogen removal effectiveness of buffers 50 m wide was greater than that of buffers from 0 m to 25 m, whereas effectiveness of buffers from 26 m to 50 m did not differ from the other categories (Figure 33). Thus, wider buffers are likely to be more effective zones of nitrogen removal than narrower buffers.

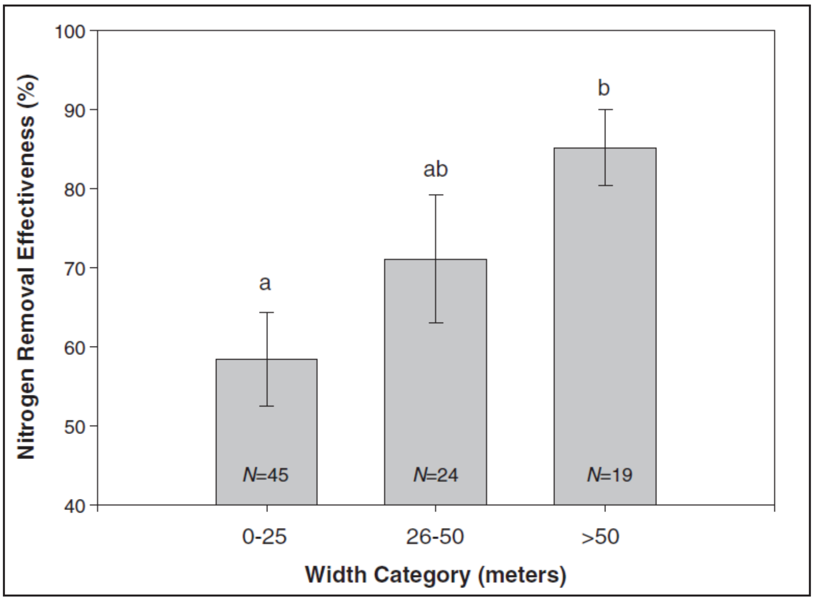


Figure 33 – Nitrogen removal effectiveness in riparian buffers by buffer width category.

The bars in Figure 33 represent means ±standard error. Mean ranks of width categories differ if denoted by different letters (Kruskal-Wallis one-way analysis of variance on ranks with Dunn's method of multiple comparisons, P, 0.05).

Based on a limited data set fitted to a log-linear model, Oberts and Plevan (2001) found that NO_3^- retention in wetland buffers was positively related to buffer width (R^2 values ranged from 0.35-0.45). Nitrogen removal efficiencies from 65% to 75%, and from 80% to 90% were predicted for wetland buffers 15 m and 30 m wide, respectively, depending on whether NO_3^- was measured in surface or sub-surface flow (Oberts and Plevan, 2001). A similar relationship was demonstrated by Mayer et al. (2007) but with their model suggesting that removal efficiencies of 50%, 75%, and 90% occurred at buffer widths of 4 m, 49 m, and 149 m respectively as illustrated in Figure 34.

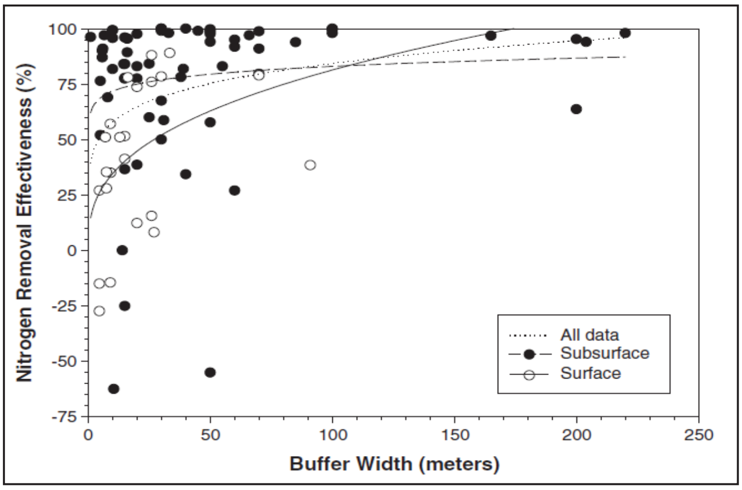


Figure 34 – Relationships of nitrogen removal effectiveness to riparian buffer width over all studies and analysed by water flow path (Mayer et al., 2007)

Zhang et al. (2009) also developed a curvilinear relationship for illustrating the relationship between buffer efficiency and nutrient removal efficiency. These relationships are presented in Figure 35, which suggest that higher levels of buffer efficiency can be achieved with small buffers less than 25 m in width.

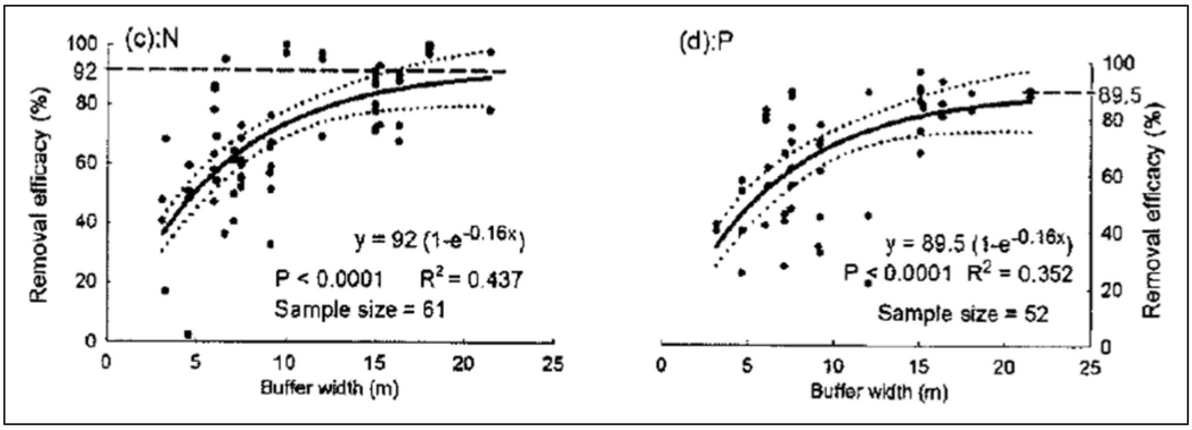
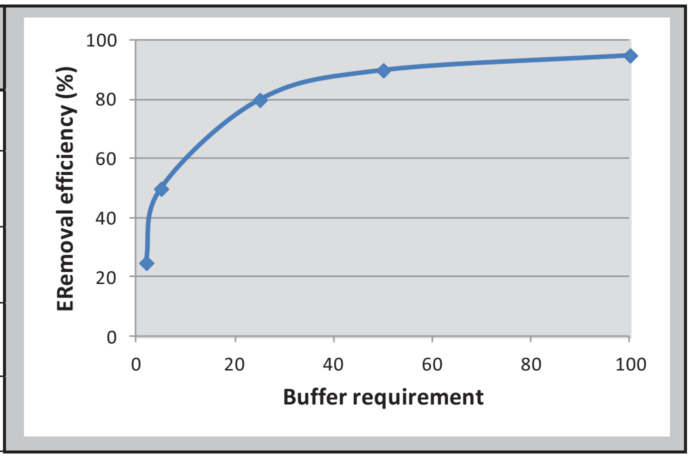


Figure 35 – Pollution removal efficiency versus buffer width for nitrogen and phosphorus.

Dotted lines in Figure 35 indicate 95% confidence band (Zhang et al., 2009). Based on this information, a curvilinear relationship between nutrient removal efficiency and buffer width is assumed, with the conservative starting buffer widths proposed based on risk and associated buffer effectiveness scores.

Table 91 – Conservative starting buffer widths based on risk and associated buffer effectiveness scores

Risk Class	Effectiveness (%)	Buffer Width
Very low	25	2
Low	50	5
Moderate	80	25
High	90	50
Very high	95	100



3. Increased Toxic Contaminants from Lateral Inputs

When developing guidelines for the width of buffer zones to address threats posed by toxic contaminants, it is firstly important to note that the term “toxic contaminants” covers a broad suite of potentially toxic substances. These include toxicants (including toxic metal ions such as copper, lead and zinc), toxic organic substances (which reduce oxygen availability), hydrocarbons, and pesticides. In addition, the efficiency of a buffer at trapping toxic substances depends on a wide range of factors, such as residence times, flushing rates, and dilution and resuspension rates of the toxic substances.

Buffer guidelines could potentially be tailored according to specific toxic substances. However, this is unrealistic for this project and little information is available on buffer zone efficiencies for all toxic substances. As an initial approach to determining the effectiveness of a buffer zone at trapping toxic substances, toxic contaminants have been considered as two broad categories, namely, organic contaminants (which include pesticides) and toxic heavy metals. Buffer widths proposed for these groups have been based on available information. In addition, the precautionary principle was also applied.

A review of international literature does provide some useful indicators of the efficiencies of buffers of particular widths for removing certain toxic contaminants. According to Blanché (2002), removal efficiencies for sediment-attached and dissolved toxics are likely to be similar to those determined for sediments and dissolved nutrients. However, literature also highlights the differences with respect to organic pollutants and pesticides, and metals. These broad categories are discussed in the following sub-sections.

a. Organic pollutants and pesticides

Organic pollutants include substances such as persistent organic pollutants (such as DDT and its metabolites), various organochlorine pesticides, polycyclic aromatic hydrocarbons, dioxin-like compounds, and non-dioxin-like polychlorinated biphenyls. Most organic toxicants are hydrophobic and do not dissolve readily in water but generally bind to organic matter in sediments. Some can stay in the sediment for long periods of time with minimal breakdown and natural decomposition while others break down relatively quickly under anaerobic conditions. Substance breakdown is dependent on environmental factors, which need to be considered when interpreting decomposition data for the different organic toxicants (Gevao et al., 2010). Bioaugmentation of the sediment and sorption by plants and organic matter is of particular importance in the removal of some organic pollutants from the environment. There is a general lack of knowledge on the detailed removal pathways for organic compounds (Haberl et al., 2003), which renders determining the effectiveness of buffers a challenge. Given the vast range of organic toxic substances and the limited literature concerning buffer removal efficiencies, pesticides have been selected as a sub-group representative of organic toxic substances.

Individual pesticide characteristics have a significant bearing on removal efficiency as this affects the mechanism of removal, which can be either by co-deposition with sediment or by immobilisation from solution. This is determined primarily by the adsorbing properties of the pesticide, which determines its ability to adsorb to organic carbon in sediment. Where pesticides have a strong adsorption capacity, most of the pesticide is lost as co-deposition with sediment (Reichenberger et al., 2007). Removal efficiencies for these pesticides are therefore likely to be similar to those for sediment retention (Zhang et al., 2009). Zhang et al. (2009) developed a model for pesticide removal efficiency based on a review of 49 studies. Buffer width alone accounted for over half the variation in pesticide removal efficiency in these studies, supporting the notion that buffer width is a primary driver of pesticide removal. This model suggested that a 30 m buffer could remove 93% of pesticides in run-off. This relationship is illustrated in Figure 36. These results are comparable to the results presented by Reichenberger et al. (2007), in a review of 14 studies which indicated that on average, pesticide load reduction efficiencies were 50% reduction for 5 m buffers strips, 90% for 10 m buffer width and 97.5% for 20 m widths. Variability in efficiencies were, however, very high, particularly for pesticides predominantly transported in the water phase (low adsorption capacity). This resulted in more conservative assumptions being applied to the full spectrum of pesticides and organic pollutants.

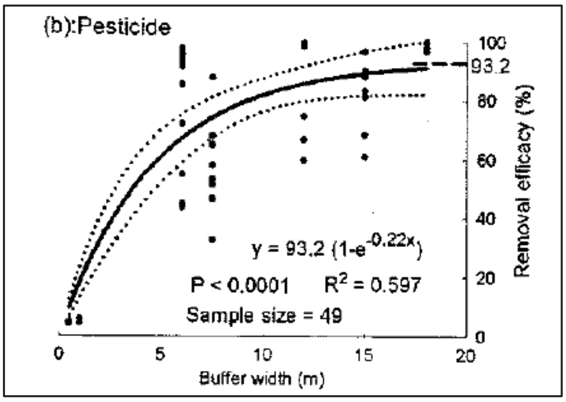


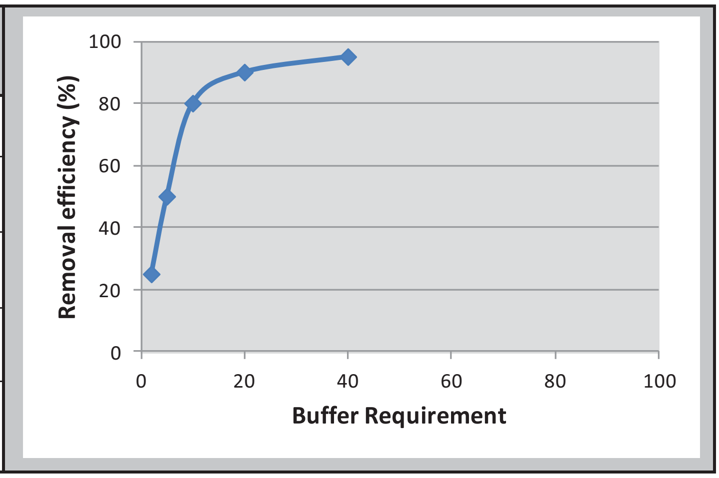
Figure 36 – Removal efficiency vs. buffer width for pesticides (Zhang et al., 2009)

Dotted lines indicate 95% confidence band in Figure 36.

Based on this information, a curvilinear relationship between organic pollutant/pesticide removal efficiency and buffer width is assumed, with the following starting buffer widths proposed based on risk and associated buffer effectiveness scores.

Table 92 – Starting buffer widths proposed based on risk and associated buffer effectiveness scores

Risk Class	Effectiveness (%)	Buffer Width
Very low	25	2
Low	50	5
Moderate	80	10
High	90	20
Very high	95	40



b. Heavy/toxic metals

Limited information is available on the mobilisation of toxic metals by overland flow through buffers. Generally, metals are transported through the landscape attached to particles in sediments or dissolved in storm water. The concentration of the metal will depend mainly on the concentration of the metal at the source and the source substance's solubility.

In a dissolved state, the biological availability and chemical reactivity (sorption or desorption, precipitation or dissolution) towards other components is determined by the chemical form of the metal (Pintilie et al., 2007). Charged species are retained by sorption processes and the removal efficiencies are governed by the predominant ionic species and complexes (Hamilton and Harrison, 1991). Preliminary findings do, however, suggest that this varies considerably for the different heavy metals considered. Dissolved species of zinc, cadmium, lead and chromium are removed more effectively than copper and iron (Yousef et al., 1987).

Yousef et al. (1987) also found swales[42] to filter out heavy metals through adsorption, precipitation and/ or biological uptake. Average mass removal rates were, however, highly site and condition specific and influenced by the total mass input (concentrations), velocity of flow and percentage of infiltration. Table 93 presents the pollutant removal efficiencies for swale lengths of 61 m and 30 m recorded in a report prepared for the US EPA (1983). Although research results varied between studies, the data clearly indicate greater pollutant removal for wider swales. Indeed, this data suggests that removal efficiencies of 30 m wide swales are limited but increase to 50-70% at widths close to 60 m.

Table 93 – Swale pollutant removal efficiencies (Barret et al., 1993; Schueler, et al., 1991; Yu, 1993; Yousef et al., 1987) as reported in Clar et al. (2004)

Design	Pollutant Removal efficiencies (%)							
	Solids	Nutrients		Metals			Other	
	TSS	TN	TP	Zn	Pb	Cu	Oil & Grease	COD**
61-m (200-ft) swale	83	25*	29	63	67	46	75	25
30-m (100-ft)swale	60	-*	45	16	15	2	49	25

*Some swales, particularly 100-ft systems, showed negligible or negative removal for TN.
**Data is very limited.

Given the lack of available data for various heavy metals, comparative studies are also useful when comparing buffer zone effectiveness relationships with that of other pollutants. In this regard, the study alluded to above suggests that sediment removal efficiency of buffer zones is likely to be higher than for metals but that nutrient removal effectiveness is lower (Table 93). Hamilton and Harrison (1991) also noted that metals are removed more effectively than nitrogen and phosphorus. This finding is also supported through a reported study by the US Department of Transportation who conducted a field study to determine the pollutant removal efficiencies of grassed channels and swales along highways in the USA (US EPA, 2000). This research showed that removal of metals was found to be directly related to the removal rate of total suspended solids, and the removal rate of metals was greater than removal of nutrients.

Various other studies have also suggested strong linkages between removal of metal and sediment removal (for example, Yousef et al., 1985; US EPA, 2000; Caltrans, 2003; Barrett et al., 2007). These findings therefore suggest that buffer requirements for metal removal should be strongly linked to that of sediment removal but that wider buffers should be advocated for nutrient removal.

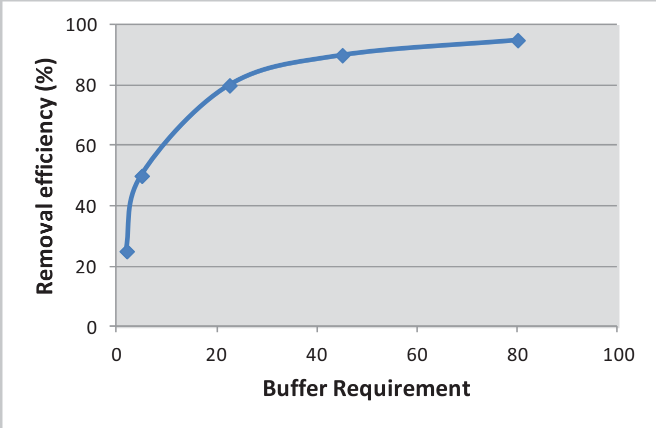
Various authors (for example, Kearfott et al., 2005) however emphasise that chemical removal ability is finite: once metals are adsorbed to soils, they can be freed for transport by further chemical or physical disturbance of the soil layer. The capacity of soils to retain heavy metals over the long term is another important consideration, and would probably require regular monitoring to ensure that assimilative capacities of the soils were not exceeded. As such, the application of somewhat conservative buffer widths is recommended in high risk scenarios where heavy contaminant loads could reduce buffer zone efficiencies over time.

Based on this information, a curvilinear relationship between metal removal efficiency and buffer width is assumed. Following a precautionary approach the following starting buffer widths have been proposed for different risk classes.

[42] According to Deeks and Milne (2005), vegetated swales and buffers perform both a storm water treatment and storm water conveyance function. Both systems treat storm water via filtration through the vegetation. Additional pollutant removal is achieved through storm water infiltration to groundwater and vegetative uptake.

Table 94 – Starting buffer widths proposed for different risk classes

Risk Class	Effectiveness (%)	Buffer Width
Very low	25	2
Low	50	5
Moderate	80	22.5
High	90	45
Very high	95	80



It is important to note that chemical removal ability is finite. Once metals have been adsorbed to soils, they can be freed for transport by further chemical or physical disturbance of the soil layer. The capacity of soils to retain heavy metals over the long term is another important consideration, and would probably require regular monitoring to ensure that assimilative capacities of the soils were not exceeded. The effectiveness of the buffer zone will also depend on the metal in question.

4. Increased Pathogen Inputs from Lateral Sources

Most pathogenic bacteria are removed by physical and chemical adsorption within the soil profile (Gerba et al., 1975), and faecal coliform bacteria (FCB) concentrations therefore typically decline substantially when transported through soil, suggesting that transport to surface water occurs mainly by surface flow (Abu-Ashour et al., 1994; Howell et al., 1996; Huysman and Verstraete, 1993; Kunkle, 1970). Buffer zones that can intercept surface flow, promote leaching, and prevent or retard overland transport may therefore be effective in reducing pathogen loads entering water resources (Sullivan et al., 2007).

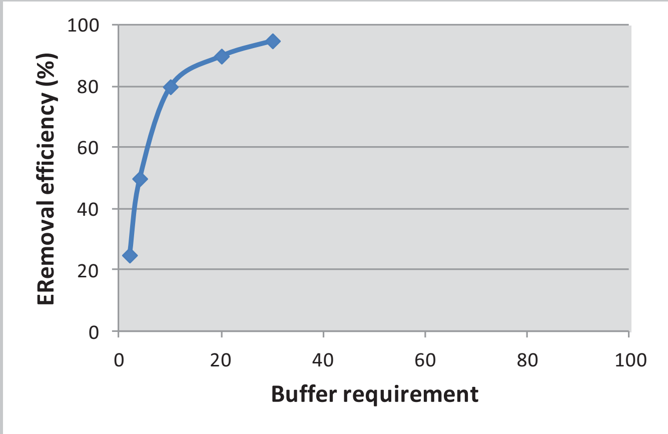
Studies undertaken on the effectiveness of buffers in removing FCB suggest that small buffers may be effective in performing this function. Indeed, Sullivan et al. (2007) showed that the presence of a vegetated buffer of any size from 1 m to 25 m generally reduced the median FCB concentration of run-off water after heavy storms from agricultural land amended with dairy cow manure by more than 99%. Only 10% of the run-off samples collected from treatment cells having vegetated buffers exhibited FCB concentrations >200 faecal coliforms/100 ml, and the median concentration for all cells containing vegetated buffers was only 6 faecal coliforms/100 ml. This suggests that very narrow vegetated buffer strips can effectively reduce FCB levels to within GLV limits of 1000 faecal coliforms/100 ml.

Results obtained by Roodsari et al. (2005) provide additional evidence that small buffers can be very effective at absorbing FCBs. The results showed that FCB released from surface-applied bovine manure through a 6 m buffer strip with a 20% slope was reduced to 1% of the applied bacterial amount on the vegetated clay loam soil and non-detectable on the vegetated sandy loam soil. These findings do, however, conflict with findings from earlier studies that suggested that wider buffer zones were required to reduce FCB levels effectively. For example, a faecal reduction model developed by Grismer (1981) suggested that 30 m buffers would only reduce FCB levels by 60%. Young et al. (1980) similarly concluded that 35 m vegetated buffers were required to reduce FCB levels from feedlot run-off during summer storms. Sullivan et al. (2007) do point out, however, that these earlier studies employed experimental designs based on high rates of artificial irrigation to force soil saturation and overland flow. They therefore conclude that new regulations specifying uniform minimum buffer sizes of 10.8 m (cf. US EPA, 2003) may be unnecessary for water quality protection under some soil and slope conditions.

Based on the information available, maximum starting buffers for FCB removal were set at 30 m, reduced to 2 m in the case of low risk activities. Given that research suggests that very small buffers are effective at removing pathogens, a curvilinear relationship was again assumed (see Table 95).

Table 95 – Curvilinear buffer width relationship

Risk Class	Effectiveness (%)	Buffer Width
Very low	25	2
Low	50	4
Moderate	80	10
High	90	20
Very high	95	30



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Annexure 14 – A Guide for Determining Buffer Requirements Based on Site Characteristics

When undertaking the assessment of aquatic impact buffer zone requirements, it is important to follow a structured sampling protocol. This should start with a systematic assessment of buffer zone attributes to break the buffer zone into reasonably homogenous buffer segments (typically >100 m in length), and be followed by an assessment of sensitivity criteria which may vary across the assessment site.

The following approach to field work is advocated during site investigations:

- **Step 1:** Ensure that the water resource boundary has been delineated and is clearly understood.
- **Step 2:** Ensure that the line from which the aquatic impact buffer zone is to be determined has been clearly delineated and can be identified in the field.
- **Step 3:** Consider the variability of the buffer slope around the delineated area and if necessary, define separate buffer segments to cater for the different slope classes. (Note: Where contour information is available, this should be done at a desktop level initially).
- **Step 4:** Assess soil properties of buffer segments by taking soil samples along the potential buffer zone. When sampling the soil, focus on the top 20 cm which can be sampled using a soil auger. 'Average' soil permeability needs to be determined based on the soil textural class present. Take soil samples at approximately 5 m, 15 m and 30 m away from the delineated edge from which the aquatic impact buffer will be determined. These samples can then either be mixed and assessed together or can be assessed as three separate samples and then used to define an "average" textural class. This assessment should be repeated at regular (such as 100 m) intervals to identify any changes in textural attributes.
- **Step 5:** Identify any major changes in vegetation attributes along each buffer segment that will affect buffer zone effectiveness and refine buffer segments accordingly (for example, differentiate between areas affected by cultivation vs intact grassland vs bare soil). When undertaking this assessment, consider options for rehabilitation and management prior to construction/operation and refine assessment units accordingly. When assessing vegetation attributes, preference should be given to the first 15 m of the buffer. If there is significant variation beyond this point, this may be used to refine your assessment.
- **Step 6:** Assess the micro-topography of the buffer with a particular focus on identifying drains, gully erosion or the likes that may compromise buffer zone effectiveness. If necessary, refine buffer segments accordingly to cater for variations across the study area.
- **Step 7:** Ensure that buffer segments are clearly demarcated on your field map/using a GPS and that buffer zone attributes are clearly documented for each segment.
- **Step 8:** Assess sensitivity criteria with an initial focus of HGM unit attributes, but then noting any changes in sensitivity of vegetation and biota across different buffer segments.

The refinement of buffer requirements based on site-specific buffer zone attributes has been informed by a review of available literature and on the outcomes of the hydrological sensitivity assessment undertaken for the development of the buffer zone guideline (Macfarlane, et al., 2014).

The guideline has been developed to cater for buffer zone efficiencies associated with each of the following threats by assessing buffer slope, vegetation characteristics, soil properties and micro-topography:

- Increases in sedimentation and turbidity.
- Increased nutrient inputs.
- Increased inputs of toxic organic and heavy metal contaminants.
- Pathogen inputs.

Table 96 outlines the characteristics used to refine buffer zone requirements to cater for the variability in sediment retention efficiency (default values are highlighted in green).

Table 96 – Buffer zone characteristics used to refine buffer zone requirements to cater for variability in sediment retention efficiency

Buffer zone characteristics	Scoring categories					
Slope of the buffer	Very gentle	Gentle	Moderate	Moderately steep	Steep	Very steep
Vegetation characteristics (basal cover)	Very high	High	Moderately low	Low		
Soil permeability	Low	Moderately low	Moderate	High		
Topography of the buffer zone	Uniform topography	Dominantly uniform topography	Dominantly non-uniform topography	Concentrated flow paths dominate		

1. Slope of the Buffer

Rationale: Several authors have indicated that slope angle is a key factor in determining sediment trapping within the buffer zone (Young et al., 1980; Peterjohn and Correll, 1984; Dillaha et al., 1989; Magette et al., 1989; Phillips, 1989; Hussein et al., 2007). In a review of many studies, Yuan et al. (2009) concluded that slope does affect sediment trapping efficiency although the relationship was weak. This weak linear relationship is explained to some degree by a meta-analysis of the effectiveness of vegetated buffers (Zhang et al., 2009) that suggests that buffer efficiency increases up to a slope of about 10%, and then begins to decline with increasing slope angles. This finding is consistent with the review by Yuan et al. (2009) that highlighted that slope becomes more important as a modifier when slopes are greater than 5%. Indeed Sheldon et al. (2003) reported that the maximum slope should be between 5-10° to prevent concentrated flows, while Blanché (2002) suggested it should be no greater than 15°. This deterioration in buffer zone effectiveness suggests that larger buffers are required for steep slopes, which is consistent with a number of review articles that concluded that buffers need to be wider when the slope is steep, generally to give more time for the velocity of surface run-off to decrease (Barling and Moore, 1994; Collier et al., 1995; Parkyn, 2004).Slope of the buffer is used to cater for variability in sediment retention, nutrient removal, toxic organic and metal contaminant retention and pathogen retention efficiencies.

Modifier ratings: From the literature, it is clear that there is negative relationship between slope and buffer effectiveness at slopes greater than *c.* 10%. Other research does, however, indicate that buffer zones remain highly effective with slopes of up to 20% (Hook, 2003). Based on available literature and results of the hydrological sensitivity analysis, buffer modifiers ranging from 0.6 to 1.75 have been proposed for different slope classes (Table 97).

Note: *'Steps' down a slope may prove to be more effective than a flat slope.*

Table 97 – Buffer zone modifier based on slope steepness

Buffer Characteristic	Slope Class	Description	Modifier Rating
Slope of the buffer zone	Very gentle	0-2%	0.6
	Gentle	2.1-10%	0.75
	Moderate	10.1-20%	1
	Moderately steep	20.1-40%	1.25
	Steep	40.1-75%	1.5
	Very steep	>75%	1.75

Note: *If the steepest slope is less than 2%, all other slopes will be less than this, so no further calculations are required. If the slope is >2%, break the boundary of the water resource into units of variable slope classes as required.*

Method: Refer to Practical Guide.

2. Vegetation Characteristics

Rationale: Vegetation mechanically filters run-off, increasing infiltration time and opportunities for plant uptake, and promoting deposition in the buffer zone. Therefore, the more suitable the vegetation is for slowing flows and mechanically intercepting sediment, the more effective the buffer zone is likely to be.

Several studies on the effect of vegetation variables on buffer function were reviewed to identify vegetation characteristics that have a positive influence on buffer zone effectiveness. Although vegetation type might be a useful surrogate, Yuan et al. (2009) found that overall, sediment trapping efficiency did not vary by vegetation type as both grass buffers and forest buffers have similar sediment trapping efficiencies. This is supported by Lowrance et al. (1998) who reported that forested buffers are good at removing sediments (>90% effective) from upstream flooding while grass is just as effective but may provide a more useful cover in areas of concentrated flow (Barling and Moore, 1994).

Hook (2003) provides some alternatives, suggesting that vegetation characteristics such as biomass, cover, or density are more appropriate than stubble height for judging capacity to remove sediment from overland run-off. The most useful suggestion is perhaps made in a report by Biohabitats Inc. (2007) who suggests that robustness and density of vegetation is an appropriate indicator since this has a direct impact on flow rate, encouraging deposition of sediment as well as minimising streambank erosion. This is certainly supported by a study by Van Dijk et al. (1998), where differences between retention by grass strips was attributed mainly to differences in grass density. This is consistent with results obtained by Hook (2003) who noted that dense vegetation of moist and wet riparian sites generally retained sediment effectively, whereas lower sediment retention was associated with sparse vegetation. The number of tillers or shoots was also identified as an important factor in trapping sediment in a study of sediment trapping and transport on steep slopes in the French Alps (Isselin-Nondedeu and Bédécarrats, 2007).

Modifier ratings: Although few studies have specifically related vegetation density to sediment trapping efficiency, an experimental study of filter strip efficiency by Jin and Romkens (2001) does provide some insights. Their findings showed that trapping efficiency increased with vegetation density. More specifically, they found that when the density of filter strips increased from 2500 bunches/m^2 to 10 000 bunches/m^2, the trapping efficiency increased by about 45%. Other studies do, however, suggest that the importance of vegetation density declines with increasing buffer width (for example, Hook, 2003). The hydrological sensitivity analysis (Annexure 9) provides some useful insights suggesting that a well-vegetated buffer zone of 30 m can reduce quick flows by 2.5 times relative to bare soil. Based on the information at hand, buffer modifiers ranging from 0.75 to 2.0 have been proposed for different vegetation characteristics (Table 98).

Table 98 – Buffer zone modifiers based on vegetation characteristics

Buffer Characteristic	Class	Description	Modifier Rating
Vegetation Characteristics	Ideal	Robust vegetation with high interception potential (for example, vetiver grass filter strips/dense tall grass stands)	0.75
	Good	Moderately robust vegetation with good interception potential (for example, good condition tufted grass stands)	1
	Fair	Moderately robust vegetation with fair interception (for example, tufted grass stands but with lowered basal cover) OR less robust vegetation with very good interception (such as kikuyu pasture)	1.25
	Poor	Vegetation either short (<5 cm) (such as maintained lawns) or robust but widely spaced plants with poor interception (for example, trees or shrubs with poorly vegetated understory)	1.5
	Very poor	Vegetation either very short (<2 cm) offering little resistance to flow or sparse and providing poor interception (for example, degraded grasslands with very poor basal cover)	2.0

Method: Refer to Practical Guide.

3. Soil Properties

Rationale: Soil properties of areas adjacent to water resources can have a significant bearing on the level of sediment entering such systems. Soil characteristics affect soil drainage which has a direct bearing on time taken for soil saturation to occur and therefore surface run-off that carries soil particles.

Soil texture determines the size of soil particles washed off exposed areas. This may have a major bearing on buffer zone effectiveness, with fine particles being held in suspension far more easily than course sediment, and therefore being washed more easily through a buffer zone. Sediment yields from riparian zones were found to be greater when finer silica sediments were introduced to overland flow than when coarser sandy loam sediment was introduced (Pearce et al., 1998). This is consistent with Syverson (2005), who found that the trapping efficiency of buffer zones was higher for coarse particles than for fine ones, with coarse clay trapped in the buffer zone independent of its width, while the silt and sand fractions were mostly trapped in the upper part of the buffer zone.

Soil texture within the buffer zone also affects infiltration and therefore the likelihood of water flow velocity being reduced as it moves through the buffer zone.

Buffers with coarse-grained, well-drained and organic rich soils are thus more effective at removing sediment by infiltration than buffers in areas with fine grained, poorly drained and organic poor soils (Kent, 1994). Although a range of soil characteristics could be used as an indicator of the risks associated with sediment entering a buffer and being removed, soil permeability is perhaps the most appropriate measure. Soils with a high permeability (typically coarse-grained) and good infiltration capacity will generally trap and remove sediments more effectively. Soils with low permeability (typically fine grained) give rise to finer sediments and have lower infiltration capacities, reducing buffer zone effectiveness.

Modifier ratings: The hydrological sensitivity assessment showed that soil texture has a moderate impact on quick flows, with reductions of close to 25% anticipated for sandy soils relative to clay loam soils. Flows can increase by as much as 75% in fine textured clay soils. When considered together with the findings of the literature review outlined above, buffer modifiers ranging from 0.75 to 1.75 have been proposed for soils with different permeability (Table 99).

Table 99 – Buffer zone modifier based on soil properties/characteristics

Buffer Characteristic	Class	Description	Modifier Rating
Soil permeability	Low	Deep fine textured soils with low permeability (for example, clay, sandy clay and clay loam) OR shallow (<30 cm) soils with low to moderately low permeability	1.75
	Moderately low	Deep moderately fine textured soils (for example, loam and sandy clay loam) OR shallow (<30 cm) moderately drained soils	1.25
	Moderate	Deep moderately textured soils (such as sandy loam) OR shallow (<30 cm) well-drained soils	1
	High	Deep well-drained soils (for example, sand and loamy sand and sand)	0.75

Method: Refer to Practical Guide.

4. Micro-topography of the Buffer

Rationale: Micro-topography has an influence on the rate at which run-off flows over the landscape. Uniform topography, with few areas where run-off can concentrate to form erosion gullies, will lead to uniform movement across the buffer zone. Where local topography concentrates flows and increases run-off velocity, buffer zones are likely to be less effective. This is supported by Helmers et al. (2005) who found through modelling that as the convergence of overland flow increases, sediment trapping is reduced. Buffers should therefore be widened in areas where concentrated flows are anticipated, resulting in a non-uniform buffer width along the length of the water resource.

Dosskey et al. (2002) developed a method for assessing the extent of concentrated flow in riparian buffers and for evaluating the impact that this has on sediment trapping efficiency. Using mathematical relationships, it was estimated that buffers could theoretically remove 41-99% of sediment, but because of non-uniform distribution, it was estimated that only 15-43% would actually be removed. These results reflect the extent of concentrated flows and their subsequent impact on sediment trapping efficiency. Blanco-Canqui et al. (2006) showed that the effectiveness of 0.7 m grass filter strips in reducing sediment fell from 25% to 10% when diffuse flow became concentrated flow. This suggests that buffer widths may need to be increased significantly where local topography encourages concentrated flows.

Note: *'Steps' down a slope may prove to be more effective than a flat slope.*

Table 100 – Buffer zone modifier based on topography of the landscape

Buffer Characteristic	Class	Description	Modifier Rating
Micro-topography of the buffer zone	Uniform topography	Smooth topography with no concentrated flow paths anticipated	
	Dominantly uniform topography	Dominantly smooth topography with few/minor concentrated flow paths to reduce interception	
	Dominantly non-uniform topography	Dominantly irregular topography with some major concentrated flow paths (i.e. erosion gullies, drains) that will substantially reduce interception	
	Concentrated flow paths dominate	Area of topography dominated by concentrated flow paths (i.e. depression, erosion gullies, drains)	

Method: Refer to Practical Guide.

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Annexure 15 – Overview of the Mitigation Measures Tool

An Excel™ tool was developed as part of this project to help assessors identify a suite of alternative mitigation measures and management guidelines that can be used to reduce potential impacts on aquatic ecosystems. This tool was developed by Douglas Macfarlane, with input from Jeremy Dickens, and was based on a review of some 70 best practice guidelines across a range of sectors.

The tool is designed to act as a quick reference for assessors for a wide range of mitigation measures and guidelines which would otherwise have to be accessed individually. References are linked to specific mitigation measures to help users find relevant supporting documentation if required. The tool is structured according to nine primary threats which are also assessed as part of the buffer zone determination process. These are:

- Alteration to flow volumes.
- Alteration of patterns of flows (increased flood peaks).
- Increase in sediment inputs and turbidity.
- Increased nutrient inputs.
- Inputs of toxic contaminants (including organics and heavy metals).
- Alteration of acidity (pH).
- Increased inputs of salts (salinization).
- Change (elevation) of water temperature.
- Pathogen inputs (such as disease-causing organisms).

The tool includes a list of some 370 mitigation measures that can be used to reduce impacts to aquatic ecosystems and is simply structured to facilitate use. Filters have been created to assist users search through the range of mitigation measures for those that are relevant to them. Filters are structured according to the following criteria:

- **Aspect**: This groups mitigation measures based on common themes such as construction management; site planning; mine management; pollution control and rehabilitation. This allows mitigation measures of a similar type to be quickly located and reviewed.
- **Relevance of management guideline/mitigation measure**: This allows users to filter mitigation measures based on a selected threat type such as "Increase in sediment inputs and turbidity". Differentiation is made here between mitigation measures with strong relevance and those mitigation measures which may contribute towards mitigating selected threat types but which are not specifically designed to do so.
- **Construction phase**: This allows users to identify mitigation measures that are specifically designed to address construction-phase impacts. These are grouped according to sector to enable easy access to relevant mitigation measures. In this way, a simple filter can be set up to search for construction-related mitigation measures for any sector such as "Agriculture" or "Mining".
- **Operational phase**: As above, but here mitigation measures relevant to operational activities can be filtered.

Although the tool does not represent an exhaustive suite of mitigation measures/management guidelines, it covers a wide variety of these and will help any assessor to identify those mitigation measures that can be used to mitigate potential impacts.

Annexure 16 – Minimum Recommended Buffer Zones

This table presents the minimum recommended buffer zones for the sub-sector and will be appropriate only under certain conditions. This would typically include a commitment to rehabilitate and manage buffer zones to ensure that these areas function optimally. Additional mitigation measures would also typically need to be implemented to reduce some of the key threats that pose a risk to water resources.

Table 101 – Minimum recommended buffer zones

SECTOR	LAND USE/ACTIVITY	MINIMUM BUFFER (m)
Agriculture	Forestry/timber	20
	Nurseries and tunnel farming operations	15
	Dryland commercial cropland – annual rotation	15
	Dryland commercial cropland – infrequent rotation	15
	Irrigated commercial cropland	20
	Subsistence cultivation	10
	Extensive livestock grazing operations	10
	Intensive livestock grazing operations	10
	Concentrated livestock operations	25
	Sludge dams associated with concentrated livestock operations	25
	Aquaculture or marine culture	15
	Agriculture (worst case)	25
Industry	High risk chemical industries	20
	Chemical storage facilities	20
	Drum/container reconditioning	20
	Paper, pulp or pulp products industries	20
	Petroleum works	20
	Breweries/distilleries	20
	Cement/concrete works	20
	Ceramic works	20
	Medium-risk chemical industries	20
	Dredging works	20
	Electricity generation works	20
	Timber milling or processing works	20
	Livestock processing operations	20
	Industries processing livestock derived products	20
	Composting facilities	20
	Industry (worst case)	20
Mixed use/ commercial/ retail/business	Core mixed use	15
	Medium impact mixed use	15
	Low impact mixed use	15
	Multi-purpose retail and office	15
	Petrol station/fuel depot	15

SECTOR	LAND USE/ACTIVITY	MINIMUM BUFFER (m)
	Maintenance and repair facilities	**15**
	Offices	**15**
	Mixed use/commercial/retail/business (worst case)	**15**
Civic and Social	Government and municipal	**15**
	Place of worship	**15**
	Education	**15**
	Cemetery	**15**
	Health and welfare	**15**
	Civic and Social (worst case)	**15**
Residential	Residential low impact/residential only	**10**
	Residential medium impact	**15**
	High density urban – Residential High Impact	**15**
	Resort	**15**
	Hotel	**15**
	Informal settlements	**15**
	Residential (worst case)	**15**
Open space	Parks and gardens	**10**
	Sports fields	**10**
	Golf courses – fairways	**10**
	Golf courses – tee boxes and putting greens	**10**
	Maintained lawns and gardens	**10**
	Open space (worst case)	**10**
Transportation infrastructure	Paved roads	**15**
	Unpaved roads	**15**
	Paved trails	**10**
	Unpaved tracks and trails	**10**
	Parking lots	**15**
	Airport – runways and taxiways	**15**
	Railway	**15**
	Transportation infrastructure (worst case)	**15**
Service infrastructure	Above-ground communication/power (electricity) infrastructure	**10**
	Below-ground communication/power (electricity) infrastructure	**10**
	Hazardous waste disposal facility	**25**
	General solid waste disposal facility	**25**
	Sewage treatment works	**25**
	Sludge dams associated with concentrated livestock operations	**25**
	Pipelines for transportation of hazardous substances	**20**
	Pipelines for the transportation of waste water	**20**

SECTOR	LAND USE/ACTIVITY	MINIMUM BUFFER (m)
	Service infrastructure (worst case)	**25**
Mining	Prospecting (all materials)	**15**
	High risk mining operations	**25**
	Moderate risk mining operations	**25**
	Low risk mining operations	**20**
	Plant and plant waste from mining operations – high risk activities	**25**
	Plant and plant waste from mining operations – moderate risk activities	**25**
	Plant and plant waste from mining operations – low risk activities	**20**
	Moderate risk quarrying operations	**25**
	Low risk quarrying operations	**20**
	Exploratory drilling	**10**
	Mining (worst case)	**25**

Annexure 17 – Examples of Biodiversity Information Sheets

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

Annexure 18 – Guidelines for Corridor Design

(Electronic Copy Only – https://sites.google.com/site/bufferzonehub/)

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