TUTORED MASTERS AND SHORT TERM LEARNING PROGRAMMES IN ENVIRONMENTAL WATER REQUIREMENTS

Report to the
Water Research Commission

by

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TUTORED MASTERS AND SHORT TERM LEARNING PROGRAMMES IN ENVIRONMENTAL WATER REQUIREMENTS

BACKGROUND

In 1996 the then Department of Water Affairs and Forestry requested support from the United Nations Educational Scientific and Cultural Organisation (UNESCO) and the World Meteorological Organisation (WMO) to assess education and training needs in integrated water resources management in South Africa. These two organisations agreed, and the assessment was conducted in 1998 at national, provincial and community levels.

The assessment evaluated the education and training needs and capacities of the Department and linked it with the needs of other government departments, non-governmental organisations and the private sector. The assessment took into account various imperatives, including South Africa being a country in transition, its affirmative action policy, staff and career development concerns, capacity building required for achieving sustainable development and the need to link and interact with efforts by southern Africa and the international community.

The major concern in South Africa at the time was the lack of appropriately-qualified individuals with sufficient experience to implement the provisions of the National Water Act, (Act No.36 of 1998-NWA), in order to ensure the achievement of integrated water resources management (IWRM). New concepts were introduced such as Reserve and Classification that existing practitioners had to familiarise themselves with before they could implement it in terms of licensing requirements. Inadequate and fragmented implementation of transfer of knowledge and capacity has the potential to hinder endeavours to manage water resources in ways that address issues of equity, sustainability and efficiency, and contribute to social and economic development and the eradication of poverty.

COURSE AIM

To provide training at a professional scientific level that qualifies candidates on a nationally and internationally recognized expertise level to achieve a holistic understanding of the processes, functions and components of inland and estuarine aquatic ecosystems for management purposes. The course was also meant to provide wider understanding of the strategies that are utilised throughout the SADC region

OBJECTIVES

- Enable training of public and private sector candidates (single module short learning programmes to a Master’s degree) in the field of Environmental water requirements (EWR) using the concepts and tools that form part of Resource Directed Measures (RDM);
- To undertake planning and managing water resource management projects/ programmes;

- To compile, analyse and disseminate information relating to water resource management;
- To gain a broad understanding of the concepts and data requirements of all the major disciplines generally involved in water resource management projects/programmes;
- Integrate the typical outputs from the various disciplines generally involved in water resource management projects/programmes; and
- Design frameworks for monitoring and auditing the effects of water resource management projects/programmes in terms of (a) the biophysical aspects of aquatic ecosystems and (b) the socio-economic implications for water resource management.

STUDY OPTIONS

The North-West University (NWU) offers a flexible suite of advanced study options:

- Accredited (SAQA) individual modules and short-term learning programmes (SLPs), which are credit-baring towards the Masters.
- A part time tutored **Masters in Environmental Management (M. Env Man) with specialisation in Environmental Water Requirements** programme at NWU completed over **two years** encompassing coursework modules and a research project.

ENTRY REQUIREMENTS

Note that successful completion of the SLPs does not automatically lead to entrance to the Masters Programme – see entrance requirements of the respective institutions.

- A Bachelor’s degree or diploma in an appropriate field or appropriate work experience.

Tutored Masters in Environmental Management programme (Note: NWU entrance requirements for admission to the Masters programme apply)

- An **Honours** or equivalent 4-year degree in a relevant discipline, or equivalent qualifications in **environmental sciences** for cross-disciplinary studies.
- Candidates lacking an adequate ecological foundation may be required to complete additional modules as co-requisites during the first year of the programme.

SHORT-TERM LEARNING PROGRAMME AND MODULE CONTENT

Module 1: *Background and context: environmental water requirements and legal framework*

The module aims at achieving a basic level of understanding, and to contextualize ecological water requirements within the framework of integrated water resource management. However it will provide a conceptual rather than a functional capability on successful completion. The module also acts as an introduction to the rest of the course. It is the only place in the Masters course where the legalities of water management is dealt with, so due care should be taken to complete the assignment thoroughly. The principles and practices and pitfalls of the public participation process is outlined and set in the context of integrated water resources management.

Module 2: *Resource economics in integrated water resources management*

The purpose of this sub-module is to provide students with an understanding of the economic issues involved in allocating water to the environment versus other uses, and of water management at a catchment level. The sub-module aims at a basic level of understanding, to provide a conceptual rather than a functional capability.

Module 3: *surface and groundwater hydrology*

This module addresses the methods and procedures needed to implement the surface and groundwater hydrology components of Resource Directed Measures (RDM). However it is important to note that the NWA clearly emphasize a unitary hydrological cycle and in the definition of a water resource, but the characteristics of surface water and groundwater sometimes require it to be considered or managed differently. In essence, this module is about the techniques to ensure that water resources will be used in a sustainable way as prescribed by the NWA. This forms the cornerstone of the long-term sustainable use of the resource – the other two components being equity and efficiency.

Module 4*: Hydraulics and hydrodynamics*

As part of the RDM process it is necessary to understand the hydraulics of the system in order to improve the results of the hydrological (rainfall-runoff) systems discussed in Module 3. These are usually required to obtain higher confidence for Level 3 RDM studies. The aim of this course is to provide the student with the relevant background information on the function and structure of estuaries and the near-shore marine environment and to demonstrate the intricate interactions between the various components of freshwater and the near shore marine environment with the focus on estuaries.

Module 5: *Fluvial geomorphology*

The purpose of this module is to provide candidates with a working knowledge of geomorphological processes so that they can communicate effectively with a competent geomorphologist, and integrate the specialist output provided by a geomorphologist into an environmental water requirement (EWR) assessment.
The module aims at a basic level of understanding, to provide a conceptual rather than a functional capability.

Module 6: *Water quality as part of the EWR process*

The purpose of this module is to provide students with an understanding of the various physicochemical constituents in aquatic ecosystems; the effect of these variables on aquatic organisms/communities; and the measurement, monitoring and management of water quality in aquatic ecosystems. The types of aquatic ecosystems that the module is of relevance to include rivers, open waterbodies (lakes and dams), wetlands and estuaries, but excludes marine ecosystems. Groundwater quality is also touched on in this module. The focus of this module is the fundamental principles and concepts that underpin a good understanding of water quality and the main issues relating to this topic, as opposed to specific methods that are used for water quality assessment, monitoring and management in South Africa. The more important methods are, however, introduced in this module and the cardinal knowledge that is gained through this module will equip students to better understand the methods and their limitations

Module 7: Aquatic ecology

The objective of this module is to provide a basic understanding of the ecology of inland waters, particularly for students who intend to become managers of aquatic ecosystems. This module studies mutual interactions between organisms as well as their interactions with the abiotic environment. Attention will particularly be given to the ways in which these interactions determine the number and distribution of organisms.

Module 8: *Technical integration as part of the EWR process and implementation EWRs*

Environmental Water Requirements (EWR) methodologies currently in use that relate to the specialist scientific aspects of ecological Reserve determinations, have been developed both locally and internationally over many years, using specialist knowledge and experience in both water resource and aquatic ecology functioning. These methodologies have been adapted where necessary to suit South African requirements and to incorporate the latest information and available knowledge. Each EWR determination requires an inter-disciplinary group of scientists and managers and is never based on the judgment and expertise of one individual or specialist. Typically the team will include ecologists, geomorphologists, water chemists, hydrologists, hydraulic engineers, social scientists and water resource managers. This module aims to provide the skills and tools required to coordinate quality and quantity EWR determinations separately for river, wetland, estuary or groundwater, as well as how to integrate the various components and implement them.

Module 9: *Implementation and management options for water supply and system operations*

The purpose of this module is to provide candidates with an overview of the planning of water resource management options used to determine the needs of users and to ensure sustainable resource use. This will enable students to contextualise environmental water requirements within the realm of water resource management, and to develop an appreciation for the various aspects of water resource management that needs to be considered in order to integrate and implement environmental flow requirements and the alternatives mechanisms to achieve water resource protection. Students undertaking this module will develop a general understanding of the water resources planning and operational aspects of water resource supply schemes, which will assist them in communicating effectively with water resource engineers and managers.

Module 10: *Research Project*

The research project will require the completion of a project management phase (including project proposal, project budget and development of the research proposal (presentation to the higher degree committee). For the one-year full-time and two year part-time degree, data gathering, analysis and write-up must be completed within the specified registration period. Research projects are encouraged within the fields of expertise of the candidate.

FURTHER INFORMATION

Only 15 participants will be accepted for the SLPs, while eight to 15 candidates will be accepted into the Masters programme.

Should interest warrant it, an SLP may be repeated in the year.

The University of North West through their contact person, Prof. Francois Retief, is coordinating the pioneers' course, the class of 2016 students.

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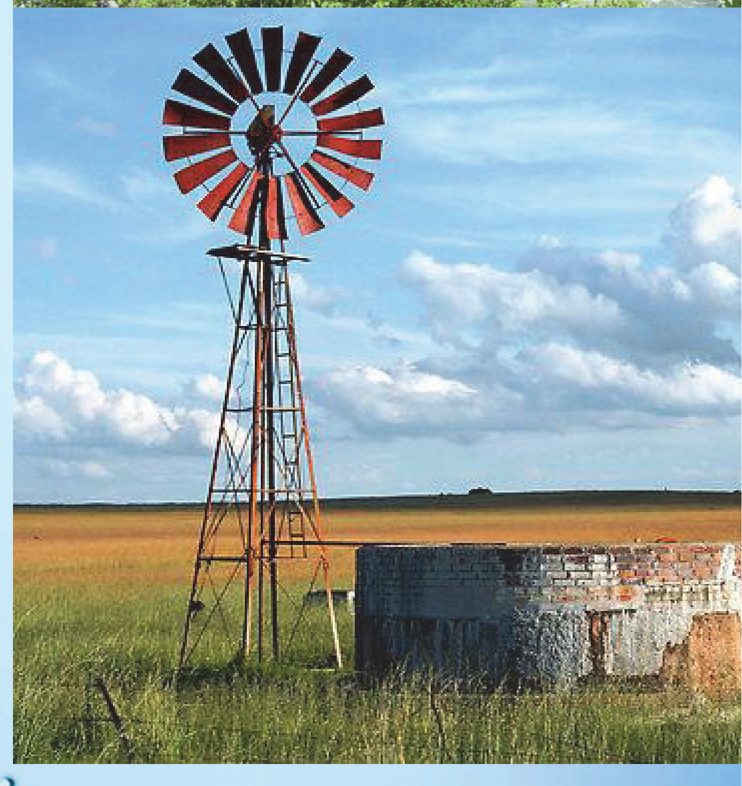
MODULE 1 BACKGROUND AND CONTEXT: ENVIRONMENTAL WATER REQUIREMENTS AND LEGAL FRAMEWORK

Tutored MSc in Ecological Water Requirements

Developed by
EH Haigh, HD Davies-Coleman, J Burt and L Jonker

November 2013



MODULE 1: INTRODUCTION TO ENVIRONMENTAL WATER MANAGEMENT

Outline of Module 1

MODULE 1:
INTRODUCTION TO INTEGRATED ENVIRONMENTAL WATER MANAGEMENT

Purpose

The module aims at achieving a basic level of understanding, and to contextualise ecological water requirements within the framework of integrated water resource management. However it will provide a conceptual rather than a functional capability on successful completion. The module also acts as an introduction to the rest of the course. It is the only place in the Masters course where the legalities of water management is dealt with, so due care should be taken to complete the assignment thoroughly. The module further aims to outline the principles, practises and pitfalls of the public participation process and set these in the context of integrated water resources management.

Outcomes – on completion of this module learners should:

- explain the need to protect water resources;
- understand the concepts behind and reasons for ecological water requirements as a key component of sustainable water resources development;
- give an overview of the legal and regulatory framework for water resources use and protection;
- employ critical and logical thinking, with a capacity to be sceptical of received wisdom and opinion;
- plan a public participation programme for water resources management.

Framework timetable – Duration

This module (total hours = 80) will be presented over a 5 day period. This will comprise:

- 10 x 2 hour lectures
- 4 x assignments (1 of which is presented as a seminar)
- 1 guided discussions of legal framework
- 1 seminar (15 minutes)
- 1 x exam (2 hours)

Mark allocation

RESOURCE USE AND PROTECTION

Purpose

Students undertaking this sub-module will develop an understanding of the overall functioning and integrated nature of inland and estuarine aquatic ecosystems.

The principles of sustainable development and necessity for resource protection in integrated water resource management are emphasised. Procedures for resource classification are briefly dealt with. Associated environmental management instruments such as resource economics and environmental accounting.

Outcomes

On completion of this sub-module, students should be able to:

- appreciate and demonstrate the social and environmental benefits of protecting aquatic ecosystems;
- comprehend the integrated functioning of different components of water resources;
- demonstrate understanding of the concept and importance of EWRs;
- explain the tradeoffs between the use and protection of water resources in terms of the *triple bottom line* (environmental, economic, and social equity requirements);
- explain to non-specialists the purposes and benefits of EWRs;
- understand the role and limitations of resource economics and other relevant instruments in policy decisions affecting water resources.

Duration

The sub-module will take 4 days to complete.

1. The Resource

The National Water Resources strategy CHAPTER 2 – South Africa's Water Situation and Strategies to balance Supply and Demand is a useful source for this module

1.1 WATER RESOURCE UTILISATION

Water is the most valuable and yet undervalued resource in the world and an improvement in the human approach to the utilization and management of this valuable commodity are essential. This course serves as an introduction to the South African approach to this task.

In the developed world – Europe, North America and most of Australasia – and in the industrializing countries of the Pacific Rim, it is consumption and waste production rather than population increase that threaten the freshwater resource. Western society uses vast amounts of water for industry, domestic purposes, washing cars and irrigating sports fields and golf courses. Many of the river catchments have been disrupted by development and increasingly car-orientated society leads to greater areas of land being concreted for shopping areas, roads, car parks and additional housing and thus unavailable for soil percolation and purification of the water and its storage. Hundreds of new chemicals enter the environment each year. There is no possibility that they can be adequately screened, under present arrangements, for the damage that they might do. Hydrological patterns are upset and river regimes, to which biota such as fish have adapted through a slow evolution, are disrupted. Much has been done to resolve gross problems of Europe, but more subtle forms are now extant – trace organics with estrogenic activity, for example. The strictures on availability of agricultural land and food security apply, but most of the developed world is not yet as short of water as the arid parts of the developing and third worlds. Nonetheless, water rationing and payment of its full cost must soon replace traditional treatment of water as free good. Conflict over water supply is already bringing nations close to war (Israel and its Arab neighbours over the Jordan; Ethiopia, Sudan and Egypt over the Nile, Turkey, and Syria over the headwaters of the Tigris and Euphrates).

The reality of the current water supply situation in South Africa

Many rural areas are deprived of treated potable water (25% of the country's population are without adequate basic water services). Although this situation has improves significantly, it is not estimated to be normalised until at least 2025 (see www.dwaf.gov.za)

Table 1. Expected increasing percentage use of total demand (www.dwaf.gov.za)

DEMAND SECTOR	1980	1990	2000	2010
DIRECT USE Municipal and domestic	9.3	12.0	14.4	17.3
Industrial	6.3	7.6	9.1	11.4
Mining	2.9	2.7	2.6	2.5
Power generation	1.7	2.3	3.5	3.5
Irrigation	52.2	50.9	48.9	45.9
Stock watering	1.6	1.5	1.4	1.4
Nature conservation	1.1	1	0.8	0.7
INDIRECT USE Forestry runoff reduction	7.9	7.5	7	6.6
Ecological use, estuaries and lakes	17	14.5	12.3	10.7
TOTAL VOLUME	16291 million m^3/a	19043 million m^3/a	22438 million m^3/a	25888 million m^3/a

In addition in South Africa, the major industrial and urban developments have not coincided with the areas of highest amount of available water. Schulze (1997) estimated that we have 49200 million m^3 available water in SA annually. As a result of the misalignment of water and people, today several catchments are already over exploited with regard to available water and water has had to be moved in from other catchments by means of interbasin transfers. Large dams have already been built which have a total storage capacity of 27000 million cubic meters, which amount to more than half of our MAR. There are currently 23 interbasin transfer schemes, 7 dams with capacity exceeding 500 million m^3, 19 between 100 and 500 million m^3, and 25 with capacity of 50-100 million m^3. That of course excludes all smaller dams, farm dams and weir. It is possible that only about 10 major mainstem rivers have no dams on them, i.e. Sabie River, although some of its tributaries have dams; and some of the larger Eastern Cape Province rivers in the Transkei region. While the development of our water resources has kept pace with requirements, the efficient use of reticulated water has only recently started receiving attention. If municipalities repaired their supply systems to reduce losses to at least 10% and consumers reduced their demand levels there should be no need for further dam building in the next 10 to 15 years.

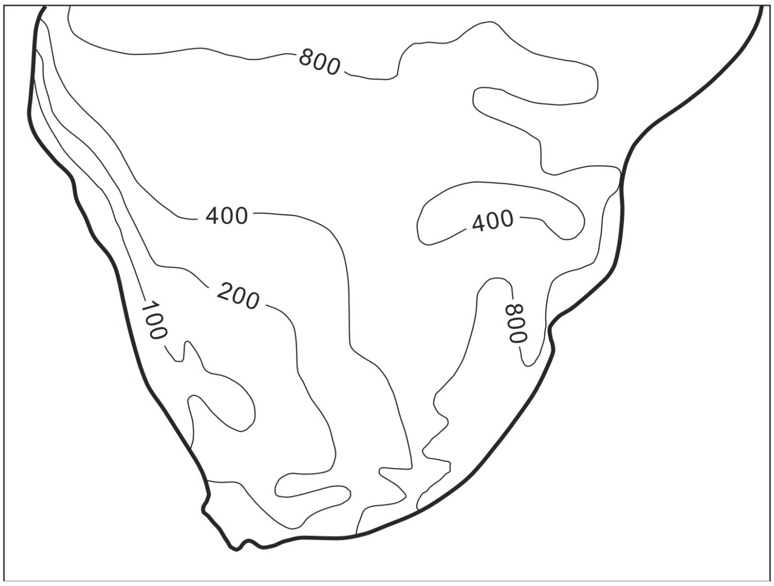


Figure 1. Distribution of mean annual rainfall over southern Africa (mm)

Sustainability

There is increasing competition for water so it is important to ensure that the resource is protected while meeting the social and economic objectives of society. In view of the increasing need to balance resource protection with social objectives (i.e. ensure equity in water allocation, and alleviate poverty) and economic objectives (i.e. to ensure wealth creation and achieve income redistribution), accounting for the environment in economic analyses plays a key bridging role in the decision making process. In view of the increasing risk of unsustainable management of the water resource leading to environmental degradation, modest attempts to assess the impacts of flow scenarios on the ecological assets derived by the river, and the economic analysis of the out of river water use ensuring a balance between protection and utilisation, are well justified.

UNDERSTANDING THE RESOURCE – COMPONENTS, FUNCTION AND INTEGRATION

Integrated Water Resources Management

Integrated Resource Management is based on the following hierarchical principles:

- Understanding the resource – components, function and integration.
- Classifying the resource components in terms of functionality, and present state.
- Setting management of objectives.
- Developing a management plan. (Palmer *et al.* 2004a)

The development of successful Integrated Water Resource Management protocols means firstly, understanding how the abiotic aquatic ecosystem components – water quality, flow regime, and physical structure – interact to provide the conditions for the biotic processes. Integration also means understanding how these combined bio-physical processes link to social and economic processes through the human use of water resources. The aquatic ecosystem is an intrinsic part of a catchment. Catchment processes are driven by climate and land-uses. Traditionally, the understanding of natural systems and their biophysical characteristics has been separated from social science approaches which address needs and aspirations of people and from economic approaches which address financial and governance issues. Sustainable resource management demands that these three areas be integrated. The key linking concept in this integration is that only functioning ecosystems can continue to provide people with valuable goods and services.

1.2.1 SOUTH AFRICAN CLIMATE AND LANDSCAPE: Present climate

The pattern of rainfall in Southern Africa is generally well understood (Tyson & Preston-White 2000). The western part of the county receives far less rain than the eastern parts, and the north, on average enjoys a more predicable rainfall pattern than the southeast. This situation is governed by two major climatic systems. In the tropics, rainfall is determined primarily by the Inter-Tropical Convergence Zone (ITCZ), which migrates north/south seasonally in response to the position of the sun relative to the earth's tilted axis. During the southern summer the ITCZ moves southwards, bringing with it moisture-laden air from the tropical Atlantic Ocean in the northern part of the subcontinent. With it comes the

Congo Air Boundary (CAB), along which recurved Atlantic air meets air masses from the Indian Ocean. The zone is characterized by frequent low-pressure systems. The equatorial zone therefore receives high rainfall of over 800 mm (Fig. 1). Occasionally, pressure lows develop across the interior of southern Africa, and when linked to the CAB, result in copious rain in the interior. The descending limbs of the southern Hadley and Ferrel Cells produce a zone of high pressure at about 30°S, creating anticyclonic conditions that dominate southern African climate. Moisture in this region originates mainly over the Indian Ocean. As this moisture-laden air moves westwards over the subcontinent, the presence of the great escarpment causes precipitation, and moisture content declines progressively towards the west, resulting in increased aridity in the interior.

The upwelling of the cold Benguela current along the south-western coast also ensures that air masses originating over the Atlantic Ocean carry little moisture. The west coast is therefore arid. Cold fronts, originating over the South Atlantic Ocean, move eastwards onto the subcontinent in winter, bringing rain to the southern and south-western coast.

Water availability is determined not just by inputs from rainfall and its contribution to runoff and groundwater, but also by atmospheric demand. Thus, it is important to consider the water balance, with potential evapotranspiration being a useful indicator of atmospheric demand for water. Solar radiation provides the energy that drives evapotranspiration. Potential evapotranspiration increases westwards in the region due to the presence of clear skies and high levels of solar radiation (Fig. 2).

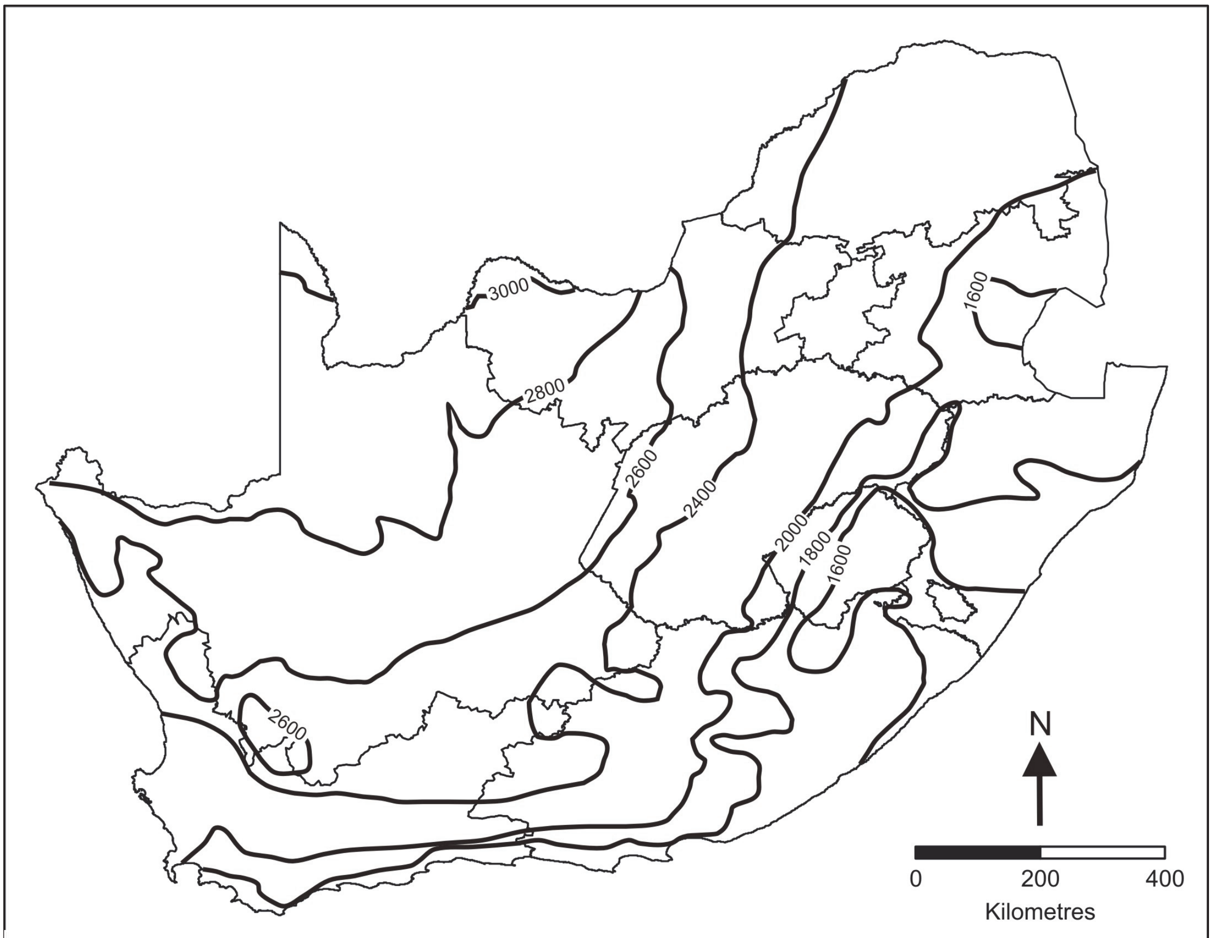


Figure 2. Mean annual potential evapotranspiration over South Africa (mm)

Given this combination of climatic circumstances where rainfall is greatest in the eastern and northern part of the subcontinent, and where potential evapotranspiration is greatest in the western part, the greatest incidence of wetlands and rivers should be expected in the eastern and northern parts of the subcontinent.

South Africa is generally semi-arid, drought prone area. Average runoff only constitutes approximately 9% of the total volume of water falling on the country (Schulze 1997). Thus approximately 91% evaporates again. The amount of runoff and the percentage of runoff as a proportion of rainfall tend to increase with rainfall such that runoff in the northwest of the country is less than 5 mm per annum, and there is a fairly systematic increase in runoff southwards and eastwards in the country. The eastern escarpment of Limpopo, Mpumalanga and the Drakensberg in KwaZulu-Natal and the Eastern Cape, and the coastal areas of KwaZulu-Natal and the Eastern and Western Cape are areas of particularly high runoff at greater than 200 mm per annum. KwaZulu-Natal is by far the wettest province in South Africa in terms of its mean runoff.

Runoff patterns reflect a combination of precipitation characteristics (amount of rainfall, its intensity, concentration of the rainfall season and persistence of consecutive rain days (Schulze 1997). It is also dependent upon features of the surface onto which it falls such as soils and geological substrate, and the extent to which surfaces have been hardened.

Mean annual runoff is the amount of water that is available for use. This water is available for storage in dams. Total surface water available water in South Africa is 49200 million m^3 annually. A portion of this water should be retained in rivers to ensure functionality. Without industrialised human intervention the environment of SA has always had sufficient water for good environmental function as the plants and animals native to our subcontinent developed with the climate.

Re-use of domestic waste water and desalination of the sea on a large scale have not been applied on large scale although the technology has improved and been reduced in cost.

Table 2. South Africa's water resources.

TOTAL Mean Annual Runoff	51.5x 10^9 m^3 (33.0x10^9 m^3 is exploitable)
Groundwater	5.4 x10^9 m^3 = 16%
Zambezi alone	39 X10^9 m^3
Dams	519 > 50 000 m^3 IMPOUND 50% of runoff
Inter Basin Transfers 12 existing transfers	1.63 10^9 m^3
When other come on stream this will rise to	4.82 x 10^9 m^3

1.2.2. CATCHMENT LINKAGES

In a relatively arid country such as South Africa, it is necessary to recognise the unity of the water cycle and the interdependence of its elements, where evaporation, clouds and rainfall are linked to underground water, rivers, lakes, wetlands and the sea, and where the basic hydrological unit is the catchment. The aquatic ecosystem can be expressed in biophysical terms and divided into drivers and biotic responders. Drivers are broadly speaking physico-chemical water quality, geomorphological and hydrological. The hydrological cycle links all elements of the catchment and the entire ecosystem. All the elements set out in Table 3 interact and influence one another to a greater or lesser extent. For example, extremely cold weather will have a tremendous effect on the stability of the geological structures. High rainfall coupled with erodible soils will result in a rapidly changing landscape, higher sediment load of rivers and if these soils are nutrient poor the landscape will have the potential to erode even faster if the vegetation cover is depleted. Often the shape and direction that a catchment slopes/faces will predicate the degree to which the prevailing winds will effect the changes in the catchment.

Catchment shape or topography will determine the velocity of the water in the channel as well as the position of any seeps and other wetlands. The geology will have some influence on the habitat types by the size and number of clasts instream as well the sediment accumulation. The underlying geology will further determine the position and size of wetlands as well as the occurrence of aquifers and aquitards and resultant springs due to the position of impervious layers. Springs may often be the source of upland rivulets as well as large seeps.

Table 3. The elements of a catchment

MAIN ELEMENT	DEPENDENT VARIABLE	QUALITIES	OUTCOMES
GEOLOGY	Rock material	Hardness and chemistry	Catchment form Water velocity and chemistry
	Soil type	Erodibility	Landscape shape and change
		Transmissivity	Degree of groundwater absorption
	Water quality	Chemistry / solubility	Deterministic on vegetation type and Usability for, i.e. domestic and industrial
CLIMATE	Rainfall	Quantity	Amount of available water for use
		Intensity	Agriculture, erosion,
		Periodicity/cyclicity	Evaporation rates and ground water accumulation
	Wind	Principal direction/ persistence	Aeolian effect in shaping landscape
		Periodicity	Evaporation rates
	Temperature	Range	Runoff/Evaporation rates Growth rates of biota

The geology will have a determining effect on the natural chemistry of the water. The erodibility of the soil coupled with the rainfall will influence the shape, width and depth of the channel as well as the amount of sediment generated in the catchment and how it is utilized by vegetation. The climate of an area results from the interplay of rainfall, temperature, elevation and evaporation and the amount of runoff is dependent on all the above while soil transmissivity will have a profound influence on the groundwater contribution to base-flow. The rainfall pattern and volume will determine the size and durability of any wetlands as well as the size and the shape of the channel.

1.2.3. INTEGRATION

The water resource encompasses all aspects of the water in the environment as set out in principle 5 of the National Water Act 36 of 1998. Figure 3 developed by Prof Kate Rowntree (Rhodes University) demonstrate how the system drivers and responses interact in aquatic ecosystems.

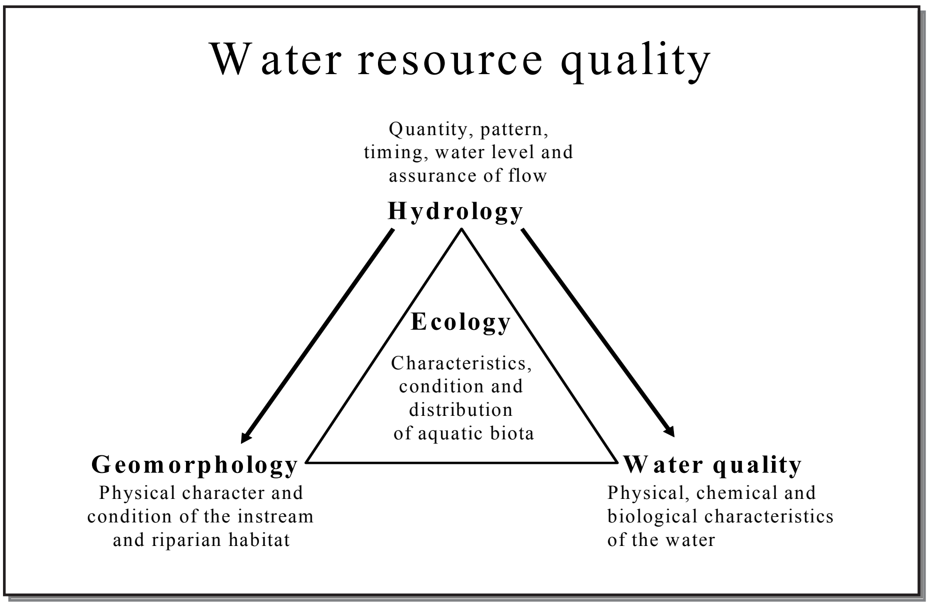


Figure 3. Interplay between the major ecosystem drivers in the aquatic ecosystem

The *principal drivers* of the aquatic ecosystem are

- the hydrological regime
- the geomorphological regime which is the interplay between rainfall and the earth, and
- the natural water quality which results from the interplay between the climatic/ hydrological regime and the earth/air chemical components.

The interaction of these three main forces determines the characteristic biotic (plant, microbes and animals) component of each ecoregion (Figure 3).

The resource consists of rivers, estuaries, lakes, wetlands, groundwater and rain (clouds). Rivers, lakes and wetlands generally fall within a watershed or catchment area, whereas groundwater is not always within these boundaries, and in fact can move through long distances, determined by geological structures. The quality of the resource is therefore dependent not only on the climate, but very strongly by the geology of a catchment. Furthermore the water resource includes the quality or character of the water, and all biota dependent on the water, both instream and riparian. However, generally the animals that are visitors to the riparian zone and utilise the water in the river for drinking, are not classified as part of the resource. Therefore a healthy functional water resource would include fish and invertebrates, plants occupying a natural range of habitats.

The *management unit* is the catchment. However catchments are considered too small for management to be implementable. A country can therefore be divided into a number of water management areas. In South Africa 19 Water Management Areas were originally established as management units and is stipulated in the national water resource strategy. However only 9 have been gazetted and there is a shift to staying with these. Within each WMA a catchment management agency will ensure the protection, use, development, conservation, management and control of water resources (DWAF 2004).

When developing a catchment management strategy for a water resource the custodians should understand the complexities of the interactions between the structure and functions of the resource, why it is so important and how it should be managed to the best advantage for development and both present and future generations of users.

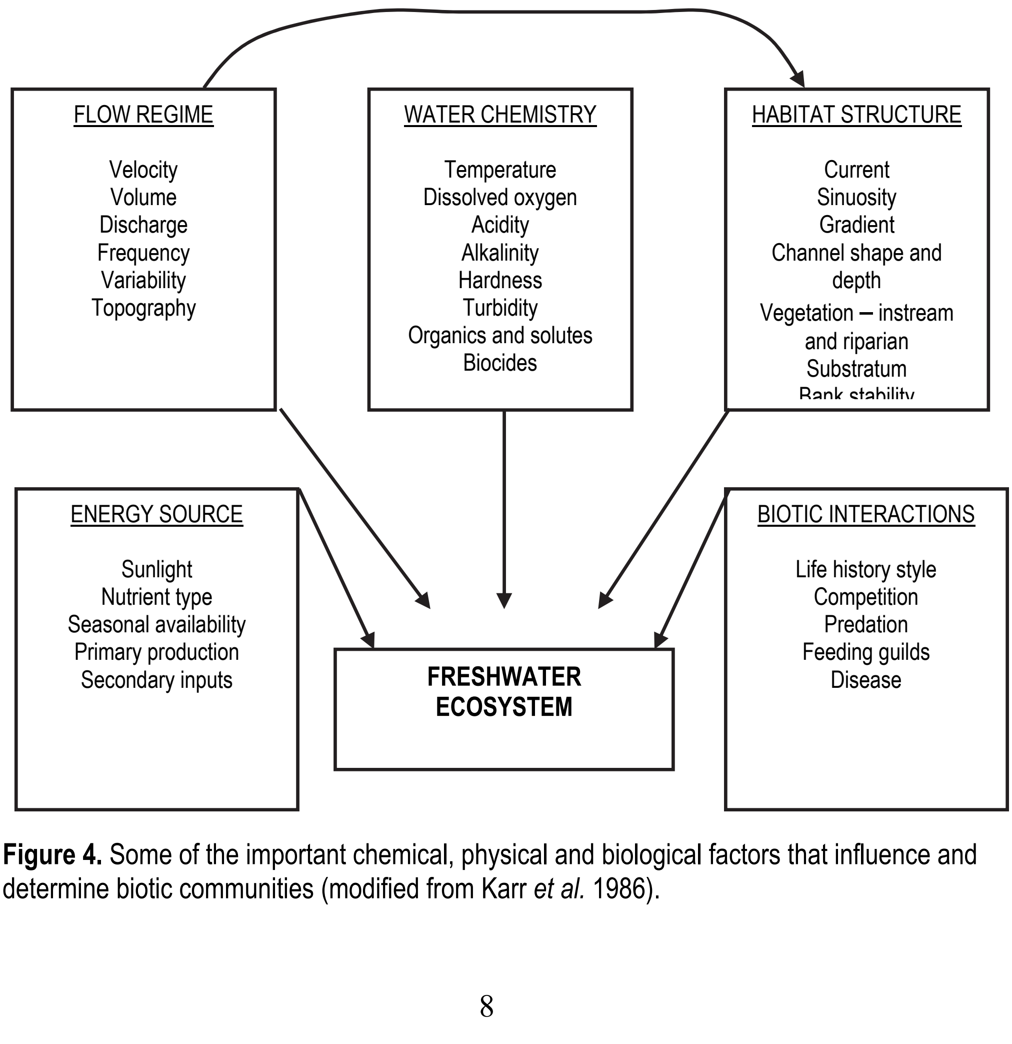


Figure 4. Some of the important chemical, physical and biological factors that influence and determine biotic communities (modified from Karr *et al.* 1986).

1.2.3.1. South African Flow Regimes

The flow regime to which a water resource is subjected will define its character. The geomorphological processes of river and wetlands are determined by the flow regime. Determining the flow regime of a river or wetland is the first step in determining the quantity aspect of the ecological water requirements of that water resource.

Three typical types of natural flow regimes occur in Southern Africa:

Permanently flowing rivers that are found in the wetter parts of SA and fed by slowly draining base flows during dry periods but nevertheless have strongly seasonal patterns of flow due to seasonal rainfall pattern.

Seasonal rivers are generally found in drier areas or areas where base flows are insufficient to sustain flow during the dry season. However wet season flows are reliable in occurrence in years of normal rainfall.

Temporary or ephemeral rivers are those where flow only occurs for relatively short periods in response to major rainfall events and is very unpredictable. These are generally found in the western desert-like regions of South Africa and Namibia.

This high degree of natural variability is compounded by a large number of anthropogenic impacts mainly:

- Land use changes (urbanization, afforestation, removal of indigenous forest & bush).
- Direct run-of-river abstractions.
- Abstractions from ground water reducing base flow inputs.
- Large dams and associated abstractions or releases. Also small farm dams
- Return flows from irrigation or municipal and industrial effluent.

Flow Regime is determined by.

- Magnitude which ranges from minimum expected flows to maximum expected flows in various seasons.
- Variability (frequency) or changeability both in the short and long term. Predictable variations tend to be seasonal and short term while unpredictable variations tend to be long term such as wet periods and droughts.
- Duration of dry or wet periods, of short term event such as floods.
- Trends are important in understanding the type of regime. Repeating trends are cycles of wet and dry periods, while non-repeating trends include progressive increases or decreases in flow through increasing abstraction or climate change.

Flow regime affects:

- instream hydraulics through sediment transport and deposition dynamics, bank and bed erosion or deposition.
- Instream hydraulics affects flow regime through provision of storage in channel reaches and effects on the routing of flows from upstream to downstream.
- Water quality through source of runoff (surface, sub-surface; different parts of catchment, etc.) and dilution of point and diffuse sources. Suspended sediment in turn affects water quality because of vegetation matter and associated nutrients.

How much water flows in a river is measured by *discharge* which is dependent on *velocity*, two important variables that should be determined in order to quantify available water, *i.e*. runoff**.**

- Discharge is the product of velocity * cross-sectional area.
  It is the volume of water flowing in a channel, measured in m^3/s or *l*/s.
  Within a limited reach length of a river, discharge remains constant.
  However, cross-sectional area and velocity vary a great deal.
- Velocity is the speed of water and can be affected by variations in:
  Boundary effects (friction with the bottom, banks and local restrictions within the channel);
  Flow characteristics (laminar and turbulent flow, eddies, *etc*.);
  Changes in surface slope (energy gradient).

1.3. UNDERSTANDING THE RESOURCE – COMPONENTS

The physical components of the water resource can be separated into four components each with unique functional characteristics, namely rivers, wetlands estuaries and ground water. These components are intimately linked and functional interdependent. Problems arise in managing the resource sustainably because the interdependencies and linkages is not always obvious nor are they clearly understood by land users.

1.3.1. RIVERS

Water, streams and sediment as factors that shape the landscape (*main source Ellery et al. 2004*)

Rivers and streams arise as a consequence of runoff that is generated ultimately by rainfall. They occur in valleys that have been shaped by the power of running water, and they are more than conduits of water: flowing water carries sediment, and the combination of water and sediment determines the characteristics of streams and rivers and their associated wetlands. **Significantly for management consideration if the hydrological regime of a system is altered the sediment characteristics and much of the habitat characteristics will be altered.**

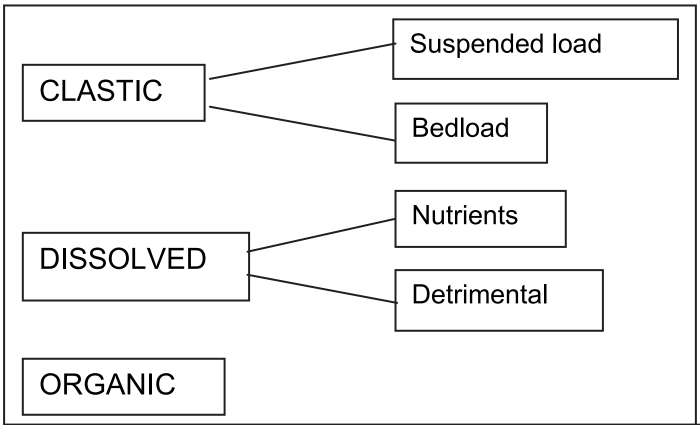


Figure 5. Types of sediment that are transported in fluvial

The word “sediment” is typically associated with the silt and mud that turns water grey or brown, but we need to recognise that a variety of sediment types are transported by rivers and streams. These are an essential part of the ecological water requirements in that they play a valuable role in ecosystem functions (Fig.5). Bedload sediment is rolled or bounced along the bed of the stream, being anything from sand to boulders and often play a significant role in shaping the habitats of river and streams (Fig. 5). Suspended sediment comprises silt- and clay- sized particles, and other nutrient sediments often adhere to these particles. Dissolved sediment includes nutrient solutes such as nitrogen and phosphorus that can limit or increase the growth of plants in streams and wetlands (primary productivity) depending on concentration. Potassium, sodium, chlorine and silica are often called detrimental solutes especially if they occur in unnaturally high concentrations. Organic sediments tend to accumulate in a benign way in low energy environments such as wetlands, but are uncommon in rivers and streams

Characteristics of streams and rivers are shaped by their interactions with rock and sediment. Bedrock rivers interact directly with rock and their characteristics are shaped primarily by characteristics of the rock with which they interact, including the location of more and less resistant features of the rock such as faults or dykes. In contrast, alluvial rivers flow on beds of their own making, through deposition of sediment, such that there is very little contact between bedrock and stream. The characteristics of such streams are determined mainly by the dominant sediment type transported by the stream, and also by the nature of the discharge (episodic or regular), and the stream gradient. Braided streams, where areas of flowing water repeatedly divide and rejoin, occur where stream sediment load is dominated by bedload sediment, discharge is very episodic (i.e. flashy) and gradient relatively steep. In contrast, in streams meandering across a floodplain deposition takes place on convex banks and erosion on concave banks, leading to channel migration. These events tend to occur where suspended sediment is predominant, discharge is more regular and gradient is relatively shallow.

Longitudinal characteristics of river systems

The classification of a river for management purposes should take the position of the river reach in the catchment and consequently its resultant character into consideration. In a drainage basin the headwaters are usually steep and fast flowing. Here streams are deeply incised and valleys are steep sided with a “V” shaped cross-section. Downstream the river gradient and current velocity usually decrease, and the stream assumes a “U” shape in cross-section. The lower reaches of rivers have shallow gradients, low current velocity, and valleys are shallow and wide in cross-section. Thus, rivers typically have a concave upward longitudinal profile from headwater to the sea (Fig. 6). This typical profile may be altered through tectonic events mid-channel and the concave upper section is followed by a steep gorged lower sequence causing rejuvenation. The river reaches with midland to lowland characteristics is followed by reaches with many headwater characteristics albeit with lager channel and increased discharge. Many rivers enter the sea via deep gorges and many estuaries along the south and eastern coast are deeply incised, or plummet into the sea via a waterfall.

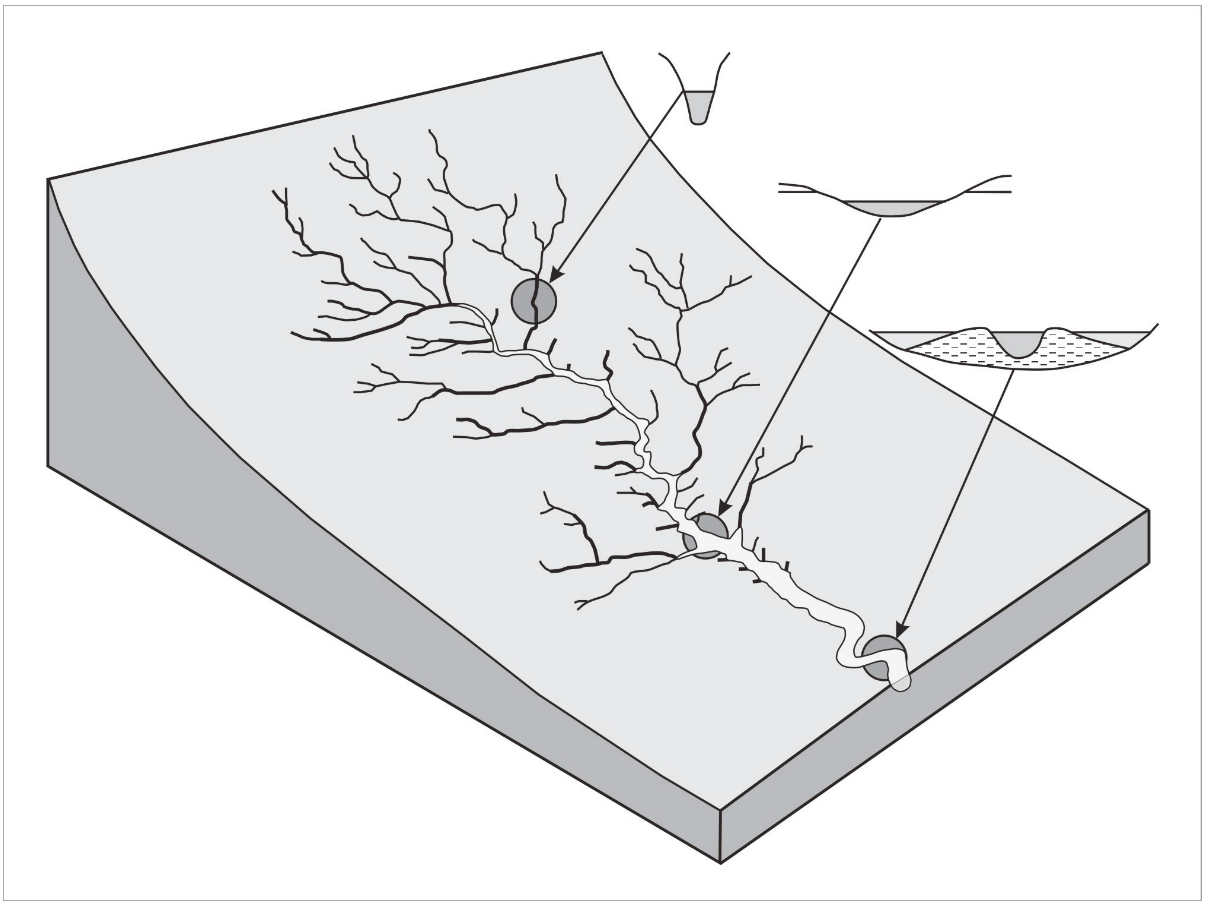


Figure 6. The typical longitudinal form of basin drainage in which grade has been achieved, showing patterns of tributary inflow and valley cross-sectional shape (after Hamblin 1992).

This concave upward longitudinal profile is accompanied by a number of systematic changes in the characteristics of the stream and its bed from the stream source to the ocean, the most important of which are:

- an increase in river cross-section and discharge,
- an increase in valley size,
- a decrease in the grain size of sediments on the stream bed,
- a decrease in the number of stream segments and length of tributary streams

These changes have been classified as shown in Table 4 below into resource units suitable for management and resource classification.

It is important to realise that the presence of concave upward longitudinal profiles is determined in part by the fact that streams that flow into the sea cannot erode their beds below the level of the sea. The lowest level to which a stream can erode its bed is known as the base level. In the first instance it is determined by the elevation of the streams mouth where the stream enters the ocean. More localised base levels occur upstream of the mouth in areas where, for example, a tributary enters the main stream, since a tributary cannot erode to a level lower than the level of the stream into which it flows. Similarly, significant impoundments along the course of a stream act as local base levels. It needs to be noted that base levels may change, as an impoundment will not last forever, and neither is the level of the sea constant: during the last ice age the sea level on the east coast of South Africa was something like 130 m below its current level, at which time coastal streams eroded their beds to depths tens of metres below their current elevation.

Table 4. Definition of geomorphological classification levels (Rowntree & Wadeson 1999)

HIERARCHICAL UNIT	DESCRIPTION	SCALE
Catchment	The catchment is the land surface which contributes water and sediment to any given stream network	Can be applied to whole river system, from source to mouth or to a lower order catchment above specified point of interest
Segment	A length of channel along which there is little change in the discharge or sediment load	Segment boundaries will tend to be co-incident with major tributary junctions
Longitudinal zone	A sector of the river long profile which has a distinct valley form and valley slope	Sectors of the river long profile
Reach	A length of a channel characterised by a particular channel pattern and morphology, resulting from a uniform set of local constraints on channel form	Hundreds of meters
Morphological unit	Basic structure recognized by fluvial geomorphologist as comprising the channel morphology and may be either erosional or depositional.	Scale similar to the channel width
Hydraulic biotope	Spatially distinct instream low environments with characteristic hydraulic attributes.	Occur at a spatial scale of the order of 1-10 m^2 and are discharge dependent

Surface water – groundwater interactions in streams

Some streams are perennial, whilst others are seasonal. Some streams are perennial along portion of their length, say in the upstream reaches, but then become seasonal lower down, or visa versa. These characteristics arise from the interaction between a stream and the groundwater regime. Streams all carry surface run-off that may make up a large proportion of the discharge. Sustained flow during the dry season results from groundwater seepage into the bed of the stream especially if the water table lies at a higher elevation than the streambed (gaining streams). Hydraulic pressure controls the discharge of groundwater into surface water. Losing streams cease to flow in the dry season as the water table lies at a similar or lower elevation than the streambed. In arid regions streams may lose significant portions of water to groundwater due to infiltration and the cross sectional area can decrease downstream. In extreme cases, the stream may lose definition altogether. This phenomenon is known as a “flood out”. (More about groundwater in section 1.3.4.)

Classification

In water resources management two types of classification has evolved. Ecological classification that describes the types of river and it state of ecological integrity and management classes that set management objectives for that river as a water resource and describes both the present ecological state and the various demands on the good and services demanded of it as a resource. Table 5 shows the geomorphological zonation of South African rivers that play an important role in the ecological classification.

Table 5. Geomorphological zonation of South African Rivers (Rowntree, Wadeson & O'Keeffe, 2000) which is an amplification of earlier ecological classification (Harrison 1965, & Noble & Hemens 1978)			
Zone, stream order & Zone class	**Physical Characteristics**	**Flow Characteristics**	**Turbidity**
Source zone (1) S	Source often with sponge or spring. Substratum bedrock or humic turf	Slow flow, often seepage but my be dispersed with waterfalls	Negligible even during storms
Mountain headwater stream (1-2) A	Mountain torrents, waterfall and rapids. Reach types include bedrock fall cascades.	Rapid, vertical flow	
Mountain stream (1-2)B	Substratum bedrock, boulder and smaller stones. Deposition negligible, stone surfaces clean. Gradient steep 0.04-0.09. Reach types include cascades, bedrock fall, step-pool,	Fast to torrential, turbulent, mixed vertical and horizontal, always oxygenated	Negligible even during storms
Transitional C	Moderately steep 0.02-0.039, dominated by bedrock boulders. Reach types include plane bed, pool-rapid, or pool-riffle, Confined to semi-confined valley floor with limited floodplain development.	Fast to turbulent, oxygenated	
Upper Foothill rocky bed. (2-3)D	Gradient moderate but still noticeable, 0.005-0.019. Substrate dominated by bedrock-cobbled bed or mixed cobble bed. Reach types include plane bed, pool-rapid, or pool-riffle. Length of pools and riffles/rapids similar. Narrow floodplain of sand gravel or cobble often present. Some epilithic growth sparsely distributed emergent vegetation.	Fast but with slower pools	Generally low, turbid during floods
Lower Foothill sandy bed (3) E	Lower gradient 0.001-0.005. Alluvia channel, sand and gravel dominated. Reach types pool-riffle or pool-rapid sand bars common in pools. Pools longer than rapid/riffles. Floodplains often present. Marginal riverine vegetation becomes noticeable and islands may form within the river channel	Lower flow velocity but fast in rapids and during flood	Extremely variable, turbid at least during floods
Lowland river (4)F	Further reduction in gradient to low, 0.0001-0.0009. Deposition increases. Channel bed predominantly sand and finer sediment. Flood plains and meanders can occur or channels may be braided. Islands often present. Emergent vegetation prominent in channels and on margins	Flow relatively slow and discharge dependent	Variable but usually turbid
Swamp	Area of wet spongy ground with a substratum of fine clays and silts high in organic matter. Channels braided, usually blind. Emergent macrophytes dominant forming dense impenetrable masses.	Generally slow	Negligible to low turbidity except during floods.
	Additional zones associated with rejuvenated profile		
Rejuvenated bedrock fall/cascades Ar, Br or Cr	Moderate to steep gradient >0.02, confine gorge resulting from uplift in middle and lower reaches of long profile limited lateral development of alluvial features, reach types include	Fast to turbulent, oxygenated	Could be turbid
Rejuvenated foothills Dr or Er	Steepened section, gradient 0.001-0.019 within the middle reaches of the river caused by uplift, often within or downstream of gorge; characteristic similar to foothills (gravel/cobble0bed rivers with pool-riffle /pool/rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro-channel activated only during infrequent flood events. A limited floodplain may be present between the active and macro-channel	Fast	Could be turbid
Upland floodplain. Fr	An upland low gradient channel, <0.005 often associated with uplifted plateau areas as occur beneath the eastern escarpment.	Lower flow velocity but fast in rapids and during flood	Turbid

1.3.2. WETLANDS

The Origin of Wetlands (source: ELLERY *et al*. 2004)

McCarthy and Hancox (2000) have attempted to describe the geomorphology of southern Africa's wetlands by illustrating the geomorphological controls on selected wetlands in the region. They list the following factors as important in determining the distribution of wetlands in the region:

- changes in sea level,
- fluvial sedimentation in deltas, alluvial fans and on floodplains,
- present climate and climate change (rainfall),
- chemical sedimentation from ground water,
- neotectonic activity,
- vegetational succession and plant-water interactions,
- aeolian processes, including deflation and dune formation,
- geohydrological factors, and
- anthropogenic factors.

These general factors can be grouped into those that:

- alter the integration of drainage (aeolian processes of deflation and dune formation),
- affect the fluvial processes of competency and capacity by affecting gradient, discharge and sediment supply and character (clastic sedimentation, chemical sedimentation, peat formation and organic matter accumulation, base level elevation, neotectonic activity, climate and climate change, and anthropogenic activity), and
- affect groundwater rest level (geo-hydrological factors). (See Parsons, 2004)

Wetland Classification

Just as character of rivers zones is dependent their positions in the landscape so to be wetland character and type determined by the geomorphological setting and hydrological regime.

Table 6. Wetland landform settings and their influence over a wetland's hydrologic components (adapted from Brinson 1993)

LANDFORM SETTING 1	DEFINITION	HYDROLOGIC COMPONENTS		
		Inputs 2	Throughputs	Outputs
Hillslope seepage not feeding a stream	Concave or convex slopes characterized by the colluvial (transported by gravity) movement of materials. Typically situated out of the drainage network	Predominantly groundwater and interflow or diffuse surface flow	Interflow & diffuse surface flow	Evapotranspiration and / or diffuse groundwater flow
Hillslope seepage feeding a stream	Concave or convex slopes characterized by the colluvial (transported by gravity) movement of materials. Outflow is typically by channel into the drainage network	Predominantly groundwater and interflow or diffuse surface flow	Interflow & diffuse surface flow	Variable but usually by channel
Valley bottom without stream	Valley bottom areas of low relief with no clearly defined stream and situated on alluvial fill.	Channel entering the wetland and adjacent hillslopes	Diffuse surface and subsurface flow	Channel outflow
Valley bottom with a stream	Valley bottom areas with a well-defined stream channel but lacking characteristic floodplain features. Water inputs are mainly from adjacent slopes while the channel itself is typically not a major source of water for the wetland.	Channel flow	Diffuse flow on elevated valley bottom and	Channel flow
Floodplain	A riparian area of low relief characterized by the alluvial transport and deposition of material by a well-defined stream channel, which gives rise to characteristic floodplain	Primarily as channel overspill and / or tributary supply	Channel flow that during flood events becomes extensive diffuse surface flow	Channel flow

	features such as levees and oxbow lakes.			
Pan/ Depression	A basin shaped area with a closed elevation contour that is not connected via an outlet to the drainage network.	Variable	Insignificant	Evapotranspiration
Fringe wetlands	Areas on the edge of open water provided by lakes or dams.	Lake or estuary (tidal)	-	Lake or estuary (tidal)

The position in the catchment and character of a wetland will have an important bearing on its ecological water requirements. Some wetlands are predominantly groundwater dependent whereas others are surface water dependent. Management strategies should take these variations in to considerations. For instance a valley bottom wetland without a stream tend to be groundwater driven and would respond adversely to lowering of the groundwater table in the vicinity whereas those with a stream would react adversely to both abstraction and changes in river flow regimes.

1.3.3. ESTUARIES

An estuary is the area where the river reaches the sea. Water in an estuary has a gradient of salinity to near marine and varies with the tidal turn. On the ebb tide water may be fresh or nearly so and on the flood tide marine water may each some distance in land depending on the topography. Because sea water is more dense that fresh, the heavier sea water usually lies under the freshwater. The size and shape of an estuary is largely determined by the size and the rainfall regime of the catchment and the geology of the coastal plain. Estuaries can be narrow and deeply gorged as on the eastern and southern Cape coast or wide flat and deep as on the Natal coast. Some estuaries are naturally only periodically open to the sea especially those in low rainfall areas or with very small catchments such as those on the south-eastern African coast. The coastal flats of mud and sediment are valuable habitats for a large range on biota from specialized salt marsh plants to a myriad of minute zooplankton and algae. Estuaries are also important nursery grounds for fish and crustaceans. Animals found in estuaries are euryhaline thus can adjust metabolically to the fluctuations in salinity. Estuaries are areas of high biodiversity and high biomass and many migratory birds are entirely dependent on the rich food found there.

Many estuaries in South Africa have become permanently cut off from the sea during tectonic events forming a large number of coastal lakes from the northern natal coastline to Cape Town. These lakes and lagoons maintain their livable water quality status because of freshwater inputs via ground water

Estuaries are therefore sensitive to catchment events and most particularly to water abstraction and pollution. The mouth of an estuary can to silt up permanently and during a drought year when insufficient fresh water enters the pool left behind, it can become hyper saline leading to large fish kills.

In terms of ecological water requirements estuaries have evolved to cope with fluctuating climatic conditions and especially South Africa with prolonged periods of drought (3-5 years). Consequently they are fairly resilient to periods of low fresh water inputs due to upstream abstractions. However when periods of prolonged drought is superimposed on this state of affairs, disturbances in the salinity regime can wreak havoc with the biota and consequently the functionality of the system.

1.3.4. GROUNDWATER. (from Parsons 2004)

* Water beneath the water table is considered by geohydrologists to be groundwater and that above the water table as soil water. The geological formation and soils of an area is the primary influence of the occurrence and types of groundwater.

Groundwater is maintained through infiltration and percolation both processes much slower than surface water movement.
Water below the land surface occurs in two principle zones:

- Saturated zone
- Vadose or unsaturated zone.

Vadose Zone.
Interstices contain both air and water and water is held in place by capillary forces and is not removed by pumping but through absorption by plants. It integrates many of the components of the hydrological cycle. It is the interface between aquifers and land, land and atmosphere and controls infiltration and surface runoff.

The transition area between the Vadose zone and the saturated zone is the capillary zone. In this zone the capillary forces of individual rock particle attract water molecules. This zone can be narrow to very deep depending of the particle size and type of the soil.

Saturated Zone.
The water table marks the beginning of the saturated zone where pore spaces are completely filled with water. Pore water pressure is equal to atmospheric pressure.
In the saturated zone groundwater occurs under various conditions. Aquifers are areas where ground water is stored in sufficient quantities to be used for domestic our agricultural purposes. Aquitards retards the movement of ground water and may store water while aquicludes prevent the movement altogether. These geological formations have considerable influence on the movement of groundwater and occurrence of exploitable aquifers. Aquifers are either confined or unconfined. Unconfined aquifers occur in permeable geological formation lateral or upward migration of waters and area primarily recharged by infiltration. Confined aquifers are overlaid by geological formations that prevent the upwards migration of the water table increasing the hydrostatic pressure in the aquifer. These aquifers are usually recharged through lateral or upward water movement.

Vegter (1996, 2001) mapped the litho-stratigraphically based groundwater regions of South Africa in order to develop a classification system for aquifer management. Parson (1995) proposed an aquifer management classification system which divided aquifer systems into five categories that take characteristic such as geological storativity potential, water quality and water use into consideration

1.4. UNDERSTANDING THE RESOURCE – HABITATS

Habitat preservation is the key to resource protection, biodiversity conservation and therefore sustainability. Therefore understanding the variables that combine to make up the array of freshwater habitats enables the water resources manager to assess what the important elements in need of protection are.

1.4.1. HABITATS IN RIVERS AND WETLANDS

The principal elements of habitats in streams, river and wetlands are substrate (size and chemistry), both organic and inorganic, both water quality (chemical and physical) and water velocity, periodicity and depth. Hydraulics of a stream affects the variation and availability of in-stream habitats; the sediment transport (type and deposition) in the stream forms an essential element of the habitat especially in terms of energy (food) and it is valuable for ecologists to understand the basic principles.

The directional flow of water is what distinguishes rivers and streams from ponds and lakes while the flow in wetlands tend to be at much slower velocities often reduced to near zero. However water flow in streams is not entirely unidirectional but can flow in a lateral direction during floods and also form vortices. Ample evidence has been accumulated which proves that current is of direct importance to the biota of these environments. The depth of water, as well as the flow velocity can influence the amount and range of habitat types available. Other limiting factors influencing available habitat is temperature, oxygen availability and chemistry as illustrated already.
Habitats in rivers fall broadly into in-stream and riparian types.
Instream include stones in and out of current, pools, back water and slack water with either stony or soft bottoms or instream vegetation.

The riparian zone is habitat area that is variously classed as a wetland, a riverine habitat but it is also found on the edges of lake (littoral zone). In this habitat type vegetation is predominant and water, although present always in the root zone can fluctuate quite widely.

The National Water Act (SA) defines

- riparian habitat" includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterized 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

Thus it is defined primarily by geomorphology of river which results in a distinct longitudinal strip of vegetation forms the riparian wetland. (Rogers, 1995)

The US Fish & Wildlife Service definition states that

- "Riparian areas are plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, or drainage ways)".

Riparian areas have one or both of the following characteristics: "distinctly different vegetative species than adjacent areas and species similar to adjacent areas but exhibiting more vigorous or robust growth forms."

Wetland habitat parameters fall broadly into the same categories as those found in riparian areas although the water supply can originate in a variety of ways. Broadly there are three habitat types in wetlands namely the temporary, seasonal and permanent zone dependent of the duration of the water supply and the consequent degree of soil saturation. This latter aspect has a direct influence of the plant community, which is also in itself an important habitat parameter.

1.4.2. HABITATS IN LAKES

The water body of a lake or dam can be divided into the *water column* and the *littoral zone*.

The water column has three distinctive zones

Neustic. Surface & meniscus. The film of high tensile strength provides a habitat for such insects as water skaters (Hemiptera – Gerridae, Hydrometridae, Notonectidae) and whirlygig beetles (Coleoptera – Gyrinidae). The larvae and pupae of mosquitoes (Diptera – Culicidae) also utilise the surface layer but migrate into deeper water at will and thus become planktonic.

Limnetic. The water column offers a wider range of habitats in lakes than in rivers. The biotic community in lakes is mainly planktonic composed large numbers of algae, bacteria and protozoa as well as zooplankton which includes fish, crustaceans and insects. The aquatic insects which are habitually found in the limnetic zone include dyticid beetles, fly larvae such as midges as well as some hemipterans such as Corixidae.

Benthic. This zone consist of two parts, a littoral and a profundal area: rocks, sediment and plants provide heterogeneous habitats which are rich in nutrients and relatively productive. In the profundal areas, little photosynthesis takes place due to lack of light. Occupied mainly by fly larvae (Diptera) chironomids, some with red pigment to enhance oxygen uptake in low oxygen areas, and predators such as chaoborid larvae that habitually swim up to the surface at night to poach animals.

The littoral zone can be divided into the disturbed area at the periphery of the lake where wave action and changing water levels will have a strong impact and the deeper more stable areas. The latter areas are perhaps the most productive, depending on the size of the water body. Plant communities provide a large number of habitats between depths of 0.5 and 64 m. Insects found here include mayflies (Ephemeroptera), stoneflies (Plecoptera), and dragonflies (Odonata), beetles (Coleoptera) and Trichoptera, Hemiptera as well as Megaloptera. Animals and plants that inhabit the littoral can also be found in wetlands (marshes) and the floodplain areas of lowland rivers where conditions can be similar.

1.5. UNDERSTANDING THE RESOURCE – BIOTA

The biotic component of a resource is the engine of a functional resource and is dependent of the array of available habitats. Further the functionality of an ecosystem is dependent on the number of functional groups present. These groups can be categorised by either their food processing method or their life history style. The species array is yet another more familiar way of categorising the biota of a system.

Familiar animal inhabitants of rivers, wetlands and lakes include invertebrates such as insects, crustaceans, mites, snails and a variety of worm-like creatures. Fish and frogs are perhaps the most well-known and recognised vertebrate inhabitants but do not forget mammals such as otters, and the huge variety of birds that depend on water for habitat and food. A few large ungulate mammals are found in marshy areas but the largest and most visible vertebrate are certainly hippopotamus and crocodiles although there are no longer widespread in southern Africa. As for the plants that are truly aquatic the largest number are certainly the algae that range from uni- to large multicellular representative, although there are small number of other groups that are partially submerged. Emergent macrophytes are predominantly reeds and sedges while some grass families are able to withstand long periods of inundation. Riparian trees and shrubs are generally not submerged but on the whole require a high degree of moisture in their root zones.

All of these groups are independent and form food webs that process energy by producing and breaking down organic matter in the endless cycle of life. Imbalances arise when key functional groups are removed due to habitat alteration and destruction.

2. MANAGEMENT APPROACHES – BALANCING PROTECTION AND USE

Integrated Water Resource Management (IWRM) can be defined as a participatory planning and implementation process, based on sound science, which brings together stakeholders to determine how to meet society's long-term needs for water and coastal resources while maintaining essential ecological services and economic benefits (USAID http://www.usaid.gov/our_work/environment/water/what_is_iwrm.html).

2.1. BALANCING ECONOMIC GAIN AND ECOLOGICAL SUSTAINABILITY

Integrated Resource Management

The elephant analogy – integration
(Palmer *et al.* 2004a)

Suppose you are one of a group of five people who are led, blindfolded, into a large room. You are told there is an animal in the room, covered with a sheet. You are led up, and told to put your hand through a hole in the sheet and to touch and feel, and then to describe the object. You put your hand in and touch what is clearly part of an animal. It is warm, flat and flexible and rough. Unbeknown to you the animal is an elephant, and you are feeling an ear. The others, when they reach out, touch the trunk, tail, leg, and parts of the body of the elephant. Everyone has completely different ideas of what it might be. You leave the room and put all your descriptions together. Just as you make the connections, the elephant trumpets, confirming your deductions. In the same way, all our techniques for observing the environment are only 'holes in a sheet'.

The environment is so complex that we only ever 'see' it in partial glimpses. But we can use different techniques to get a variety of perspectives of its complexity. However inadequate the picture from each technique, by putting all the information together we can begin to build a picture of the whole.

2.1.1. PRINCIPLES OF SUSTAINABLE DEVELOPMENT

1. INTEGRATION OF ENVIRONMENTAL AND ECONOMIC DECISIONS: requires that we ensure economic decisions adequately reflect environmental impacts including human health. Environmental initiatives shall adequately take into account economic consequences.

2. STEWARDSHIP: requires that we manage the environment and economy for the benefits of present and future generations. Stewardship requires the recognition that we are caretakers of the environment and economy for the benefit of present and future generations. A balance must be struck between today's decisions and tomorrow's impacts.

3. SHARED RESPONSIBILITY: requires that everybody acknowledge responsibility for sustaining the environment and economy, with each being accountable for decisions and actions, in a spirit of partnership and open cooperation.

4. PREVENTION: requires that we anticipate, prevent or mitigate significant adverse environmental (including human health) and economic impacts of policy, programs and decisions.

5. CONSERVATION: requires that we maintain essential ecological processes, biological diversity and life-support systems of our environment; harvest reusable resources on a sustained yield basis; and make wise and efficient use of our renewable and non-renewable resources.

6. WASTE MINIMIZATION: requires that we endeavour to reduce, reuse, recycle and recover the products of our society.

7. ENHANCEMENT: requires that we enhance the long term productive capability, quality and capacity of our natural ecosystems.

8. REHABILITATION AND RECLAMATION: requires that we endeavour to restore damaged or degraded environments to beneficial uses. Rehabilitation and reclamation require ameliorating damage caused in the past. Future policies, programs and developments should take into consideration the need for rehabilitation and reclamation.

9. SCIENTIFIC AND TECHNOLOGICAL INNOVATION: requires that we research, develop, test and implement technologies essential to further environmental quality including human health and economic growth.

10. GLOBAL RESPONSIBILITY: requires that we think globally when we act locally. Global responsibility requires that we recognize there are no boundaries to our environment, and that there is ecological interdependence among provinces and nations. There is a need to work cooperatively within Canada, and internationally to accelerate the merger of environment and economics in decision making and to develop comprehensive and equitable solutions to problems.

2.1.1.1 Guidelines of sustainable development

1. EFFICIENT USE OF RESOURCES: we shall encourage and support development and application of systems for proper resource pricing, demand management, and resource allocation together with incentives and disincentives to encourage efficient use of resources and full environmental costing of decisions and developments.

2. PUBLIC PARTICIPATION: we shall establish appropriate forums which encourage and provide opportunity for consultation and meaningful participation in decision making processes by all Manitobans. We shall endeavour to ensure due process, prior notification and appropriate and timely redress for those affected by policies, programs, decisions and developments.

3. UNDERSTANDING AND RESPECT: we shall be aware that we share a common physical, social and economic environment in Manitoba. Understanding and respect for differing social and economic views, values and traditions and aspirations is necessary for equitable management of these common resources. Consideration must be given to the aspirations, needs and views of various regions and groups in Manitoba.

4. ACCESS TO ADEQUATE INFORMATION: we shall encourage and support the improvement and refinement of our environmental and economic information base and promotion of the opportunity for equal and timely access to information by all Manitobans.

5. INTEGRATED DECISION-MAKING AND PLANNING: we shall encourage and support decision making and planning processes that are open, cross-sectoral, incorporate time horizons relevant to long-term implications and are efficient and timely.

6. SUBSTITUTION: we shall encourage and promote the development and use of substitutes for scarce resources where they are both environmentally sound and economically viable. (Manitoba Round Table on sustainable development, www.gov.mb.ca/conservation/pollutionprevention/index.html)

2.2 SOUTH AFRICAN APPROACH TO INTEGRATED WATER RESOURCES MANAGEMENT

2.2.1 INTER-GOVERNMENTAL PLANNING

Each sphere of government is "distinctive, inter-dependent and inter-related". Whilst responsible for planning the activities for which it is constitutionally mandated, the activities and the plans and strategies that guide that must be aligned with one another and with those of other spheres of mutually cooperative government, the opportunity to participate in the development of national plans and strategies, and in making decisions that will affect their areas of jurisdiction. Accordingly –

- National government provides a framework of common policies and principles, and co-ordinated and prioritised programmes, within which provincial, municipal and sectoral planning can take place;
- Provincial growth and development strategies provide a more specific framework for the development of projects and programmes on a provincial level, as well as the co-ordination of sectoral and municipal planning; and

- Under the Municipal Systems Act, 2000 district municipalities are required to prepare five-year Integrated Development Plans to guide and inform all aspects of planning, implementing and managing service provision in their areas. The plans must be compatible with national policy and legislation and be aligned with provincial strategies and plans.

Fig. 7 illustrates in broad terms the links between the strategies and plans for water resources management and water services provision, and the strategies and plans of other national, provincial, municipal and sectoral interests.

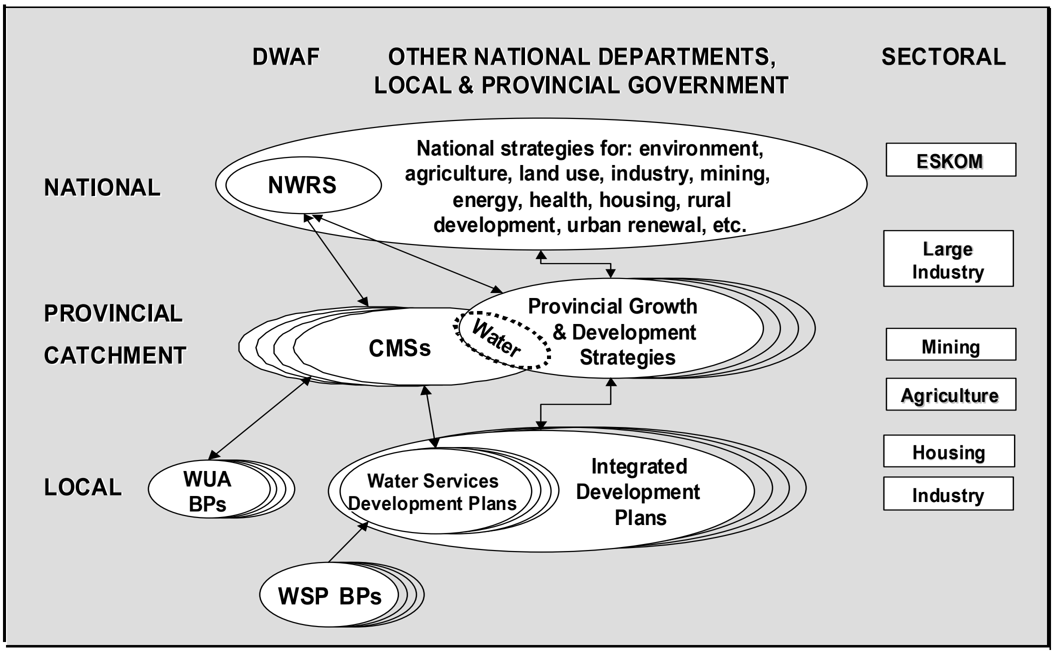


Figure 7. Interrelationships between spheres of government and sectors of society in South Africa from a water resource management perspective (source NWRS)

2.2.2. FUNDAMENTAL PRINCIPLES AND OBJECTIVES OF THE WATER ACT 36 (1998) OF SOUTH AFRICA

The principles are captured well in the Department of Water Affairs and Forestry's slogan:
"Some, for all, forever"

Some – acknowledges that water is a limited resource,
for all – emphasises fairness of access to using the resource,
forever – indicates wise use so the resource is not damaged for the future.

The National Water Act recognises that the water cycle should be managed as a connected cycle. It recognises that water belongs to the whole nation and is administered by the government for the people. The Act protects the rights of all people to have water for their basic needs – drinking, cooking and washing. It also takes into account the needs of aquatic ecosystems (lakes, rivers, wetlands estuaries and ground water). The amount of water necessary for ecosystem function and for basic human needs is termed Reserve.

The Act protects the rights of ecosystems because ecosystems provide people with so many services necessary to life – water supply, waste processing and dilution, natural products (reeds, fish, medicinal plans), nature, and biodiversity conservation, flood control, recreation, a "sense of place" and places for religious rituals.

Fundamental Principles and Objectives
The principles on which the act is based can be grouped into 5 main categories.

LEGAL ASPECTS OF WATER

Principle 1
The water law shall be subject to and **consistent with the Constitution** including the
* determination of the public interest
* rights and obligations of public and private parties

The water law will actively promote the values enshrined in the Bill of Rights.

Principle 2

All water, wherever it occurs in the **water cycle**, **is a resource common to all**, the use of which shall be **subject to national control**. All water shall have a **consistent status in law**, irrespective of where it occurs.

Principle 3
There shall be **no ownership of water**, only a right (for **environmental and basic human needs**) or **an authorisation** for its **use**.
Any authorisation to use water in terms of the water law shall **not be in perpetuity**.

Principle 4
The location of the water resource in relation to land shall not in itself confer preferential rights to usage. The riparian principle shall not apply.

THE WATER CYCLE

Principle 5.
In a relatively arid country such as South Africa, it is necessary to recognise **the unity of the water cycle and the interdependence of its elements**, where evaporation, clouds and rainfall are linked to underground water, rivers, lakes, wetlands and the sea, and where the **basic hydrological unit is the catchment**.

Principle 6.
The **variable, uneven and unpredictable distribution of water** in the water cycle should be acknowledged.

WATER RESOURCE MANAGEMENT PRIORITIES

Principle 7
The objective of **managing the quantity, quality and reliability** of the nation's water resources is to achieve optimum, long term, **environmentally sustainable social and economic benefit** for society from their use.

Principle 8
The **water required** to ensure that all **people have access to sufficient water shall be reserved.**

Principle 9
The **quantity, quality and reliability of water required to maintain the ecological functions** on which humans depend shall be **reserved** so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems.

Principle 10

The water required meeting the **basic human needs** referred to in Principle 8 and the **needs of the environment** shall be identified as **"the Reserve**" and shall enjoy priority of use by right.

The use of water for all other purposes shall be subject to authorisation.

Principle 11.
International water resources, specifically shared river systems, shall be managed in a manner that optimises the benefits for all parties in a spirit of mutual cooperation. **Allocations** agreed for **downstream countries** shall be respected.

WATER RESOURCE MANAGEMENT APPROACHES

Principle 12
The national government is the custodian of the nation's water resources, as an indivisible national asset.
Duties
1. promote the public trust,
2. ultimate responsibility for, and authority over, water resource management,
3. ensure equitable allocation and usage of water
4. transfer of water between catchments
5. international water matters.

Principle 13
The custodian shall ensure that the **development, apportionment, management and use** of those resources is carried out using the criteria of **public interest, sustainability, equity and efficiency of use** in a manner which reflects its **public trust obligations** and the **value of water** to society while ensuring that **basic domestic needs**, the **requirements of the environment** and **international obligations** are met.

Principle 14
Water resources shall be developed, apportioned and managed in such a manner as to **enable all user sectors to gain equitable access to the desired quantity, quality and reliability** of water**.**

Conservation and other measures to manage demand shall be **actively promoted** as a **preferred option** to achieve these objectives.

Principle 15.
Water quality and quantity are interdependent and **shall be managed in an integrated manner**, which is **consistent with broader environmental management** approaches.

Principle 16

Water quality management options shall include the use of economic incentives and penalties to reduce pollution; and the possibility of **irretrievable environmental degradation as a result of pollution shall be prevented**.

Principle 17
Water **resource development** that is **consistent** with the broader national approaches to **environmental management**.

Principle 18
Since many land uses have a significant impact upon the water cycle, the regulation of land use shall, where appropriate, be used as an instrument to manage water resources within the broader integrated framework of land use management.

Principle 19
Any **authorisation** to use water shall be given in **a timely** fashion and in a manner which is **clear, secure and predictable in respect of the assurance of availability**, **extent and duration of use**
The purpose for which the water may be used shall not arbitrarily be restricted.

Principle 20
The **conditions upon which** is granted to use water shall take into consideration **the investment** made by the user in **developing infrastructure to be able to use** the water.

Principle 21
The **development and management** of water resources shall be carried out in a manner that **limits to an acceptable minimum the danger to life and property due to natural or manmade disasters.**

Water institutions
Principle 22.
The **institutional framework** for water management shall as far as possible, be **simple, pragmatic and understandable**. It shall be **self-driven and minimise the necessity for state intervention**.
Administrative decisions shall be subject to appeal.

Principle 23
Responsibility for the development, apportionment and management of available water resources shall, where possible and appropriate, be delegated to a **catchment or regional level** in such a manner as to **enable interested parties to participate.**

Principle 24
Beneficiaries of the water management system shall contribute to the **cost of its establishment and maintenance**, on an equitable basis. Water services

Principle 25
The **right of all citizens to have access to basic water services** (the provision of potable water supply and the removal and disposal of human excreta and waste water) necessary to afford them **a healthy environment** on an **equitable and economically and environmentally sustainable** basis shall be supported.

Principle 26

Water services shall be **regulated** in a manner that is consistent with and **supportive of the aims and approaches of the broader local government framework.**

Principle 27
While **the provision of water services** is an **activity distinct from the development and management of water resources**, water services **shall be provided in a manner consistent** with the **goals of water resource management**.

Principle 28

Where **water services are provided in a monopoly situation**, the **interests of the individual consumer and the wider public must be protected and the broad goals of public policy promoted.**

2.2.3. CATCHMENT MANAGEMENT

Under the National Water Act the river as a resource is managed by Catchment Management Agencies.
All the factors in the whole catchment need to be taken into account and managed in a way that is best for all the people who live there.

Catchments – the units of water resource management

A key feature of the NWRS is the identification of 19 Water Management Areas (WMAs) for South Africa. A WMA can either include a major catchment with its component sub-catchments, such as WMA 14 (the Lower Orange River) or several smaller catchments, such as WMA 15 (the Fish to Keiskamma Rivers). The NWRS provides maps of each WMA, and further subdivides them into component sub-areas made up of quaternary catchments, which are the smallest units of water resource management (DWAF 2004). Each WMA will, in time, have its own Catchment Management Agency (CMA) to take responsibility for water resource management in that area. The CMAs will be regional institutions accountable to the Minister of Water Affairs and Forestry for water resource management. Until these CMAs are in place, the regional DWAF offices are undertaking regional water resource management responsibilities.

Water resource management decisions also have to be made at smaller scales than WMAs and catchments. Within each WMA, the NWA requires 'significant' water resources (all but very small resources) to be classified, and an ecological Reserve assigned to each one, as discussed above. This ecosystem class defines the RQOs that will guide management decisions. If monitoring indicates that the plan is not working (for example if key objectives are not met), then management returns to Step 1 (as listed above) and modify the plan. If monitoring indicates the plan is working, then management cycles between Steps 2 and 3 until the need to replan arises. This cyclical shift between steps is adaptive, and ensures that management learns as it goes.

Catchment Management Agencies

What are CMAs?

CMAs are statutory bodies established under Section 77 of the Act. One CMA will be established for each Water Management Area. They are governed by a Board, which represents a broad stakeholder grouping together with experts. They must seek co-operation and agreement on water-related matters from the various stakeholders and interested persons.

Legal provisions for establishing CMAs

The Minister may initiate the establishment of a CMA in a water management area (s78) (1).
Stakeholders may initiate and submit a proposal for CMA establishment in a particular water management area (s77).

Role players

The need for public consultation is implicit in the required contents of the proposal to establish the CMA (s81) (3) and in the requirement for the advisory committee: governing board to consult with relevant organs of state and interest groups (s81) (4).

- Department of Water Affairs and Forestry (particularly the Regional Office) as the *a priori* CMA and the body responsible for ensuring the process meets the requirements of the Act.
- Other statutory water institutions may play a role in water resources management or water supply within a particular water management area.
- Stakeholders and water users who have an interest in the water management area.
- Local, provincial and national government (and other organs of state) in the water management area with which the CMA will need to encourage cooperative governance.

Powers of a CMA need to be either ***delegated*** to the CMA by the Minister in writing (s63) or ***assigned*** by the Minister through a notice in the Gazette (s73).

Water Management and Service Institutions

Water management and service institutions are listed below. In terms of the Water Act (s1) 'water management institutions' are

CMAs
Water User Associations
International Water Management Bodies
Any person who fulfils the functions of a water management institution in terms of the Act

In terms of the Water Services Act (Act 108 of 1997)(s1) 'water services institutions' provide either bulk water or water supply and sanitation and can be:

Water Boards
Water Services Authorities
Water Services Providers
Water Services Committees.

What is the role of CMAs?

A CMA manages water resources within a defined Water Management Area. Such management is carried out in accordance with a Catchment Management Strategy prepared by each CMA. A Catchment Management Strategy may be defined as an overall plan or campaign to handle the affairs of a WMA to achieve specific objectives.
The CMA must give effect to the Catchment Management Strategy, which is underpinned by the principles of equity, efficiency, sustainability and representivity.

Initial role:

1. Investigate, and advise interested persons on, the protection, use, development, conservation, management and control of the water resources in its Water Management Area.
2. Develop a Catchment Management Strategy.

3. Co-ordinate the related activities of water users and of water management institutions within its Water Management Area.
4. Promote the co-ordination of the implementation of its Catchment Management Strategy with the implementation of any applicable development plan in terms of the Water Services Act (Act 108 of 1997).
5. Promote community participation in its functions.

<u>Schedule 3 of the Act sets out more general powers and duties relating to the management of the water resource.</u>

1. Manage, monitor, conserve and protect water resources and implement catchment management strategies.
2. Make rules to regulate water use.
3. Require establishment of management systems by water users.
4. Require alterations to waterworks.
5. Temporarily control, limit or prohibit use of water during periods of water shortage.

<u>The powers and duties of a responsible authority are set out in Chapter 4 of the Act and relate to the ability to authorise, licence and regulate water use.</u>

1. Issue general authorisations and licences in respect of water use subject to conditions
2. Extend the licence period under certain conditions
3. Review licences at periods stated in the licence and make amendments to its conditions or renew it
4. Waive the need for a licence if the water use is authorised under another law
5. Promote 'one stop shop' licensing
6. Require licence applicants to provide security for licence obligations
7. Require registration of existing lawful water uses
8. Require an existing water user to apply to verify its water use
9. Undertake compulsory licensing where there is water stress
10. Suspend or withdraw entitlements to use water
11. Enforce licence conditions

Proposed functions of CMAs, including functions to be assigned/delegated to it
This is a crucial component of the proposal and must balance the need for management of priority water resource issues at a catchment (Water Management Area) scale available in the water management area for the CMA. As a minimum, the proposal must provide a detailed interpretation of the initial functions of CMAs (s80) and the way in which it is envisaged that these will be performed.

How do CMAs fit into the overall context of water management?
CMAs provide the second tier of the water management structure provided under the Act. Each CMA is responsible for the progressive development and broad implementation of a Catchment Management Strategy within their Water Management Area. They operate within its broader framework provided by the Minister of Water Affairs and Forestry (Minister) and the National Water Resource Strategy. Local implementation of a Catchment Management Strategy may be carried out through other institutions to which the CMA may delegate functions.

2.2.4. APPROACHES TO WATER RESOURCE PROTECTION

2.2.4.1. INTRODUCTION
Empowering people: water, people and the law (Dr CG Palmer)

The Act protects the rights of ecosystems because ecosystems provide people with so many services necessary to life – water supply, waste processing and dilution, natural products (reeds, fish, medicinal plans), nature, and biodiversity conservation, flood control, recreation, a "sense of place" and places for religious rituals.

The Act uses the word "sustainability" to describe how aquatic ecosystems have to be managed or assisted to supply water for our grandchildren and future generations.

Focus on "water resource protection to ensure sustainable water resource use" of the

The process by which people choose what they want from their aquatic ecosystem is called in the National Water Act a Reserve assessment.

- Basic human needs assessment, and an
- Ecological Reserve assessment to determine the ecological water requirements (EWR)

There are four classes of ecosystem health (Table 7):

- Protected,
- Good,
- Fair,
- Poor.

The **first step in an ecological Reserve assessment** is to find out the **present state or health of the resource** – whether it is a river, wetland, groundwater or estuary.

This is quite a complicated process.

Information is collected about rainfall, river flow, water chemistry,
what habitats plants & animals need, which plants and animals should be in a particular place.

Which patterns of flow and patterns of water chemistry is needed is needed for the system to function at each class of ecosystem health (Table 7)

Then the Act requires management of the river to involve all stakeholders in the catchment area. The community consists of stakeholders & institutions.

Institutions:
Catchment management agencies
Local or provincial government
Water user associations or
any other fora such as water committees,
These have to be fair and representative and gender-respectful

Those who are dependent on the river should be informed about the present class of the river and what can be done to keep it like that, or what can be done to improve it.

They will be invited to discuss how much development the river can tolerate.

Stakeholders can influence, discuss and decide on how much water is taken out of the river and how the water from the river is used and for what purpose.
Decisions are also made about waste disposal and zoning for recreation and nature conservation.

The Reserve
The Reserve specifies quantity and the quality of the water in the resource.
Every aspect of the water resource has rights under the Act.

Ecological water requirements:
For every river, wetland, and estuary and even for groundwater, before any use is made of the water resources, a certain amount of water of specified quality has to be reserved in order to protect and maintain "the ecological functions on which humans depend". To determine the EWR of a river or portion thereof the Ecostatus will be assessed.

The Act requires that all water uses have to be authorised in order to protect the Reserve.
The Reserve is really the "speed limit" for water resources – a set of rules to prevent rivers and other aquatic ecosystems from being over-used.

ANALOGY: You can think of maintaining a river like running a bus.
A luxury bus that carries some people comfortably can travel long distances but is expensive. A truck that can get people to where they want to go at a much lower expense, but not very comfortably. A taxi driven at top speed all the time – it might get the passengers to their destinations quickly, but there's a high risk that it will break down or crash. You can load up the vehicle beyond its capacity, it might break down completely, then no-one gets to their destination. There's only one way , which is to maintain the vehicle well and drive carefully.

Rivers often have to serve a number of different users, some of whom want lots of water, some only a little.

Some users need very good water quality, some don't mind.
Some rivers have been used extensively for industry and agriculture.

A river like the Vaal has a number of big (expensive) dams and water transfer schemes which can cause environmental problems. Many rivers have smaller storage, extraction, and water treatment schemes. A few rivers, like the Sabie in Mpumalanga, need to be kept as near to natural as possible.

The Water Act aims to reserve some water of good quality, to ensure enough water for people's basic needs and to maintain the essential ecological processes. Water for basic human use should be provided at minimal or no cost. The remaining water can be allocated to users.

The water requirements of the bigger users in many catchments are often greater than what the local river can supply. If too many abstraction licenses are granted, the river may fail to supply enough water during droughts, or become so polluted that the water is of no use to anyone.

The Act requires that all water uses have to be licensed either generally (general authorisations) or specifically for certain uses. The licences are there to make sure that users modify their demands, and use less water.

Ecostatus: A framework for assessing ecological conditions for river health and ecological reserve determinations and monitoring

The Ecostatus is defined as "totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support and appropriate natural flora and fauna and its capacity to provide a variety of good and services." (Iversen *et al*. 2000)

To derive the Ecostatus, an assessment of the degree of ecological integration of a river is reached by evaluating the state of the drivers (hydrology, geomorphology, physico-chemistry) and the responses of the biota.
To accomplish this, consistent indices for the assessment of the ecological state of each of the biophysical components have been devised (Box 3) and consistent protocols for the integration of the results obtained from these assessments have been developed (WRC report KV168/05).

This process will:
- Identify symptoms,
- Identify and measure signs
- Make provisional diagnosis
- Conduct tests to verify the diagnosis
- Make a prognosis
- Prescribe treatment

of a river that is no longer in an optimal state (Based on Shaeffer *et al.* 1988).

Various levels of Reserve Determination can be undertaken (to suit available funds and the importance and size of the resource) each with its own Ecological Water Requirement method and modified EcoClassification process. Depending on available information and detail required there are 5 Ecostatus levels:
- Desktop Ecological Reserve method → desktop Ecostatus level
- Rapid 1 Ecological Reserve method → Ecostatus level 1
- Rapid II Ecological Reserve method → Ecostatus level 2
- Rapid III Ecological Reserve method → Ecostatus level 3
- Intermediate or comprehensive ecological Reserve method → Ecostatus level 4.

A generic EcoClassification procedure is a follows (see flow diagram below)
- Determine the reference condition for each component of the resource
- Determine the Present Ecological State (PES) of each component and the Ecostatus
- Determine the trend for each component and Ecostatus trend
- Determine reasons for PES and if it is flow related or not
- Determine Ecological Importance and Sensitivity (EIS) for biota and habitat
- Considering the PES and EIS suggest a realistic recommended ecological category (EC) for each component as well as the Ecostatus.
- Determine the EC for both components and Ecostatus (Table 7)

Additional use of the ecostatus approach will be:
In terms of determining river condition/integrity for systematic river conservation purposes. Depending on the availability of information and knowledge on the river, the approach for this purpose may vary between the more typical River Health Programme type procedure and the typical full suite of ecostatus determination.

Where a comprehensive (or even intermediate) reserve determination and compulsory licensing is not a priority within the foreseeable future, it can be envisaged that an ecostatus assessment more detailed than the RHP assessment as for “typical” State of River purposes would be followed. This would allow a basis for formulating resource quality objectives that can be used in an ecological monitoring programme (determination of trends, etc.) with an emphasis on biomonitoring) and resource management.

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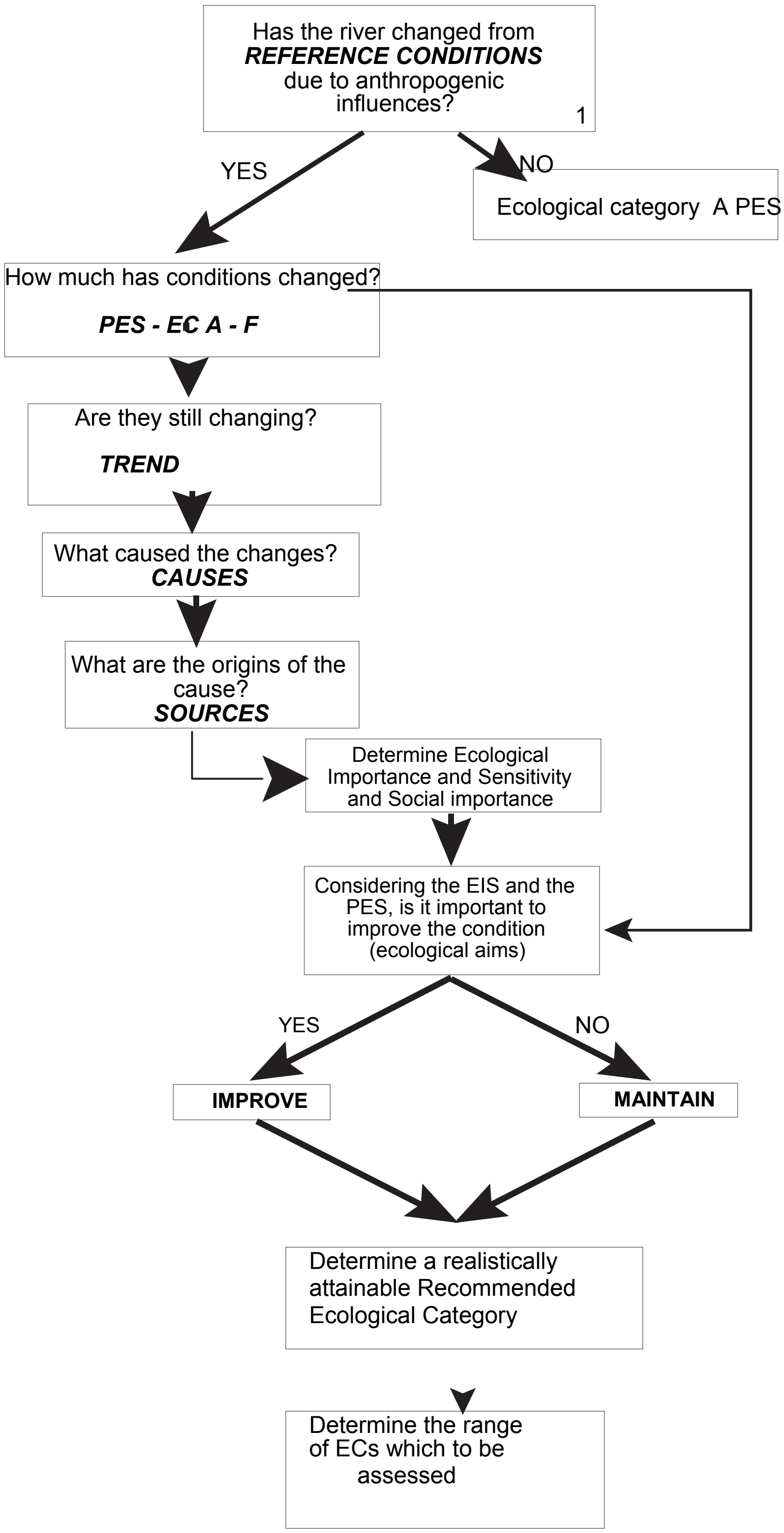

Flow diagram illustrating the information generated to determine the range of EC for which EWR will be determine

2.2.4.2. NATIONAL WATER RESOURCES STRATEGY CHAPTER 3
PROTECTION OF WATER RESOURCES

INTRODUCTION

Chapter 3 of the National Water Act (NWA) (1998) requires that water resources be protected and managed to meet the water quality requirements of ecosystems. At the same time the Act also requires that water be used for social and economic benefit.

Integrated Water Resource Management can be defined as a participatory planning and implementation process, based on sound science, which brings together stakeholders to determine how to meet society's long-term needs for water and coastal resources while maintaining essential ecological services and economic benefits (USAID http://www.usaid.gov/our_work/environment/water/what_is_iwrm.html).

Equitable access has both a short-term and long-term dimension. It is important that the needs of present and future generations are considered in the management of water resources.

To give effect to the interrelated objectives of sustainability and equity an approach to managing water resources has been adopted that introduces measures to protect water resources by setting objectives for the desired condition of resources, and putting measures in place to control water use to limit impacts to acceptable levels.

The approach comprises two complementary strategies as follows

Resource-Directed Measures: These measures focus on the quality of the water resource itself. Resource quality reflects the overall health or condition of the water resource, and is a measure of its ecological status. Resource quality includes water quantity and water quality, the character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota. Resource quality objectives will be defined for each significant resource to describe its quality at the desired level of protection. (See Note 3 in Chapter 1 and Part 2 of this chapter for the definition of water use).

Source-Directed Controls: These measures contribute to defining the limits and constraints that must be imposed on the use of water resources to achieve the desired level of protection. They are primarily designed to control water use activities at the source of impact, through tools such as standards and the situation-specific conditions that are included in water use authorizations. Source-directed controls are the essential link between the protection of water resources and the regulation of their use. (Conditions of use are discussed in Part 2 of this chapter).
Coherent and integrated approaches to balancing the protection and use of water resources will therefore require the collective application of resource-directed measures and source-directed controls in respect of water quantity and quality, as well as the biological and physical dimensions of the resource.

Although the Act promotes, among other things, resource protection to support long-term sustainable use and development, water resources are sometimes polluted or damaged through accident, negligence or deliberate actions. In such cases the Act holds the parties responsible for the pollution or damage liable for any clean-up or rehabilitation that may be necessary.

Resource-Directed Measures

The system for classifying water resources, the process to determine a class for each significant water resource, and the process to determine the Reserve and resource quality objectives for the resource in accordance with its class are still under development.

These measures will not be established via the National Water Resource Strategy (NWRS), because the Act requires the following

-The classification system for water resources is to be established (prescribed) in terms of section 12 of the Act by means of regulations after mandatory public consultation and consideration by Parliament [1].
-The determination of the class, the Reserve and resource quality objectives for a water resource are to be established by Government Notices in terms of sections 13 and 16 of the Act respectively, following mandatory public consultation.

It is anticipated that the Department will invite comments on these proposals, in accordance with the Act's requirements for consultation, by the end of 2004.

Information on possible approaches to resource protection is provided in the NWRS to present as complete an account as possible of the Department's intentions for water resources management.

An important consideration in the development of resource-directed measures is that they should be technically sound, scientifically credible, practical and affordable.

* More details about the current state of the classification system are to be found in section 2.2.4.3.below.

Biodiversity conservation

It is not possible for all resources throughout the country to be given a high level of protection without prejudicing social and economic development. Equally it is not desirable for all resources to be classified at a uniformly low level so as to permit maximum use. An ad hoc approach to resource protection would not address the variability among living organisms and their habitats required to represent all aspects of biological diversity. Accordingly a systematic and strategic approach is being developed to ensure that biodiversity conservation – required to conserve representative diversity and ecological functioning of South Africa's water resources is achieved.

Classification of Water Resources, Determination of the Reserve and Resource Quality Objectives

The class of a resource, the Reserve and its resource quality objectives are intimately related to one another.

- **The Reserve** includes the quantity and quality of water to meet basic human needs and to protect aquatic ecosystems (Ecological water requirements).
- **Resource quality objectives** provide numerical and/or descriptive statements about the biological, chemical and physical attributes that characterise a resource for the level of protection defined by its class. Thus resource quality objectives might describe, among other things, the quantity, pattern and timing of instream flow; water quality; the character and condition of riparian habitat, and the characteristics and condition of the aquatic biota.
- **Resource quality objectives** must take account of user requirements and the class of the resource. Accordingly, the determination of the management class of a resource and the related Reserve and resource quality objectives (jointly, a **resource-directed measures** determination) will usually be undertaken as an integrated exercise. This will be done once the resource classification system is established. At present, until the classification system is established, all determinations are "preliminary" in terms of the Act (see Box 3.3.1).

Because water use authorisations may be considered before the class and the Reserve have been determined for the resource in question (see Box 1), the appropriate procedures will be applied on an ad hoc basis when required for individual and ad hoc applications for water use.

Box 1: Determinations and preliminary determinations

The Act speaks of determinations of class and resource quality of the Reserve objectives (section 13(1)), and of the Reserve (section 16(1)), as well as of preliminary determinations (sections 14(1) and 17(1) respectively).

"Preliminary" in this context refers to a determination carried out before the formal prescription of the classification system. This is a transitional measure that makes it possible to license water use while the classification system is being developed and established in terms of the Act.

Preliminary does not refer to the method used for the determination, the resolution of the determination or to the level of confidence in the results. A preliminary determination may be carried out using any method and at any resolution.

Authorisation of water use is however always subject to the preliminary determination, and considering the requirements of the Reserve.

The Act does not require a process of public consultation for preliminary determinations, nor does it require them to be published. In practice, however, in the interests of openness and transparency, the Department will as far as possible consult with the public in respect of major preliminary determinations.

Resource-directed measures may be determined for a localised area or for a larger area such as a whole catchment area. In a larger area, resource units that require individual attention will be identified on the basis of different biophysical characteristics.

Source-Directed Controls

Source-directed controls were implemented to a limited extent under the 1956 Water Act, notably in respect of the waste discharge permit system. Source-directed controls are now incorporated into conditions in water use licences and general authorisations. The conditions that may be imposed on water use are described in section 29 of the Act, and cover all aspects of all types of water use. They are closely associated with the resource quality objectives discussed previously, and are intended to ensure that the cumulative impact of water use, in respect of quantity and quality, does not exceed the limits appropriate to the class of the resource.

Source-directed controls for all water use will continue to be implemented as licences are issued, and will contribute to the achievement of the objectives for the protection and use of a resource in terms of its class. Source-directed controls will also inform the drafting of regulations on water use under section 26 of the Act. Licence conditions and regulations on water use are discussed in Part 2 of this chapter.

Source directed controls may be categorised as follows –
- Best management practice measures that relate to measures and standards that applies nationally with respect to water use.
- Special measures relate to source-related requirements dictated by and/or derived from catchment management strategies and/or plans.
- Site specific measures relate to measures arising from the process of authorising water use.

They take account, among other considerations, of general authorisations specified at national or regional levels, and considerations that are specific to the water use being considered in a particular location.

2.2.4.3. THE PROPOSED NATIONAL WATER RESOURCE CLASSIFICATION SYSTEM (WRCS)

The desired characteristics of the resource are represented by a Management Class (MC), derived from the WRCS through a consultative classification process to facilitate a balance between protection and use of the nation's water resources. The economic, social and ecological implications of choosing a MC will need to be established and communicated to all Interested and Affected Parties (I&AP) during the Classification Process. For each MC derived, Resource Quality Objectives (RQOs) will be set by the Minister or her delegated authority for every significant water resource (river, estuary, wetland and aquifer). This will be binding on all authorities or institutions when exercising any power, or performing any duty under the NWA. This MC, which may range from Natural to Heavily Used/Impacted essentially, describes the desired condition of the resource, and concomitantly, the degree to which it can be utilised. The MC of a resource therefore sets the boundaries for the volume, distribution and quality of the Reserve and RQOs, and thus the potential allocable portion of a water resource for off-stream use. This has considerable economic, social and ecological implications.

Proposed levels of classification for management.

Class I. Natural

A resource classified as Natural will be one in which –

- human activity has caused no or minimal changes to the historically natural structure and functioning of biological communities (animals and plants), hydrological characteristics and the bed, banks and channel of the resource; (ecological category A)
- chemical concentrations are not significantly different from background concentration levels or ranges for naturally occurring substances.
- Safe for contact recreation and most water uses and
- can be used for basic human needs with minimum treatment;
- The resource is situated in a national or international heritage site or wilderness area;
- It has compelling biodiversity characteristics;
- It is a protected site under the Ramsar Wetlands Convention;
- It is situated in an area that has economic importance for tourism or the harvesting of medicinal plants;
- It has social and/or cultural significance; or
- It is an area designated as Natural under other legislation.

The Natural class will provide **a reference condition** for other resources classified at greater levels of impact, that is, resources in other classes will be defined in terms of the degree of deviation from the Natural class.

Class II. Moderately used / impacted

- Resources that are slightly to moderately altered from their natural condition due to the impacts of human activity and water use;
- retain a high degree of ecological function and integrity (ecological category B to high C);
- safe for some recreation and non-sensitive water uses; and
- can be used for basic human needs with conventional treatment.

Class III. Heavily used / impacted

- Resources that are significantly changed from the Natural class reference conditions due to the impacts of human activity and water use but are nevertheless ecologically sustainable;
- where there are pressing social and economic reasons to permit uses that will cause limited, short-term and reversible degradation of the resource, cases will be considered on their merits within the framework of long-term sustainability;
- retain at least some ecological function, but probably highly modified from Natural (ecological category D);
- safe for some non-contact recreation and some non-sensitive water uses; and
- may require advanced treatment to meet basic human needs requirements.

Class IV. Unacceptably degraded resources

- Unacceptably degraded resource due to over-exploitation
- MC set at one class up with the aim to rehabilitate this resource to at least one higher class.

Water resources will normally be managed in order to achieve the long-term goals of the management class. When there are pressing social and economic reasons to permit uses that will cause limited, short-term and reversible degradation of the resource, these cases will be considered on their merits, within the framework of resource protection for long-term sustainability.

Until the procedures and protocols are completed a preliminary process is in place (Box 1)

Box 2. National Water Resource Classification Strategy guiding principles

Principle 1: Balance and trade-off for optimal use

The chosen management class should balance protection of the resource with its utilisation in line with societal norms and values. Utilisation of the resource provides economic and social benefits; it also has the potential, however, to compromise ecosystem integrity, which has economic and social costs. This balance will require trade-offs. The NWRCS should therefore clearly outline the implications of different management classes to facilitate informed decision-making.

Principle 2: Sustainability

The principle reason for the protection of water resources is to maintain ecosystem integrity at a level that ensures the continued delivery of desired ecosystem goods, services and attributes for use. The NWRCS therefore needs to provide a framework to help facilitate the sustainable use of water resources. It is also recognised that there is a sustainability baseline that if crossed, could result in the non-delivery of the goods, services and attributes necessary for economic growth, poverty alleviation and the redress of historical inequality. As there is a degree of uncertainty as to the exact position of this baseline, and as the risks exceeding the limits of sustainability are considerable, the precautionary principle will be applied.

Principle 3: National interest and consistency

A management class of a resource may produce solutions that are acceptable at a local-level, but are sub-optimal when considered at a national-level. Catchment-level decisions therefore need to be evaluated against national-level interests (and where appropriate, international-level constraints, e.g. international obligations). The NWRCS should also outline a clear intention with respect to the characteristics of different management classes and provide for consistency in this regard.

Principle 4: Transparency

Stakeholders should be consulted both in the development of the NWRCS and in the process of classifying the nation's water resources. The approach should be legitimate and transparent, and ensure that the valuation method used for determining trade-offs is fair. As the management class has considerable economic, social and ecological implications, stakeholders will need to be informed in a meaningful way of the potential impacts on and risks (and benefits) of the NWRCS to them. Further, stakeholders will need to be informed about the level of uncertainty that accompanies many of the economic, social and ecological predictions inherent in the Classification (and 'Larger') Process.

Principle 5: Implementability

The NWRCS needs to be used, at reasonable cost, by trained DWAF/CMA staff at an operational level. The institutional and transactional costs associated with making a decision on the management class should be as low as possible. The NWRCS should also be sufficiently robust to make a decision in the light of imperfect knowledge. The final outcome of the Classification Process should take into consideration the impacts of existing entitlements to use water (for both abstraction and disposal) as well as regional- and national-development objectives.

Principle 6: Interdependency of the hydrological cycle

All components of a water resource are linked. As such, the NWRCS needs to account for the interlinkages between all resources dependent on water; rivers, aquifers, wetlands and estuaries.

Principle 7: Legally defensible and scientifically robust

The NWRCS should be legally defensible and scientifically robust. It should be based on sound socio-economic and ecological principles in line with IWRM goals. The NWRCS and Classification Process should be legally defensible, apply due diligence in the decision-making process, and prevent legal liability accruing to DWAF or the stakeholders. It should also be consistent with South Africa's international obligations and other environmental legislation both at a national- and international-level. The guidelines should indicate the best available tools and data sets to be used in the Classification Process. These will need to be regularly updated to account for developments in science and technology.

Principle 8: Management scales

The scale at which the NWRCS is applied should be appropriate to the problem at hand. The end result of the Classification Process will be the recommendation of a management class. The implications of this will need to be understood, implemented and checked at multiple scales.

Principle 9: Auditable and enforceable

The NWRCS needs to be auditable and enforceable to ensure that it is operationalised. Thus, the regulator will need to ensure that a transparent, permanent record of the procedures, information and logic used for classifying a particular resource is created and maintained. The outcomes of the NWRCS also need to be monitored and enforced.

Principle 10: Lowest level of contestation and the highest level of legitimacy

Given the strategic importance of the NWRCS, the principle of lowest level of contestation and highest level of legitimacy should be applied. This requires consultation with, and the highest level of buy-in from, internal (DWAF) and external strategic stakeholders and I&APs.

Principle 11: Utilisation of existing tools, data and information

The NWRCS will use existing tools, data and information wherever possible. Where applicable, existing tools, data and information will be modified or extended to meet the requirements of the NWRCS. Unless there is an urgent need to do so, no new tools, data or information will be developed or collected.

Outline of the Envisaged Classification Procedure

Step 1: Delineate units of analysis and description of the status quo; including:

a. Identification and description of sectoral use of water and Ecological Goods, Services and Attributes (EGSAs).
b. Description of water resource infrastructure.
c. Delineation of aquifers, estuaries, rivers and wetlands and description of Present Ecological Status (PES) and Ecological Importance and Sensitivity (EIS). (Table 7)
d. Delineation and description of socio-economic communities and their use of water and EGSAs.
e. Overlay of units delineated in Steps 1a to 1d.
f. Consolidation and definition of Integrated Units of Analysis (IUA).

Step 2: Flow response extrapolation; including:

a. Identify EGSAs used in each IUA
b. Identify nodes to which existing RDM data can be extrapolated.
c. Consolidate and define IUA.

Step 3: Quantify Ecological Water Requirements (EWRs); including:

a. Define non-negotiable constraints (national- and regional-level constraints and second-level constraints).
b. Determine six starter catchment configurations.
c. Develop node rule curves for classes in catchment configurations.

Step 4: Pre-testing hydrological feasibility of catchment configuration scenarios; including:

a. Screen catchment configurations for hydrological feasibility.
b. Discard/adjust non-feasible configurations.
c. Group river nodes into IUA.

Step 5: Description of changes in EGSAs for feasible scenarios; including:

a. Description of water quality implications for users.
b. Describe changes in EGSAs identified in 2c.
c. Re-test configurations for hydrological feasibility, if necessary.

Step 6a: Internal DWAF IWRM process

Step 6a involves an internal DWAF IWRM process of evaluating scenarios generated during Steps 4 and 5 in conjunction with the verification of Existing Lawful Use (ELU) process, Compulsory Licensing process (including reconciliation and licence applications), water requirements for redress and equity, CMS and future use scenarios. This will include description of the socio-economic and ecological implications of scenarios at catchment,-, regional- and national-scales. This will constrain the number of scenarios for Step 6b.

Step 6b: Iterative process of evaluating alternative scenarios with stakeholders

Step 6b forms part of the 'Larger Process' where the economic, social and ecological trade-offs will be made. Emerging from this 'Larger Process' will be the recommended MC, RQOs and Reserve, CMS, allocation schedule, modelling system and the monitoring, auditing and compliance strategy. A number of key questions will need to be addressed in this 'Larger Process'. These include:

- at what level will the trade-offs be negotiated?
- in what institutional setting will they be negotiated?
- what types of scenarios will inform the process of negotiation?; and
- the recommended MC, Reserve, RQOs, CMS and allocation schedule will impact on specific groups of people, so the key question will be who benefits and who pays the social and economic cost?

These key questions should be framed (and assessed) in the context of equity, efficiency and sustainability as required by the NWA, and by the core objectives of the present government which are, amongst others, to '…halve poverty and unemployment by 2014', reduce the regulatory burden on small and medium businesses and eliminate the second economy[1]. Step 6 should therefore contribute to meeting government's objective of '…reduce(ing) inequality and virtually eliminating poverty'[2].

Step 7: Presentation of summary information and recommendation of a class configuration scenario to the Minister or her delegated authority

A template will be developed for presenting the summary information from the generated scenarios to the Minister or her delegated authority for a decision on the MC. This will include:

- the economic, social and ecological implications of each scenario;
- the input from the stakeholders; and
- the recommended class configuration.

Table 7	**Ecological integrity status categories**
Category	**Ecological integrity status**
A	Unmodified, natural; the resource base reserve has not been decreased – the resource capability has not been exploited.
B	Largely natural with few modifications; the resource base reserve has been decreased to a small extent. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged.
C	Moderately modified; the resource base reserve has been decreased to a moderate extent. Changes of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified; the resource base reserve has been decreased to a large extent. Large changes in natural habitat, biota and basic ecosystem functions have occurred.
E	Seriously modified; the resource base reserve has been seriously decreased and regularly exceeds the resource base. The loss of natural habitat, biota and basic ecosystem functions are extensive.
F	Critically modified; the resource base reserve has been critically decreased and permanently exceeds the resource base. Modifications have reached a critical level and the resource has been modified completely with an almost total loss of natural habitat and biota. In the worst instances, the basic ecosystem functions have been destroyed and the changes are irreversible.

[1] www.info.gov.za/issues/asgisa/

Box 3. Indices to determine Ecological Categories (EC) for each component

HAI – hydrological driver assessment index
GAI -geomorphological driver assessment index
PAI – physico-chemical driver assessment index
FRAI – fish response assessment index
MIRAI – macro-invertebrate response assessment index
VEGRAI – riparian vegetation response assessment index

Ecostatus definition
" The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support and appropriate natural flora and fauna and it capacity to provide a variety of goods and services. (Iversen *et al.* 2000)
See WRC Report KV 168/05 2006.

Additional tools and processes to facilitate a decision on the desired MC of a resource

It is proposed that in addition to existing DWAF tools, a hybrid Cost-Benefit Analysis (CBA) and Multi-Criteria Decision-Analysis (MCDA) tool be utilised to help facilitate a decision on the MC of a resource. The hybrid CBA/MCDA tool should help facilitate the Classification Process at a number of levels:

1. Selecting a subset of flow scenarios for detailed analysis from a broad range of scenarios.
2. Identifying the criteria that are required for evaluation, and
3. Evaluating (scoring and weighting) the criteria that have been chosen, and comparing the consequences of different scenarios.

MC scenarios will need to be assessed and aligned with existing DWAF approaches and methodologies for water resources/catchment planning, system management, compulsory licensing, source directed controls (SDCs) and related management instruments (including command and control, economic instruments (e.g. WDCS) and through system operation and/or resource remediation (i.e. as part of the 'Larger IWRM Process')).

Key Institutional Requirements

A complex institutional environment will have to be constructed to implement the NATIONAL WATER RESOURCE CLASSIFICATION SYSTEM, to maintain the balance between use and protection, both in terms of the systems and processes of integrated water resource management (IWRM), and the division of roles and responsibilities between DWAF and the Catchment Management Agencies (CMAs).

The WRCS is, necessarily, an integral component of the IWRM environment and the Classification Process is fundamentally linked to other processes in the integrated planning of water resource protection, development and utilisation, and in the management and control of water use. In particular, the Classification Process and the Catchment Management Strategy (CMS) are iterative, while the proposed MC has significant implications for water allocation, Compulsory Licensing and the Waste Discharge Charge System (WDCS). A key component of IWRM is therefore an iterative process of evaluating scenarios with stakeholders where the economic, social and ecological trade-offs will be made, and out of which will emerge the allocation schedule, installed modelling system, MC, reserve, RQOs and the CMS. This process is referred to as the 'Larger Process'.

Given the complex and interrelated nature of the IWRM process, careful consideration of the linkages between the evolving WRCS and the 'Larger Process' is required. As a result, the institutional arrangements to support such linkages are an important element of the evolving WRCS.

Institutionally, the IWRM environment is complicated by the DWAF institutional change process with the decentralisation of roles and responsibilities, and the establishment of CMAs. Once decentralisation is complete, the institutional and management arrangements to support the WRCS and the Classification Process follow the division of roles and responsibilities between DWAF and the CMAs. DWAF assumes custodianship of the resource and of the broad strategic objectives of IWRM (including the WRCS and Classification Process) through oversight and regulation of the resource and its management, and through support to the CMAs. The CMAs are fundamentally responsible for management of the resource. Accordingly, the CMAs develop recommendations on the class, which are assessed and reviewed by

DWAF for ultimate consideration and gazetting by the Minister. Before decentralisation is complete, DWAF both acts as custodian of the resource and manages the resource, which includes developing recommendations on the class.

Beyond the IWRM environment, the WRCS has bearing on a range of broader processes, given the wider socio-economic, political and ecological implications of the class. Accordingly, cooperation with all three spheres of Government, participation of stakeholders and engagement with civil society is required to ensure appropriateness and acceptability of the WRCS and, ultimately, of the proposed class. This implies that the WRCS process is founded on consensus-seeking, participation and cooperative governance to ensure socio-economic balance and sustainability in addition to the technical elements of ecological sustainability. The institutional arrangements and, importantly, the capacity for implementation of the WRCS must take cognisance of this socio-economic imperative.

Accordingly, the key institutional issues in terms of the evolving WRCS should focus on:

- creating an enabling environment, both in terms of the enabling legislation and the institutional environment, to ensure integration with associated systems and processes in IWRM;
- clarifying the roles and responsibilities of different groups and institutions in the Classification Process, considering the process of institutional change; and
- developing appropriate institutional arrangements and the requisite capacity for implementation, particularly in the CMAs, to enable cooperative governance, participation and stakeholder consultation, and to support the technical processes of the WRCS.

2.2.5 PROTECTION OF WETLANDS

Wetlands are important features of water resource systems. If they are sufficiently protected they offer multiple benefits including a range of services such as flood attenuation, groundwater recharge and sediment control, and act as natural filters by trapping pollutants. However, they also “use” significant quantities of water through evaporation. They are biologically productive, and can be also important centres of biodiversity. Wetlands offer a range of resources for human use, such as reeds and grasses. Many wetlands have however been completely destroyed or severely damaged, most often by draining to provide additional croplands. Some wetlands are registered protected areas, including World Natural Heritage and Ramsar sites. The protection of wetlands will be effected by the strategies and procedures prescribed for resource directed measures, and in conjunction with the national and provincial departments of environmental affairs which have a key role in the protection of biodiversity.

Wetland classification is the first step in devising an RDM system and Brinson (1993) as set out in Table 6 above provide the basis for classification which has been modified and adapted for South African conditions. Wetland PES assessment differs from that for rivers in that it requires the inclusion of soil analyses as an indicator and relies more on plants than on fish and invertebrates as measures of biotic integrity.

Box.4. Determination of Wetland Environmental Water Requirements (Role and type of Assessment)

By Gary Marneweck and Mandy Uys (DWAF 2004(c))

While the wetland Reserve Determination process proposed in 1999 has been used in a number of wetland systems, it is under review for further development.

A key issue in the current method is the reliance on a Habitat Integrity Assessment method for determination of Present Ecological State Category (PESC), Ecological Importance and Sensitivity Category (EISC), and Ecological Category. This is considered an inadequate basis for the determination of these key parameters. Two recommendations are made. Firstly, the inclusion of a new South African hydrogeomorphic (HGM, functional) assessment protocol, WETLAND-ASSESS, as a means of determining wetland functionality and assessing likely changes in function as the result of altered hydrology. Secondly the incorporation of one or more indices of biological integrity (IBIs) to evaluate aspects of wetland ecological character and to provide information for use in determining the relevant biotic water requirements needs development to support WETLAND-ASSESS

WETLAND-ASSESS which is being tested, includes an HGM classification system recommended for use in the Reserve process. It is designed for palustrine wetlands only, but has already been used in Reserve Determinations by Marneweck and colleagues. These specialists recommend alternative procedures for the determination of PESC, EISC and EC in lacustrine wetlands and pans.

In Australia, programmes exist for the monitoring of ecosystem response to Environmental Water Allocation (EWA) delivery. Two key reports using similar approaches, regarding EWA are referred to: one a framework for assessing the success of EWAs in maintaining important wetland systems; and the other a guide to the means of estimating water requirements of plants in Australian floodplain wetlands. These are valuable in providing a perspective on the type of information required in setting (and evaluating) the Ecological Reserve for rivers; and stimulate thought as to how this information could be collected alongside that required for bio-assessment.

Tools for Assessment

Three groups of variables are commonly used in wetland assessment: functional, physical and biotic.

Soil is one of the most important of the physical variables, and its use as an indicator of the wetting regime in wetlands.

Vegetation is the component of the biota that is best known and understood in South Africa, wetland. Plants, with soil are commonly used to delineate wetland boundaries. Clear relationships have been demonstrated between changes in wetland plant community composition and a suite of wetland stressors, including hydrologic alterations, nutrient enrichment, sediment loading, turbidity, metals and other pollutants. Community composition is however also affected by natural disturbances, which can complicate the interpretation of plant data.

Diatoms A South African research from the University of the North West, is currently testing a French diatom index, the Specific Pollution Sensitivity Index (SPI) in aquatic ecosystems. Algae are generally less studied in South Africa.

Invertebrates in wetlands differ from stream invertebrates in their greater tolerance of low dissolved oxygen concentration, so the SASS5 index cannot be used. A number of Invertebrate Biotic Integrity-type indices have been developed in the US based on macro-invertebrates and could bear testing here. (DWAF 2004

2.2.6. PROTECTION OF GROUNDWATER RESOURCES

Groundwater resources differ from surface water resources in that they are not confined to distinct, visible channels, move very slowly and are less prone to rapid temporal variations than surface water. Without proper monitoring and management human impacts are usually difficult to detect. As the rehabilitation of polluted or impacted aquifers is technically very difficult, lengthy and costly, a careful approach to groundwater protection is required. Because of the Technical differences between surface and groundwater, groundwater management has to be considered in its own right, although an integrated approach is required if effective water resource management is to be achieved.

Resource-directed measures will continue to play an important role in the management of groundwater resources, specifically to ensure that groundwater use is sustainable. The protection of groundwater quality will, however, mainly is achieved by source-directed controls focusing on land-based activities that impact underlying groundwater bodies. Examples of this include the siting and construction of waste disposal sites and sewage treatment plants. The widespread, but usually highly localised occurrence and use of groundwater makes it economically impossible to protect all sources to the same degree. Effective and focused protection interventions will be facilitated by a differentiated approach, based on a system of resource classification designed specifically for groundwater resources.

2.3. ECOLOGICAL GOODS AND SERVICES AND ATTRIBUTES.

The move towards protection of ecosystems and in particular aquatic ecosystem goods and services has arisen for the need to convince people in the broader community about the value of that a healthy functional ecosystem has for them. It is felt that people will more readily be convinced to modify lifestyles and consume less if they can CLEARLY understand what free benefits they reap from the ecosystem.

GOODS AND SERVICES' PROVIDED BY AQUATIC ECOSYSTEMS

WATER IS LIFE – AMANZI BUBOMI!

ABIOTIC PROCESSES IN RIVERS that result in ecosystem services to humans
Drain landscape
Leach solutes from rocks
Sculpt the land
Move sediments to coastal seas (e.g. Protection of beaches)
Provide nutrients to coastal seas (e.g. Inshore fisheries)

SERVICES provided by rivers (to humans):
Provide water (storage, hydroelectricity)
Cleanse water by Nutrient re-cycling – removal during growth season, return during senescence.
Provide floodplains with silt that enriches soil
Support living resources (fish, reeds, grazing hunting,.)
Transport by water
Medicinal plants. Fibre for handicraft & construction,
Recreation & education

PROCESSES IN WETLANDS:
deposition (not erosion as in rivers)
accumulation (not transport as in rivers)
therefore act as **sinks** in the landscape, not drains
filtration of water by plants and soils

FUNCTIONS
Sinks in the landscape through sediment deposition, denitrification & phosphorus removal, mineral uptake by vegetation
Stores of water
Recharge of aquifers

SERVICES PROVIDED BY WETLANDS

Amelioration of flood waters
Storage of water and flow regulation
Cleansing: filtration of suspensoids (sediments and organic debris)
Uptake of nutrients
Huge productivity (>tropical forests) ➔ living resources (reeds, grazing, fish, ...)
High biodiversity
Recreation

NB: also artificial = constructed = treatment wetlands

RIPARIAN WETLAND – additional ecological benefits:
Corridors & habitats (otter, birds, snakes, etc.)
Cover for fish (spawning areas) and invertebrates
Food source for vegetarian fish
Control excessive weed growth by shading
Physical link between water and air for many invertebrates
Lotic waters offers a more oxygenated root zone

RIPARIAN WETLAND – Hydrological benefits:
Improve water yields less evaporation and storage.
Regulate water flow as debris can increase flow resistance and vegetation prevent the damage of floods

3. Ecological or Resource Economics – an introduction

An introduction based on the analyses of a water resource. Summarised from a paper delivered at the SASAQS 2004 by T Tlou, D Mullins; HH Pienaar; NJ van Wyk; G Huggins.

3.1 INTRODUCTION

Ecology can be said to be the study of nature's housekeeping while economics is the study of human housekeeping. Ecological economics can be said to be the study of how these two sets of housekeeping are related to one another. This is the origin of the sustainability problem. The need to ensure sustainability is the cornerstone of the National Water Act 36 of 1998. The distinguishing characteristics of ecological economics are that it "treats the economic system as part of the larger system that is planet earth" (R Perman *et al*. 1999). According to Roger Perman *et al.*. it starts from the recognition that the economic and environmental systems are interdependent, and studies the joint economy-environment system in the light of developments in natural sciences, particularly thermodynamics and ecology over the last decade.

The concept of sustainability involves linking three major points of view; economic (to achieve efficient use of the scarce resource), social (to achieve equity objectives and poverty alleviation) and ecological (to achieve resource protection for the long term use of the resource).

Sustainability can be promoted by better economic accounting of the natural capital. That highlights the value of integrating economic valuation in ecological reserve determination to promote informed decision making of the use of the scarce water resource. This is the background of the approach and process used in the determination of the preliminary Reserve of Thukela River catchment at a comprehensive level.

Water as natural capital provides important benefits to society, both commodity benefits and environmental values. Integrating economic valuation of the ecosystem with conventional markets could provide a more holistic picture of the implications and related risks in balancing resource protection with socio-economic objectives.

Water and Environmental Sustainability

Water is critical for sustaining the natural function of the ecosystem ensuring the maintenance of the resource base from which goods and services are provided for society's use. The protection of the resource base through the determination of the ecological reserve attempts to ensure continued services to human society. The consequences of water resource degradation must be incorporated into the decision making process. The services provided by the ecosystem can be described as follows:

- The natural resource base provides essential raw materials and inputs which support human activities. In some river systems, communities living close to the river are dependent on the river for subsistence fishing, harvesting of reeds and sedges, floodplain agriculture, while in others the main services may be of recreational or spiritual nature.

- A functioning ecosystem serves as a sink to absorb and recycle (often at little or no cost to society) the waste products of the economic activity through waster assimilation.

- The ecosystem provides not only benefits but also costs to society. For example waterborne diseases such as bilharzia and malaria are disservices that accrue to society as a direct result of the water resource supporting the natural functioning of the ecosystem.

- Water for commercial use

The potential conflict between resource protection (ecological water requirements (EWR)) and resource utilisation should not be underestimated. Water left in the river provides for the ecosystem from which goods and services are derived. Increasing amounts of water is needed to improve the welfare of society through socio-economic development. While this process removes increasing amounts of water from the ecosystem it also increases the amount and range of waste product inputs to the ecosystem. A trade-off between protection and utilisation can be better understood by economic valuation of the ecology as well as the market economy.

The economic valuation of water for socio-economic benefits and the valuation of the ecological water requirements to sustain natural functioning of the ecosystem and assist in the decision-making process aimed at balancing development and protection measures of water resources have not been done extensively in Reserve determinations before. The determination of a preliminary Reserve for the Thukela River catchment and the Thukela River mouth provided new approaches to integrated water resources management in attempting to provide a balance between water resource protection and socio-economic development to maximise the welfare of the communities in the catchment.

During the Thukela River comprehensive reserve determination study during which nine flow scenarios was proposed, an integration of the three pillars of sustainable development and management of water resources was conducted. During the process an analysis of both the conventional economic and ecological values derived from the river were undertaken.

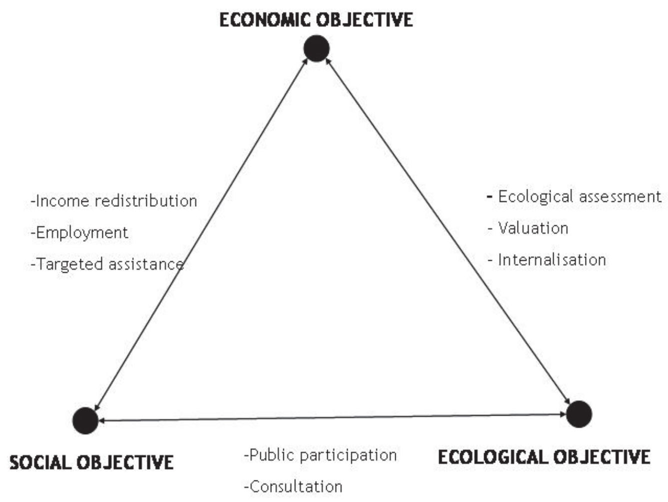

Figure 8. Tradeoffs among the three main objectives of sustainable water resource management (from Tlou *et al.* 2004).

3.2. PROCESS FOR DETERMINING RESOURCE VALUE

Two procedures are undertaken when determining the value of a resource, conventional economic and ecological value of the river system.

Process for the conventional regional economic analysis

1. The first step of the conventional economic analysis of the impact of the ecological water requirements for the Reserve is to determine the level of economic activity in a catchment for the base scenario (defined as the without taking Ecological Water Requirements into consideration). This step involves identification of the entities or groupings involved in economic activities in the catchment that use water directly and indirectly and incur costs and benefits from the use of water on an annual basis with a planning horizon for the economic analysis fifteen or so years in the future. The turnover of each economic sector identified is then calculated, after which these figures are fed into a Social Accounting Matrix (SAM) structure to isolate the value added per economic grouping.

2. The second step is the development of the water accounts. The water accounts are generated from the results of the water resources yield model (WRYM) that determines the available water to each sector for the scenario being investigated. The average volume of water available to each sector together with the sector coefficients is then used to calculate value added and the level of employment each sector will support. This is done after accounting for the ecological water requirement for each ecological category scenario that is looked at.

3. The third step is the use of the water accounts to determine the volume of water used by each economic grouping (*e.g.* irrigated agriculture, forestry, industry, mining, municipal use, *etc.*) at the different levels of assurance of supply for each user sector. The water accounts are then used to generate the economic value of water per m^3 of water use for each sector. These value added figures are then divided by the volume of water consumed by the sector to arrive at the so-called coefficient.

The impact on economic value added and employment opportunities for each scenario for sub-systems of a given catchment are also calculated in order to improve the resolution of the economic analysis.

Process followed for the valuation of the water for ecology

The valuation of the ecological goods and services derived from the river system because of the ecological water left in the river is then determined in economic terms. The steps followed are similar to the conventional economic analysis of the use of water taken out of the river to generate wealth and distribute the total wealth (i.e. economic value added) among the sectors and the individuals of society (i.e. income distribution).

1. The first step in the ecological valuation process is the identification of the ecological goods and services that would be derived from the river including the estuary. These are mainly the direct use value as indicated in Figure 2. In order to estimate the economic value for these goods and services, the survey is conducted to identify the number of users of the river for that particular service. The number of households dependent on the goods and services from the river in each subsystem is estimated using a 5 km buffer zone.

2. The approach used for determining the goods and services such as subsistence fishing, craftwork sedges, construction reeds, floodplain agriculture, is by examining market-like transactions to determine the value of the good or service, identifying the households benefiting from the ecological functions, estimating the demand curve and then calculating the value of the goods and services made available because of maintaining ecological water requirements left in the river.

3. The process followed for the impact of illness due to water borne diseases such as bilharzia because of changes of the flow regimes of the different ecological categories are determined differently. The costs of illness

estimates consist of the cost of treatment, costs of lost production and cost for extra transportation. For treatment costs the costs for private treatment is used as the opportunity costs.

4. The final step was the determination of the changes in the goods and services for each scenario. This was conducted through a workshop environment where ecologists estimated the likely changes in the quantity of the goods and services. The biological and physical environment scientists then identify the potential change that each key service may undergo in the each of the three scenario clusters. The potential change was noted as a factor. For example, no change = 1, a 50% increase = 1.5, and a 20% decrease = 0.8.

The current value of services is then multiplied by the factors of change identified for each tributary in each scenario to provide an indication of the potential future value of the service, and the change in value was measured.

Multi-Criteria Decision-Analysis evaluates or 'scores' alternatives from different perspectives (criteria), weighting and combining these scores to obtain an overall ranking of alternatives. Selection of the criteria against which scenarios are evaluated, the relative weights of those criteria and the scoring are done by representative stakeholders.

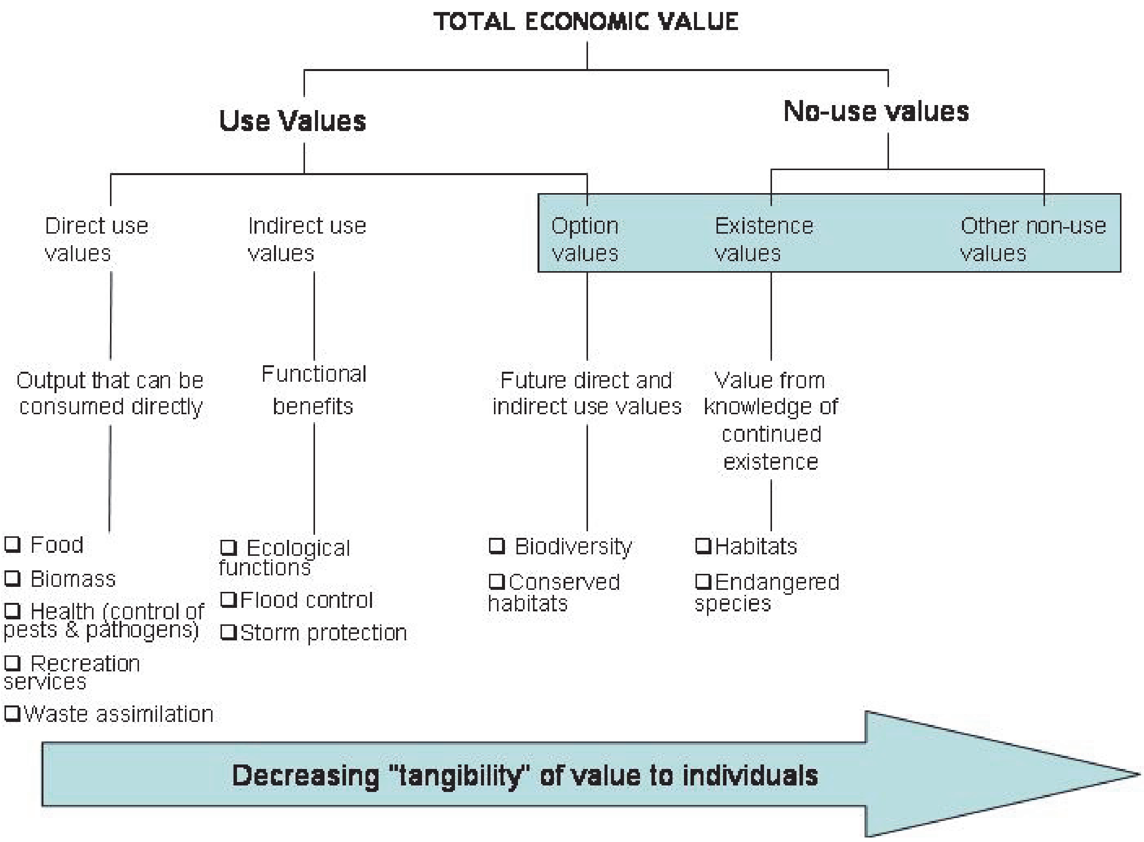

Figure 9. Categories of economic values attributed to the natural capital generated by the Thukela ecological assets. (Source: Adapted from Munasinghe, (1993) in Tlou *et al.* 2004).

3.2.1. OUTCOMES

Table 8. Summary of economic values described for the Thukela Catchment in Tlou *et al.* 2004.

The following six (6) economic sectors directly using water from the river (out of river water use) were identified in the Thukela River catchments and ranked in terms of value per m^3 of water used:	**The following services were identified for subsistence user groups and ranked in order of economic value**	**The following disease impacts were ranked in diminishing cost**
1. Urban requirements (incl. light industries)	1. Recreational services (rafting canoeing swimming)	1. Bilharzia
2. Mining & Heavy industries	2. Cultivation and grazing of floodplains	2. Other pathogens
3. Livestock farming	3. Waste assimilation and dilution	3. Cholera
5. Afforestation	4. Fibre (crafts and building)	
6. Sugar cane	5. Fishing (subsistence, trout and estuarine)	
7. Irrigated agriculture		

3.3. ESTIMATING THE ECONOMIC IMPACT OF VARIOUS FLOW SCENARIOS FOR THE ECOLOGICAL RESERVE

The implications of the changes in the ecological water requirements for each ecological category scenario on the ecological goods and services provided by this water were determined in economic terms. These ecological goods and services ranged from the value of effluent dilution due to the assimilative capacity of the river system, floodplain agriculture, subsistence fishing to recreation services. The value of the ecological water in each scenario was then incorporated into the conventional market economy for comparison of the different ecological category scenarios.

Table 9: Reasons for significant changes in values of goods and services under different flow scenarios cited as an example of the results of the analytical process of balancing economic gains against ecological loss

Environmental asset	Sub catchments	Scenario	Extent of Change	Reason for Change
Subsistence fishing	Upper and Little Thukela	2/5, 9	0.5	Reduction in water volume, with habitat loss
Subsistence fishing	Mooi	8	0.05	No flows in winter with major habitat loss
Subsistence fishing	Thukela estuary	8	1.5	Low flows result in salt water intrusion with entry of marine fish
Reed and sedge harvesting	Bushman's	8	1.5	Increase flows increase habitat available for reeds
Reed and sedge harvesting	Mooi & Little Thukela	8	0.6	Low flows result in habitat reduction for reeds and sedges
Waste assimilation	Bushman's	8	1.5	Increased flows result in greater assimilation capacity
Waste dilution	Buffalo	8	0.5	Lower flows reduces dilution capacity
Floodplain agriculture	Mooi	2/5, 8, 9	0.5	Lowering of water table in surrounding floodplain
Floodplain agriculture	Buffalo	8	0.5	Lowering of water table in surrounding floodplain
Cynodon lawns	Mooi	2/5, 8, 9	0.5	Lowering of water table in surrounding floodplain
Canoeing	Little Thukela	8	0.5	Lower water levels with insufficient water depth

3.4. TOWARDS A FRAMEWORK FOR ECOLOGICAL- ECONOMIC DECISION MAKING PROCESS

The implementation of the Reserve requires a pluralistic and consultative social framework. This process should facilitate the exchange of information between stakeholders and water resource managers in order to ensure stakeholder buy-in and long term sustainability. (See also module 1c Public Participation). The determination of preliminary Reserve in the absence of a classification system has not been tested with stakeholders in a manner that ensures that implications of protecting the resource are clear to them. Implementation of such reserves is not likely to succeed if communities are not well informed, given the choices in a manner they can understand and informed of the implications of the choices they have in the medium to long term.

The scenario approach and economic valuation of water for both the environment and the economic use as conducted in this study provides firstly the choices available and secondly the implications of those choices for the sustainable use of the water resource to both stakeholders and water resource managers (and ultimately the Minister) who have to make the final decision for balancing protection with water use.

Framework for incorporating economic valuation in reserve determinations

Reserve determination does not only involve focusing on protection of the ecological systems and preserving the resilience and dynamic ability of such systems to adapt to change. Its determination also has an impact on the other two main objectives namely social and economic objectives. Figure 4 below presents the framework for incorporating economic valuation in reserve determinations in order to improve the decision process on resource protection and resource utilisation. If the ecological requirements are determined in isolation of the socio-economic objectives, this will result in a non-inferior solution. The same applies for achieving socio-economic objectives. However by incorporating ecological valuation into the conventional economic valuation, the best compromise solution can be achieved and a multi-objective framework in the decision process is essential to ensure sustainability.

Incorporating economic valuation in scenario planning during the reserve determination process provides stakeholders with the choices on which informed decision-making can be done. This has been demonstrated in the Thukela River system Reserve determination (Tlou *et al.* 2004). In order to ensure environmental sustainability, there is a need to elicit communities' preference of the level of protection that can be achieved. By providing communities with the implications of the different levels of protection through incorporating economic valuation in the decision process there is a much better probability of the level of protection set required in their opinion? This approach also provides elements for classifying the resource in the absence of the classification system.

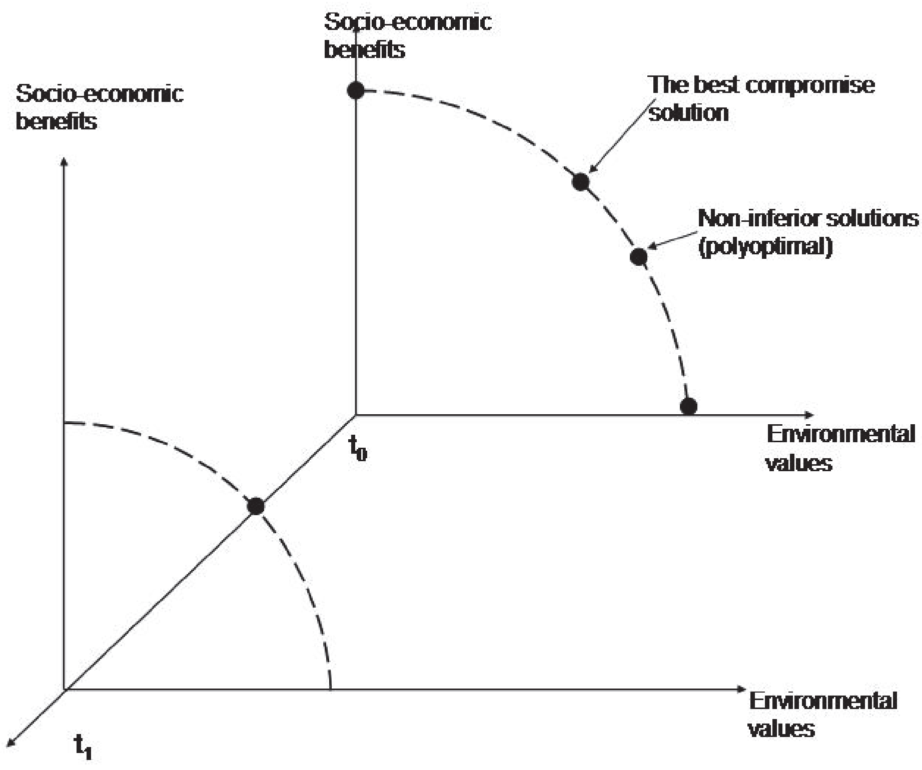

Figure 10. Framework for trade-off between socio-economic objective and environmental objectives

4. COST BENEFIT ANALYSES – DECISION-MAKING TOOLS FOR ENVIRONMENTAL MANAGEMENT: (Source "The Green Buck" Using economic tools to deliver conservation goals: a WWF field guide. www.iaia.org)

Cost-benefit analysis (CBA) takes place in the context of a specific project, for example a proposed infrastructure development. CBA is a key tool used by governments and businesses as part of the assessment of whether to go ahead with a proposed project or programme. However, environmental costs and benefits are often disregarded in these analyses. For example, better uses of resources such as land and water are not assessed, or the economic impacts of damage to biodiversity are not considered. The widespread use of CBA as the primary means of informing policy decisions is contested and often criticised as too narrow by environmental groups. However, despite these important objections, CBA can still be used to promote conservation objectives in one of two very closely related ways.

Firstly, a CBA of a proposed project can be conducted that seeks to include the economic costs of environmental damage that have not been adequately evaluated in the existing analysis of that project. The case of the Ebro Water Transfer (below) is an example of such a CBA.

Alternatively, a CBA can compare an existing proposal with an alternative, less environmentally damaging proposal that has not been considered sufficiently to date. The CBA of alternative land-uses on the Danube Islands is an example of such an approach that explicitly assesses two alternatives. Undertaking CBA will typically involve commissioning a consultant or economic expert to conduct the analysis and prepare a CBA of some form on behalf of WWF and any partners. This can range from a full CBA through to a critique of existing analyses. There is an extensive technical literature surrounding the conduct of full CBA. However, not all use of CBA for advocacy needs to follow this extensive procedure to the full. Different approaches will be appropriate in different circumstances.

Cost-benefit analyses carried out by government and business often disregards environmental costs and benefits.
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4.1. KEY ELEMENTS IN USING DECISION-MAKING TOOLS

1. Good communications can contribute to success. Good analysis is only a part of the successful use of economics in influencing policies and plans. Communicating the results is equally important. As with all advocacy work, different communications will be more appropriate for different audiences. Treasury officials may look for rigorous economic analysis, while the public may require the expression of the conclusions in more easily understandable and relevant terms. A range of communications approaches may, therefore, be necessary for any specific case.
2. The depth of analysis can vary. It is not always necessary to spend a huge sum of money conducting an expensive, technical analysis. Sometimes relatively simple calculations followed up by good advocacy can be effective. In assessing this, it is necessary to consider the audience that is being targeted and the extent and quality of the alternative analyses that have already been conducted. Quick analysis may have little impact on a treasury department that has commissioned extensive technical analyses of its own. On the other hand, where the existing analysis has significant gaps and flaws, a more preliminary approach can yield results. Nevertheless, there are dangers with seriously flawed analysis.
3. Clear understanding with the consultant of the uses of any analysis is vital It is important that any consultant used is clear on what outputs are required from them, in particular if outputs need to be translated into a form that is easily and clearly communicable to the public.
4. The promotion of alternatives is important. The promotion of alternative ways of achieving the same objective as the proposed policy or development is an important part of making the case. Where an infrastructure development project is being criticised, for example, an alternative should be suggested that will achieve the same aims and generate economic development. This proved important in the case of the Ebro Water Transfer.
5. The use of existing data can reduce costs and time. Where existing data and analysis is available, the use of this can save on the very costly process of starting analysis from scratch. It is important to check what has already been done, therefore, as a first step.

4.2. CASE STUDY: THE EBRO WATER TRANSFER, Spain

Application: The cost-benefit analysis demonstrated the overall negative economic impact of a proposed major infrastructure project.

Problem

The Spanish National Hydrological Plan (SNHP), approved by the Spanish government in July 2001, consisted of a huge water transfer of 1,050 cubic hectometres (hm^3) from the Lower Ebro River in the north of the country. The project was split into two large projects: the Northern Transfer, which would involve transferring 189 hm^3 to the metropolitan area of Barcelona for urban uses; and the Southern Transfer, which proposes to transfer 861 hm^3 to the Levante Region and South-east Spain for urban and agricultural uses. The Spanish authorities asked for funding from the EU to develop the Plan, totalling over 1.2 billion in the case of the Ebro transfer alone. The SNHP would have led to serious impacts for the river Ebro, including the complete disappearance of the Ebro Delta (designated as a Natura 2000 zone and Ramsar site). New dams would also have been needed in the High Pyrenees Mountains to regulate the water flow of the Ebro, leading to further significant environmental impacts. The SNHP would have contravened EU environmental legislation including the Birds, Habitats, Environmental Impact Assessment and Water Framework Directives.

Economic approach used to address the problem

WWF commissioned a cost-benefit analysis of the SNHP from economists at the University of Zaragoza who had worked on Spanish water economics and the SNHP for a number of years. The study found that the government had significantly under-estimated the costs of providing the water by, among other things, failing to account for all of the infrastructure required, failing to account for water treatment costs, and failing to account for water loss in transportation. Taken together, the WWF-commissioned study found that the proposed SNHP, rather than contributing to economic development, had a net negative value of over 3.5 billion. The cost-benefit analysis also drew a sharp distinction between the economic viability of the Northern and Southern transfer projects, arguing that they should be considered separately. In addition to the direct cost-benefit analysis of the government proposals, the study evaluated alternative solutions to the water needs of the areas covered by the SNHP. The study found that urban water supply for the Barcelona area could be satisfied through a combination of water-saving technologies and alternative water provision methods such as desalination, the reuse of waste water and improved use of ground water. These would meet the city's water needs at 45% of the government estimated costs of the SNHP, and only 30% of the real costs estimated in the WWF study. The study also highlighted the considerable differences in wealth between the poverty of the area from which the water was being taken and the comparative affluence of the areas to which it was being transferred. WWF was able to use the results of the study as the basis for lobbying politicians and civil servants in Europe and in Spain, and for extensive work with the media.

How did the economic approach contribute to conservation?

By using economic arguments, WWF was able to introduce powerful new arguments into the debate. The economic arguments provided access to officials and politicians outside environment ministries who would otherwise have paid little attention to WWF's case. During March 2004 four internal reports of four Directorate General of the European Commission (Environment, Regional Policy (2) and Internal Market) – which had been asked their advice in relation to EU funding allocations – strongly criticised the Ebro transfer project. All of these reports used the arguments that WWF had been making on the basis of the cost-benefit analysis. WWF and others lobbied the Spanish Socialist Party, then in opposition, on the basis of the arguments in the cost-benefit analysis. In March 2004 the Socialist Party won the Spanish General Election, and in June 2004 announced that they would be cancelling the SNHP and seeking other ways to solve the water problems of Spain.

Influencing Policies and Plans – Lessons Learned

- Communicating the original economic study proved to be exceptionally difficult. The original report was highly technical and economically complex. It was necessary to convert this into a summary document presenting the results of the study in a way that could be accessed by a non-technical audience, and this took considerable work.
- Proposing and evaluating alternative options was crucial in generating opposition to the scheme.
- The cost-benefit analysis was greatly eased by the existence of previous studies, considerable data and existing expertise. Undertaking a cost-benefit analysis in the absence of these would have been expensive.
- The results of the CBA were effective when they could be made relevant to people's own activities, for example the cost of the project per tax-payer – over 100 per Spanish tax-payer – or the relationship between tourism growth and the need for the transfer. Proposing alternatives was crucial in generating opposition to the Spanish National Hydrological plan.

Further information

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APPENDIX TO MODULE 1A:
ECOCLASIFICATION OF THE RESOURCE

Louw D, Kleynhans CJ, and Thirion C.

The objective of the Eco-classification is to create an understanding of the Present Ecological State (PES) and ecological functioning of the river. Based on this, attainable ecological aims and objectives can be set. This information is used within a scenario-based approach and a range of ecological aims and states therefore have to be considered. For each of these, a flow scenario must be described.

Ecological classification must not be confused as being equivalent to the Classification System which has as its aim the determination of Management Classes as indicated in the National Water Act. Rather, it is a component of the Classification System which considers a much wider suit of aspects than just the ecological.

The sequential steps followed in Ecological Classification are indicated in Table A2.1

Table A0.1 Ecoclassification sequential steps: The sequence of questions and actions required to provide relevant answers pertaining to the provision of information on the Ecological Category.

QUESTION	ACTION
1. What was the river like before human impact?	1. Determine Natural Reference Conditions.
2. Compared to how the river used to look like, what does it look like now?	2. Determine Pes. (Category A-F).
3. Is the river changing, and if so, how severely? how fast?	3. Determine Trend Of Change If The Status Quo Is Maintained.
4. What is the main cause for the change?	4. Determine Critical Cause For The Pes And/Or The Trend Of Change.
5. What is the source of the causes?	5. Determine The Source Of The Cause. (Should This Be Number 5?)
6. How ecologically and socially important is the river?	6. Determine Ecological Importance and Sensitivity Categories (Low, Moderate, High, Very High) & Socio-Cultural Importance.
7. What would the ecological aims be for the river?	7. Considering the Importance And The Present Ecological State, Should The PES Be Improved (If So, By How Much) Or Maintained? (NOTE: Maintaining The PES Could Still Require Restoration Management Depending On The Trend Of Change). (Category A-D).
8. Can the main cause realistically (and practically) be addressed to achieve the ecological aims?	8a. Determine What Measures/Actions? Would Be Required To Address The Causes. 8b. Determine How Difficult It Would Be To Address The Source. (Restoration/Reversibility Potential). (Easy, Reasonable, Difficult, Very Difficult). Provide Reasons.
9. What should the Ecological category be for the river?	9. Considering The Ecological Objectives For The River, And Assessing The Difficulty Of Achieving These, Determine The Recommended EC And The Range Of Ecs To Be Addressed.

The range of Ecological Categories (ECs) for which flow scenarios must be supplied are guided by the groupings indicated in Table A2.2. This must be seen as guidelines to determine a *realistic* range of ECs which can be addressed within the scenario-approach.

Table A0.2 Guidelines for the range of ECs to be addressed (DWAF, 2004b).

PES	Range of ECs
A	A
A/B	A/B, B/C
B	B, C
B/C	B, B/C, C/D
C	B, C, D
C/D	B/C, C/D, D
D	C, D
D/E, E, E/F, F	D

The flow diagram below illustrates the process. The diagram blocks are discussed below according to the numbers in the flow diagram (Figure A2.3) (adapted from DWAF, 2001b).

The natural reference condition describes the condition of the river reach or delineation prior to anthropogenic change and is formulated for each component (i.e. fish, invertebrates, riparian vegetation, water quality, geomorphology, hydrology) following the process below:

- Search for the least-impacted sites, either in the same or in comparable river zones.
- Use the results of historical ecological surveys before major human impacts.
- Use historical aerial photographs.
- Use expert judgement to derive an approximation of expected natural reference conditions.

Historical information and data, and/or data from reference sites (minimally impacted sites) are used to describe the reference conditions for the channel, hydrology, biota, and the water quality. Due to data limitations and/or the absence of any existing category A resource units, the reference condition may not represent an actual natural river state, but rather the best estimate of a minimally impaired baseline state. If the river has not changed, then the present ecological state can be described as in an A category condition, and the resource is in a natural, near to pristine, or minimally impacted state. For such a resource, the present state equals the reference condition. If the river has changed, it leads to the next step.

2. How much has it changed (Categories B-F)?

The Present Ecological State (PES) is derived from a change from the perceived reference condition, which ideally relates closely to an A category condition, i.e. the expected natural condition. The PES of the river is expressed in terms of various components: habitat (habitat integrity), biological integrity (fish, riparian vegetation and aquatic invertebrates) physical integrity (geomorphology) and water quality (physico-chemistry) integrity. A process is followed to assign each component to a category level (A-F). Categories A-D are judged to be ecologically sustainable, and categories E and F indicate a current state that is ecologically unsustainable. The PES is compared with the reference conditions using:

- Biophysical surveys conducted during the project.
- Information and data from historical surveys and databases.
- Aerial photographs and videos
- Land-cover data and GIS coverages.
- Expert judgement.

Initially no integration of the different PES components into a single category was required, as this would detract from the specific details provided. However due to management requirements as well as for presentation of the river status to all stakeholders, an overall 'Ecostatus' is provided which consists of incorporating all the component categories into an Ecostatus using a rule-based model (see Section B). At all stages however, the Ecostatus can be unpacked to the specific component categories. The factors which contribute to an overall classification of the ecological status of a resource unit, are complex and highly integrated.

3. Is it still changing, if so, how, and how fast? (Trend of Change)

The Trend of Change is addressed to determine whether the biota at the time of the study have adapted to any catchment changes, or whether a process of adaptation is still in progress. Therefore, if a PES for a specific component has been assessed, is this PES likely to change in future if nothing else different happens in the catchment. These Trends of Changes can be ascribed to the causes and sources described in block 3 of the diagram (Figure A2.2). The trajectory can be stable, negative (moving away from reference conditions) or positive (back towards natural, i.e. when alien vegetation is cleared). The trend is described for each of the components for which a PES is determined, and from this information it is therefore possible to derive whether the PES evaluation reflects a stable state, or whether it is still changing under present conditions. The Trend of Change evaluation is provided as '0' for stable, '+' for positive, and '-' for degrading. The rate of change is illustrated by providing the resulting category the component would be in 5 years and/or in 20 years.

4. What caused the changes and what are the sources of the causes?

Cause (no change): Definition: A stressor that occurs at an intensity, duration and frequency of exposure that results in a change in the ecological conditions (EPA, 2000).
SOURCE : Definition: Source is the origin of a stressor. It is an entity or action that releases or imposes a stressor into the waterbody (EPA, 2000).

The impacts on the river are listed and separated into flow-related and non-flow related activities and are referred to as causes. Proximal causes observed in the system due to changes in water quality, flow and external factors are for example higher salinity, sedimentation, loss of indigenous riparian plants, flow reduction, low abundance of indigenous fish, etc.

Certain causes may be related to changes in flow, for example a decrease in fish population. Loss of indigenous riparian vegetation could, however be caused by catchment related activities such as deforestation for purposes of collecting firewood. The determination of whether the causes are flow or non-flow related is important as this influences the decision of whether mitigation solely by flow manipulation is possible and appropriate, or whether source-directed measures are necessary. For example: Flow reduction due to abstraction for irrigation could be mitigated by flow measures; loss of indigenous riparian vegetation due to overgrazing could not be mitigated by flow manipulation; water quality problems due to sewage treatment works could be mitigated by increasing flows for dilution, but it would be inappropriate to recommend Reserve flows for this purpose.

Best professional judgement of the impact of activities which have been responsible for the changes from the reference state to the PES, such as: overgrazing, irrigation, mining effluent, sewage treatment works, etc. is used.

5. Determine the Ecological Importance and Sensitivity (EIS) and Socio-cultural Importance (SI).

EIS: The Ecological Importance of a river is an expression of its importance to the maintenance of ecological diversity and functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience). Both abiotic and biotic components of the system are taken into consideration in the assessment of Ecological Importance and Sensitivity.

SI: Specific methods to determine Socio-cultural Importance have not yet been determined. At present a simple set of questions is asked to determine the dependency of people on a healthy functioning river and also to assess the cultural and tourism potential. This provides some measure of the importance.

The underlying assumptions when considering Socio-cultural Importance, within the context of Ecological Importance and Sensitivity are:
If the EIS is High or Very High, the EC should be an improvement of the PES.
If the EIS is Low or Moderate, the SI is also considered, and if also Moderate or Low, the EC should be a Category that equals the PES.
If the EIS is Low or Moderate, but the SI is High or Very High, the EC should be an improvement of the PES.

6. Considering the EIS, SI and PES, determine the ecological aims for the river.
If the Ecological Importance or Socio-cultural Importance is high or very high, the ecological aims should be to improve the river. However, the PES should also be considered to determine whether improvement is realistic and attainable. If the EIS and SI evaluation is moderate or low, the ecological aims should be to maintain the river in its PES.

7. If the sources are addressed, what needs to be done to achieve the aim?
The recommended EC must be attainable and it must therefore be considered whether the problems in the catchment can be addressed and alleviated to ensure that the ecological aims are achieved. The specialists decide to the best of their ability what would have to be done to address the causes of degradation, how effective such remedial actions might be, and how difficult they might be to achieve (for example, if a major supply dam had to be demolished to improve the river, this would be classed as 'very difficult') (O'Keeffe & Louw, 1999). It is acknowledged that this process is subjective and that ecological specialists should undertake evaluations to assess the technical possibility of achieving this.

8. Considering the difficulty of addressing the source of critical causes.

In general it can be accepted that if the PES is a C or D category or lower, and the importance is High or Very High, more effort would be indicated to attain an EC which is an improvement on the PES. However, the kind of change(s) that resulted in a particular PES may vary in terms of the possibility of reducing their impact in order to achieve restoration of the system. It follows that each of the attributes will have to be assessed in terms of the perceived possibility of restoring them to a condition where such an improvement, will lead to an improvement of the PES. Some changes may be practically irreversible within the limits of time and effort (including financial resources) required to achieve this. While five years is a commonly used time frame for many institutions and is considered a realistic period for attempting to estimate future conditions (Gonzalez, 1996), it is difficult to put limits to what can be regarded as realistic efforts.

9. Recommend attainable EC.

Based on the above, the specialists recommend and motivate for a particular EC. This is referred to as the Recommended EC (REC). Based on the REC, a range of ECs to be addressed are identified and defined.

The PES and the difficulty of addressing and alleviating the sources of integrity degradation are assessed. As the EC must be realistic and attainable, even if only in the long term, an assessment must now be made whether the aims (i.e. improvement or maintenance) can be met (see 6 above). For each component, an EC is set on this basis and then the component ECs are integrated into one value, i.e. the Ecostatus EC and if necessary, a long term EC. The integration process is the same as followed when determining the PES for the Ecostatus.

LEGAL FRAMEWORK

CONTENTS AND OUTLINE

1. GLOBAL INITIATIVES, POLICIES AND AGREEMENTS

1.1. INTRODUCTION TO WATER ON THE INTERNATIONAL AGENDA

The South African legal framework for environmental management is set in the context of international treaties and agreements.

Globally water demand and management is driven by the major forces of economics, demographic and social requirements, governance, technology and environmental imperatives (Gallopin & Rijsberman 2000). Since the African Convention on the Conservation of Nature and Natural Resources took place in September 1968 in Algiers, there have been several similar international conferences where the effect of humans on their environment were deliberated. A United Nations Conference on the Human Environment took place in Stockholm (1972), and the Ramsar Convention on Wetlands of International Importance in 1975. The United Nations Environment Programme (UNEP) resulted from the Stockholm programme. The New Delhi statement of 1990 highlighted that the goals for providing clean drinking water and adequate sanitation for all, set in 1981 for the water decade, had not been achieved. Since the Dublin conference on Water and the Environment and the Rio Earth Summit of 1992, where several international institutions and programmes for the management of international water bodies were instituted, many subsequent meetings have been held. Agenda 21, produced at Rio de Janeiro focussed on several environmental issues and specifically in Chapter 18, on water resource management. The overall goal of Chapter 18 is to ensure that the supply and quality of water should be sufficient to meet both human and environmental needs worldwide (Giordano & Wolf, 2003). At the first World Water Forum in Marrakech in 1997, where the increasing crisis in the world of water was again highlighted, a call was made for an increased effort to publicise this crisis and to increase human awareness worldwide. The widely participative global World Water Vision was initiated at this meeting and was then presented and discussed during the 2nd World Water Forum and Ministerial Conference in March 2000 in The Hague (Gallopin & Rijsberman 2000). This resulted in the creation of two agencies, the World Commission on Water for the 21st century and the Global Water Partnership. The Johannesburg Summit on sustainable development in 2002 further highlighted the seven challenges facing water resources management namely: sharing water across boundaries; ensuring basic human needs, securing food, protecting the ecosystem, managing risk, valuing water and wise governance (Giordano & Wolf, 2003).

It is interesting to note that the South African Water Act which was promulgated in 1998, but developed in the preceding 2 years, contains prescripts to address all seven of these challenges. Moreover policies prescribed by the international community to build capacity in integrated water resources management, expand stakeholder participation and improve monitoring and evaluation schemes are actively pursued by the Department of Water Affairs and Forestry. This Masters course is a focussed effort to address capacity in integrated water resources management, while catchment management agencies and water user associations are both institutions devised to improve stakeholder participation.

1.2. LIST OF TREATIES AND THEIR MAIN AIMS

1975

Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat. Signed 12 March 1975 Ratified 12 March 1975

Aims and framework: The broad aims of this convention are to stem the loss and to promote the wise use of all wetlands. The convention addresses one of the most important issues in South Africa, namely the conservation of the country's water supplies, of which marshes vleis and seeps form an integral part. A Wetland Conservation Bill has been proposed which will help to South Africa to meet the aims of the convention.

1977

UN Conference on Water, Mar del Plata

First international gathering to have major impact on both global thinking and UN programming.
Water is defined as a common good.
Basic principle: Whatever the development stage and the socio-economic situation, people have the right to have access to drinking water whose quantity and quality are equal to their basic needs.

Action Plan, recommendation: A systemic assessment of water resources should be implemented.

1981- 1990

International Drinking Water Supply and Sanitation Decade (launched by the UN)

Goal: "Provide every person with access to water of safe quality and adequate quantity, along with basic sanitary facilities, by 1990."
The quantitative goals were not achieved.

Realization:
- Comprehensive and balance country-specific approaches are needed
- Achievement of these goals will take far more time and cost than originally thought.

1990

Global consultation on Safe Water and Sanitation for the 1990's, New Delhi. organised by UNDP

"Some for all rather than more for some." New Delhi Statement
The New Delhi Statement is an appeal to all nations for concerted action to enable people to obtain two of the most basic human needs – safe drinking water and environmental sanitation.

1992

International Conference on Water and the Environment – Preparatory session to the Earth Summit, Dublin – organised by WMO

4 Dublin principles:
- Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels
- Women play a central part in the provision, management and safeguarding of water.
- Water has an economic value in all its competing uses and should be recognize as an economic good.

1992

UN Conference on Environment and Development (UNCED Earth Summit), Rio de Janeiro

Action plan: Agenda 21 Chapter 18 is dedicated to water.

Are encouraged:
- the global management of freshwater
- the integration of sectoral water plans and programmes within the framework of national economic and social policy

For the first time, development and environment are seen as strongly associated. However, water is not yet a great priority.

Creation of the Commission on Sustainable Development, to assess the followings of the Conference.

United Nations Framework Convention on Climate Change.

Aims and Framework. The convention addresses the threat of global climate change by urging governments to reduce the sources of greenhouse gasses. The ultimate objective is stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate of the world. In South Africa the energy sector has several programmes in place to improve the efficiency of coal fired thermal power systems.

1994
Ministerial Conference on Drinking Water Supply and Environmental Sanitation, Noordwijk
Action programme: "To assign high priority to programmes designed to provide basic sanitation and excreta disposal systems to urban and rural areas."

1994
International Conference on Population and Development, Le Caire.
Population, environmental and poverty eradication factors should be integrated in sustainable development policies.

1996
UN Conference on Human Settlements (Habitat II), Istanbul
It is necessary to promote healthy living environments, especially through the provision of adequate quantities of safe water and effective management of waste.

1997
First World Water Forum, Marrakech
Water runs the risk of being considered as a marketable and expensive good. We should then pay attention that water would not be the object of a war, like petrol.

Priorities:
- water and sanitation
- shared water management
- ecosystem conservation
- gender equality
- efficient use of water.

United Nations Convention on the Law of the Non-Navigable Uses of International Watercourses 1997

2000
2nd World Water Forum, La Hague
For the first time, it is recognized that better governance and an integrated water resources management is needed. Water should become everybody's business. Water security becomes as crucial as hunger and environment protection in the world. Water is defined as an absolutely necessary element to the life and health of both humans and ecosystems, and a fundamental condition to countries' development.

Presentation of the World Water Vision, coordinated by the WWC. (Available electronically)

Key-messages:
- Involve all stakeholders in integrated water resources management
- Move towards full-cost pricing of water services for all human uses
- Increase public funding for research and innovation in the public interest
- Recognise the need for co-operation to improve integrated water resources management in international basins
- Massively increase the investments in water

The Ministerial Declaration identified meeting basic water needs, securing food supply, protecting ecosystems, sharing water resources, managing risks, valuing water and governing water wisely as the key challenges for our direct future. Full-cost pricing of water is contested, hence not present in the declaration.

2000
United Nations Millennium Declaration

Definition of the Millennium Development Goals:
"Halve, by 2015, the proportion of people who are unable to reach or to afford safe drinking water."

Goals:
By 2015, using 1990 as a benchmark:-

- Halve the proportion of people living in extreme poverty and hunger
- Halve the proportion of people without access to safe drinking water (with sanitation added at the World Summit on Sustainable Development, 2002)
- Achieve universal primary education
- Empower women and promote equity between women and men
- Reduce under-five mortality by two-thirds
- Reduce maternal mortality by three-quarters
- Reverse the spread of killer diseases, especially HIV/AIDS and malaria
- Ensure environmental sustainability
- Develop a global partnership for development, with targets for aid, trade and debt relief.

2001
International Conference on Freshwater, Bonn – convened by the Government of the Federal Republic of Germany
Water is recognised as a key to sustainable development.

Bonn keys:
- The first key is to meet the water security needs of the poor.
- Decentralisation is a key. The local level is where national policy meets community needs.
- The key to better water outreach is new partnerships.
- The key to long-term harmony with nature and neighbour is cooperative arrangements at the water basin level, including across waters that touch many shores.
- The essential key is stronger, better performing governance arrangements.

Bonn recommendations for action:
- Governance
- Mobilising financial resources
- Capacity building and sharing knowledge

2002
World Summit on Sustainable development, (Rio + 10), Johannesburg, Convened by the UN

New affirmation of the Millennium Development Goals. Sanitation issue is added.

The Johannesburg Plan of implementation (JPoI) affirmed the Millennium Development Goals for water, and also agrees to develop integrated water resources management and water efficiency plans by 2005, through actions to, among other things -

- Develop and implement national/regional strategies, plans and programmes with regard to integrated river basin, watershed and groundwater management, and introduce measures to improve the efficiency of water infrastructure to reduce losses and increase recycling of water
- Employ the full range of policy instruments
- Improve the efficient use of water resources and promote their allocation among competing uses in a way that gives priority to the satisfaction of basic human needs and balances the requirement of preserving or restoring ecosystems and their functions
- Develop programmes for mitigating the effects of extreme water-related events
- Support the diffusion of technology and capacity-building for non-conventional water resources and conservation technologies
- Facilitate the establishment of public-private partnerships.

Goal 7: Ensure environmental sustainability

Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation.

Plan of implementation:
- Develop and implement efficient household sanitation systems
- Improve sanitation in public institutions, especially schools
- Promote safe hygiene practices
- Promote education and outreach focused on children, as agents of behavioural change
- Promote affordable and socially and culturally acceptable technologies and practices
- Develop innovative financing and partnership mechanisms
- Integrate sanitation into water resources management strategies.

2003
3rd World Water Forum, Kyoto
Publication of the report World Water Actions, coordinated by the WWC.
The 3000 actions studied prove that significant progress has been made since the 2nd World Water Forum, showing that it is both possible to meet the water challenges and that the effort should continue.

Priorities:
Governance, integrated water resources, gender, pro-poor policies, financing, cooperation, capacity-building, water use efficiency, water pollution prevention, disaster mitigation.

A Panel of financial experts, formed in 2002 and chaired by Michel Camdessus, presented its solutions to the global financial needs of the water sector, estimated at $US180 billion. These conclusions were contested, but still integrated into the Water Plan of the G8 Evian Summit in 2003.

During the Ministerial Declaration, a "*Portfolio of Water Actions*" was presented, gathering all political commitments already engaged.

2003
International Water Year

2006
4th World Water Forum, Mexico

"Local Actions for a Global Challenge"
A novel local focus was developed as a means to confront global water problems. An important space was designed for the participation of local actors, so they contributed with experiences and knowledge.

2005-2015
International Decade for Action. Water for Life? (launched by the UN)

Goals:
- Focus more on water-related issues at all levels and on the implementation of water-related programmes and projects
- Ensure the participation and involvement of women in water-related development efforts
- Deepen the cooperation at all levels

Priorities: scarcity, sanitation access, disaster prevention, pollution, trans-boundary water issues, water, sanitation and gender, capacity-building, financing, valuation, integrated water resources management, Africa as a region for priority action.

1.3. OTHER TREATIES AND CONVENTIONS THAT IMPACT WATER RESOURCES

POPs Convention on persistent pollutants: under negotiation.
Aims and framework. The objectives is to take international action to minimise the risks associated with persistent chemicals that have already been identified and are proven to pose a threat to the environment and to human health trough their toxicity and persistence. Also to further Identify additional

POPs as candidates for future international action. In southern Africa special efforts has been made so far to co-ordinate and collaborate with SADC countries.

1995 Allied to convention on Climate Change is the **Convention to Combat Desertification** signed in 1995, ratified in 1997.

1991
Bonn Convention (CMS). **Convention on the conservation of migratory species** of wild animals urging cooperation among nations to conserve all migratory terrestrial aerial and marine species. South African is an active participant and is in the process of drafting an African-Eurasian agreement regarding migratory birds for which we are an important destination.

1993
Convention on Biological Diversity.
Main aim is to conserve biological diversity and to promote the sustainable use of living natural resources worldwide. It also aims to bring about the sharing of the benefits arising from the utilisation of natural resources**.** The NEM Biodiversity Act 2004 is a direct response to this convention.

1.4 AGREEMENTS WITH SOUTH AFRICAN DEVELOPMENT COMMUNITY (SADC) COUNTRIES

Introduction

To pre-empt potential conflict and resolve existing disputes, the Institute of International Law has published a set of basic recommendation in Madrid Declaration on 1911. To refine and expand these guidelines the Helsinki Rules were developed in 1966 by the international Law association. The Helsinki Rules outlines principles related to the "equitable utilization" of shared watercourses and a commitment not to cause "substantial injury" to co-riparian states (Caponera 1985).Through region-specific guidelines neighbouring states such as SADC have formulated agreements and protocols supporting collaborative water resource initiatives. SADC member states have established the Protocol on Shared Water courses in the Southern African Development community in 2000 based on the United Nations Convention on the law of the non-navigable uses of international watercourses 1997. It is at the basin scale that the greatest development in cooperative water management has been seen. A 1969 agreement between South Africa (now Namibia) and Portugal on the Kunene River (Angola) allows for "humanitarian" diversions solely for human and animals in south west Africa (Namibia). Because conditions and priorities in basins can change over time it is very important for treaties to be flexible and adaptable

Table 1. Overview of treaties between South Africa and a neighbouring state(s) regarding water use/management

DATE	STATE(S)	BASIN	TREATY NAME
1983	Mozambique, Swaziland	Umbeluzi	Tripartite permanent technical committee
1983	Mozambique, Swaziland	Shared waters	Agreement to establish a tripartite permanent technical committee
1983	Mozambique, Swaziland	Limpopo	Agreement to establish a tripartite permanent technical committee
1984	Mozambique, Portugal	Zambesi	Agreement relative to Cahora Bassa project
1986	Lesotho	Orange/Senqu	Treaty on Lesotho Highlands water Project
1992	Namibia	Orange	Agreement to establish permanent water commission
1992	Swaziland	Maputo/Komati	Treaty on establishment and functioning of a joint water commission,

1991 to 1999	Lesotho	Orange	Protocols IV, VI and various agreements to implement above treaty on Lesotho Highlands water Project; governance of project
Source: *Atlas of International Freshwater Agreements 2000*			

Guidelines for successful co-operative water management structure:

1. Adaptable management structure
2. Clear flexible criteria for water allocation and quality
3. Equitable distribution of benefits
4. Detailed conflict resolution mechanisms.

(*For more details see the Atlas of International Water Agreements*).

NEPAD Water and Sanitation Sector Policy Objectives:

- Ensure sustainable access to safe and adequate clean water supply and sanitation, especially for the poor
- Plan and manage water resources to become a basis for national and regional co-operation and development
- Systematically address and sustain ecosystems, biodiversity and wildlife
- Co-operate on shared rivers among member states
- Effectively address the threat of climate change
- Ensure enhanced irrigation and rain-fed agriculture to improve agricultural production and food security (*source NWRS*).

2. NATIONAL LEGISLATIVE FRAMEWORK

Chapter 1 of the National Water Resources Strategy provides an admirable overview of the legislative landscape of South Africa. In addition Chapter 5 lays out the imperatives for intra-governmental alignment and coordination in planning and strategy development.

2.1. OVERVIEW OF THE NATIONAL LEGISLATIVE LANDSCAPE.

NATIONAL WATER RESOURCE STRATEGY CHAPTER 1 – Water Policy, Water Law and Water Resources Management

2.1.1 The National Water Policy

Government policy since 1994 has focused strongly on equitable and sustainable social and economic development for the benefit of all South Africa's people. However, many existing laws, including the law relating to water, were not at all appropriate to achieving these objectives. The National Water Policy for South Africa (NWP), adopted by Cabinet in 1997, was introduced in response to the new direction set by government and as part of a thorough review of existing water law. The NWP was preceded by the development of 28 Fundamental Principles and Objectives for a New South African Water Law, which are reproduced in full in Appendix A. Principle 7 is particularly relevant: it states that –

> *The objective of managing the quantity, quality and reliability of the Nation's water resources is to achieve optimum, long-term, environmentally sustainable*[1] *social and economic benefit for society from their use.*

Three fundamental objectives for managing South Africa's water resources, which are firmly grounded in the provisions of the Bill of Rights of the Constitution of South Africa, 1996 (No. 108 of 1996) arise from the Principles. These are the following -

- **To achieve equitable access to water**, that is, equity of access to water services, to the use of water resources, and to the benefits from the use of water resources.
- **To achieve sustainable use of water** by making progressive adjustments to water use with the objective of striking a balance between water availability and legitimate water requirements, and by implementing measures to protect water resources.
- **To achieve efficient and effective water use** for optimum social and economic benefit.

Important proposals to facilitate achievement of the NWP's objectives include the following:-

- Water will be regarded as an indivisible national asset. National government will act as the custodian of the nation's water resources and its powers in this regard will be exercised as a public trust.
- Water required to meet basic human needs and to maintain environmental sustainability will be guaranteed as a right, whilst water use for all other purposes will be subject to a system of administrative authorisations.
- The responsibility and authority for water resource management will be progressively decentralised by the establishment of suitable regional and local institutions. These will have appropriate community, racial and gender representation to enable all interested persons to participate.

Implementation of the Policy proposals will fundamentally change the ways in which South Africa's water resources are managed.

2.1.2. The National Water Act

(The purpose of the National Water Act, which embodies the NWP's objectives for water resources management, is given in section 2 of the Act – see Appendix B)

The National Water Act, 1998 (No. 36 of 1998 – the Act) derives directly from the Fundamental Principles and Objectives for a New South African Water Law and the NWP's proposals for managing water resources[2]. The Act is the principal legal instrument relating to water resources management in South Africa and contains comprehensive provisions for the protection, use[3], development, conservation, management and control[4] of South Africa's water resources. It is these legal provisions that enable the proposals in the NWP to be implemented[5].

The Act is not, however, the only instrument through which the objectives of the NWP will be achieved. Since water is essential for all life and human endeavours, there are many other policies and laws, administered by a number of departments in all spheres of government, which govern activities dependent on water, or affect water resources. The 1994 Water Supply and Sanitation Policy White Paper (now superseded by the Strategic Framework for Water Services, 2003)[6], and the Water Services Act, 1997 (No. 108 of 1997), which deal with the provision of potable water and sanitation services, are particularly closely related to the Act.

In addition, the management of water as a renewable natural resource must be carried out in a manner consistent with the broad environmental policy of government and within the framework of environmental legislation, that is, the National Environmental Management Act, 1998 (No. 107 of 1998), and those parts of the Environment Conservation Act, 1989 (No. 73 of 1989), that have not yet been repealed by the more recent legislation.

Successful water resources management will therefore depend on co-operation among all spheres of government, and the active involvement of water users and other organisations and stakeholders. The necessity for an integrated approach to water resources management is discussed later in this chapter, while the relationships between water policy and law, and other relevant policies and laws, are discussed in Chapter 5.

Many of the Act's provisions are described briefly in this document in order to provide the context for subsequent explanations of their practical application. An important provision, which is key to the achievement of Policy objectives, is the establishment by the Act of national government, acting through the Minister of Water Affairs and Forestry (the Minister), as the public trustee of the nation's water resources. (Public trusteeship is described in section 3 of the Act – see Appendix B). This provision resolves a significant difficulty of the Water Act, 1956 (No. 54 of 1956)[7], which was based largely on the riparian system of water rights[8] and resulted in no single organisation or institution being able to exercise complete authority over water in South Africa. Public trusteeship does not mean that government owns the water, since the Preamble to the Act recognises that "water is a natural resource that belongs to all people", but it does mean that the Minister has overall responsibility and, importantly, the authority to ensure that all water everywhere in the country is managed for the benefit of all persons. This responsibility includes ensuring that water is allocated equitably, and that environmental values are promoted.

2.1.3 The National Water Resource Strategy

(The Act requires the National Water Resource Strategy to "… set out the strategies, objectives, plans guidelines and procedures of the Minister and institutional arrangements relating to the protection, use, development, conservation, management and control of water resources … ". The Act's requirements are described in sections 5, 6 & 7, which are reproduced in full in Appendix C).

The Act requires the Minister[9] to establish a National Water Resource Strategy (NWRS) as soon as reasonably practicable by publishing a Notice in the *Government Gazette*.

The NWRS must provide information about the ways in which water resources will be managed and the institutions to be established. It must also provide quantitative information about the present and future availability of and requirements for water in each of 19 water management areas (see Chapter 2, Fig. 2.2, Part 5 of Chapter 3, and Appendix E), and propose interventions by which these may be reconciled. The NWRS must also quantify the proportion of available water in each water management area that falls under the direct control of the Minister in terms of her or his national responsibilities[10].

The Purposes of the National Water Resource Strategy

The national framework for managing water resources

After its establishment the NWRS will provide the framework within which water resources will be managed throughout the country, because section 5(3) of the Act states that South Africa's water resources must be protected, used, developed, conserved, managed and controlled in accordance with the NWRS.

The NWRS will be legally binding since section 7 specifies that the Minister, the Director-General, other organs of State and water management institutions must give effect to its provisions when exercising any power or performing any duty in terms of the Act.

Although the NWRS is intended to be an enduring framework for water resources management, it may be amended to suit changing circumstances during the reviews specified in section 5(4)(b). However, such amendments may only be made after mandatory consultations with stakeholders. Reviews must take place at least every five years.

The framework for the preparation of catchment management strategies

A catchment management strategy is the framework for water resources management in a water management area. The NWRS provides the framework within which all catchment management strategies will be prepared and implemented in a manner that is consistent throughout the country. In particular, in terms of section 9(b), a catchment management strategy must not be in conflict with the NWRS. It is anticipated that insights and information gathered during the development of catchment management strategies will inform the regular review of the NWRS, enabling it to remain relevant to local conditions and circumstances.

In this regard an important component of the NWRS is the data and information provided in Chapter 2 and Appendix D, which quantify water availability and water requirements in each water management area. Consideration of this information in conjunction with the Minister's national responsibilities enables the amount of water for which each catchment management agency will be responsible to be determined.

Provision of information

In accordance with the general requirement for transparent and accountable public administration in all spheres of government, the Act requires the Minister to ensure that all aspects of water resource management that will affect other organs of State, water users and the public in general are brought to their attention. The NWRS is the vehicle by which South African society is informed of the Minister's intentions concerning water resource management. Every subsequent edition of the NWRS must also be made publicly available.

In addition, each edition of the NWRS may be formally established only when the Minister is satisfied that everyone who wishes to comment on the Proposed Strategy has been afforded an opportunity to do so, that all comments have been given careful consideration and that all changes arising from this process have been incorporated in the revised Strategy.

Identification of development opportunities and constraints

The water availability information presented in the NWRS – for each water management area in Chapter 2, and for subdivisions of each area in Appendix D – makes it possible to identify the areas of the country in which water resources are available to support social and economic development initiatives, as well as areas in which limited water resources may be a constraint to development.

Appendix D provides a broad strategic perspective for each water management area in which, among other things, indications are given of possible developments for which available water might be used. These are however by no means definitive, and the possible opportunities and constraints will be investigated in more detail in the process of developing and refining the catchment management strategies.

It must also be emphasised that the purpose of the NWRS is to strategically direct the management of water resources from a national perspective, and the water availability information is therefore relatively coarse. The information is not appropriate, nor is not intended to be used, for planning individual projects. These must be investigated using more detailed information, as well as being the subject of the impact assessments required by environmental legislation.

2.1.4. Integrated Water Resources Management

(The need for an integrated approach to water resources management is discussed in the National Water Policy. It is also explicitly acknowledged in the Preamble to the Act, which recognises that water occurs in many different forms which are all part of a unitary, inter-dependent cycle. The Preamble also recognises the need for the integrated management of all aspects of water resources).

There is increasing understanding internationally that water resources can be successfully managed only if the natural, social, economic and political environments in which water occurs and is used are fully taken into consideration.

Integrated water resources management (IWRM) may be defined as a process which promotes the co-ordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. IWRM therefore aims to strike a balance between the use of resources for livelihoods and conservation of the resource to sustain its functions for future generations, and promotes social equity, environmental sustainability and economic efficiency. Because the resource cannot be considered separately from the people who use and manage it, a balanced mix of technological and social approaches must be used to achieve integrated management.

The dimensions of integrated water resources management

Freshwater is a complex ecological system that has a number of dimensions. Surface water, groundwater, quantity and quality are all linked in a continuous cycle – the hydrological cycle – of rainfall, runoff from the land and infiltration into the ground, and evaporation from the surface back into the atmosphere. Each component may influence the other components and each must therefore be managed with regard to its inter-relationships with the others.

Water as a system also interacts with other systems. Human activities such as land use, waste disposal and air pollution can have major impacts on the quantity and quality of water available for human use, while the abstraction and storage of water and the discharge of waste into water resources can impact on the quality of the natural environment. These interactions must be considered and addressed by water resource managers.

Taking an even broader view, water must also be managed in the full understanding of its importance for social and economic development.

It must also be borne in mind that South Africa shares four major river basins, which together cover about 60 per cent of South Africa's land area and account for around 40 per cent of the total surface runoff, with neighbouring countries. The NWP accords high priority to harmonious relations over water with neighbouring states, and the NWA provides for water to be made available to meet international rights and obligations. The international dimensions of IWRM are therefore critically important for South Africa. The framework within which international water-related issues are addressed is discussed in more detail in Chapter 5.

Co-operative planning and management of water resources

The complexity of managing water as a system and its interactions with other systems is further compounded by the large number of institutions and organisations – both domestic and international – involved in the administration and management of the various systems.

The Department of Water Affairs and Forestry (the Department) is currently responsible for water resources management at national level. The Act requires the Department to ensure that its programmes are in accordance with government policy and are co-ordinated with relevant programmes of other national departments (see Chapter 5). Similarly, other departments have a responsibility to ensure that, where relevant, their programmes take account of the realities of South Africa's water situation. This is particularly important when it comes to planning developments that depend on water for their success. In these instances the availability of water must be factored into plans at the beginning of the development process. One of the purposes of the NWRS is therefore to provide sufficient information about water resources to facilitate coherent and holistic planning, as well as establishing a platform for informed interactions between water resource managers and development planners in other sectors.

In terms of the Act and the NWRS the Department is in the process of establishing 19 catchment management agencies, each operating in a defined water management area, to manage water resources at a regional level. These agencies will be responsible, among other things, for ensuring that there is consonance between their water-related plans and programmes and the plans and programmes of all other role players in the catchments they manage. The agencies will therefore have to establish co-operative relationships with a range of stakeholders, including other water management institutions, water services institutions, provincial and local government authorities, communities, water users ranging from large industries to individual irrigators, and other interested parties.

The success of integrated water resources management will therefore depend heavily on the development of a framework of co-operation among all relevant institutions, organisations and individuals. This co-operative framework must facilitate planning at all geographic scales ranging from international projects to activities on individual smallholdings, and the co-ordination of programmes.

Integrated water resources management, poverty and gender

The need for an integrated approach to managing water resources has been articulated at a number of international meetings during the last three decades, each of which has stressed the importance of water for human survival, health and productivity. The two most recent global forums – the United Nations Millennium Summit, September 2000, and the World Summit on Sustainable Development, August 2002 – reaffirmed that people must be at the centre of the sustainable development and use of water resources. Resolutions, agreements and targets arising from these events emphasised, among other things, the importance of water in addressing poverty issues, and the importance of factoring gender considerations into all aspects of water management. In an African context these sentiments are echoed in the policy objectives of the New African Partnership for Development and the Southern African Vision for Water, Life and the Environment in the 21st Century[11].

IWRM does not provide a complete solution to all the dimensions of poverty, but no strategy for poverty eradication will be successful unless it includes strategies for managing water. The provision of basic water and sanitation services is an essential element of water's contribution to poverty eradication, because it addresses issues of health and hygiene, and the effort required in collecting and carrying water from remote, often polluted water sources. Providing free basic services goes some way to making water affordable to the poor. Basic water services do not however make adequate provision for productive livelihoods

The rural poor, many of whom do not yet have access to reliable water supplies or sanitation services, often rely for their livelihoods on cultivating food, gathering natural products and other water-dependent activities. But their water sources are often unreliable and insufficient, threatened by droughts and floods, and eroded or degraded by developments over which they have no control.

In South Africa water is regarded as a social, environmental and economic good. Nevertheless, after basic human needs and the requirements for maintenance of ecosystems have been satisfied, there will inevitably be competition for access to the remaining available water. It is essential that water-related policies are implemented in ways that give special attention to ensuring that the poor can meet their needs, and that they are given a voice in decisions that affect them.

In order to successfully address issues of equity IWRM must also consider gender – that is, the implications for men and women of legislation, polices, and implementation strategies and programmes, and the measures required to enable them to participate in water resources management on an equal footing. It has also been shown by international and local experience that poverty eradication initiatives are greatly enhanced by the involvement of women in all aspects of water resources management at all levels.

Women and men bring different perspectives and viewpoints to water management, and play different roles. There are however often considerable imbalances between women and men, in for instance their levels of education and the influence they are able to exercise, and these imbalances must be addressed in initiatives to capacitate the two groups to participate in decision-making. Poor black women are one of the most marginalised groups in South African society. Conscious efforts must therefore be made to involve them in water resources management processes and to ensure that the management of water contributes to meeting their needs.

Careful analysis will be required of water-related developments, whether they involve the construction of infrastructure or relate to demand-side management, to take into account the benefits and costs that accrue to women and men, and to ensure that one group does not benefit at the expense of the other. Special emphasis must be placed on the involvement of women in water resources management institutions and in policy development.

It is not possible to separate issues of poverty, race and gender, but it is necessary to understand how they interact with and impact each other. An integrated approach to managing water resources will contribute to building a society free from poverty and discrimination.

Notes to Chapter 1

1 In this context "environment" means: The surroundings within which humans exist, and that are made up of (i) the land, water and atmosphere of the earth, (ii) micro-organisms, plant and animal life, (iii) any part or combination of (i) and (ii) and the inter-relationships among and between them and (iv) the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being. (National Environmental Management Act, 1998, Definitions, section 1(xi)).

2 "Water resource" means surface water found in watercourses (rivers and streams), impoundments (dams), wetlands and estuaries, and groundwater found in underground aquifers (see section 1(1)(xxvii)).

3 The Act's definition of water use (section 21) is broad. It relates to the quantitative use of water, as well as to uses that affect water quality and the quality of the resource itself. Accordingly, water use includes abstraction and storage, all aspects of the discharge of wastes into water resources, making changes to the physical structure of rivers and streams, and use for recreational purposes. Water use also includes certain land-based and instream activities that may affect the quantity or quality of water in the resource (stream flow reduction activities, and controlled activities such as hydro-electric power generation and disposal of waste onto land). Water use is described in more detail in Part 2 of Chapter 3.

4 Throughout the NWRS "managed" is used as shorthand for the Act's "protected, used, developed, conserved, managed and controlled".

5 In the remainder of this document the expressions "implementing the Act", "implementing the Act's provisions" and similar are used as shorthand for "implementing the National Water Policy through the provisions of the National Water Act".

6 The 1994 Water Supply and Sanitation Policy, which focused largely on the Department's direct role in the delivery of basic services for households, has been reviewed to account for the completion of the local government transformation process and the establishment of the local government legislative framework. Local Government can now assume full operational responsibility for its constitutional mandate for water and sanitation services, and the Department's role must change from direct service provision to that of the sector leader, regulator and supporter. The Strategic Framework for Water Services was approved by Cabinet in September 2003. It sets out a comprehensive approach to the provision of water services to eliminate the backlog in basic water services and progressively improve levels of service over time in line with the original aims of the Reconstruction and Development Programme. It also focuses on developing the institutional framework best suited to support Local Government in its responsibilities. The White Paper on Basic Household Sanitation (2001) will also be amended to ensure that it is compatible with the Strategic Framework

7 The National Water Act, 1998 (No. 36 of 21998) repeals the Water Act, 1956 (No. 54 of 1956).

8 Riparian system: Those who owned land next to rivers and streams had exclusive and in-perpetuity rights to the use of (but not ownership of) a portion of the water which flowed in them. Those who owned land under which groundwater occurred also effectively had exclusive use of the water. This was "private" water, over which the State had little or no control.

9 The Act imposes many duties and responsibilities on the Minister, but for practical reasons allows her or him to delegate most of them to others. See also Part 5 of Chapter 3.

[10] The Minister's national responsibilities include the Reserve, water to meet international obligations, a "contingency" to meet projected future water needs (which may, for instance, require transfers of water between water management areas) and water use of strategic importance.

[11] Summary of water-related outcomes from international forums:-

Millennium Development Goals (*see Section1***)**

World Summit on Sustainable Development Plan of implementation (*see Section1***)**

NEPAD Water and Sanitation Sector Policy Objectives (*see Section 2***)**

Southern African Vision for Water, Life and the Environment in the 21st Century:

A southern Africa where there is equitable and sustainable planning, use, development and management of water resources for poverty alleviation, local and national socio-economic development, regional co-operation and integration, and the environment.

3. NATIONAL LEGISLATION
3.1 OVERARCHING LEGISLATION.

- **The Constitution**
- **National Environmental Management Act**

These two acts together with Agenda 21 set the context within which the National Water policy and Act was formulated. Many sections of a statute deal with rules of administration of the relevant department and minister and these will not be reproduced here. However copies of all the Acts are to be found on the sa.gov website. Only those sections relevant to water resources management and protection will be dealt with in this document.

3.1.2. THE CONSTITUTION OF SOUTH AFRICA (ACT 108 OF 1996)

South Africa has adopted a rights-based approach to governance, as reflected in the country's Constitution and Bill of Rights. Access to clean water is recognised as a human right. Access to water and the health of water directly affects everyone, so everyone should have the opportunity to participate in water management. (for a more in-depth discussion see Module 1(c) PARTICIPATION)

Chapter 2 has many relevant provisions that relate to the right to water:

Section 7(2): Rights

The State must respect, protect, promote and fulfil the rights in the Bill of Rights

Section 9: Equality

1) Everyone is equal before the law.
2) Equality includes the full and equal enjoyment of all rights and freedoms.

Article 21 of South Africa's Constitution states: "everyone has the right to take part in the government of his/her country directly or through freely chosen representatives."

Section 24 titled Environment stipulates that:

Everyone has the right-

(a) to an environment that is not harmful to their health or well-being; and

(b) to have the environment protected, for the benefit of present and future generations, through reasonable legislature and other measures that-

(i) prevent pollution and ecological degradation;
(ii) promote conservation; and
(iii)secure ecological sustainable development and use of natural resources while promoting justifiable economic and social development.

There are five principal acts that provide for the protection or conservation, development and management of the water resource and its biodiversity. In addition to the environmentally focussed acts discussed below, those which govern the responsibilities of local government may also affect water resource management and should be administered in alignment with or in subservience to these Acts.

Section 26: Health Care, Food, Water and Social Security

1) Everyone has the right to have access to sufficient food and water
2) The State must take reasonable legislative and other measures, within its available resources, to achieve the progressive realization of each of these rights.

Section 39: Interpretation Clause

1) When interpreting the Bill of Rights, a court, tribunal or forum:
a) must promote the values that underlie an open and democratic society based on human dignity, equality, and freedom;

b) must consider international law; and
c) may consider foreign law.

Section 8:
The Constitution enshrines rights and responsibilities with regard to local government that may have bearing on the water resource management responsibilities and responses of local government i.e. section 152 (objects of local government) and section 153 (developmental duties).

Recurring themes in the Constitution and all the environmental acts are the rights of access to environmental goods and services by citizens, provision for consultation and participation of ordinary citizens in the drafting of policy and formulation of management plans. Furthermore provision is made for education of citizens in environmental and water conservation matters and for research programmes (in some acts). Provision is also made for environmental rehabilitation and remediation measures and the cost recovery thereof.

3.1.3. THE NATIONAL ENVIRONMENTAL MANAGEMENT ACT (NEMA 107 OF 1998)

NEMA provides procedures and institutions for integrated, cooperative governance on national and provincial scale on matters affecting the environment (the Constitution, section 41). Water resources management is subject to the requirements of national environmental legislation as contained in the NEMA and those parts of the Environment Conservation Act, 1989 (No. 73 of 1989) (ECA) that have not yet been repealed by NEMA.
The principles on which the NEMA is based are wide-ranging (section 2 (1- 4r) and cover many aspects of environmental management, impacts, measures to limit negative impacts, but also details the constitutional rights of people. It makes provision for the drafting and implementation of integrated environmental management plans at all levels of government. In Section 28 of NEMA the duty of care for the prevention, minimising and remediation of environmental damage such as pollution and degradation is made provision for.
The Department of Water Affairs and Forestry is therefore obliged not only to ensure that all activities related to the management of water forestry resources are carried out in accordance with the requirements of the Act, but also that they comply with the requirements of NEMA, ECA and other related environmental legislation.

Chapter 5 of NWRS is essential reading to understand the interrelationships required between the different government departments and their policies and strategies.

3.2 NATIONAL LEGISLATION REGARDING WATER RESOURCE PROTECTION AND MANAGEMENT

3.2.1 NATIONAL WATER ACT, 1998 (ACT 36 OF 1998) – STRUCTURE AND FUNCTIONS

INDEX

CHAPTER 1: INTERPRETATION AND FUNDAMENTAL PRINCIPLES
- **1.** Definitions and interpretation
- **2.** Purpose of Act
- **3.** Public trusteeship of nation's water resources
- **4.** Entitlement to water use

CHAPTER 2: WATER MANAGEMENT STRATEGIES
Part 1: National water resource strategy
- **5.** Establishment of national water resource strategy
- **6.** Contents of national water resource strategy
- **7.** Giving effect to national water resource strategy

3.2.1.1. Summary of National Water Act

The National Water Act is a wide-ranging Act as it legislates the development, use and protection of water resources. Sustainability is suggested in the provision that basic human needs of present and future generations should be met in an equitable manner, embodied in the slogan **"Some, for all, forever"**

Some – acknowledges that water is a limited resource,
for all – emphasises fairness of access to using the resource,
forever – indicates wise use so the resource is not damaged for the future.

While facilitating social and economic development, at the same time a degree of protection for aquatic and associated ecosystems and their biological diversity is afforded as stipulated in Chapter 3. The protection of water resources is fundamentally related to their use, development, conservation, management and control. Parts 1, 2 and 3 of this Chapter lay down a series of measures, which are together, intended to ensure the comprehensive protection of all water resources to a greater or lesser degree. This is achieved through "the ecological reserve" and the "the basic human needs reserve". The basic human needs reserve provides for the essential needs of individuals and includes water for drinking, for food preparation and for personal hygiene. The ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the ecological or management class that is assigned to that particular part of the resource. Once the Reserve is determined for a water resource by the minister it is binding in the same way as the class and the resource quality objectives (sections 12-18).

The prevention of pollution of water resources and measures to remedy the effects of pollution of water resources are dealt with in section 19 and stipulates that the person(s) who owns, controls, occupies or uses the land in question or a catchment management agency to be responsible for taking measures to prevent pollution of water resources. The catchment management agency can recover all reasonable costs from the responsible persons. Sections 36-38 ***can*** allow the Minister, to regulate land-based activities, which reduce stream flow, after public consultation. Although this section is aimed mainly at forestry industry, it may be possible to declare other similar activities as stream flow reduction activities depending the extent of stream flow reduction, its duration, and its ***impact*** the relevant water resource and on other water users.

Section 2: Purpose of the Act is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors –

- meeting the basic human needs of present and future generations;
- promoting equitable access to water;
- redressing the results of past racial and gender discrimination;
- promoting the efficient, sustainable and beneficial use of water in the public interest;
- facilitating social and economic development;
- providing for growing demand for water use;
- **protecting aquatic and associated ecosystems and their biological diversity;**
- **reducing and preventing pollution and degradation of water resources;**
- **meeting international obligations;**
- promoting dam safety;
- managing floods and droughts,
- and for achieving this purpose, to establish suitable institutions and to ensure that they have appropriate community, racial and gender representation.

3.2.1.2 Extracts from the Act relating to resource protection and management.

Those section that have direct bearing of resource protection are given in full and those parts that are allied but nor direct are summarised from the Act. The most important sections are rendered bold. It is advisable to read Chapter 3 of the NWRS in conjunction with this part of the Act.

NWA CHAPTER 3
PROTECTION OF WATER RESOURCES
The protection of water resources is fundamentally related to their use, development, conservation, management and control. Parts 1, 2 and 3 of this Chapter lay down a series of measures that are together intended to ensure the comprehensive protection of all water resources. These measures are to be developed progressively within the contexts of the national water resource strategy and the catchment management strategies provided for in Chapter 2. Parts 4 and 5 deal with measures to prevent the pollution of water resources and measures to remedy the effects of pollution of water resources.

Part 1: Classification system for water resources deals with the prescription of a classification system
Part 2: Classification of water resources and resource quality objectives prescribes the process of class determination for water resources and resource quality objectives and giving effect to these classes for the water resource and the resource quality objectives
Part 3: The Reserve determination and giving effect to these.
Part 4: Prevention and remedying effects of pollution

Part 1: Classification system for water resources
Part 1 provides for the first stage in the protection process, which is the development by the Minister of a system to classify the nation's water resources. The system provides guidelines and procedures for determining different classes of water resources.

Prescription of classification system
12. (1) As soon as is reasonably practicable, the Minister must prescribe a system for classifying water resources.
(2) The system for classifying water resources may –
(a) establish guidelines and procedures for determining different classes of water resources;
(b) in respect of each class of water resource –
(i) establish procedures for determining the Reserve;

(ii) establish procedures which are designed to satisfy the water quality requirements of water users as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource;

(iii) set out water uses for instream or land-based activities which activities must be regulated or prohibited in order to protect the water resource; and

(c) provide for such other matters relating to the protection, use, development, conservation, management and control of water resources, as the Minister considers necessary.

Part 2: Classification of water resources and resource quality objectives

Under Part 2 the Minister is required to use the classification system established in Part 1 to determine the class and resource quality objectives of all or part of water resources considered to be significant. The purpose of the resource quality objectives is to establish clear goals relating to the quality of the relevant water resources. In determining resource quality objectives a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other. Provision is made for preliminary determinations of the class and resource quality objectives of water resources before the formal classification system is established. Once the class of a water resource and the resource quality objectives have been determined they are binding on all authorities and institutions when exercising any power or performing any duty under this Act. (See draft position paper on the development of a national water resource classification system- Appendix 2)

Determination of class of water resources and resource quality objectives

13. (1) As soon as reasonably practicable after the Minister has prescribed a system for classifying water resources the Minister must, subject to subsection (4), by notice in the *Gazette*, determine for all or part of every significant water resource –

(a) a class in accordance with the prescribed classification system; and

(b) resource quality objectives based on the class determined in terms of paragraph *(a)*.

(2) A notice in terms of subsection (1) must state the geographical area in respect of which the resource quality objectives will apply, the requirements for achieving the objectives, and the dates from which the objectives will apply.

(3) The objectives determined in terms of subsection (1) may relate to –

(a) the Reserve;

(b) the instream flow;

(c) the water level;

(d) the presence and concentration of particular substances in the water;

(e) the characteristics and quality of the water resource and the instream and riparian habitat;

(f) the characteristics and distribution of aquatic biota;

(g) the regulation or prohibition of instream or land-based activities which may affect the quantity of water in or quality of the water resource; and

(h) any other characteristic, of the water resource in question.

(4) Before determining a class or the resource quality objectives in terms of subsection (1), the Minister must in respect of each water resource –

(a) publish a notice in the *Gazette* –

(i) setting out –

(aa) the proposed class;

(bb) the proposed resource quality objectives;

(cc) the geographical area in respect of which the objectives will apply;

(dd) the dates from which specific objectives will apply; and

(ee) the requirements for complying with the objectives; and

(ii) inviting written comments to be submitted on the proposed class or proposed resource quality objectives (as the case may be), specifying an address to which and a date before which the comments are to be submitted, which date may not be earlier than 60 days after publication of the notice;

(b) consider what further steps, if any, are appropriate to bring the contents of the notice to the attention of interested persons, and take those steps which the Minister considers to be appropriate; and

(c) consider all comments received on or before the date specified in paragraph *(a)*(ii).

Preliminary determination of class or resource quality objectives

14. (1) Until –

(a) a system for classifying water resources has been prescribed; or

(b) a class of a water resource or resource quality objectives has been determined, the Minister may, for all or part
of a water resource make a preliminary determination of the class or resource quality objectives.

(2) A determination in terms of section 13 supersedes a preliminary determination.

Giving effect to determination of class of water resource and resource quality objectives

15. *The Minister, the Director-General, an organ of state and a water management institution, when exercising any power or performing any duty in terms of this Act, must give effect to any determination of a class of a water resource and the resource quality objectives as determined in terms of this Part and any requirements for complying with the resource quality objectives.*

Part 3: The Reserve

Part 3 deals with the Reserve, which consists of two parts – the basic human needs reserve and the ecological reserve. The basic human needs reserve provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene. The ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the class of the resource. The Minister is required to determine the Reserve for all or part of any significant water resource. If a resource has not yet been classified, a preliminary determination of the Reserve may be made and later superseded by a new one. Once the Reserve is determined for a water resource it is binding in the same way as the class and the resource quality objectives.

Determination of Reserve

16. **(1)** As soon as reasonably practicable after the class of all or part of a water resource has been determined, the Minister must, by notice in the *Gazette,* determine the Reserve for all or part of that water resource.

(2) A determination of the Reserve must –

(a) be in accordance with the class of the water resource as determined in terms of section 13; and

(b) ensure that adequate allowance is made for each component of the Reserve.

(3) Before determining the Reserve in terms of subsection (1), the Minister must –

(a) publish a notice in the *Gazette* –

(i) setting out the proposed Reserve; and

(ii) inviting written comments to be submitted on the proposed Reserve, specifying an address to which and a date before which comments are to be submitted, which date may not be earlier than 60 days after publication of the notice;

(b) consider what further steps, if any, are appropriate to bring the contents of the notice to the attention of interested persons, and take those steps which the Minister considers to be appropriate; and

(c) consider all comments received on or before the date specified in paragraph *(a)*(ii).

Preliminary determinations of Reserve

17. (1) Until a system for classifying water resources has been prescribed or a class of a water resource has been determined, the Minister –

(a) may, for all or part of a water resource; and

(b) must, before authorising the use of water under section 22(5), make a preliminary determination of the Reserve.

(2) A determination in terms of section 16(1) supersedes a preliminary determination.

Giving effect to Reserve

18. The Minister, the Director-General, an organ of state and a water management institution, must give effect to the Reserve as determined in terms of this Part when exercising any power or performing any duty in terms of this Act.

Part 4: Pollution prevention

Part 4 deals with pollution prevention, and in particular the situation where pollution of a water resource occurs or might occur as a result of activities on land. The person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources. If these measures are not taken, the catchment management agency concerned may itself do whatever is necessary to prevent the pollution or to remedy its effects, and to recover all reasonable costs from the persons responsible for the pollution.

Prevention and remedying effects of pollution

19. (1) An owner of land, a person in control of land or a person who occupies or uses the land on which –

(a) any activity or process is or was performed or undertaken; or

(b) any other situation exists, which causes, has caused or is likely to cause pollution of a water resource, must take all reasonable measures to prevent any such pollution from occurring, continuing or recurring.

(2) The measures referred to in subsection (1) may include measures to –

(a) cease, modify or control any act or process causing the pollution;

(b) comply with any prescribed waste standard or management practice;

© contain or prevent the movement of pollutants;

(d) eliminate any source of the pollution;

(e) remedy the effects of the pollution; and

(f) remedy the effects of any disturbance to the bed and banks of a watercourse.

(3) A catchment management agency may direct any person who fails to take the measures required under subsection (1) to –

(a) commence taking specific measures before a given date;

(b) diligently continue with those measures; and

(c) complete them before a given date.

(4) Should a person fail to comply, or comply inadequately with a directive given under subsection (3), the catchment management agency may take the measures it considers necessary to remedy the situation.

(5) Subject to subsection (6), a catchment management agency may recover all costs incurred as a result of it acting under subsection (4) jointly and severally from the following persons:

(a) Any person who is or was responsible for, or who directly or indirectly contributed to, the pollution or the potential pollution;

(b) the owner of the land at the time when the pollution or the potential for pollution occurred, or that owner's successor-in-title;

*(c)*the person in control of the land or any person who has a right to use the land at the time when

(i) the activity or the process is or was performed or undertaken; or

(ii) the situation came about; or

(d) any person who negligently failed to prevent –

(i) the activity or the process being performed or undertaken; or

(ii) the situation from coming about.

(6) The catchment management agency may in respect of the recovery of costs under subsection (5), claim from any other person who, in the opinion of the catchment management agency, benefited from the measures undertaken under subsection (4), to the extent of such benefit.

(7) The costs claimed under subsection (5) must be reasonable and may include, without being limited to, labour, administrative and overhead costs.

(8) If more than one person is liable in terms of subsection (5), the catchment management agency must, at the request of any of those persons, and after giving the others an opportunity to be heard, apportion the liability, but such apportionment does not relieve any of them of their joint and several liability for the full amount of the costs.

Part 5: Emergency incidents
Part 5 deals with pollution of water resources following an emergency incident, such as an accident involving the spilling of a harmful substance that finds or may find its way into a water resource. The responsibility for remedying the situation rests with the person responsible for the incident or the substance involved. If there is a failure to act, the relevant catchment management agency may take the necessary steps and recover the costs from every responsible person.

NWA CHAPTER 4
Use of Water
As this Act is founded on the principle that National Government has overall responsibility for and authority over water resource management, including the equitable allocation and beneficial use of water in the public interest, a person can only be entitled to use water if the use is permissible under the Act. This Chapter is therefore of central significance to the Act, as it lays the basis for regulating water use. The various types of licensed and unlicensed entitlements to use water are dealt with in detail.

Part 1: General Principles. Sections 21-27.
This Part sets out general principles for regulating water use. Water use is defined broadly, and includes taking and storing water, activities which reduce stream flow, waste discharges and disposals, controlled activities (activities which impact detrimentally on a water resource), altering a watercourse, removing water found underground for certain purposes, and recreation. In general a water use must be licensed unless it is listed in Schedule I, is an existing lawful use, is permissible under a general authorisation, or if a responsible authority waives the need for a licence. The Minister may limit the amount of water which a responsible authority may allocate. In making regulations the Minister may differentiate between different water resources, classes of water resources and geographical areas.

Part 2: Considerations, conditions and essential requirements of general authorisations and licences. Sections 27-31.
This Part deals with matters relevant to all general authorisations and licences issued under the Act. It guides responsible authorities in the exercise of their discretion to issue and to attach conditions to general authorisations and licences. It also sets out the essential features of licences, such as effective periods, purposes and places for which they may be issued, and the nature of conditions that may be attached to them. The granting of a licence does not imply any guarantee regarding the availability or quality of water which it covers

Part 3: Existing lawful water uses. Sections 32-35.
This Part permits the continuation under certain conditions of an existing water use derived from a law repealed by this Act. An existing lawful water use, with any conditions attached, is recognised but may continue only to the extent that it is not limited, prohibited or terminated by this Act. No licence is required to continue with an existing lawful water use until a responsible authority requires a person claiming such an entitlement to apply for a licence. If a licence is issued it becomes the source of authority for the water use. If a licence is not granted the use is no longer permissible.

Part 4: Stream flow reduction activities. Section 36.
This Part allows the Minister, after public consultation, to regulate land-based activities which reduce stream flow, by declaring such activities to be stream flow reduction activities. Whether or not an activity is declared to be a stream flow reduction activity depends on various factors, such as the extent of stream flow reduction, its duration, and its impact on any relevant water resource and on other water users. The control of forestry for its impact on water resources, currently exercised in terms of the Forest Act, is now exercised under this Part.

Part 5: Controlled activities. Section 37-38.

This Part allows the Minister to regulate activities having a detrimental impact on water resources by declaring them to be controlled activities. Four such activities – irrigation using waste or water containing waste from certain sources, modification of atmospheric precipitation, altering the flow regime of a water resource as a result of power generation, and aquifer recharge using waste or water containing waste – are identified in the Act as controlled activities. Provision is made for the Minister to declare other controlled activities as the need arises, but in these cases public consultation is required. Following the identification or declaration of a controlled activity an authorisation for that particular category of activity is required under this Act.

Part 6: General authorisations. Section 39.

This Part establishes a procedure to enable a responsible authority, after public consultation, to permit the use of water by publishing general authorisations in the Gazette. A general authorisation may be restricted to a particular water resource, a particular category of persons, a defined geographical area or a period of time, and requires conformity with other relevant laws. The use of water under a general authorisation does not require a licence until the general authorisation is revoked, in which case licensing will be necessary. A general authorisation does not replace or limit an entitlement to use water, such as an existing lawful water use or a licence, which a person may otherwise have under this Act.

Part 7: Individual applications for licences. Section 40-42.

This Part sets out the procedures which apply in all cases where a licence is required to use water, but where no general invitation to apply for licences has been issued under Part 8. Water users who are not required to license their use, but who wish to convert the use to licensed use, may also use the procedure set out in this Part, but the responsible authority may decline to grant a licence when the applicant is entitled to the use of water under an existing lawful use or by a general authorisation. In considering an application a responsible authority may require additional information from the applicant, and may also require the applicant to undertake an environmental or other assessment, which assessments may be subject to independent review

Part 8: Compulsory licences for water use in respect of specific resource . Sections 43-48.

This Part establishes a procedure for a responsible authority to undertake compulsory licensing of any aspect of water use in respect of one or more water resources within a specific geographic area. It includes requirements for a responsible authority to prepare schedules for allocating quantities of water to existing and new users. The procedure is intended to be used in areas which are, or are soon likely to be, under "water stress" (for example, where the demands for water are approaching or exceed the available supply, where water quality problems are imminent or already exist, or where the water resource quality is under threat), or where it is necessary to review prevailing water use to achieve equity of access to water.

In such cases the responsible authority must publish a notice in the Gazette and other appropriate media, requiring people to apply for licences in the designated area. Applicants may be required to submit additional information, and may also be required to undertake an environmental or other assessment, which assessment may be subject to independent review.

In determining the quantities of water to be allocated to users, the responsible authority must consider all applications received, and draw up a schedule detailing how the available water will be allocated among the applicants. In drawing up an allocation schedule the responsible authority must comply with the plans, strategies and criteria set out elsewhere in the Act and must give special consideration to certain categories of applicants. A responsible authority need not allocate all the available water in a water resource, and may reserve some of the water for future needs. Provision is also made for any water still available after the requirements of the Reserve, international obligations and corrective action have been met to be allocated on the basis of public auction or tender. A system of objections and appeals in relation to proposed and preliminary allocation schedules ensures that licences may be issued only after the allocation schedule has been finalised.

Licences issued under this Part replace previous entitlements to any existing lawful water use by the applicant.

Part 9: Review and renewal of licences, and amendment and substitution of conditions of licences. Sections 49-52 .

This Part deals with the review and renewal of licences, and the amendment and substitution of their conditions. Review of a licence is by the relevant responsible authority, at periods stipulated in the licence as part of a general review process.

A review of a licence may lead to the amendment or substitution of its conditions, but only if certain requirements are satisfied. If the amendment or substitution of conditions severely prejudices the economic viability of any undertaking in respect of which the licence was issued there is a claim for compensation. Minor amendments to licences (for instance, to correct clerical mistakes, or changes in format), and those agreed to by the licensee may be made outside of the review process. In addition, a licensee may apply to the responsible authority for the renewal or amendment of a licence before it expires. In considering such applications the responsible authority must again consider the matters dealt with in the initial application, and there are limitations to the new conditions to which the licence may be subjected.

Part 10: Contravention of or failure to comply with authorisations. Sections 53-55.

This Part deals with the consequences of contraventions of licence conditions. These range from the responsible authority requiring the licensee to take remedial action, failing which it may take the necessary action and recover reasonable costs from that person, to the suspension or withdrawal of a licence. Where a licensee offers to surrender a licence the responsible authority is obliged to accept the surrender and cancel the licence unless there is good reason for refusal.

NWA CHAPTER 10

International Water Management

Under this Chapter the Minister may establish bodies to implement international agreements in respect of the management and development of water resources shared with neighbouring countries, and on regional co-operation over water resources. The governance, powers and duties of these bodies are determined by the Minister in accordance with the relevant international agreement, but they may also be given additional functions, and they may perform their functions outside the Republic. Certain existing international bodies are deemed to be bodies established under this Act.

3.3. SUPPORTING ACTS.

- **Conservation of Agricultural Resources Act (CARA)**
- **National Environmental Management (NEMA)**
- **National Environmental Management: Biodiversity Act (NEM:BA)**
- **National Environmental Management: Protected Areas Act (NEM:PAA)**
- **Water Services Act (WSA)**
- **Local government Municipal Systems Act (LG-MSA)**

See also pages 22-30 of Roux *et al.* 2006 for a brief outline of the policies, acts and strategies governing fresh water biodiversity conservation.

3.3.1. CONSERVATION OF AGRICULTURAL RESOURCES ACT (CARA 43 OF 1983) (*UNDER REVIEW)*

This is the only act that specifies the actions that may not be undertaken in water courses and wetlands. It also specifies plants that are designated and invasive and or threatening to water resources and must be controlled. It also makes provision form soil conservation works and the combating of erosion both processes with impact on water resources. The proposed general authorisations to NWA sections 21(c) and (i) will support portions of this act section 6(2).

Objects of the Act are to provide for the conservation of the natural agricultural resources of the Republic by the

- ♦maintenance of the production potential of the land,
- ♦**by the combating and prevention of erosion and**
- ♦**weakening or destruction of water resources and**
- ♦by the protection of the vegetation and the
- ♦combating of weeds and invader plants.

Section 6: (2) Control measure:

(a) cultivation of virgin soil
(b) utilisation and protection of land that is cultivated.
(c) the irrigation of land
(d) the prevention and control of water logging or salinization of land
(e) the utilisation and protection of vleis, marshes, water sponges, watercourses and water sources.
(f) the regulation of the flow pattern of run-off water;
(g) the utilization and protection of the vegetation
(h) the grazing capacity of veld, expressed as an area of veld per large stock unit;

3.3.2. NATIONAL ENVIRONMENTAL MANAGEMENT: BIODIVERSITY ACT (NEM: BA 10, 2004)

This act supports the Water Act in two ways: If river or wetland of special significance can be declared as a protected or threatened ecosystem special management provisions can be put in place. The level of classification that a water resource is assigned will further be influenced if a rare endangered or protected species is resident there. Only sections relevant to water resource protection is summarised and/or reproduced here. A study was conducted in 2005-2006 to develop cross-sectoral policies for conserving inland water biodiversity (Roux et al. 2006). The full paper can be found on the accompanying CD.

Purpose of the Act is to provide for

- the management and conservation of South Africa's biodiversity within the framework of the National Environmental Management Act 1998;
- the protection of species and ecosystems that warrant national protection;
- the sustainable use of indigenous biological resources;
- the fair and equitable sharing of benefits arising from bioprospecting involving indigenous biological resources;
- the establishment and functions of a South African Biodiversity Institute and for matters connected therewith

CHAPTER 4
Threatened or Protected Ecosystems and Species
Section 51. Purpose of Chapter is to-
(a) provide for the protection of ecosystems that are threatened or in need of it
(h) provide for the protection of species that are threatened or in need of it
(c) give effect to the Republic's obligations under international agreements
(d) ensure that the utilisation of biodiversity is managed in an ecologically protection to ensure the maintenance of their ecological integrity; protection to ensure their survival in the wild; regulating international trade in specimens of endangered species; and sustainable way.

Outline of contents of the sections.

Part 1. Sections 52-55. Protection of threatened or protected ecosystems. *This section is potentially the most valuable in terms of protection of water resources. However the Act is so new that these possibilities have not at this stage been addressed.*

Part 2. Sections 56-58. Protection of threatened or protected species. *This section will be of use to water resource protection is a rare or endangered species is resident in the resource unit. At present the presence of these biota are already addressed in the reserve determination process when the ecological class is determined.*
Part 3. Sections 59-62. Trade in listed threatened or protected species. *Of no direct interest.*
Part 4. Section 63. General provisions

Contents of each section mentioned above

Part 1. Protection of threatened or protected ecosystems

Section 52. Ecosystems that are Threatened or in need of Protection

(1) (a) The Minister may, by notice in the *Gazette*, publish a national list of ecosystems that are threatened and in need of protection.

(b) An MEC for environmental affairs in a province may, be notice in the *Gazette*, publish a provincial list of ecosystems in the province that are threatened and in need of protection.

(2) The following categories of ecosystems may be listed in terms of subsection (1):

(a) critically endangered ecosystems, being ecosystems that have undergone severe degradation of ecological structure, function or composition as a result of human intervention and are subject to an extremely high risk of irreversible transformation;

(b) endangered ecosystems, being ecosystems that have undergone degradation of ecological structure, function or composition as a result of human intervention, although they are not critically endangered ecosystems;

(c) vulnerable ecosystems, being ecosystems that have a high risk of undergoing significant degradation of ecological structure, function or composition as a result of human intervention, although they are not critically endangered ecosystems or endangered ecosystems; and

(d) protected ecosystems, being ecosystems that are of high conservation value or of high national or provincial importance, although they are not listed in terms of paragraph (a), (b) or (c).

(3) A list referred to in subsection (1) must described in sufficient detail the location of each ecosystem on the list.

(4) The Minister and the MEC for environmental affairs in a relevant province, respectively, must at least every five years review any national or provincial list published by the Minister or MEC in terms of subsection (1).

(5) An MEC may publish or amend a provincial list only with the concurrence of the Minister.

Section 53. Threatening Processes in Listed Ecosystems

(1) The Minister may, by notice in the *Gazette*, identify any process or activity in a listed ecosystem as a threatening process.

(2) A threatening process identified in terms of subsection (1) must be regarded as a specified activity contemplated in section 24(2)(b) of the National Environmental Management Act and a listed ecosystem must be regarded as an area identified for the purpose of that section.

Section 54. Certain plans to take into account in protection of listed ecosystems

An organ of state that must prepare an environmental implementation or environmental management plan in terms of Chapter 3 of the National Environmental Management Act, and a municipality that must adopt an integrated development plan in terms of the Local Government: Municipal Systems Act, 2000 (Act No. 32 of 2000), must take into account the need for the protection of listed ecosystems.

Section 55. Amendment of notices

The Minister or the MEC for Environmental Affairs in any relevant province may, by notice in the *Gazette,* amend or repeal any notice published by him or her in terms of section 52(1) or 53(1).

Part 2 Protection of threatened or protected species

Section 56. Listing of species that are threatened or in need of national protection

(1) The Minister may, by notice in the *Gazette,* publish a list of-

(a) critically endangered species, being any indigenous species facing an extremely high risk of extinction in the wild in the immediate future;

(b) endangered species, being any indigenous species facing a high risk of extinction in the wild in the near future, although they are not a critically endangered species;

(c) vulnerable species, being any indigenous species facing an extremely high risk of extinction in the wild in the medium-term future, although they are not a critically endangered species or an endangered species; and

(d) protected species, being any species which are of such high conservation value or national importance that they require national protection, although they are not listed in terms of paragraph *(a), (b)* or (c).

(2) The Minister must review the lists published in terms of subsection (1) at least every five years.

Section 57. Restricted activities involving listed threatened or protected species

(1) A person may not carry out a restricted activity involving a specimen of a listed threatened or protected species without a permit issued in terms of Chapter 7.

(2) The Minister may, by notice in the *Gazette,* prohibit the carrying out of any activity-

(a) which is of a nature that may negatively impact on the survival of a listed, threatened or protected species; and

(b) which is specified in the notice,

or prohibit the carrying out of such activity without a permit issued in terms of Chapter 7.

(3) Subsection (1) does not apply in respect of a specimen of a listed threatened or protected species conveyed from outside the Republic in transit through the Republic to a destination outside the Republic, provided that such transit through the Republic takes place under the control of an environmental management inspector.

Section 58. Amendment of notices.

The Minister may by notice in the *Gazette* amend or repeal any notice published in terms of section 55(1) or 56(2).

Part 3. Trade in listed threatened or protected species

Section 59. Functions of Minister

Section 60. Establishment of scientific authority

(1) The Minister must establish a scientific authority for purpose of assisting in regulating and restricting the trade in specimens of listed threatened or protected species.

(2) The Institute must provide logistical, administrative and financial support for the proper functioning of the scientific authority.

Section 61(1a-i; 2a&b). Functions of scientific authority (in terms of the trade in listed threatened or protected species)

Section 62. Annual non-detriment findings

Part 4 General provisions

Section 63. Consultation process by Minister or MEC in terms of sections 99 and 100

3.3.3. NATIONAL ENVIRONMENTAL MANAGEMENT: PROTECTED AREAS ACT, NO. 57 OF 2003.

In terms of Water Resources management the main interest in this act lies in section15 and 16 wherein mountain catchment areas can be declared as protected areas.

Purpose
To provide for the protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its natural landscapes and seascapes; for the establishment of a national register **of** all national, provincial and local protected areas; for the management of those areas in accordance with national norms and standards; for intergovernmental co-operation and public consultation in matters concerning protected areas; and for matters in connection therewith. ***** indicate section of the act to be amended.

ARRANGEMENT OF SECTIONS
CHAPTER 1. INTERPRETATION, OBJECTIVES AND APPLICATION OF ACT
1. Definitions
2. Objectives of Act
3. State trustee of protected areas
4. Application of Act
5. Application of National Environmental Management Act
6. Application of Biodiversity Act in protected areas
7. Conflicts with other legislation
8. Status of provincial legislation on provincial and local protected areas

CHAPTER 2. SYSTEM OF PROTECTED AREAS IN SOUTH AFRICA
9. Kinds of protected areas
10. Register of Protected Areas
11. Norms and standards
12. Provincial protected areas
13. World heritage sites

15. Specially protected forest areas, forest nature reserves and forest wilderness
16. Mountain catchment areas.

CHAPTER 3 DECLARATION OF PROTECTED AREAS
17. Purpose of protected areas

Part 1. Special nature reserves
18. Declaration of special nature reserves
19. Withdrawal of declaration or exclusion of part of special nature reserve

Part 3. Nature reserves
23. Declaration of nature reserve
24. Withdrawal of declaration or exclusion of part of nature reserve
25. Designation of nature reserve as specific type
26. Designation of nature reserve as wilderness area
27. Notice to be given to Minister of provincial declarations

Part 4. Protected environments
28. Declaration of protected environment
29. Withdrawal of declaration or exclusion of part of protected environment
30. Notice to be given to Minister of provincial declarations

Part 5. Consultation process

31. Consultation by Minister
32. Consultation by MEC
33. Public participation
34. Affected organs of state, communities and beneficiaries

Part 6. General

35. Initiation of declaration
36. Endorsement by Registrar of Deeds

CHAPTER 4. MANAGEMENT OF PROTECTED AREAS

37. Application of Chapter

Part 1.Management authorities and management plans

38. Management authorities
39 Preparation of management plan
40. Management criteria
41. Management plan
42. Co-management of protected area

Part 2. Monitoring and supervision

43. Performance indicators
44. Termination of mandate to manage protected area

Part 3. **Access to protected areas**

Part 4. Restrictions

48. Prospecting and mining activities in protected area
49. Regulation or restriction of activities in protected areas
50. Commercial and community activities in nature reserve and world heritage site
51. Regulation or restriction of development and other activities in protected environment
52. Internal rules
53. Certain rights and entitlements to be respected

CHAPTER 6. ACQUISITION OF RIGHTS IN OR TO LAND

80. Acquisition of private land by State

CHAPTER 7. ADMINISTRATION OF ACT

86. Regulations by Minister
87. Regulations by MEC
88. General

CHAPTER 8. OFFENCES AND PENALTIES

89. Offences and penalties

CHAPTER 9. MISCELLANEOUS

3.3.4. WATER SERVICES ACT 108 OF 1997

The purpose of this act is:

- to provide for the rights of access to basic water supply and basic sanitation;
- to provide for the setting of national standards and of norms and standards for tariffs;
- to provide for water services development plans;

- to provide a regulatory framework for water services institutions and water services intermediaries;
- to provide for the establishment and disestablishment of water boards and water services committees and their powers and duties;
- to provide for the monitoring of water services and intervention by the Minister or by the relevant Province;
- to provide for financial assistance to water services institutions;
- to provide for certain general powers of the Minister;
- to provide for the gathering of information in a national information system and the distribution of that information;
- to repeal certain laws; and
- to provide for matters connected therewith.

This Act should be administered in conjunction with (among others) the National Water Act, the Municipal Systems Act, Municipal Finance Management Act and the Development Facilitation Act.

Contents

61. Regulations

CHAPTER VIII Monitoring and intervention

62. Monitoring of water services institutions
63. Intervention

CHAPTER IX Financial assistance to water services institutions

64. Powers of Minister
65. Applications for financial assistance
66. Regulations on financial assistance

CHAPTER X. National information system

67. Establishment of national information system
68. Purpose of national information system
69. Provision of information
70. Funding of national information system

CHAPTER XI General powers and duties of Minister

71. Procedure for making regulations
72. Consultation by Minister
73. General powers of Minister
74. Delegation of powers
75. Scrutinising of draft regulations
76. Advisory committees

CHAPTER XII General provisions

77. Transferability of servitudes
78. Compliance with other laws
79. Ownership of water services works
80. Entry and inspection of property
81. Expropriation
82. Offences
83. State bound by Act
84. Repeal of laws, and savings
85. Short title

3.3.4. LOCAL GOVERNMENT: MUNICIPAL SYSTEMS ACT. (ACT NO. 32, 2000)

The purpose of this act is *inter alia* "to provide for the core principles mechanisms and processes that are necessary to move progressively towards the social and economic upliftment of local communities and to ensure universal access to essential services that are affordable to all:" As far as water resources planning and management is concerned, the main provisions are encapsulated in "framework for core processes of planning…resource mobilisation." In particular chapters 5 and 6 specify the need for Integrated development planning.

Noted from NEMA:BA section 54*: An organ of state that must prepare an environmental implementation or environmental management plan in terms of Chapter 3 of the National Environmental Management Act, and a municipality that must adopt an integrated development plan in terms of the Local Government: Municipal Systems Act, 2000 (Act No. 32 of 2000), must take into account the need for the protection of listed ecosystems.*

Note*: The sections of particular importance have been rendered bold*

CHAPTER 5

Contents – Integrated Development Planning

Part 1: General

Relevant sections

Section 23. Municipal planning to be developmentally oriented

(1) A municipality must undertake developmentally-oriented planning so as to ensure that it—

(a) strives to achieve the objects of local government set out in section 152 of the Constitution;
(b) gives effect to its developmental duties as required by section 153 of the Constitution; and
(c) together with other organs of state contribute to the realisation of the fundamental rights contained in sections 24, 25, 26, 27 and 29 of the Constitution.

Subsection (1) must be read with Chapter 1 of the Development Facilitation Act, 1995 (Act No, 67 of 1995),

Section 24. Municipal planning in co-operative government

(1) The planning undertaken by a municipality must be aligned with, and complement, the development plans and strategies of other affected municipalities and other organs of state so as to give effect to the principles of co-operative government contained in section 41 of the Constitution.

(2) Municipalities must participate in national and provincial development programmed as required in section 153(b) of the Constitution.

(3) If municipalities are required to comply with planning requirements in terms of national or provincial legislation, the responsible organs of state must —

(a) align the implementation of that legislation with the provisions of this Chapter; and
(b) in such implementation—
(i) consult with the affected municipality; and
(ii) take reasonable steps to assist the municipality to meet the time limit mentioned in section 25 and the other requirements of this Chapter applicable to its integrated development plan.

(4) An organ of state initiating national or provincial legislation requiring municipalities to comply with planning requirements, must consult with organised local government before the legislation is introduced in Parliament or a provincial legislature, or, in the case of subordinate legislation, before that legislation is enacted.

Part 2: Contents of integrated development plans

Section 26. Core components of integrated development plans

An integrated development plan must reflect—

(a) the municipal council's vision for the long term development of the municipality with special emphasis on the municipality's most critical development and internal transformation needs:

(b) an assessment of the existing level of development in the municipality, which must include an **identification of communities which do not have access to basic municipal services**;

(c) the council's development priorities and objectives for its elected term, including its local economic development aims and its internal transformation needs;

(d) the council's development strategies which must be aligned with any national or provincial sectoral plans and planning requirements binding on the municipality in terms of legislation;

(e) **a spatial development framework** which must include the provision of basic guidelines for a land use management system for the municipality;

(f) the council's operational strategies;

(g) applicable **disaster management** plans

(h) a financial plan, which must include a budget projection for at least the next three years; and

(i) the key performance indicators and performance targets determined in terms of section 41.

Part 3: Process for planning, drafting, adopting and review of *integrated development plans*

Section 27. Framework for integrated development planning.

(1) Each **district municipality**, within a prescribed period after the start of its elected term and after following a consultative process with the local municipalities within its area, must **adopt a framework for integrated development planning** in the area as a whole.

(2) A framework referred to in subsection (1) binds both the district municipality and the local municipalities in the area of the district municipality, and must at least-

(a) identify the plans and planning requirements binding in terms of national and provincial legislation on the district municipality and the local municipalities or on any specific municipality;

(b) identify the matters to be included in the integrated development plans of the district municipality and the local municipalities that require alignment;

(c) specify the principles to be applied and co-ordinate the approach to be adopted in respect of those matters: and

(d) determine procedures-

(i) for consultation between the district municipality and the local municipalities during the process of drafting their respective integrated development plans; and

(ii) to effect essential amendments to the framework.

Section 29. Process to be followed

(1) The process followed by a municipality to draft its integrated development plan, including its consideration and adoption of the draft plan, must –

(a) be in accordance with a predetermined programme specifying timeframes for the different steps;

(b) through appropriate mechanisms, processes and procedures established in terms of Chapter 4, allow for—

(i) the **local community to be consulted on its development needs and priorities**;

(ii) the local community to participate in the drafting of the integrated development plan; and

(iii) **organs of state, including traditional authorities, and other role players to be identified and consulted on the drafting of the integrated development plan;**

(c) provide for the identification of all plans and planning requirements binding on the municipality in terms of national and provincial legislation; and

(d) be consistent with any other matters that may be prescribed by regulation.

(2) A district municipality must

(a) plan integrated development for the area of the district municipality as a whole but in close consultation with the local municipalities in that area:

(b) align its integrated development plan with the framework adopted in terms of section 27; and 35.

(c) draft its integrated development plan, taking into account the integrated development processes of, and proposals submitted to it by the local municipalities in that area.

(3) A local municipality must

(a) align its integrated development plan with the framework adopted in terms of section 27;

(b) draft its integrated development plan, taking into account the integrated development processes of. and proposals submitted to it by the district municipality.

Section 37. Regulations and guidelines

(1) The Minister may for the purposes of this Chapter make regulations or issue guidelines or, terms of ….. to provide for or to regulate the following matters: –

(a) incentives to ensure that municipalities adopt their integrated development plans within the applicable prescribed period and comply with the provisions

(b) of this Act concerning the planning, drafting, adoption and review of those plans;

(c**) the detail of integrated development plans taking into account the requirements of other applicable national legislation;**

(c) criteria municipalities must take into account when planning, drafting, adopting or reviewing their integrated development plans.

3.4. PERIPHERAL ACTS

3.4.1. NATIONAL FORESTS ACT, 1998 (ACT 84 OF 1998)

Section 1:	Purposes
Section 2:	Interpretation
Section 3:	Principles to guide decisions affecting forests
Section 4:	Promotion and enforcement of sustainable forest management
Section 7:	Prohibition of destruction of trees in natural forests
Section 10:	Effect of setting aside protected areas
Section 12:	Declaration of trees as protected trees
Section 15:	Effect of declaration of protected trees
Section 23:	Activities which might be licensed in state forests
Section 58:	Penalties
Section 59:	Compensatory orders in criminal proceedings
Section 61:	Offences relating to sustainable forest management
Section 62:	Offences relating to the protection of forests and trees
Section 63:	Offences relating to the use of forests

3.4.2. NATIONAL VELD AND FOREST FIRE ACT, 1998 (ACT 101 OF 1998)

Section 1:	Purpose
Section 2:	Interpretation
Section 9:	Fire danger rating
Section 12:	Duty to prepare and maintain firebreaks
Section 13:	Requirements for firebreaks

Section 16:	Exemption from prohibition on damaging plants
Section 18:	Actions to fight fires
Section 24:	Penalties
Section 25:	Offences
Section 34:	Presumption of negligence

4. COOPERATIVE GOVERNANCE AND THE LEGAL INSTRUMENTS

These are the section in the following acts that encourage or require cooperative governance. The state of cooperative governance n South Africa is still in its infancy. There is an inter-ministerial structure to encourage this process. However at provincial and local government level this still seems a goal too far. However the need is widely recognised and will hopefully be achieved.

4.1. THE CONSTITUTION

Chapter 3

Section 41(2) of the Constitution requires an Act of Parliament-

(a) to establish or provide for structures and institutions to promote and facilitate intergovernmental relations; and

(b) to provide for appropriate mechanisms and procedures to facilitate the settlement of intergovernmental disputes.

4.2 National Environmental Management Act 1997

Chapter 3. Procedures for co-operative governance

Environmental implementation plans and management plans

11. (1) Every national department listed in Schedule 1 as exercising functions which may affect the environment and every province must prepare an environmental implementation plan within one year of the promulgation of this Act and at least every four years thereafter.

(2) Every national department listed in Schedule 2 as exercising functions involving the management of the environment must prepare an environmental management plan within one year of the promulgation of this Act and at least every four years thereafter

(3) Every national department that is listed in both Schedule 1 and Schedule 2 may prepare a consolidated environmental implementation and management plan.

(4) Every organ of state referred to in subsections (1) and (2) must, in its preparation of an environmental implementation plan or environmental management plan, and before submitting such plan take into consideration every other environmental implementation plan and environmental management plan already adopted with a view to achieving consistency among such plans.

(5) The Minister may by notice in the *Gazette*—

> *(a)* Extend the date for the submission of any environmental implementation plans and environmental management plans for periods not exceeding 12 months;
>
> *(b)* on application by any organ of state, or on his or her own initiative with the agreement of the relevant Minister where it concerns a national department and after consultation with the Committee, amend Schedules 1 and 2.

(6) The Director-General must, at the request of a national department or province assist with the preparation of an environmental implementation plan.

(7) The preparation of environmental implementation plans and environmental management plans may consist of the assembly of information or plans compiled for other processes and may form part of any other process or procedure.

(8) The Minister may issue guidelines to assist provinces and national departments in the preparation of environmental implementation and environmental management plans.

Purpose and objects of environmental implementation plans and environmental management plans

12. The purpose of environmental implementation and management plans is to

(a) co-ordinate and harmonize the environmental policies, plans, programmed and decisions of the various national departments that exercise functions that may affect the environment or are entrusted with powers and duties aimed at the achievement. Promotion and protection of a sustainable environment, and of provincial and local spheres of government, in order to

(i) minimize the duplication of procedures and functions; and

(ii) promote consistency in the exercise of functions that may affect the environment;

(b) give effect to the principle of co-operative government in Chapter 3 of the Constitution;

(r) secure the protection of the environment across the country as a whole:

(d) prevent unreasonable actions by provinces in respect of the environment that are prejudicial to the economic or health interests of other provinces *or* the country as a whole; and

(e) enable the Minister to monitor the achievement. promotion, and protection of a sustainable environment.

16. (1) (a) Every organ of state must exercise every function it may have, or that has been assigned or delegated to it, by or under any law, and that may significantly affect the protection of the environment.

substantially in accordance with the environmental implementation plan or the environmental management plan prepared. submitted and adopted by that organ of state in accordance with this Chapter: Provided that any substantial deviation from an environmental management plan or environmental implementation plan must be reported forthwith to the Director-General and the Committee.

4.3. NEM: BIODIVERSITY ACT

Section 2. The objectives of this Act are-
(b) to give effect to' ratified international agreements relating to biodiversity
(c) to provide for co-operative governance in biodiversity management and

Part 2
Consultation process
Consultation
Section 99. (2) The Minister must, in terms of subsection (1)-
(a) consult all Cabinet members whose areas of responsibility may be affected by the exercise of the power;
(b) in accordance with the principles of co-operative governance set out in Chapter 3 of the Constitution, consult the **MEC** for Environmental Affairs of each province that may be affected by the exercise of the power; and
(c) allow public participation in the process in accordance with section

4.4. INTERGOVERNMENTAL RELATIONS FRAMEWORK BILL (2005)

CONTENTS

5. REGULATORY FRAMEWORK

5.1 NATIONAL WATER RESOURCE STRATEGY FIRST EDITION, SEPTEMBER 2004.

The strategy is a large document that sets out the South African approach to the implementation of Water Act and the management of our water resources. A full text of the strategy is available on the DWAF website and is available on the accompanying CD.

5.1.2 AN OVERVIEW OF THE NATIONAL WATER RESOURCE STRATEGY

The strategy consists of 5 chapters namely:

Chapter 1 – Water policy, water law and water resources management (full text as introduction to section 3 of this document)

The relationships between the Constitution, the National Water Policy and the National Water Act are described in this chapter, together with the purposes of the National Water Resource Strategy as -

- The national framework for managing water resources;
- The framework for the preparation of catchment management strategies;
- Provision of water-related information; and
- Identification of development opportunities and constraints.

A brief description is given of the need to manage water resources in an integrated way, and in co-operation with all relevant government institutions, the private sector, water users and other interested and affected persons, and of the contribution that integrated water resources management can make to eradicating poverty and addressing gender issues.

Chapter 2 – South Africa's water situation

This chapter provides aggregated estimates of the present availability of and requirements for water in each of the water management areas, indicates how water availability and water requirements may be expected to change in the future, and describes possible strategies and interventions for achieving a balance between water availability and requirements. Some basic concepts relating to water resources management are explained. See also Appendix D – *Additional Information and Strategic Perspectives with respect to Water Management Areas*, which presents a more detailed analysis of South Africa's water situation by providing present and future water balance information and possible reconciliation interventions for subdivisions of the 19 water management areas.

Chapter 3 – Strategies for water resources management

The strategies, objectives, plans, guidelines and procedures required to implement the provisions of the National Water Act are described in this chapter. Brief explanations of the requirements of the Act are given to put the strategies, etc. into context. Successive parts of the chapter give information about strategies for the protection of water resources, water use, water conservation and water demand management, water pricing, water management institutions, monitoring and information systems for water resources, and disaster management. The last two parts of the chapter present an indicative programme for the major implementation activities, and the broad financial implications of implementation.

The chapter is divided into nine parts as follows

Part 1: Protection of Water Resources
Part 2: Water Use
Part 3: Water Conservation and Water Demand Management
Part 4: Water Pricing and Financial Assistance
Part 5: Water Management Institutions
Part 6: Monitoring and Information Systems
Part 7: Disaster Management

Part 8: Anticipated Programme of Implementation Activities
Part 9: Financial Implications

Chapter 4 – Complementary strategies

The chapter includes a broad overview of the ways in which water management capacity can be built among practitioners in the South African water sector, describes the Department's approach to creating awareness and understanding of water issues among water users and other stakeholders, and outlines the Water Research Commission's plans for water research.

Chapter 5 – National planning and co-ordination, and international co-operation in water management

The principal relationships between water resources management strategies and other relevant policies and laws are described in this chapter. The necessity for co-operation among all spheres of government to achieve national development goals is emphasised. The final section of the chapter discusses international co-operation in water matters.

5.1.3. REGULATIONS TO SUPPORT LEGISLATION TO THE NATIONAL WATER ACT.

5.1.3.1. General authorisations in terms of Section 39 of the National Water Act, 1998. no. 1191 of 1999.

1. Schedule for section 21(a) and (b) Taking water from a water resource and storage of water.
2. Schedule for section 21(e). Engaging in a controlled activity identified as such in Section 37(1): irrigation of any land with waster or water containing waste generated through any industrial activity or by a waterwork.
3. Schedule for section 21(f) and (h). Discharge of waste or water containing waste into a water resource through a pipe canal sew rot other conduit; and disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generating process.
4. Schedule to section 21(g). Disposing of waster in manner which may detrimentally impact on a water resource.

5.1.3.2. Proposed general authorisation – August 2002.

1. Schedule for section 21(c) Impeding or diverting the flow in a watercourse.
2. Schedule for section (i). Altering the bed, banks or characteristics of a watercourse.
3. Schedule for section 21(j). Removing water found underground if it is necessary for the efficient continuing of an activity for the safety of people.

5.2. CROSSECTORAL POLICY OBJECTIVES FOR CONSERVING SOUTH AFRICA'S INLAND BIODIVERSITY (*the full document is available on CD*)

Summary of the executive summary of the discussion paper on Cross-Sector Policy Objectives For Conserving South Africa's Inland Water Biodiversity *(Roux, Nel, MacKay, Ashton 2006)*

The discussion paper was based on a process of searching for and negotiating a shared understanding of key concepts related to the conservation of inland water biodiversity. A shared vision for the conservation and management of inland water biodiversity was achieved after a remarkable convergence of thinking among the representatives from allied government departments and scientists.

It is recommended that the executive summary be read and that SECTIONS 7-11 be used to complete the assignment.

The value of and need for biodiversity conservation is summarised by The Paris Declaration on Biodiversity (see Section 3.9) as follows: "*Biodiversity, as the natural heritage and a vital resource for all humankind:*

- *Is a source of aesthetic, spiritual, cultural, and recreational values;*
- *Provides goods that have direct use values, such as food, wood, textiles and pharmaceuticals;*

- *Supports and enhances ecosystem services on which human societies depend often indirectly, such as plant and animal production, crop pollination, maintenance of water quality and soil fertility, carbon sequestration, nutrient cycling, protection against pathogens and diseases, and resistance of ecosystems to disturbances and environmental changes; and*
- *Provides opportunities for human societies to adapt to changing needs and circumstances, and discover new products and technologies*."

A set of five core objectives and associated implementation principles are presented in Sections 7 to 11 of the discussion paper (Roux *et al.* 2006) as imperatives to achieving the inland water biodiversity conservation goal stated above. Objectives one to three deal with planning and design issues, while objectives four and five deal with implementation issues.

Objective 1: Set and entrench quantitative conservation targets for inland water biodiversity

Implementation principles associated with this objective.

1. *Set and endorse national targets for conservation of inland water biodiversity*.
2. *Cascade the national targets differentially to sub-national implementation levels*.
3. *Improve and refine national and sub-national targets over time*.

Each implementation principle is accompanied by a set of policy recommendations

Objective 2: Plan for representation of inland water biodiversity

Implementation principles associated with this objective.

1. *Use surrogate measures as indictors to describe and classify inland water biodiversity*.
2. *Define the appropriate scale*. (ranging from regional (SADC) to *countrywide* conservation plans for representative samples of all *major ecosystem types to* catchment-based biodiversity plans aligned with and complementing national – level plans.
3. *Incorporate local ecological knowledge*.

Each implementation principle is accompanied by a set of policy recommendations

Objective 3: Plan for persistence of inland water biodiversity.
Implementation principles for this objective

1. *Select inland water ecosystems of high integrity*
2. *Ensure connectivity*.
3. To *include large-scale ecosystem processes*.
4. *Select areas of sufficient size*

Objective 4: Establishing a portfolio of inland water conservation areas (IWCAs)

Implementation principles:

1. *Legislate IWCAs through complementary legal mechanisms*.
2. *Strive for optimal land-use efficiency*.
3. *Prioritise and initiate conservation actions timeously*.
4. To *conserve first where appropriate, rather than restore later*.
5. *Provide explicit selection options and management guidelines*.

Each implementation principle is accompanied by a set of policy recommendations

Objective 5: Enable effective implementation

Implementation principles:

1. *facilitate stakeholder adoption of inland water conservation targets and priority areas*
2. *Reflect the conservation of inland water ecosystems as an explicit function in institutional design*.
3. *Enable cooperative governance in the conservation and management of inland water biodiversity*.
4. *Facilitate a science-management continuum*.
5. *Promote discovery, inventory and improved understanding of inland water biodiversity*.

Each implementation principle is accompanied by a set of policy recommendations

REFERENCES

ACTS & AMMENDMENTS

Conservation of Agricultural Resources Act 43 of 1983
Constitution of South Africa. (Act 108 of 1996)
Local Government: Municipal Systems Act 32,of 2000
National Environmental Management Act 107 of 1997
National Environmental Management: Biodiversity Act 10 of 2004
National Environmental Management: Protected Areas Act 57 of 2003
National Forests Act, 1998 (Act 84 of 1998)
National Veld and Forest Fire Act 101 of 1998
National Water Act 38 of 1998
Water Services Act 108 of 1997

General authorisations, 1999, no 1191 in terms of section 39 of the NWA: Section 21 (a & b), – schedule 1); section 21 (e) – schedule 2; section 21 (f & h) – schedule 3; section 21(g) – schedule 4.

General authorisations 2002 in terms of section 39 of the NWA: Section 21(c) schedule 1: section 21(i) – schedule 2 currently open for comment.

BILLS & STRATEGIES

Intergovernmental Relations Framework Bill 2005
National Water Resource Strategy. DWAF. 1st Edition 2004
Cross-Sector Policy Objectives For Conserving South Africa's Inland Water Biodiversity – Discussion paper *(Roux, Nel, MacKay, Ashton, DWAF 2006)*

REFEREED PUBLICATIONS

Caponera D.A.1985. *Patterns in Cooperation in International Water Law: Principles and Institutions. Natural resources Journal 25(3); 563-588*

Gallopin G. & Rijsberman F.R. 2000. World Water Vision. Earthscan Publications, London

Giordano MA & Wolf, A. 2001. Incorporating equity into International Water Agreements. Social Justice Research. 14(4).

Giordano MA & Wolf, A. 2003 Sharing Waters; Post Rio international Water Management. Natural resources Forum. 27:163-171

BOOKS and WEBSITES

Atlas Of International Water Agreements. Wolf and Giordano 2000. www.Ad.Unep.Org.Documents

Roadmap of Environmental Legislation

World Water Vision. 2000. World Water Council, Earthscan Publications, London. www.Earthscan.Co.Uk

World Water Council.org

Climate Change – an introduction. SciDev.net

Global Land Cover: http://edcsns17.cr.usgs.gov/glcc/

APPENDICES

MODULE 2

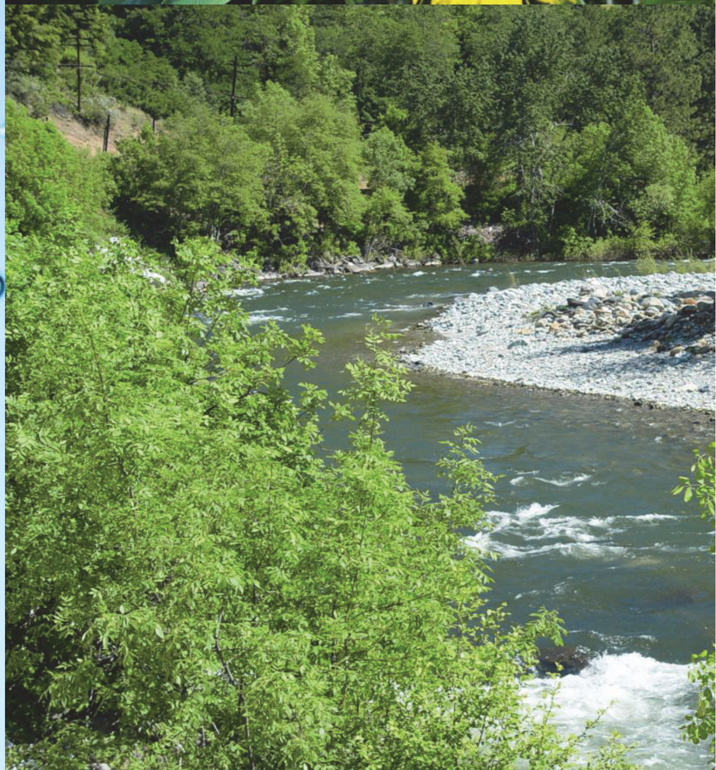
RESOURCE ECONOMICS

Tutored MSc in Ecological Water Requirements

Developed by

Dr Jane Turpie and Mr. Lewis Jonker

November 2013



Purpose of the module

The purpose of this sub-module is to provide students with an understanding of the economic issues involved in allocating water to the environment versus other uses, and of water management at a catchment level. The sub-module aims at a basic level of understanding, to provide a conceptual rather than a functional capability.

Outcomes

On completion of this module students should be able to:

- describe the way in which economics contributes to decision-making about the allocation of environmental water requirements;
- define basic economic concepts, such as demand, supply and opportunity cost;
- demonstrate an understanding of the concepts of marginal costs and benefits, tradeoffs, and economic value, and relate them to aquatic resources;
- describe the relationships between aquatic ecosystem health and/or functioning and the supply of economic goods and services;
- demonstrate their familiarity with the types of methods used for estimating the social and economic value of aquatic resources, their minimum requirements and their potential shortcomings;
- promote the importance of ecological measures in determining economic value and tradeoffs;
- comprehend the potential role of ecological-economic modelling in understanding tradeoffs;
- estimate the influence of efficiency of resource management at a catchment level on tradeoffs at a resource level;
- describe the economic instruments that improve the efficiency of water resources management;
- discuss the characteristics of suitable social and economic indicators for EWR assessments;
- use case studies to illustrate the social and economic impacts of water allocation decisions; and
- outline the role of a resource economist in an EWR study.

Duration and timetable

This sub-module will be presented over a five day period (Table 1).

Mark allocation

• Exercise 1	• 10
• Exercise 2	• 10
• Exercise 3	• 15
• Exercise 4	• 15
• Final exam	• 50

Table 1. Layout of the module

Day	Hrs 1-2	Hrs 3-4	Hrs 5-6	Hrs 7-8
1	Lecture 1: Introduction to economics: General concepts and microeconomics	Exercise 1. Microeconomics	Lecture 2: Introduction to economics: Basic macroeconomics	Exercise 2. Macro-economics
2	Lecture 3: Decision-making for water resources allocation: Balancing economic demands, ecosystem needs and basic human needs in making water allocation decisions	Reading	Lecture 4 Decision-making for water resources allocation: cost-benefit analysis	Exercise 3: Cost-benefit analysis
3	Lecture 5: Decision-making for water resources allocation: multi-criteria decision analysis	Exercise 4: MCDA	Lecture 6. The social and economic values of aquatic ecosystems	Reading
4	Lecture 7: Estimating the value of aquatic ecosystems	Reading	Lecture 8. Valuation case studies	Reading
5	Lecture 9: Economic instruments for improving management efficiency	Reading	Lecture 10. Payments for Ecosystem Services	Reading

Lecture 1. Introduction to economics - General concepts and microeconomics

What is economics?

- The ‘science of making choices’
- Opportunity costs
- Marginal value
- The economic problem
- Needs and wants
- Commodities, goods and services
- Utility
- The ‘practical economist’

Factors of production

- Land
- Capital
- Labour
- Enterprise

The production-possibilities frontier

- The simple model
- Opportunity cost
- The law of increasing cost
- Growth of the PPF

Economic goals

- Economic efficiency
- Distributional equity
- Economic freedom
- Price stability
- Full employment
- Economic growth

Economic systems

- The economic questions
- Traditional economies
- Command economies
- Market economies
- Mixed economies

Markets

- Production and consumption
- Division and specialisation
- Comparative advantage
- Trade
- Property rights
- Competition

Supply and demand

- Axes and shape of the demand curve

- Movement along a demand curve
- Shift in demand
- Factors leading to shifts in demand
- Axes and shape of the supply curve
- Movement along a supply curve
- Shift in supply
- Factors leading to shifts in supply

Equilibrium price and quantity

- Interaction between demand and supply
- How shifts in demand or supply change price and quantity
- The dynamic nature of value
- Manipulating prices

Elasticity

- The responsiveness of demand and supply to changes in price, etc.

Exercise 1

Students are asked to undertake an exercise in micro-economics. This could be the construction/interpretation of a PPF curve, or of a set of demand and supply curves.

Lecture 2. Introduction to economics – Basic macroeconomics

The circular economy

- The basic circular economy model with households and firms
- Introduction of the financial, foreign market and government sectors
- How the ecological-economics model differs from the circular model

National accounts

- Purpose of national accounting
- Calculation of constant prices
- Gross domestic expenditure
- Gross domestic product
- Gross national product
- Net national product
- The informal sector
- Natural resource accounting
- South Africa's water accounts

The balance of payments

- Current accounts
- Capital account

Inflation

- The consumer price index
- Calculating inflation
- How reliable is the inflation rate
- The causes of inflation
- The consequences of inflation

Exchange rates

- What determines the rate of exchange
- Impact on foreign trade
- Impact on GDP
- Impact on inflation

Monetary and fiscal policy

- The role of government
- Expansionary versus restrictive policy
- Fiscal policy
- Monetary policy

Exercise 2

Students are asked to undertake an exercise in macro-economics. This could be an assignment in which students are asked to consider the multiplier and other macroeconomic effects of large dams or interbasin transfers.

Lecture 3. Balancing economic demands, ecosystem needs and basic human needs in making water allocation decisions

Background

- Water rights and the National Water Act
- Basic human needs
- Resource Directed Measures
- Classification
- Strategic Adaptive Management

Economic trade-offs in water allocation

- Types of users
- Trade-offs between environment and water use
- Efficiency, equity and sustainability
- Scale issues

Reading

Hassan, R.M & Farolfi, S. 2006. Water value, resource rent recovery and economic welfare cost of environmental protection: A water-sector model for the Steelpoort sub-basin in South Africa. Water SA 31: 9-16.

Franklin Dam case study in Pearce, D. 1984. Cost-benefit analysis. Palgrave Macmillan.

Lecture 4. Cost-benefit analysis

Costs and benefits of water projects

- Capital costs
- Operating costs
- Project benefits
- Environmental costs and benefits

Economic versus financial analysis

- Financial analysis
- Economic analysis
- Shadow pricing

Time and discounting

- Time frames for analysis
- Discounting the future
- Discounting calculation
- Discount rates

Evaluation of alternatives

- Net present value
- Internal rate of return
- Cost-benefit ratio

Exercise 3

Students will undertake a cost-benefit analysis of two development options. They will set up spreadsheets, and based on information provided, will enter a series of values, from which they will compute net present values, rates of return, etc., in order to evaluate the two alternatives. Follow the format in H.F. Campbell and R. Brown *Benefit-Cost Analysis: Financial and Economic Appraisal using Spreadsheets*), Cambridge University Press, 2003.

Lecture 5. Multi-criteria Analysis

Introduction

- The development of MCA as an alternative means of decision-making
- Advantages and disadvantages of MCA
- Extent to which MCA is used globally

MCDA methodology

- Scoring and weighting techniques
- Analytical techniques
- Criteria for selecting MCA techniques

The use of MCA in water resource classification

- MCA framework for assessing water allocation scenarios
- Integrating ecological, economic and social criteria
- Development of indices and weightings
- Data and practical applications

Exercise 4

Students will undertake a group practical to evaluate similar alternatives as in the previous exercise, but in which MCA procedures are carried out with the aid of computer software.

Lecture 6. The social and economic values of aquatic ecosystems

The concept of value

- Value and utility
- Willingness to pay
- Contribution to the economy

Ecosystem goods, services and attributes

- Origins of the concept of ecosystem services
- Defining goods, services and attributes
- How goods services and attributes relate to biodiversity concepts
- The Millennium Assessment's view on ecosystem services

The 'Total Economic Value' framework

- The value tree
- How different types of value relate to the goods and services concept

Examples of the value of aquatic ecosystems

- Direct consumptive use values
- Direct non-consumptive use values
- Indirect use values
- Non-use value

Reading

Turner, R.K., van den Bergh, J.C.J.M., Söderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E. and van Ierland, E.C. 2000. Special issue: The values of wetlands: landscape and institutional perspectives. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35: 7-23.

Lecture 7. Estimating the value of aquatic ecosystems

Typology of methods

- Different groups of methods used for different types of value

Market price methods

- Social survey methods for estimating direct use
- Replacement cost methods for estimating indirect use values

Revealed preference methods

- Travel cost method for estimating tourism values
- Hedonic price methods for estimating property values

Stated preference methods

- Contingent valuation methods for estimating non-use value
- Conjoint valuation methods for predicting impacts of multiple scenarios

Deciding on the valuation approach

- Consideration of the research question
- Importance of understanding marginal value
- Data requirements from biophysical specialists
- The merits of 'benefits transfer' as an approach
- Integrated modelling approaches.

Reading

Ruitenbeek, H.J. 1994. Modelling economy-ecology linkages in mangroves: economic evidence for promoting conservation in Bintuni Bay, Indonesia. Ecological Economics 10: 233-247.

Lecture 8. Valuation case studies

Introduction

- Overview of the extent and geographic spread of valuation studies on aquatic ecosystems

Case studies

The lecturer should choose a selection of her own case study work in order to illustrate the following:

- Purpose of the study
- The methodology used
- The logistics of gathering the data
- The assumptions made
- Conclusions of the study
- The lessons learned

Case studies should include examples of each of the types of methods described in the previous lecture.

Reading

Turpie, J.K. & Joubert, A.R. 2001. Estimating potential impacts of a change in river quality on the tourism value of Kruger National Park: an application of travel cost, contingent and conjoint valuation methods. Water SA 27: 387-398.

Lecture 9. Economic instruments for improving management efficiency

Expanding the production possibilities frontier

- How efficient water management can influence economic possibilities and trade-offs
- Ecosystem sensitivity and the possibilities frontier

Economic incentives

- Why economic incentives are necessary
- Types of economic incentive measures

Supply management

- Actions that improve water supply (quantity and quality)
- Economic instruments that increase water supply, e.g. tradeable pollution permits

Demand management

- Water pricing as a demand management tool
- Tradeable water use rights

Reading

Everard, M. 2004. Investing in sustainable catchments. Science of the Total Environment 324: 1-24

Lecture 10. Payments for ecosystem services

Definition of PES

- Definition of PES
- What PES is not
- Types of ecosystem services traded
- Water as the key resource

Why PES is efficient

- Incentive mechanism
- Financing mechanism

Development of PES systems

- History and global development of PES
- Ways in which PES are initiated
- Enabling factors
- Types of arrangements

PES in South Africa

- The Working for Water Programme as a unique type of PES
- Expansion of the WWF concept in South Africa
- The development of PES in the Maloti-Drakensberg bioregion

Reading

Pagiola, S. Ramírez, E., Gobbi, J., de Haan, C., Ibrahim, M. Murgueitio, E.. Ruíz, J.P. 2007 Paying for the environmental services of silvopastoral practices in Nicaragua. Ecological Economics

Additional readings on selected topics

1. An economist perspective of the environment
   The purpose of this topic is to familiarise persons trained in the environmental field with the way economists look at natural phenomena.
   Readings: Condea (2008) – Environmental issues from an economist's perspective.
   Fullerton (1998) – How economists see the environment

2. Water as an economic good
   The purpose of this topic is to show the dual character of water and the implications for managing water.
   Readings: Savenije (2002): Why water is not an ordinary economic good.
   Savenije (2009) – Water as an economic god and demand management: Paradigm with pitfalls.
   Perry et al (1997): Water as an Economic Good: A solution, or a problem?

3. The role of the government in the economy
   Given the dual character of water as discussed in topic 2, its management requires that the dual nature must be considered. One approach could be as an economic good and the other as a social good. The purpose of this topic is to explain the role of government in society in general and in the economy of a country specifically.
   Reading: Black et al (2008): Public Economics

4. Cost-Benefit Analysis
   Cos-Benefit Analysis is an important tool in economics to determine the net benefit of a decision for society.
   Readings: Black et al (2008): Public Economics, Chapter 8 – cost-benefit analysis
   Ward (2009): Economics in integrated water resources management.

5. Economic value of water
   The purpose of this topic is to illustrate how to calculate the value of water of different uses. These values would then form the basis for comparing the value of water between the different water use sectors.
   Readings: Ward et al (2002): The economic value of water in agriculture.
   Ward et al. (1996): The economic value of water in recreation: evidence from the California drought
   Wang (2002): Valuing water for the Chinese Industries
   Ku (2012): Economic Value of water in the Korean Manufacturing Industry.
   Frederick (1996): Economic values of freshwater in the United States.

6. Water allocation based on the economic value of water
   The purpose of this topic is to understand the complexity of water reallocation.
   Readings: Green (2000): Water allocation, transfer and the link between policy and hydrology.

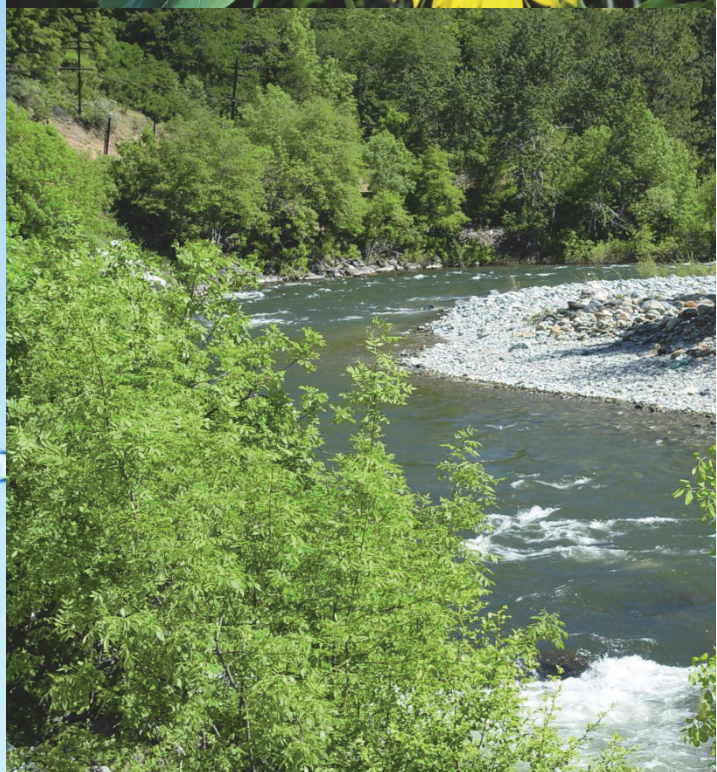
MODULE 3

SURFACE AND GROUNDWATER HYDROLOGY

Tutored MSc in Ecological Water Requirements

Developed by
Prof. Ingrid Dennis

November 2013



LIST OF ABBREVIATIONS

BFI	Baseflow Index
BHN	Basic Human Needs
CMA	Catchment Management Agency
CRD	Cumulative Rainfall Departure
DEAT	Department of Environmental Affairs and Tourism
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Category
ER	Ecological Reserve
EWR	Ecological Water Requirements
GGP	Gross Geographic Product
GRIP	Groundwater Resource Information Project
ICM	Integrated Catchment Management
IFR	Instream Flow Requirements
IUA	Integrated Unit of Analysis
IWRM	Integrated Water Resource Management
K	Hydraulic Conductivity
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MLF	Maintenance Low Flow
NEMA	National Environmental Management Act
NGA	National Groundwater Archive
NGDB	National Groundwater Data Base
NWA	National Water Act (Act 36 of 1998)
NWRS	National Water Resource Strategy
PES	Present Ecological State
PESC	Present Ecological State Category
RDM	Resource Directed Measures
RQO	Resource Quality Objectives
RU	Resource Unit
S	Storativity
SA	South Africa

SDC	Source Directed Controls
T	Transmissivity
UA	Unit of Analysis
WARMS	Water Use Authorisation and Registration Management System
WMA	Water Management Area
WMS	Water Management System
WR2005	Water Resources of South Africa 2005
WRC	Water Research Commission

TABLE OF CONTENTS

RATIONALE

Water is a natural resource and belongs to all the people of South Africa. Sustainability, equity and efficiency are identified by the South African government as central guiding principles in the protection, use, development, conservation, management and control of water resources. These principles recognise the following:

- basic human needs of present and future generations,
- the need to protect water resources (for use),
- the need to share some water resources with other countries,
- the need to promote social and economic development through the use of water and
- the need to establish suitable institutions in order to achieve the purpose of the National Water Act (Act No. 36 of 1998) (NWA).

To be able to implement the NWA, the Minister needs to ensure that the tools and expertise required to implement the Act are available. This module addresses the methods and procedures needed to implement the surface and groundwater hydrology components of Resource Directed Measures (RDM). However it is important to note that the NWA clearly emphasise a unitary hydrological cycle and in the definition of a water resource, but the characteristics of surface water and groundwater sometimes require it to be considered or managed differently.

In essence, this module is about the techniques to ensure that water resources will be used in a sustainable way as prescribed by the NWA. This forms the cornerstone of the long-term sustainable use of the resource – the other two components being equity and efficiency.

> The NWA aims to ensure access to a limited resource on an equitable basis in an integrated, manageable and sustainable manner. The NWA moves away from riparian and property rights, but recognises basic human needs and water needs to sustain the environment. The promulgation of the NWA has resulted in significant changes in the way in which we use and manage water. Because of the shift from private to public water, this is particularly true of the groundwater component of the hydrological system that was previously regarded as private.

The contents can be subdivided into five main facets:

1. Introduction to surface and groundwater hydrology.
2. Summary of Resource Directed Measures.
3. Classifying of surface and groundwater bodies.
4. Determining the Reserve for surface and groundwater bodies.
5. Determining Resource Quality Objectives (RQOs) for surface and groundwater bodies.

LAYOUT OF THE MODULE

In this course, you will get to know the following aspects of the Resource Directed Measures:

- Provides a detailed discussion of the National Water Act. More specifically it focuses on Chapter 3 of the NWA which discusses protecting the health of South Africa's water resources. The aim of protecting water resources is to ensure that water is available for current and future use. Protection therefore involves the sustaining of a certain quantity and quality of water to maintain the overall ecological functioning of rivers, wetlands, groundwater and estuaries. (Study Unit 1) (10%).

- Focuses on data requirements. The purpose of collecting data is to obtain information on which to base management decisions. The aim and purpose of data collection for the Reserve must be defined before the process is actually started. The purpose of data collection for the Reserve must be to assist in the quantification of the resource. A wide range of data and information can be used to characterise the hydrology of an area. Based on the amount and quality of data available, the hydrologist will need to provide an indication of the level of confidence of the assessment. (Study Unit 2) (10%).

- Explains the initiation of a RDM study. It is largely a DWA management task undertaken by the RDM Chief Directorate and the assigned RDM Study Manager, with specialist hydrology input being provided by DWA personnel. (Study Unit 3) (5%).

- Discusses the development of a classification system for water resources, the classification of water resources, the determination of RQOs (desired level of protection of a water resource) as well as the protection of the Reserve for all or part of any significant water resource. (Study Unit 4) (15%).

- Includes requirements for the Reserve. The Reserve is part of the national water resource within each water management area that is under the direct control of the Minister. It is water that is 'set aside' to: provide for basic human needs, and protect water ecosystems (sustain healthy ecosystems). (Study Unit 5) (10%).

- Discusses how each major water resource will be protected and used. This is called determining the resource quality objectives. RQOs must set objectives for the management of water resources in a catchment or other UAs, (if applicable) and by its very nature be applicable on that scale. (Study Unit 6) (10%).

- Presents a set of tools to assist in all the calculations necessary to conduct a RDM study. (Study Unit 7) (10%).

- Case study: Practical implementation of all that has been learnt in study units 1-9. (Study Unit 8) (30%).

NB: The percentages in brackets show the ratio regarding the time you have to spend on the various aspects.

PREREQUISITES

Before attending the course you need to read Chapter 3 of the National Water Act (Appendix A) and the Regulations for the establishment of a Water Resource Classification System (Appendix B).

You need the following resources to complete this course successfully:

- Study material as indicated
- GPS
- Dip metre
- Flow metre
- Pocket calculator
- Laptop or computer

STUDY MATERIAL

The following sources are needed for this course:

- Water Research Commission (2012) Groundwater Resource Directed Measures. Water Research Commission Project No: K8/891, Pretoria.
- Water Research Commission (2010) Developing a method for determining the environmental water requirements for non-perennial systems Project No: TT 459/10, Pretoria.
- Water Research Commission (2008) Environmental flow assessments for rivers: Manual for the building block methodology Project No: TT 354/08

HOW TO STUDY

The module is presented by means of study units where the core principles are discussed. At the beginning of each section, a time allocation is given, which is an indication of the extent of the study task. You may use this allocation to plan your study process. The learning outcomes are also indicated at the beginning of each study unit and guide you as learner about what the problems in the particular study unit are and where you have to pay special attention. Make sure that you have the study guide always at hand, so that you can easily add additional notes to reach the outcome set for each study unit. At the end of study units, there are also evaluation questions. It is essential to answer these questions before moving on to the next study unit. By doing so and by making sure that the learning outcomes have been reached, you can make sure that you have completed the study unit successfully. It is expected of you as a senior student that you will have developed the skill (and that you will further develop this skill) to gather additional information independently in books, journals as well as from the internet. The study guide serves as framework to guide you through the learning content.

ASSESSMENT

Continuous assessment will take place in the form of assignments. Note the dates in the study letter on which these assignments should be handed in. Examination opportunities at the end of the module are also indicated in the study letter. Admission to the examination is dependent on an adequate participation mark, obtained from the assignments.

PRACTICALS AND FIELD REPORTS

A case study forms a unit that contributes to the reaching of outcomes. A two day site visit, data collection and interpretation will be included in this case study. The case study will include collecting existing data and field data to complete the RDM process. A report will be submitted similar to the RDM reports submitted to the Chief Directorate: Resource Directed Measures at the Department of Water Affairs.

MODULE OUTCOMES

At the end of the module, students should be able to:

- show insight, knowledge and skills regarding the interactions between surface water and the groundwater environment;
- classify surface water and groundwater within an integrated unit of analyses;
- calculate the surface water and groundwater contribution to the Reserve;
- run various management scenarios based on the economic/social requirements;
- set resource quality objectives for each scenario;
- complete RDM documentation as required by DWA.

ACTION WORDS

The following words or verbs are important in understanding what to do in example, test, and exam questions:

Calculate:	Determine using numerical data.
Contrast:	Show differences and similarities through comparison.
Derive:	Establish by deduction.
Describe:	Give the relevant facts, characteristics, properties without any further discussion.

Discuss:	Comment on the topic using your own words.
Define:	Give the precise meaning of something.
Explain:	Make comprehensible/understandable.
Illustrate:	To explain something using examples and/or diagrams.
Name/mention/list:	To make a list of characteristics or facts asked for without giving descriptions or explanations.

WARNING AGAINST PLAGIARISM

ASSIGNMENTS ARE INDIVIDUAL TASKS AND NOT GROUP ACTIVITIES. (UNLESS EXPLICITLY INDICATED AS GROUP ACTIVITIES)

Copying of text from other learners or from other sources (for instance the study guide, prescribed material or directly from the internet) is **not allowed** – only brief quotations are allowed and then only if indicated as such.

You should **reformulate** existing text and use your **own words** to explain what you have read. It is not acceptable to retype existing text and just acknowledge the source in a footnote – you should be able to relate the idea or concept, without repeating the original author to the letter.

The aim of the assignments is not the reproduction of existing material, but to ascertain whether you have the ability to integrate existing texts, add your own interpretation and/or critique of the texts and offer a creative solution to existing problems.

Be warned: students who submit copied text will obtain a mark of zero for the assignment and disciplinary steps may be taken by the Faculty and/or University. It is also unacceptable to do somebody else's work, to lend your work to them or to make your work available to them to copy – be careful and do not make your work available to anyone!

STUDY UNIT 1:

CHAPTER 3 OF THE NATIONAL WATER ACT - SURFACE AND GROUNDWATER HYDROLOGY

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

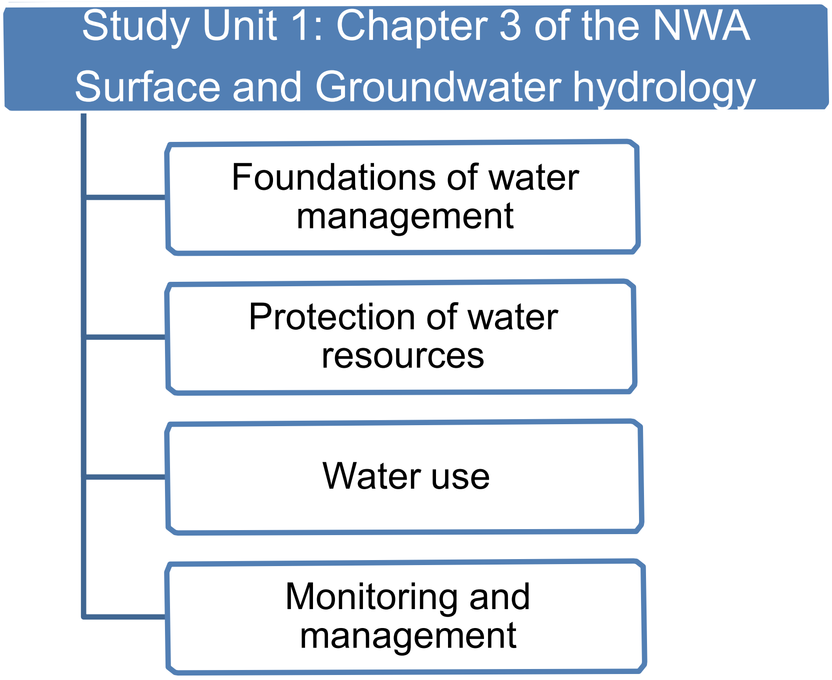
- DWAF (2008) National Water Resource Strategy. Department of Water Affairs and Forestry, Pretoria.
- Department of Water Affairs. (2010) Regulations for the Establishment of a Water Resource Classification System. Pretoria.
- National Water Act (Act 36 of 1998).
- Water Services Act (Act 108 of 1997).
- Thompson, H (2006) Water Law: A practical approach to resource management and the provision of services. Juta and Co Ltd, ISBN 10: 0-7021-6732-0, Cape Town.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about surface water and groundwater hydrology:

- Describe the importance thereof, in the management of South Africa's water resources;
- Discuss and understand the integrated water cycle and associated integrated water resource management;
- Discuss the RDM steps;
- Explain the role of the RDM steps in the licensing of water resources;
- Understand that the quantification of water resources refers to both quantity and quality;

The study unit will be conducted as follows:



INTRODUCTION

Sustainability, equity and efficiency are identified as central guiding principles in the protection, use, development, conservation, management and control of water resources. These principles recognise the following:

- basic human needs of present and future generations,
- the need to protect water resources,
- the need to share some water resources with other countries,
- the need to promote social and economic development through the use of water and
- the need to establish suitable institutions in order to achieve the purpose of the National Water Act (Act No. 36 of 1998).

National government is responsible for the achievement of these fundamental principles in accordance with a mandate for water reform. The Minister of Water Affairs has ultimate responsibility to fulfil obligations relating to the use, allocation, protection and access to water resources.

To be able to implement the National Water Act (Act No. 36 of 1998), the Minister needs to ensure that the tools and expertise required to implement the Act are available. The Department of Water Affairs (DWA) set about developing the required methods and procedures needed to address the Reserve, a provision in the Act that requires water be set aside for basic human needs and aquatic ecosystems before allocation to other users.

1. Foundations of Water Management

During Water Year held in 1970, it was clear that South Africa would run into water supply problems by the year 2000, especially in Gauteng and major metropolitan areas. Complex inter-basin transfer schemes, such as the Lesotho Highlands Water Project and the Tugela-Vaal, Usutu-Vaal and Orange-Fish-Sundays Rivers schemes, helped postpone the onset of water shortages. Had no action had been taken, South Africa would currently be facing a supply crisis. Addressing the problem required innovative thinking, strategies, legislation and timeous implementation. The National Water Act (NWA) (Act No. 36 of 1998) is one of the outcomes of the process aimed at addressing issues relating to water in the country.

The now-repealed Water Act of 1956 (Act 54 of 1956) dealt with water in public streams. Groundwater was considered a private use. It received virtually no protection, except in the so-called Government Subterranean Water Control Areas. The old Act also largely ignored environmental issues, equity issues and downstream water requirements. The Forestry Act of the time allowed the planting of commercial forests in sensitive runoff and recharge areas, under a permit system affording virtually no cognisance to ecological and environmental issues.

A change in government in 1994 was opportune to address the shortcomings of existing legislation and the water needs of the country. Nearly all components of the hydrological system (including groundwater) now fall under the NWA. The integrated management of all water resources and, where appropriate, delegation of management functions to regional or catchment levels enables everyone to participate in the management of the country's water resources.

The NWA provides a legal framework for the effective and sustainable management of South Africa's water resources. The purpose of the Act is to ensure the nation's water resources are protected, used, developed, conserved, managed and controlled in ways that take into account, among other factors, wide consultation with all interested and affected parties and environmental and socio-economic factors. As the public trustee of the nation's water resources, the National Government, acting through the Minister of Water Affairs and Forestry, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate.

The Constitution is the highest law of the land, and all other laws must be aligned with it. As a result, the Constitution and Agenda 21 (which is an international plan for sustainable development to which South Africa is a signatory) formed the basis for water management in South Africa. To implement water policy, two new acts were drafted and signed into law:

- National Water Act (Act No. 36 of 1998): This Act deals with the management of water resources, and its purpose is to ensure that there will be water for basic human needs and for the economic development of the country. The NWA recognises the interdependency of all the components of the water cycle and that these should be managed as a single resource.

- Water Services Act (Act No. 108 of 1997): This Act provides the right to access to basic water supply and sanitation and provides the framework for delivery of these water services to the people of the country.

Water is a natural resource and belongs to all the people of South Africa. The Department of Water Affairs (DWA) has the responsibility of managing water resources on behalf of the people of South Africa. In order to achieve this, a National Water Resource Strategy (NWRS) was developed. The strategy describes the ways in which all water resources will be protected, used, developed, conserved, managed and controlled. This long-term plan is to be reviewed every five years.

This module focuses on Chapter 3 (sections 12-18) of the National Water Act, which deals with the protection of water resources. This includes Classification, Resource Quality Objectives and the Reserve – collectively referred to as Resource Directed Measures or RDM.

2. Protection of Water Resources

GROUP WORK: Read Chapter 3 of NWA and discuss the protection of water resources

Chapter 3 of the NWA provides legal decision-making tools for attaining a balance between protecting and using water resources. These include:

- Classification systems for water resources
- The Reserve
- Resource Quality Objectives
- Source-directed controls (pollution prevention and remediation)
- Emergency incidents.

Those approaches that target protecting the health of a water resource are described as Resource Directed Measures. These address the quantity and quality of water in a water resource, the animals that live in that resource, and vegetation around the resource. Those approaches that target the control of impacts that result (or could result) from the use of a water resource or adjacent areas are described as source-directed measures or controls. Source-directed controls typically aim to control and manage pollution (disposal of effluents) and over-use of water resources (abstraction of water). Though these two controlling mechanisms are interlinked and have a degree of overlap, this course focuses on Resource Directed Measures, commonly abbreviated as RDM.

Source-directed controls

Some examples of source-directed measures already in place are:

- General authorisation of water use
- Licensing of water use
- License-specific conditions
- Minimum requirements for waste disposal
- General and special standards for effluent disposal
- Special standards for phosphate for the discharge of water containing waste.

It is important to recognise that RDM is a strategy and approach developed to implement the National Water Act, although this is not mentioned *per se* in the Act. Classification, the Reserve and Resource Quality Objectives are mentioned as tools in the Act, but not RDM.

3. Water Use

The NWA requires all water use to be authorised. This tool aims to promote the wise use of water. Before any water use can be authorised, water has to be set aside for Classification, the Reserve, international obligations, inter-basin transfers, strategic use and future use. These allocations are to be done at a national level by DWA. CMAs are responsible for authorising and allocating the balance of the water resource at a catchment level.

Four main mechanisms for authorising water use have been established. It is recognised that the biggest water users have the biggest risk impacting negatively on water resources. Moreover, DWA does not have sufficient resources to authorise all water use. To overcome this problem, various mechanisms of authorisation were developed (Figure 1):

- Schedule 1 Use – the National Water Act automatically authorises people who use small amounts of water for household use, watering gardens and animals (not for commercial purposes) and storing or using rainwater from a roof to do so. No limit is specified for Schedule 1 Use.
- General Authorisation – in terms of section 39 of the National Water Act, users may use water without a licence provided the water use is within the conditions of the General Authorisation. The General Authorisation was first published in the *Government Gazette* of 8 October 1999 (GG No. 20526 Notice 1191). However, a revised General Authorisation was published on 27 February 2004 (they are currently under revision). In terms of the General Authorisation, water users must still register their use, but need not apply for a licence.
- Continuation of Existing Lawful Use – any lawful water use under any law passed between 1 October 1996 and 31 September 1998 can continue, until such users are licensed.
- Licensing – All water users who fall outside these definitions require a licence. A licence entitles a water user to use water within the conditions of the licence. These conditions must be reviewed every five years and a licence may only be issued for a maximum of 40 years. At present, a process for individual licence application and evaluation is in use, but this will shortly be streamlined.

In instances where there is not enough water for all users and the water resource is considered stressed, e.g. water use (or demand) is greater than the volume of water available, then a process of compulsory licensing will be invoked. This could result in the withdrawal of generally authorised use and continuation of existing lawful use. All water users – excluding Schedule 1 users – will have to apply for a licence.

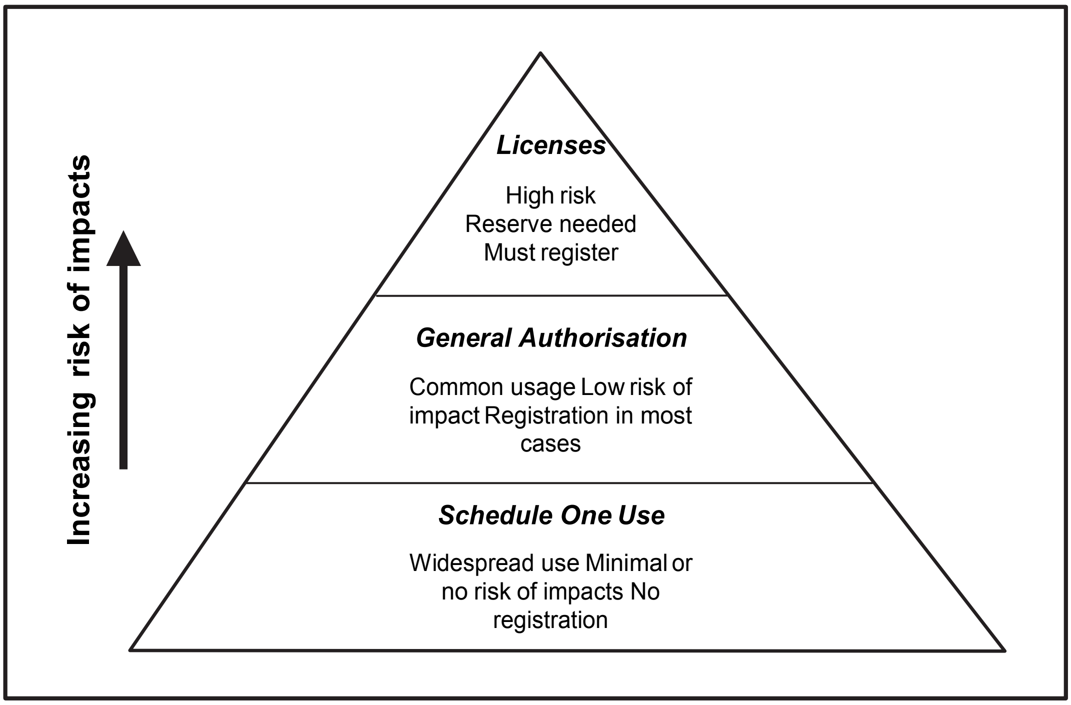


Figure 1: Schematic representation of mechanisms used to regulate the use of water

From the National Water Act: Definition of Water Use

Under Section 21 of the National Water Act (Act No. 36 of 1998), water use includes:

- taking water from a water resource;
- storing water;
- impeding or diverting the flow of water in a watercourse;
- engaging in a stream flow reduction activity contemplated in section 36;
- engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);
- discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
- disposing of waste in a manner which may detrimentally impact on a water resource;
- disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
- altering the bed, banks, course or characteristics of a watercourse;
- removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
- using water for recreational purposes.

4. Monitoring and Management

ASSIGNMENT: Research current monitoring conducted in South Africa, including monitoring locations, frequency and water quality parameters. Consider national, regional and local scale.

The Minister of Water Affairs is the public trustee of water resources and has the overall responsibility for all aspects of water management. However, responsibility and authority for water management will eventually be devolved to a local level. It is planned that DWA will ultimately provide national policy and a regulatory framework for water resource management, and will make sure that other water institutions are effective. It is expected that the Department will be responsible for quantifying the Reserve, for example, while CMAs will be responsible for allocating available water resources, managing the allocation process and monitoring both water use and resource response to that use.

Monitoring and monitoring information systems form a crucial part of the management of the country's water resources. Extensive monitoring already takes place, but both surface and groundwater monitoring programmes need to be extended. Similarly, the information systems on to which monitored data are captured also need to be revised and updated on a regular basis.

SELF-EVALUATION QUESTIONS

1. Explain integrated water resource management. [ANSWER: National Water Resource Strategy]
2. Explain protection of South Africa's water resources. [ANSWER: Chapter 3 of NWA].
3. Discuss the 3 major components of the RDM [ANSWER: Chapter 3 of NWA]
4. Discuss why monitoring is important. [ANSWER: National Water Resource Strategy]

SUMMARY

The NWA aims to ensure access to a limited resource on an equitable basis in an integrated, managed and sustainable manner. The Act moves away from riparian and property rights, but recognises basic human needs and water needs to sustain the environment. The promulgation of the Act has resulted in significant changes in the way in which we use and manage water. Because of the shift from private to public water, this is particularly true of the groundwater component of the hydrological system. Because strategies, methods and tools are in the process of being developed and refined, methods and tools discussed in this manual remain preliminary (in a legal context) until published in the *Government Gazette*.

STUDY UNIT 2:

DATA

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

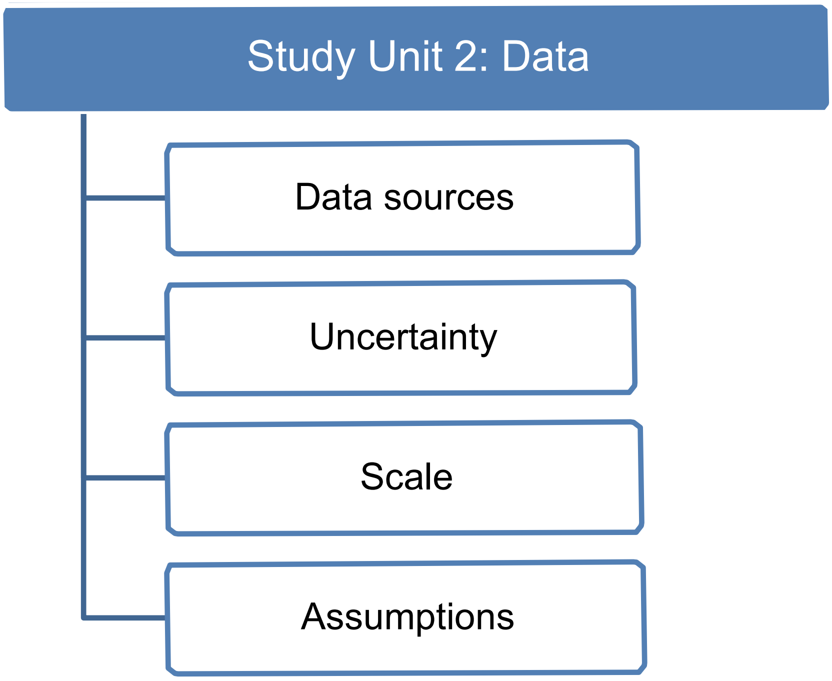
- Council for Geoscience webpage: www.geoscience.org.za
- Department of Environmental Affairs webpage: www.environment.gov.za
- Department of Water Affairs webpage: www.dwa.gov.za
- River Health Programme webpage: www.csir.co.za/rhp
- South African Weather Services webpage: www.weathersa.co.za
- Water Research Commission webpage: www.wrc.org.za
- Water Research Commission (2007) Water Resources of South Africa 2005. WRC Report No. K5/1491, Pretoria.
- Water Research Commission (2010) Identification, estimation, quantification and incorporation of risk and uncertainty in Water Resources Management Tools in South Africa. WRC Report No. K5/1838, Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about surface water and groundwater hydrology:

- List data sources
- Discuss the importance of quality data
- Discuss of uncertainties related to data and associated methodologies to reduce these uncertainties
- Understand scale and how it can affect the results of a study
- List all assumptions related to the various data sets

The study unit will be conducted as follows:



INTRODUCTION

The purpose of collecting data is to obtain information on which to base management decisions. Water science is based on quantitative methods to delineate, evaluate and understand water resources. The main purpose is to determine water quantities and qualities to be able to plan ahead for management purposes. The aim and purpose of surface water and groundwater data collection for the Reserve must be defined before the process is actually started. The purpose of data collection for the Reserve must be to assist in the quantification of the resource.

1. Data Sources

A wide range of data and information can be used to characterise the hydrology and geohydrology of an area. Based on the amount and quality of data available, the hydrologist/geohydrologist will need to provide an indication of the level of confidence of the assessment. Possible sources of data are listed in Table 1.

Table 1: Possible sources of data used during GRDM assessments

DATA NEEDED	DATA AND INFORMATION	SOURCE
Study area	Quaternary catchment boundaries	WR2005
Population data	Population statistics	Central Statistical Services Regional and local municipalities
Conservation areas		DWA
Water sources	Flow-gauging stations	DWA
Physiography	Topographical maps – 1:250 000 – 1:50 000 (if needed)	Dir. Surveys and Land Information
Climatic data	Rainfall data	Weather Bureau

DATA NEEDED	DATA AND INFORMATION	SOURCE
	Evaporation data	Agriculture Research Council WR2005 SA Atlas of Agrohydrology and Climatology Local communities, mines and industry DWA Department of Agriculture, Forestry and Fisheries
Geology	Geological maps – 1:250 000 – 1:50 000 (if available)	Council for Geoscience DWA Consultants Mines
Physiography	Remote sensing maps and data – satellite images – aerial photographs	Satellite Applications Centre Directorate Surveys and Land Information
Soils	Soil maps	Department of Agriculture, Forestry and Fisheries Agricultural Research Council WR2005
Drainage	Flow data Wetland inventory Springs	DWA WR2005 Working for Wetlands DWA
Surface water information	Cross sections of river beds Dam releases and seepages	DWA Consultants River Health Program
Vegetation and land-use		SANBI WR2005 DEAT
Geohydrology	Geohydrological maps – national groundwater maps – harvest potential map – groundwater vulnerability map – 1:500 000 geohydrological maps	WRC DWA
Hydrological/geo-hydrological data	Hydrological/geohydrological data – national database – hydrochemical database – reports – field assessments	DWA: NGDB/NGA DWA Regional Offices Water Research Commission Local authorities Consultants GRIP (where applicable) River Health Programme
Water use (for vegetation, mining, agriculture, forestry, domestic supply, etc.)	WARMS database Regional databases Reports Satellite images	DWA Regional Offices Water Research Commission Local authorities Consultants GRIP (where applicable)
Catchment study reports	General and historical information relating to water resources	DWA
Internal Strategic Prospective (ISP) Reports	General and historical information relating to water resources	DWA

2. Uncertainty

Hydrological parameters that are used to measure data, and are used to interpret and analyse information, are evaluated in terms of levels of uncertainty in this section. The data parameters are listed and classified in terms of the character of the variable, field measurement methods, statistical distribution, methods of interpretation and level of uncertainty. The evaluation shows the following:

- Direct field measurements: The level of uncertainty at the data points are low, but spatial analyses techniques are required to interpolate the data across the area of interest. The spatial interpolation introduces a level of uncertainty.

- Rainfall is also an important direct field measurement that can be made. It is the driving force behind recharge and requires statistical analysis. It can be considered as an indirect parameter as it influences recharge that is a more complex variable. Uncertainty in rainfall is also introduced where interpolations between measurement stations are made.

- Derivations based on analytical models: Hydraulic parameters such can be indirectly derived from analytical and numerical models, based on field tests. The indirect nature of these parameters introduces a higher level of uncertainty.

- Other sources and sinks (dams, springs, wetlands, alien vegetation, etc.) that are estimated using qualitative field measurements or remote sensing: Remote sensing would, for example, be used to determine the area of a wetland or alien vegetation patch which will be used to derive water use values. A higher level of uncertainty is introduced as derivations are made based on remote sensing information. The quantification of these sources and sinks are usually conservative estimates as very few field measurements are available.

- Estimations based on a qualified guess: Parameters such as recharge cannot be measured or determined directly from field measurements. In most cases only an initial estimation or guess can be made that can be qualified using analytical techniques or from long-term monitoring data.

Based on the above hydrology/geohydrology can be classified as a non-unique science associated with a high degree of uncertainty. The aim has to be on maximising the data that exists and the analysis methods that can be used to characterise and understand the level of uncertainty. The level of uncertainty needs to be reduced for the purposes of decision-making for management purposes as it is becomes very difficult, expensive and even impossible to reduce uncertainty beyond certain ranges. Data and uncertainty can therefore not be evaluated in the absence of a decision-making framework or methodology, which should underpin the point of sufficiency of data.

Data is often sparse and multivariate, associated with a high degree of uncertainty. This problem can be addressed by utilising geospatial methodologies that are designed for this purpose. The various methods that are recommended to be used for the purposes of the assessment of the groundwater component of the reserve are:

A. Temporally variable data:

- Mean

- Standard deviation

- Percentile values for levels of assurance

- Regression (correlation)

- Hypothesis testing
- Bayesian estimation using preconditioning and posterior conditioning.

B. Spatially variable data:

- Linear interpolation
- Kriging
- Inverse distance to a power
- Nearest neighbour

Two methodologies are suggested to accommodate uncertainty, namely:

- Probabilistic analyses which are well established. These methods do require large datasets which can be skewed.
- Fuzzy Set Theory is an emerging method which includes the knowledge of experts and is well-suited for small datasets.

Important outcomes are to determine the variability of the various parameters as it is the variability (temporal and spatial) that increases the uncertainty, which in turn makes the management of the resource more challenging.

3. Scale

Scales are an important element in RDM assessments for different reasons. Firstly, place-based analysis seeks for detecting vulnerability at a certain locality, implying the selection of a unit of analysis. Secondly, systems and processes operate at a wide variety of spatial and temporal scales requiring a holistic overview of processes at multiple scales. Thirdly, cross-scale interaction exerts a crucial influence on outcomes at a given scale.

The analyst must pre-determine the scale of the assessment as it will influence the data collection programme and the uncertainty. All data and uncertainty will be relative to the scale of the assessment.

4. Assumptions

In all investigations, assumptions must be made. In reality, assumptions are part of the data collection and interpretation process. The derivation of parameters is based on analytical and numerical analysis techniques or models that make assumptions in order to arrive at solutions.

It is proposed that conservative assumptions be used, in line with the precautionary principle required by the National Environmental Management Act (NEMA, 1998). Assumptions used in this way would always have the effect that more water is available than the actual case. The assumption would serve as a safety factor against uncertainty; the higher the uncertainty, the larger the safety factor. Care should be taken not to become over-conservative in the use of assumptions.

ASSIGNMENT: Class to divide into 3 groups. Each group is to research and write an essay of 1000 words on one of the following topics:

- Data uncertainty
- Scale
- Assumptions

Some useful references include:

Bear, J. (1979) Hydraulics of Groundwater. McGraw-Hill Inc. New York.

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Ellison, A.M. (1996) An Introduction to Bayesian Inference for Ecological Research and Environmental Decision-Making. Ecological Applications, 6 (4), pp 1036-1046.

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Olkin, I. Gleser, L.J. and Derman, C. (1978) Probability Models and Applications. Macmillan Publishing Co., Inc. New York.

Wisniewski, M. (2002) Quantitative Methods for Decision Makers. Prentice Hall. Harlow, England.

SELF-EVALUATION QUESTIONS

1. Define data uncertainty. [ANSWER: In literature provided]
2. Discuss methods to reduce data uncertainty. [ANSWER: In literature provided].
3. Discuss typical assumptions in a surface water and groundwater RDM [ANSWER: In literature provided]

SUMMARY

Hydrology/geohydrology is not an exact science and there are no unique solutions. It is therefore not useful to consider data as exact and to look for unique solutions. Data forms the basis of the decision-making process. When data is analyzed, it becomes information which upon interpretation, is used to base management decisions on. The aim and purpose of data collection for the reserve must be defined before the process is actually started. The purpose of data collection for the reserve must be to assist in the quantification of the resource for the purposes of the reserve classification. Evaluation of the data and uncertainty shows that data is highly variable, sparse and associated with a high degree of uncertainty. The data collection and interpretation process should be defined within the decision-making framework of the RDM. Data collection especially field work is associated with high expenses and is limited by financial constraints. Statistical methods and analysis techniques such as modelling should be used to optimize data collection programmes.

STUDY UNIT 3:

INITIATION OF RDM

TIME

You will need approximately 5 hours to master this study unit.

REFERENCES

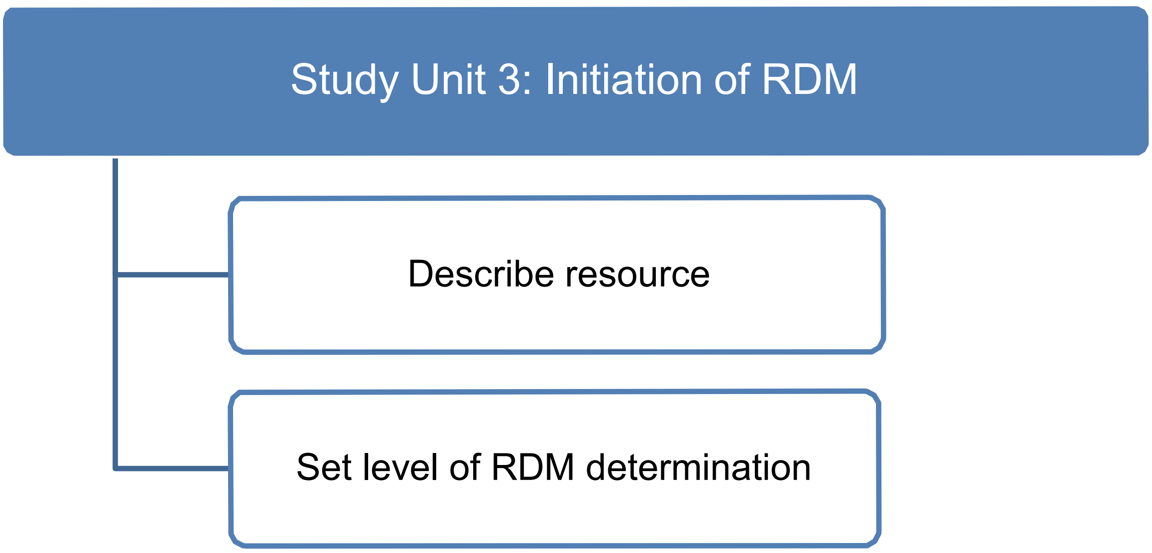
- National Environmental Management Act (Act 107 of 1998).
- National Water Act (Act 36 of 1998).
- Parsons, R & Wentzel, J (2007) *Groundwater Resource Directed Measures Manual*. Water Research Commission Project No: TT299/07, Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Describe surface and groundwater resources for a RDM study
- Set the level of a Reserve determination

The study unit will be conducted as follows:



INTRODUCTION

The initiation of a RDM study is largely a DWA management task undertaken by the RDM Chief Directorate and the assigned RDM Study Manager, with specialist input being provided by DWA personnel.

When initiating a study:

- the area to be studied needs to be defined
- the level of confidence of the GRDM set
- the project Terms of Reference set
- the study team needs to undertake the assessment identified and appointed.

However as the last 2 points are primarily DWA responsibilities, this study unit will focus on the first 2 points.

1. Describe the Resource

At the earliest stage of a RDM assessment, whether it is a pre-emptive activity or in response to a licence application, a decision has to be made on whether on the level of the assessment.

The resource can be defined according to:

- the possible geographical extent of the study area and a brief description thereof
- the role of the resource in terms of sustaining other components of the hydrological system (baseflow to rivers, surface water contribution to groundwater, wetlands and estuaries)
- the degree of resource dependence (both social and environmental), including volumes of water abstracted
- any identified aquifer stresses (quantity and quality)
- data and information available.

This phase is probably the longest in the RDM determination process, as it entails the collection of data and information on which the RDM assessment is based. The collected information is then analysed and a conceptual understanding of the study area developed.

2. Define level of RDM study

Four levels of RDM determination are recognised, with each expected to yield a greater level of confidence in the results. However, it must be noted that data availability will dictate the confidence level. The following general features characterise the differences between the four levels:

- Desktop: These determinations are done using readily available data and information; extrapolate the results from previous more detailed and localised assessments; have low intensity information requirements and yield results of very low confidence.

- Rapid: Similar to desktop determinations, but include a short field trip to assess present state; typically used to assess individual licence applications with low impact, in unstressed catchments and/or catchments of low ecological importance and sensitivity.

- Intermediate: These determinations yield results of medium confidence; require field investigations by experienced specialists. They are used to assess implications of individual licences of moderate impacts in relatively stressed catchments.

- Comprehensive: Comprehensive RDM determinations aim to produce high confidence results and are based on site-specific data collected by a team of specialists; used for all compulsory licensing exercises, as well as for individual licence applications that could have a large impact in any catchment, or a relatively small impact in ecologically important and sensitive catchments. It is important to note that a comprehensive study does not GUARANTEE high confidence results – there might be more confidence in your DATA, but all that might achieve is increased appreciation of the COMPLEXITY of the system, and NO increase in confidence on what USE is SUSTAINABLE.

Accepting that DWA does not have the time or resources to undertake comprehensive RDM assessments of each significant water resource, a hierarchical approach is required. Lower levels of confidence can be accepted in unstressed catchments, in catchments where the impact of water use is low or in catchments where water plays a limited role in sustaining the EWRs. Conversely, high levels of confidence are required in stressed, ecologically sensitive or important catchments (or parts thereof) and where water abstraction is known to have significant negative regional impacts.

At present, no formal methods exist to guide the level of RDM determination that is required. DWAF (2003) presented a similar guide, but based on only stress and impact (Figure 2).

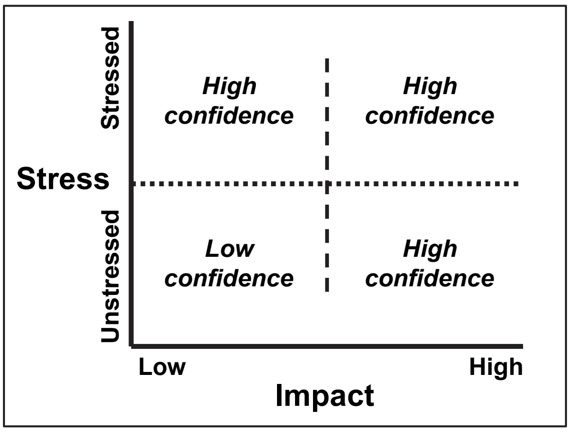


Figure 2: Level of confidence required for a RDM assessment based on stress and impact

This approach requires that the level of stress of a significant water resource be assessed as well as the potential impact of water use or proposed water use.

The same level of assessment need not be applied across a study area. Rapid level assessments could suffice in low usage areas, in low stress areas or in instances where usage is expected to have limited impact. Assessments that are more detailed could be undertaken in areas where specific problems occur or in areas where the resource is clearly stressed. During the preparatory phase and prior to commissioning RDM assessments, significant water resources in a study area requiring higher levels of assessment must be identified. These are referred to as multilevel RDM assessments.

Once this has been completed the future stresses/impacts (such as type of proposed development) need to be taken into account.

The results of the entire investigation lead to the assigning of the level at which the RDM assessment is to happen and DWA can set up the terms of reference. A key factor controlling the success of any project is the completeness and clarity of the terms of reference. The terms of reference should:

- set out the nature and extent of work required;
- form the basis of the tender process; and
- used to ascertain whether the RDM assessment has been completed to specification.

ASSIGNMENT: Choose 2 comprehensive RDM studies published on the following webpage: http://www.dwa.gov.za/rdm/Default.aspx and describe the study areas and discuss why they were assigned comprehensive status.

SELF-EVALUATION QUESTIONS

1. Describe surface water and groundwater conditions for a study area. [ANSWER: In literature provided]
2. Decide on level of RDM study based on existing data. [ANSWER: In literature provided].

SUMMARY

Four levels RDM assessments are recognised – desktop, rapid, intermediate, comprehensive – with each providing an increased level of confidence. Increased levels of commitment and resources are required to attain higher levels of confidence. Desktop RDM assessments can be completed in a matter of hours, but comprehensive RDM assessments may take over a year to complete. The same level of assessment need not be applied across a study area, and a multilevel RDM assessments approach can be adopted. Rapid level assessments could suffice in low usage areas, in low stress areas or in instances where usage is expected to have limited impact.

STUDY UNIT 4:

CLASSIFICATION

TIME

You will need approximately 15 hours to master this study unit.

REFERENCES

- Department of Water Affairs and Forestry (1996). South African Water Quality Guidelines Vol. 1 – Domestic use. 2nd ed., Department of Water Affairs and Forestry, Pretoria.
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- Dollar, EJ, Brown, C, Turpie, J, Turton, A, Colvin, C, Hallowes, J and Manyaka, S, (2006). Rationale and proposed framework for an integrated National Water Resource Classification System. "Straw-dog One". Department of Water Affairs and Forestry, Pretoria.
- SANS 241-2 (2006). Drinking water Part 2: Application of SANS 241-1. South Africa Bureau of Standards.
- Winter, TC, Harvey, J., Franke, OL and Alley W. (1998). Ground water and surface water : a single resource. U.S. Geological Survey circular 1139. Denver, Colorado.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Define the present status of a water resource (quantity and quality)
- Define the state towards a water resource needs to be managed sustainably (quantity and quality)

The study unit will be conducted as follows:

Study Unit 4: Classification

- Steps to classify a resource

INTRODUCTION

The NWA makes provision for the protection of water resources, which is fundamentally related to their use, development, conservation, management and control. The NWA lists several measures to ensure a comprehensive protection of all water resources, including classification, the Reserve and RQOs, which focus on the water resource as an ecosystem rather than simply on water itself as a commodity. RDM comprise of the development of a classification system for water resources, the classification of water resources, the determination of RQOs (desired level of protection of a water resource) as well as the protection of the Reserve for all or part of any significant water resource. The latter specifies the quantity and quality of water required to satisfy basic human needs by securing a basic water supply, and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource. These measures are to be developed progressively within the contexts of the National Water Resource Strategy and Catchment Management Strategies, though a preliminary determination of the Reserve may be made and later superseded by a new one if a resource has not yet been classified.

Under Chapter 3 of the NWA, the Minister is required to develop and use a classification system to determine the Class and RQOs of all or part of water resources considered significant. Each class in the classification system needs to state what kinds of impacts on the water resources are acceptable and what kinds of impacts are not acceptable in order to protect the resource. With regard to water quality management, the NWA states that the classification system for water resources may establish procedures which are designed to satisfy the water quality requirements of water users as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource. The water quality, in this regard, includes all aspects of a water resource, i.e. beyond quantitative and ecological aspects; and also the water quality, including the physical, chemical and biological characteristics of the water.

The main objective of the classification process is to ensure that the resource can be utilised sustainably in the long term if the proposed class is adhered to. This has led to the concept of stress as an indicator. Stress should be defined in such a way that it reflects the long-term sustainable utilisation of the resource, incorporating all the legal requirements that must be considered.

Classification is a legal mechanism that can be used to protect resources in the absence of an ecological link. The intention of the NWA is that the Reserve process should cover the detail of resource protection, and that protection measures be quantified in setting the RQOs.

1. Steps to classify a resource

The procedure for determining the different classes of a water resource is divided into six steps (as shown in Figure 3):

Step 1: Delineate the units of analysis (UA) and describe the *status quo* of the water resource(s)

The key outcome of this step is a map demarcating UAs, each of which is to be classified, a Reserve assessment undertaken and RQOs set. In most instances, it is assumed that the UA is the quaternary catchment[1]; however, this might not always be the case. The UAs are decided based on geohydrological, hydrological and ecological criteria, taking into account the significance of the resource. Other aspects such as physical and management criteria must also be considered (Figure 3).

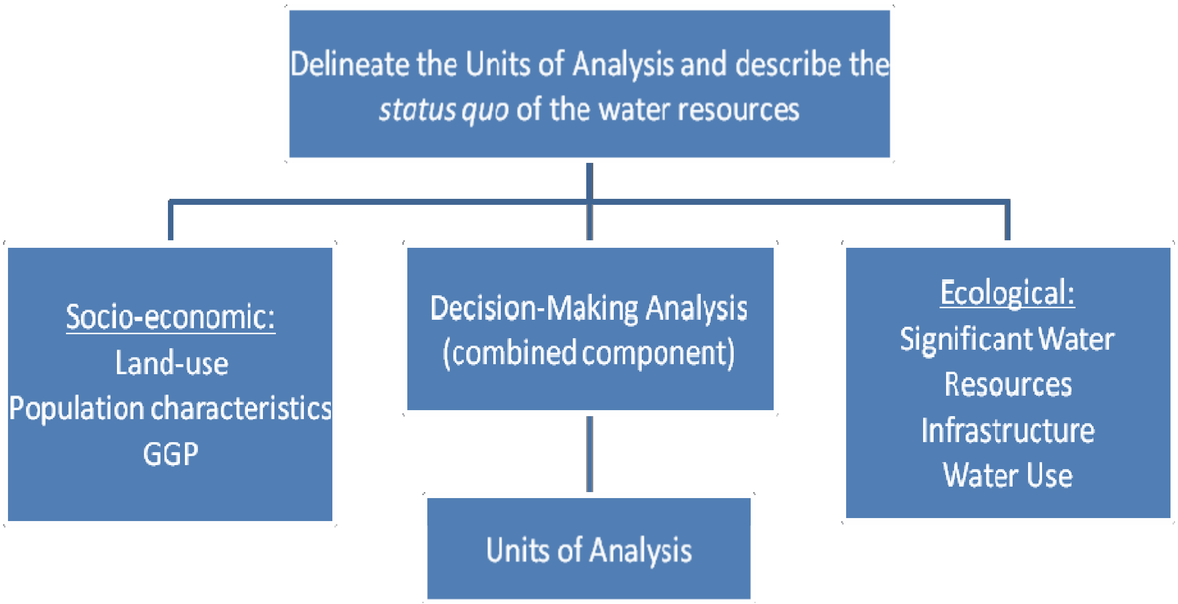


Figure 3: Delineation of UAs

The catchment should be described in as much detail as possible with appropriate maps included to assist the specialists in collecting data (relevant to the particular catchment area) on their specialist fields and to identify the main areas of impact in the catchment. This would then also assist the GIS specialist in determining the UAs.

Step 2: Link socio-economic and ecological value and condition of the water resource(s)

The project team can then select areas for more detailed studies. Nodes need to be established with the objective of predicting probable surface water – groundwater areas of interaction, specifically, of the water resource supplying water to rivers, springs, wetlands

[1] Surface water and groundwater divides do not correspond. However the water resource must be considered in terms of an integrated water resource.

and other ecosystems. To this end, a multi-tiered approach to establishing the location and number of nodes in a target catchment is recommended.

Stakeholders should be the primary drivers of the RDM process and they should be included in the assessments to ensure all their concerns and issues are addressed. Socio-economic[2] issues must be taken into account. These include factors such as land-use, population statistics and gross geographical product (GGP).

Step 3: Quantify the ecological water requirements and changes in non-water quality ecosystems goods, services and attributes

This step is where the ecological requirements, basic human needs etc. are calculated. The data required and documented in Study Unit 2 are used in the quantification of the resource. Tools are provided (Study Unit 7) to do the actual calculations. Typical calculations include:

- Recharge estimation
- Runoff calculations
- Groundwater surface water interaction
- Water use
- Quality estimations
- Resource vulnerability

Step 4: Assess system and set baseline class (or configuration)

The concept of a baseline configuration for a water resource is not easy to quantify. However, the objective of Step 3 of the classification procedure is to set the water quantity (use) and quality base configuration in terms of long-term sustainability.

Indexes or indicators are selected to describe the baseline class and are used in scenarios to describe change. They should cover the main physical and chemical aspects of the system, including issues raised by stakeholders. Potential indicators are suggested in this section.

Defining the point at which a resource is no longer being used in a sustainable manner is generally very difficult. The level of sustainability probably fluctuates through time, and impacts from over-use could manifest themselves sometime after the impact was caused. The change from sustainable use to over-use is gradational, and not necessarily marked by some distinct change. Indicators of quantitative unsustainable groundwater use include:

- Land subsidence or sinkhole formation.
- Long-term declining water levels/flow conditions.
- Long-term declining water quality levels.

A guide for assessing the status of groundwater units based on observed impacts resulting from groundwater abstraction is presented in Table 2.

[2] A summary of a socio-economic assessment is documented in Appendix C.

Table 2: Guide for setting the present Class of a resource unit based on observed environmental impact indicators

PRESENT CLASS	GENERIC DESCRIPTION	AFFECTED ENVIRONMENT
Minimally used (I)	The water resource is minimally altered from its pre-development condition	No sign of significant impacts observed
Moderately used (II)	Localised low level impacts, but no negative effects apparent	Temporal, but not long-term significant impact to: – spring flow – river flow – vegetation – land subsidence – sinkhole formation – groundwater quality
Heavily used (III)	The water resource is significantly altered from its pre-development condition	Moderate to significant impacts to: – spring flow – river flow – vegetation – land subsidence – sinkhole formation – groundwater quality

Defining stress

The concept of stressed water resources is addressed by the NWA, but is not defined. Part 8 of the Act gives some guidance by providing the following qualitative examples of ‘water stress’:

- Where demands for water are approaching or exceed the available supply.
- Where water quality problems are imminent or already exist.
- Where water resource quality is under threat.

The NWA states that the system for classifying water resources may consider water quality requirements of water users without significantly altering the natural water quality characteristics of the resource. It gives a clear mandate to consider the fitness for the proposed beneficial use under consideration of the natural or geogenic background, which may actually render it unsuitable for the proposed use (e.g. natural fluoride concentrations exceeding drinking water limits).

Domestic use (human consumption) is considered by the authors as the highest beneficial use, with the supposedly most stringent quality requirements. It is assumed that any water resource, which is deemed fit for human consumption, also meets the requirements of aquatic ecosystems. While the water quality requirements of aquatic ecosystems might differ and are in fact for several elements even more stringent than for domestic use (e.g. Cd), the chosen approach avoids the pitfall of equating groundwater quality in the sub-surface to water quality discharging into a surface water body. In other words, the methodology recognises the processes occurring in discharge areas in general (e.g. evapotranspiration) and the enhanced microbiological and chemical reactions (e.g. Redox or cation exchange reactions) in the hyporheic zone specifically (Figure 4), without trying to quantify them by setting only domestic use requirements for the groundwater resource itself.

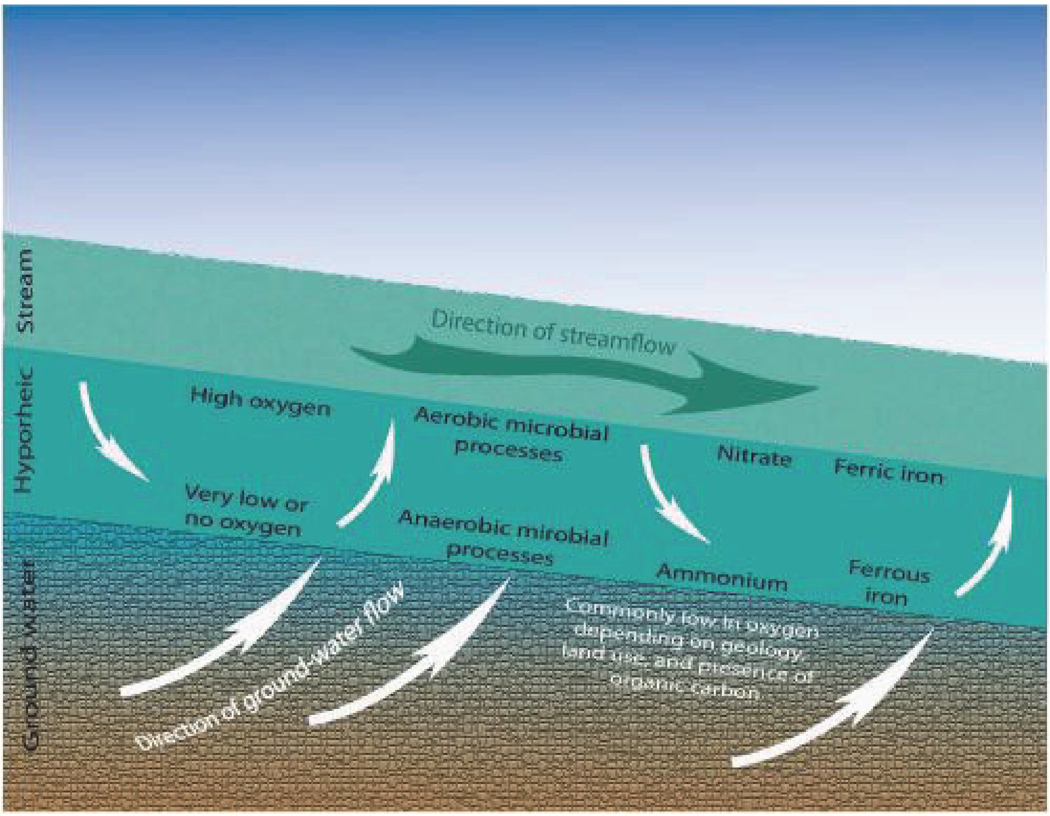


Figure 4: Chemical reactions in the hyporheic zone (Winter *et al*. 1998)

It is therefore recommended to use the South African Water Quality Guidelines Vol. 1 – Domestic use (DWAF, 1996), or the national drinking water standard (SANS 241: 2006) for the present status category assessment of a water resource (Table 3).

Table 3: Present status category based on DWA water quality guidelines for domestic use

PRESENT CLASS	DESCRIPTION	COMPLIANCE (SPATIAL/TEMPORAL)
I	DWA class 0 or 1 or natural background	95 %
II	DWA class 2 (95 % compliance) or natural background (75 % compliance)	75 %
III	DWA class 3 or 4 or natural background (<75 % compliance)	<75 %

Step 5: Scenario development within the IWRM process

The objective of Step 5 of the classification procedure is to evaluate scenarios within the IWRM process so that a subset of catchment configuration scenarios can be put forward for stakeholder evaluation in Step 5. The current Classification (*status quo* and management) of the Resource should be presented to stakeholders and they must be informed of the implications thereof. Different management scenarios can include changes in land use and climate change impacts. It is for them to decide, taking the social and economic considerations into account, whether they would like to change the Management Class.

Step 6: Evaluate scenarios with stakeholders

This phase will normally be part of the bigger assessment where groundwater has been integrated into the other components of the Reserve. The procedure as spelt out by Dollar *et al*. (2006) should be followed.

Step 7: Gazette class configuration

This phase will normally be part of the bigger assessment where groundwater has been integrated into the other components. The procedure as spelt out by Dollar *et al.* (2006) should be followed.

Step 6 and 7 are not included in the scope of this module.

ASSIGNMENT: Use the 2 comprehensive RDM studies you discussed in Study Unit 3. Use the data obtained and discussed in the previous scenario to classify the resources.

SELF-EVALUATION QUESTIONS

1. Understand and discuss the steps needed to classify a water resource in terms of quantity and quality. [ANSWER: In literature provided]
2. Provide a current classification for a resource.
3. Define a future management class for the resource taking into account various land use scenarios.

SUMMARY

The purpose of this phase of a RDM assessment is to define the present status of each IUA (and local trouble areas) based on levels of sustainable use, stress indexes and other parameters. This requires an assessment of the impact of anthropogenic activities on that IUA (and local trouble areas). A single present status category is assigned to each unit (and local trouble areas). Scenarios are then run to set a management class. The Reserve is set for each IUA.

STUDY UNIT 5:

THE RESERVE

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

DWAF (1999) Resource directed measures for protection of water resources – Volume 6: Groundwater component, Version 1.0. Department of Water Affairs and Forestry, Pretoria.

Herold C (1980) A model to compute a monthly basis diffuse salt loads associated with runoff. HRU Report No. 1/80. Rhodes University, Grahamstown.

Hughes DA and Munster F (1999) A decision support system for an initial low confidence estimate of the quantity component of the Reserve for rivers. Institute for Water Research, Rhodes University.

Hughes DA (2003) Incorporating ground water recharge and discharge functions into an existing monthly rainfall-runoff model. In press.

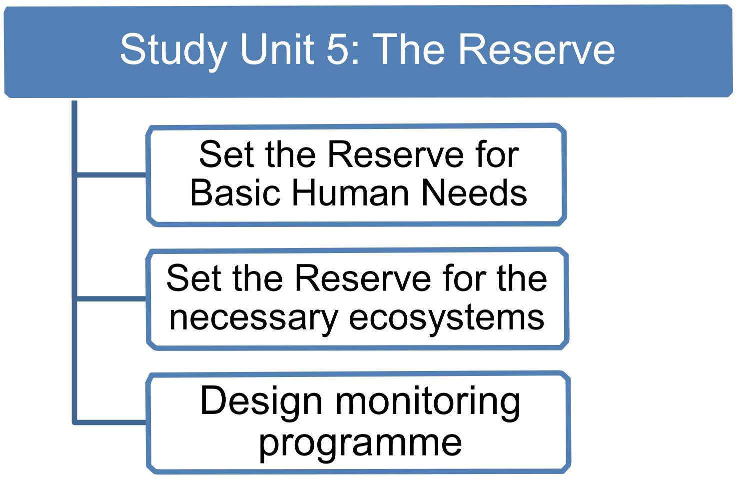
Smaktin VY and Watkins DA (1997) Low flow estimation in South Africa. WRC report 494/1/97. Water Research Commission, Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Quantify basic human needs (quantity and quality)
- Quantify water requirements for aquatic (and groundwater dependent) ecosystems (quantity and quality)

The study unit will be conducted as follows:



INTRODUCTION

The Reserve is an integral part of the RQOs and should be set as soon as the class is determined for each water resource. The requirements of the Reserve and all other demands on the water resource are covered by the determination of the RQOs. The Reserve is part of the national water resource within each water management area that is under the direct control of the Minister. It is water that is 'set aside' to:

- provide for basic human needs, and
- protect water ecosystems (sustain healthy ecosystems).

The Reserve is the only right to water in the NWA. It therefore has priority over all other water use. In other words the amount of water required for the Reserve must be met before water resources can be allocated to other water users.

1. Quantify Basic Human Needs

Currently, basic human needs (BHN) are set at 25 ℓ/p/d. The source of population statistics used for this calculation must be clearly referenced. Although normally quite small in comparison to other uses, it must be borne in mind that this is a right to water and must be legally protected. It is important to note that BHNs must be calculated for all management scenarios

2. Quantify ecological requirements

Ecological Water Requirements (EWR) refers to the quantity and quantity of water of that resource that is required to maintain the said water resource in its assigned ecological category. It is important to note that this cannot be calculated by the hydrologist or geohydrologist. The hydrologist can only quantify the runoff in the river for various scenarios and similarly the geohydrologist can only quantify the groundwater contribution to surface water bodies for various scenarios. It is important to note the EWRs must be calculated for all management scenarios.

3. Design monitoring programme

The Minister of water Affairs is the public trustee of water resources and has the overall responsibility for all aspects of water management. However, responsibility as well as authority for water management will eventually be devolved to a local level. It is planned that DWA will ultimately provide national policy and a regulatory framework for water resource management, and will make sure that other water institutions are effective. Monitoring essentially falls outside the RDM process, but is required to ensure that the Reserve and Resource Quality Objectives are both realistic and are adhered to. Monitoring forms an essential part of what must be a seamless process of managing the country's water resources.

Monitoring has the simple goal of quantifying the behaviour and response of systems to various controls and stressors (recharge, discharge, abstraction, etc.). The response of systems is typically manifested by variation in water levels/flow, a change in water quality, or both. Analysis and interpretation of monitoring data and information enables the resource to be better understood and is therefore vital for sound and responsible resource management.

Extensive monitoring already takes place, but both surface and groundwater monitoring programmes need to be extended. Similarly, the information systems used to capture monitored data also need to be revised and updated on a regular basis. However it is costly and labour intensive to monitor extensively.

ASSIGNMENT: Review monitoring protocols for surface water and groundwater. Develop a monitoring protocol for the RDM process.

SELF-EVALUATION QUESTIONS

1. Calculate BHNs. [ANSWER: In literature provided]
2. Understand EWRs.
3. Develop a monitoring protocol for an associated RDM study.

SUMMARY

The Reserve is the part of the resource that sustains basic human needs and aquatic ecosystems. Water can only be allocated to users and potential users once the volume of water that contributes to sustaining the Reserve has been quantified and RQOs have been met.

STUDY UNIT 6:

RESOURCE QUALITY OBJECTIVES

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

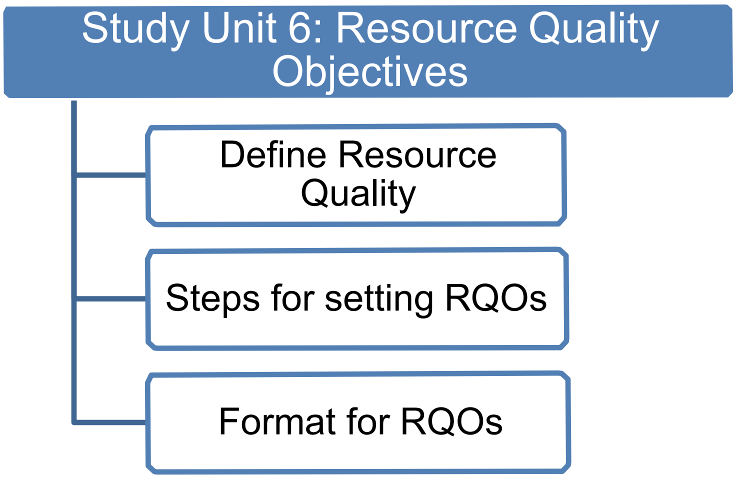
- All references from previous study units.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Establish clear goals relating for the quantity and quality of the water resource, taking into account the classification of the IUA.

The study unit will be conducted as follows:



INTRODUCTION

The purpose of the RQOs is to establish clear goals relating to the quality of the relevant water resource. When setting RQOs, a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other. Once the Class of a water resource and the RQOs have been determined, they are binding on all authorities and institutions when exercising any power or performing any duty under this Act.

RQOs are used to put a classification and Reserve into practice by specifying conditions that will ensure that the Class is not compromised and the Reserve can be met. Resource quality may relate to critical flows, groundwater levels and quality that must be maintained.

1. Defining resource quality (NWA, 1998)

"Resource quality" means the quality of all the aspects of a water resource including:

- the quantity, pattern, timing, water level and assurance of instream flow;
- the water quality, including the physical, chemical and biological characteristics of the water;
- the character and condition of the instream and riparian habitat; and
- the characteristics, condition and distribution of the aquatic biota.

Please note in this module we will only focus on the first 2 points.

2. Steps for setting RQOs

Setting RQOs requires an understanding of groundwater resources and their boundary conditions, uses of water, the importance of various uses and the agreed degree of modification of the resource as measured through the Classification. When setting RQOs, consideration must also be given to ecological dependencies on water and the consequences of modifying the hydrological/geohydrological regime. It is crucial that RQOs are directly linked to both the Classification and the Reserve to ensure their legal position in the event of disputes. Therefore for each water resource class, the procedure for establishing resource quality objectives must comprise of the following six steps:

- **Step 1: Identify water users within each water resource management unit, and where appropriate, align with Step 1 of the water resource classification procedure set out in Regulation 2(4) of gazetted Classification.**
- **Step 2: Determine the present state per water user and, where appropriate, align with Step 5 of the water resource classification procedure set out in Regulation 2(4).**
- **Step 3: Determine the desired water quality per user and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).**
- **Step 4: Determine water user specifications and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).**
- **Step 5: Determine water quality requirements of water uses and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).**
- **Step 6: Gazette and implement the Resource Quality Objectives.**

From the NWA: Resource Quality Objectives

Under Section 13.3 of the National Water Act (Act No. 36 of 1998), Resource Quality Objectives may relate to:

the Reserve;

a) the instream flow;
b) the water level;
c) the presence and concentration of particular substances in the water;
d) the characteristics and quality of the water resource and the instream and riparian habitat;
e) the characteristics and distribution of aquatic biota;
f) the regulation or prohibition of instream or land-based activities which may affect the quantity of water in or quality of the water resource; and
g) any other characteristic of the water resource in question.

3. Format for RQOs

In setting RQOs, one has to recognise that they need to be transparent, and that all calculations and assumptions made in the setting of RQOs need to be recorded. RQOs also need to be semi-quantitative in that they have to effectively combine expert knowledge, stakeholder values and measurable aquifer parameters. Importantly, they must be practical, implementable and measurable. It is pointless to develop a set of objectives that cannot be implemented or monitored to check whether the objective is not being exceeded. Each RQO should be defined in terms of:

- The resource attribute value, e.g. water level/flow, a specific water quality parameter
- The location or area of water management to which it should apply
- Acceptable temporal and spatial range of values
- Frequency and density of monitoring to ensure compliance.

ASSIGNMENT: Use the 2 comprehensive RDM studies you discussed in Study Unit 4. Evaluate the RQOs set for each of the IUAs.

SELF-EVALUATION QUESTIONS

1. Define RQOs for each IUA (water quantity and quality)
2. Relate RQOs to management class.

SUMMARY

Resource Quality Objectives articulate goals that result from the classification and Reserve determination. They are considered powerful tools for implementing resource protection for sustainable use. As part of the RDM assessment, the hydrologist/geohydrologist is to prepare a set of RQOs based on technical considerations. RQOs may be numeric or descriptive, but need to be simple and measurable. Furthermore, they can never be more stringent than natural conditions.

STUDY UNIT 7:

TOOLS

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

- Environmental Protection Agency (2002). Impact of groundwater abstractions on river flows: Phase 2 – "A numerical modelling approach to the estimation of impact" (IGARF II). Report prepared by Parkin, G., Birkinshaw, S., Rao, Z. Murray, M. & Younger, P.L., R&D Project Record W6-046/PR, Environment Agency, Bristol.

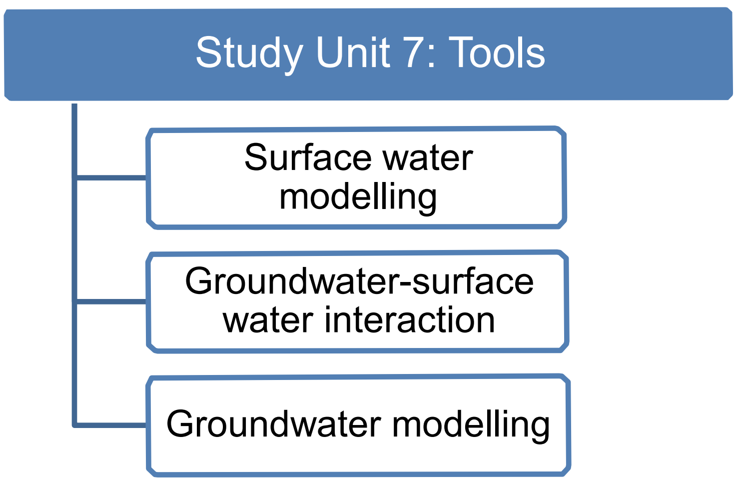
- USGS (1998). Groundwater and Surface water: A single resource. U.S. Geological Survey Circular 1139. Denver, Colorado.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Quantify surface water flows and related water quality.
- Quantify groundwater-surface water interaction.
- Quantify groundwater levels and related water quality.

The study unit will be conducted as follows:



INTRODUCTION

This section describes some of the tools and methods that can be used to quantify various components of RDM. While undertaking a RDM assessment requires a degree of experience and expert knowledge, new tools and methods are constantly being developed to address the challenges of the day. It remains the responsibility of the hydrologist/geohydrologist undertaking a RDM assessment to use appropriate tools, methods and supportive software packages. RQOs are used to put a classification and Reserve into practice by specifying conditions that will ensure that the Class is not compromised and the Reserve can be met.

1. Surface water modelling

A runoff model is a mathematical model describing the rainfall-runoff relations of a rainfall catchment area. More precisely, it produces the surface runoff hydrograph as a response to a rainfall hydrograph as input. In other words, the model calculates the conversion of rainfall into runoff.

The runoff model with a non-linear reservoir is more universally applicable, but still it holds only for catchments whose surface area is limited by the condition that the rainfall can be considered more or less uniformly distributed over the area. The maximum size of the catchment then depends on the rainfall characteristics of the region. When the study area is too large, it can be divided into sub-catchments and the various runoff hydrographs may be combined using flood routing techniques.

PCSWMM accounts for various hydrologic processes that produce runoff from rural and urban areas. These include:

- time-varying rainfall
- evaporation of standing surface water
- infiltration of rainfall into unsaturated soil layers
- percolation of infiltrated water into groundwater layers
- interflow between groundwater and the drainage system
- nonlinear reservoir routing of overland flow

In addition to modelling the generation and transport of runoff flows, PCSWMM can also estimate the production of pollutant loads associated with this runoff.

2. Groundwater-surface water interaction

The interaction of groundwater with surface water depends on the physiographic and climatic setting of the landscape. For example, a stream in a wet climate might receive groundwater inflow, but a stream in an identical physiographic setting in an arid climate might lose water to groundwater.

The hydrology of mountainous terrain is characterised by highly variable precipitation and water movement over and through steep land slopes. On mountain slopes, macropores created by burrowing organisms and by decay of plant roots have the capacity to transmit subsurface flow downslope quickly. In addition, some rock types underlying soils may be highly weathered or fractured and may transmit significant additional amounts of flow through the subsurface. In some settings this rapid flow of water results in springs.

Between rainfall periods, streamflow is sustained by discharge from the ground-water system. During intense rainfall events, most water reaches rivers very rapidly by partially saturating and flowing through the highly conductive soils. On the lower parts of hill slopes, the watertable sometimes rises to the land surface during rainfall events, resulting in overland flow. When this occurs, precipitation on the saturated area adds to the quantity of overland flow.

When rainfall persists in mountainous areas, near-stream saturated areas can expand outward from streams to include areas higher on the hillslope. In some settings, especially in arid regions, overland flow can be generated when the rate of rainfall exceeds the infiltration capacity of the soil.

Near the base of some mountainsides, the watertable intersects the steep valley wall some distance up from the base of the slope. This results in perennial discharge of groundwater and, in many cases, the presence of wetlands. A more common hydrologic process that results in the presence of wetlands in some mountain valleys is the upward discharge of groundwater caused by the change in slope of the watertable from being steep on the valley side to being relatively flat in the alluvial valley. Where both of these water-table conditions exist, wetlands fed by groundwater can be present.

Another dynamic aspect of the interaction of groundwater and surface water in mountain settings is caused by the marked longitudinal component of flow in mountain valleys. The high gradient of mountain streams, coupled with the coarse texture of streambed sediments, results in a strong down-valley component of flow accompanied by frequent exchange of stream water with water in the hyporheic zone. Streams flowing from mountainous terrain commonly flow across alluvial fans at the edges of the valleys. Most streams in this type of setting lose water to groundwater as they traverse the highly permeable alluvial fans.

The geochemical environment of mountains is quite diverse because of the effects of highly variable climate and many different rock and soil types on the evolution of water chemistry. During heavy precipitation, much water flows through shallow flow paths, where it interacts with microbes and soil gases. In the deeper flow through fractured bedrock, longer term geochemical interactions of groundwater with minerals determine the chemistry of water that eventually discharges to streams. Mixing of these chemically different water types result in geochemical reactions that affect the chemistry of water in streams.

In some landscapes, stream valleys are small and they commonly do not have well-developed flood plains. However, major rivers have valleys that usually become increasingly wider downstream. Terraces, natural levees, and abandoned river meanders are common landscape features in major river valleys, and wetlands and pools commonly are associated with these features.

The interaction of groundwater and surface water in river valleys is affected by the interchange of local and regional groundwater flow systems with the rivers and by flooding and evapotranspiration.

Small streams receive groundwater inflow primarily from local flow systems, which usually have limited extent and are highly variable seasonally. Therefore, it is not unusual for small streams to have gaining or losing reaches that change seasonally. For larger rivers that flow in alluvial valleys, the interaction of groundwater and surface water usually is more spatially diverse. Groundwater from regional flow systems discharges to the river as well as at various places across the flood plain. If terraces are present in the alluvial valley, local groundwater flow systems may be associated with each terrace, and pools and wetlands may be formed because of this source of groundwater. At some locations, such as at the valley wall and at the river, local and regional groundwater flow systems may discharge in close proximity. Furthermore, in large alluvial valleys, significant down-valley components of flow in the streambed and in the shallow alluvium may also be present. Added to this distribution of groundwater discharge from different flow systems to different parts of the valley is the effect of flooding. At times of high river flows, water moves into the groundwater system as bank storage. The flow paths can be as lateral flow through the riverbank or, during flooding, as vertical seepage over the flood plain. As flood waters rise, they cause bank storage to move into higher and higher terraces.

The water table generally is not far below the land surface in alluvial valleys. Therefore, vegetation on flood plains, as well as at the base of some terraces, commonly has root systems deep enough so that the plants can transpire water directly from groundwater. Because of the relatively stable source of groundwater, particularly in areas of groundwater discharge, the vegetation can transpire water near the maximum potential transpiration rate, resulting in the same effect as if the water were being pumped by a borehole. This large loss of water can result in drawdown of the water table such that the plants intercept some of the water that would otherwise flow to the river.

A river hydrograph consists of three components: direct runoff, interflow through the unsaturated zone and groundwater discharge from the saturated zone. Although a baseflow is often defined as the groundwater discharge from the saturated zone in classic hydrogeological textbooks the word *baseflow* is generally known to many hydrologists as delayed flow components (mainly groundwater), as opposed to a quick, direct runoff. Thus, baseflow itself is not indicative of origins of water sources. The baseflow is normally separated by removing the direct runoff from a hydrograph. As a result, such a baseflow component may still contain some interflow component.

Suggest methods to calculate groundwater-surface water interaction:

Herold method of baseflow separation

The Herold method is one of the common methods used in South Africa to determine the groundwater contribution to flow in a river. The method is based on the total flow in the river being equal to the groundwater contribution and surface runoff. The assumption is then made that all flow below a certain value (called *GGMAX*) is groundwater flow. The value of GGMAX is adjusted each month according to the surface runoff during the preceding month and is assumed to decay with time.

Recession curve by Moore

The recession curve is the specific part of the hydrograph after the crest (and the rainfall event) where streamflow diminishes (Figure 5). The slope of the recession curve flattens over time from its initial steepness as the quickflow component passes and baseflow becomes dominant. A recession period lasts until streamflow begins to increase again due to subsequent rainfall. Hence, recession curves are the parts of the hydrograph that are dominated by the release of water from natural storages, typically assumed to be groundwater discharge. Recession segments are selected from the hydrograph and can be individually or collectively analysed to gain an understanding of these discharge processes that make up baseflow.

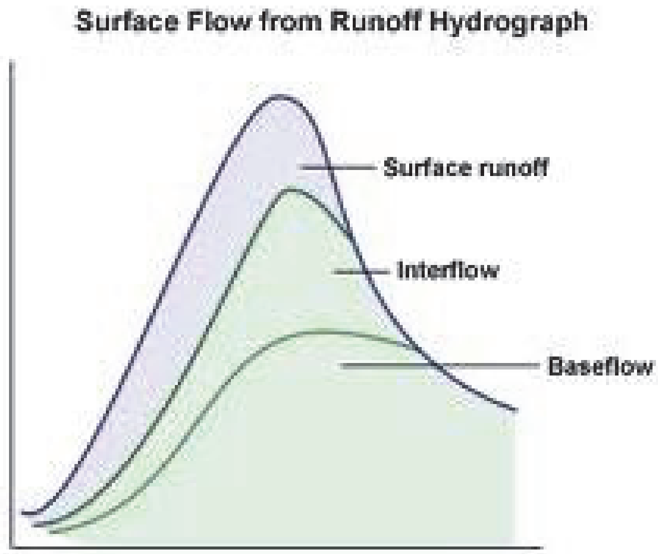


Figure 5: Recession curve

3. Groundwater modelling

SHE and SHETran (numerical model)

The Système Hydrologique Européen (SHE) is a physically-based distributed hydrological numerical modelling system that integrates surface and subsurface flow (including unsaturated vertical flow) on a catchment scale. The model assumes an unconfined aquifer underlain by an aquiclude (impermeable layer). The surface-groundwater interaction is a function of the head difference between the river and the aquifer and can account for clogging layers on the streambed as well as disconnected streams (Bathurst & Cooley, 1995).

MODFLOW – SFR1 (numerical model)

The STREAMFLOW ROUTING, package SFR1, allows for water in-/outflows from run-off, precipitation and evapotranspiration within each reach. In comparison to the RIVER or BRANCH packages, the hydraulic conductance of the riverbed is calculated from input data (hydraulic conductivity, thickness, stream length and stream width) or computed based on streamflow (conductance as a function of river width). Leakage from perched rivers is modelled with a unit gradient between the bottom of the streambed and the water table and assuming that the hydraulic conductivity of the underlying aquifer exceeds the leakage rate.

MODFLOW – SFR2 (numerical model)

A recent extension of the SFR2 package by Niswonger and Prudic (2005) allows modelling the unsaturated vertical flow between streams and aquifers, hence enabling the description of, for example, limited leakage due to the relative permeability of the unsaturated zone.

It is recommended that more than one method be applied to validate results.

ASSIGNMENT: Install PCSWMM on your computer. Follow the tutorial to setup a hydrological model and associated water quality model (Appendix D).

SELF-EVALUATION QUESTIONS

1. Set up, calibrate and run integrated model (water quantity and quality)
2. Run various scenarios with the model.

SUMMARY

This model presents some of the modelling tools available to calculate runoff, groundwater-surface water interaction and groundwater levels. It is important to note that it is not only important to quantify a resource, the associated quality must also be assessed.

STUDY UNIT 8:

CASE STUDY

TIME

You will need approximately 30 hours to master this study unit.

REFERENCES

- All references from previous study units.
- Barnard HC. 2000. An explanation of the 1:500 000 general hydrogeological map: Johannesburg 2526. Department of Water Affairs and Forestry.
- Department of Water Affairs and Forestry. 2004. Internal Strategic Perspective: Limpopo WMA. Prepared by Goba Moahloli Keeve Steyn in association with Tlou and Matji Engineering and Management Services (Pty) Ltd and Golder Associates (Pty) Ltd. Report No. P WMA 01/000/00/0304.
- Department of Water Affairs and Forestry. 2005. Mokolo River Catchment WC/WDM Study: Situation Assessment And Business Plan For Lephalale Municipality. Prepared by Tlou & Mallory (Pty) Ltd on behalf of Directorate: Water Use Efficiency. Report No. WUE WMA 1/000/A42/0503.
- Department of Water Affairs and Forestry. 2008. Intermediate Reserve determination study for Selected Water Resources (Rivers and Groundwater) in the Mokolo Catchment. Desktop EcoClassification report. Prepared by Clean Stream Biological Services and Water for Africa. Authored by Louw D, Huggins G P, Kotze P. Report no: 26/8/3/10/14/002
- Department of Water Affairs 2010. Intermediate Reserve determination study for Selected Water Resources (Rivers and Groundwater) in the Mokolo Catchment. Groundwater-surface water interaction report. Authored by Water Geosciences Report no: 26/8/3/10/12/013
- River Health Programme (RHP). 2006. State-of-Rivers Report. The Mokolo River System. Department of Environmental Affairs and Tourism Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Use all information from study unit 1 -7 to conduct a rapid RDM study.

The study unit will be conducted as follows:

Study Unit 8: Case Study

- Data gathering
- Field assessment
- Modelling
- Report writing

INTRODUCTION

In this study unit, students are expected to apply what they have learnt in study units 1-7. The Mokolo River study areas within the Limpopo WMA forming part of the Limpopo Province in the northern part of the Republic of South Africa (Figure 6). The area consists of quaternary catchments A42A-A42J covering an area of approximately 8100 km^2. The two main towns located in the study area include Lephalale (Ellisras) and Vaalwater. The Mokolo River is the major river system flowing through the study area eventually joining the Limpopo River to form the international boundary between South Africa and Botswana.

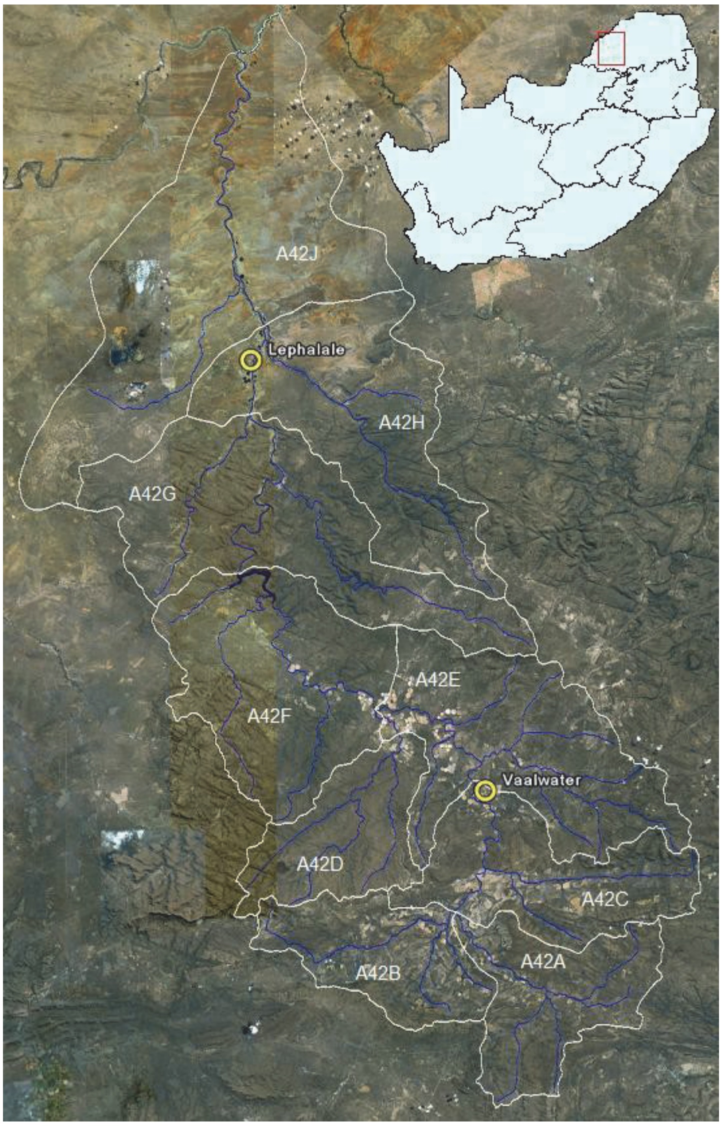


Figure 6: Location of study area

1. Data gathering

All data sets available must be collected and IUA delineated. Some background information is provided below:

The topography (Figure 7) varies depending on the type geological formations present. The northern part of the study area, is typically characterized as relatively flat lying with elevations ranging between 600 to 700 mamsl. Hills are associated with the Bushveld Igneous Complex. The central and southern part of the area is underlain by rocks of the Karoo Supergroup and Waterberg Formation. The mean annual precipitation on average varies between 300 mm and 500 mm. The mean annual potential evaporation is more than twice the amount of rainfall over most of the area. It varies across the Mokolo Catchment from about 1600 mm/a in the south to about 2000 mm/a in the north.

The vegetation of the Mokolo Catchment is characterized by mostly *Bushveld Biomes* in the north, central regions, southeast and southwest. *North Eastern Mountain Sourveld biome* occur in localized areas in the south (Low *et al.,* 1996).

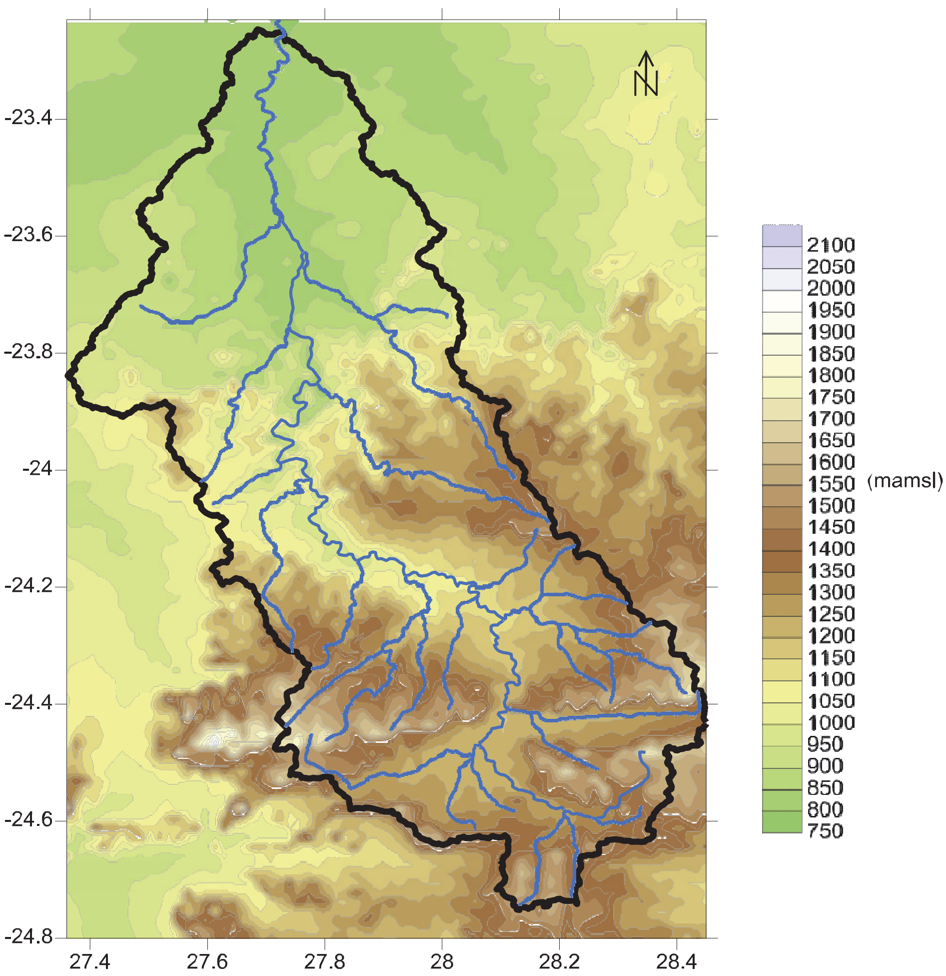


Figure 7: Topography

The geology of the study area is discussed in the following sub-sections:

The north of the study area is underlain by rocks of the Beitbridge Complex and Hout River Gneiss formation forming part of the Basement Complex. The Basement Complex is mainly characterized by granites, granodiorite, migmitites and gneiss but also comprises of metamorphosed sediments, slate, talc schists and sandstone.

Intrusive igneous rocks (Bushveld Igneous Complex) are found to the north, south and east of the study area consisting mainly of the Rustenburg layered suite (Rooiberg Group). This rock formation ranges in composition from ultramafic to acidic rocks and includes an economically (Platinum) important layer comprising mainly of granodoirite, gabbro, norite, anorthosite and granite.

The southern part of the study area is underlain by the Waterberg Formation that consists of three main subgroups; the Setlaole, Makgabeng and Mogalakwena formations. The basal Setlaole Formation is composed of coarse granulestone and is locally conglomeratic. This formation is interpreted to have been deposited in a fluvial, braided river environment. The Makgabeng Formation consists of large-scale trough and planar cross-bedded fine- to medium-grained sandstone. The Mogalakwena Formation consists of interbedded sheets of granulestone and conglomerate.

The Karoo Supergroup, consists mainly of sedimentary rocks. The Waterkloof Formation (Ecca Group), forming part of the Ellisras basin, comprises of diamictite, mudstone and conglomerates. The mudstones are believed to represent glacio-lacustrine deposits whereas the conglomerates and diamictite are believed to have formed as subaqueous outwash deposits formed due to the retreating glacier.

Quaternary deposits cover large portions of the Basement Complex and the northern reaches of the Waterberg Formation. Sediments such as calcrete, ferricrete, gravel red sand and alluvium are found throughout the Mokolo Catchment. Alluvium of up to 5 meters in thickness with a coarse sand base is present along the Mokolo River.

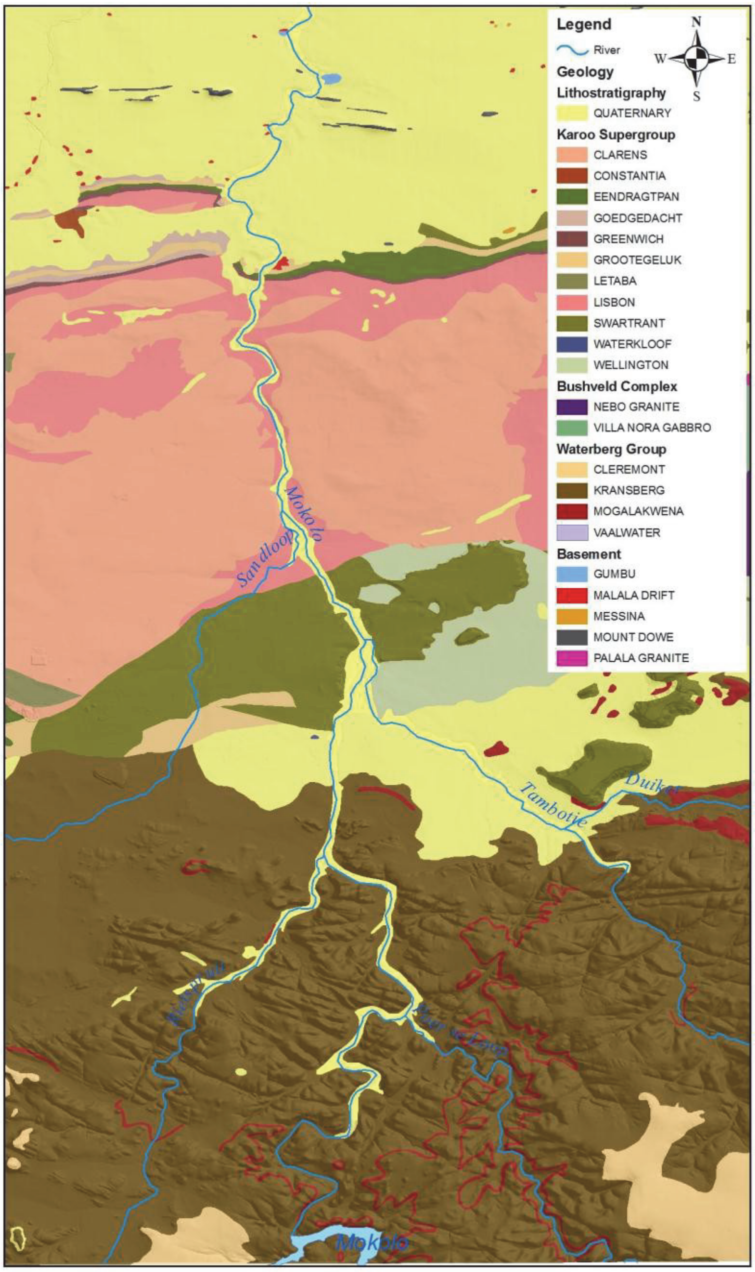


Figure 8: Geology of the study area (taken from DWA, 2010)

There is a State of the Rivers Report for the Mokolo River (2006) which provides an overview of the state of the river for the various sections of the river together with the ecosystems associated with these sections. Impacts on the river are also documented.

In 2010 DWA completed an intermediate Reserve determination for the Mokolo River catchment. The main conclusions taken directly from this report can be summarised as:

- The Mokolo River (upstream) is assumed to be perennial under reference conditions. The Mokolo River (downstream) is presumed to have been near-perennial; only drying up during drought periods. Present day flow modifications to the lower Mokolo have significantly increased the frequency and duration of low and zero flow periods. In future, increased utilisation of the water in the Mokolo Dam is likely to result in further reductions in the size and frequency of high flows coming down the lower Mokolo River. The pools within this lower section of the river are critical for instream biota during times of very low and zero flow. If a viable fish population is to be maintained in the river, and the vegetation of the pools is to be maintained (which provides cover and habitat for biota), then the functioning of the pools themselves must be maintained.
- There are numerous large, deep pools along the lower Mokolo River. Pools within the main macro-channel sit within the coarse sandy matrix of the river bed and are consequently hydraulically well-connected to the water level within the main channel. During dry periods when water levels fall and flows stop, these pools similarly become shallower and eventually dry out.
- In contrast to this, the pools that form in the backwaters of the tributary confluences tend to have higher clay content in their beds and banks and, at low flows, these pools become hydraulically isolated from the main channel.
- . The lower Mokolo River is an alluvial depositional river reach which has, over time, increased its elevation relative the inflowing tributaries The pools that have developed along these backwaters are consequently clay-lined and at low flows largely hydraulically isolated from the river and associated water levels.
- The pools are predominantly maintained by flows from the Mokolo River which backflood into the pools. Some minor inputs from interflow (subsurface seepage) from the adjacent slopes and upstream tributary catchments may also play a role in providing water to the pools, but the hydraulic gradients identified by the groundwater study indicate that these inputs are unlikely or negligible. During critical low flow/dry periods then, it can be expected that the pools are dependent on recharge from high flow events from the Mokolo River.
- The longitudinal river distance between the closest upstream (i.e. A4H010) and downstream (i.e. A4H014) gauging stations are approximately 116.1 km. The remote locations of these gauging stations presents a major challenge to estimating historical river discharges at the study sites. This is because the lower Mokolo River is characterised by substantial run-of-river "losses".
- DWA estimated that the "losses" to the sand bed and surface storage (e.g. pools, weirs and dams) amounted to approximately 5.04 Mm^3
- Present day operation of the Mokolo Dam includes periodic releases (pulses) over a few days for the purpose of supplying surface and subsurface storage that is abstracted for irrigation.
- The gauge data from A4H014 indicates that the releases from the Mokolo Dam do not (generally) produce surface flow into the Limpopo River.
- The typical current day irrigation releases (generally 3 to 4 Mm^3 with a maximum discharge of approximately 10 m^3/s) are unlikely to result in recharge of many of the downstream pools.
- Under natural conditions the Mokolo River (downstream) will be connected during most months (especially wet season) with some isolation during the dry months

(especially end of dry seasons or drought years). Under reference condition the connection would have allowed fish movement between pool and river for ecological processes such as spawning, provision of nursery and feeding habitats.

- Gauging stations are A4H014 – located approximately 48.4 km downstream (approximately 0.7 km upstream of the Limpopo River confluence), and A4H010 – located approximately 67.7 km upstream (approximately 1.8 km downstream of the Mokolo Dam Wall). Tributaries that contribute substantial runoff between these two gauges include Poer se Loop (confluence approximately 29.5 km downstream of the Mokolo Dam Wall), the Rietspruit (confluence a further approximately 14.6 km downstream of the Poer se Loop confluence) and the Tambotie River (confluence a further approximately 15.2 km downstream of the Rietspruit confluence). Of these tributaries, only the Tambotie River is gauged – at station A4H007, which is located approximately 26.5 km upstream of its confluence with the Mokolo River near the town of Lephalale. Details of the gauge stations used in the study for obtaining historical discharge records are provided in Table 4. Table 5 gives the naturalised mean annual runoffs (MAR) at the closest upstream and downstream gauging stations on the Mokolo River, as well as for the intervening tributaries (DWAF, 2007).

Table 4: DWA gauging stations used in this study

River	Station[1] no.	Catchment area (km^2)	Latitude S (dec. deg.)	Longitude E (dec. deg.)	Record length
Mokolo	A4H005	3786	23 45 49.5	27 54 29.9	25/09/62 - 12/01/10
Mokolo	A4H010	4319	23 58 19.5	27 43 33.9	01/08/80 - 13/01/10
Mokolo	A4H014	8431	23 14 08.5	27 43 23.5	23/02/04 - 30/11/09
Tambotie	A4H007	398	24 05 00.5	27 46 21.9	27/08/62 - 12/10/09

1 http://www.dwa.gov.za/hydrology/cgi-bin/his/cgihis.exe/station

Table 5: Naturalised MAR of the Mokolo River and tributaries relevant to this study (DWAF, 2007)

River	Location	MAR (Mm^3)
Mokolo	A4H005	214.4
Mokolo	A4H010	291.9
Tambotie	Mokolo confluence	23.3
Poer se Loop	Mokolo confluence	13.3
Rietspruit	Mokolo confluence	13.1
Sandspruit	Mokolo confluence	5.6

- The longitudinal[3] river distance between the closest upstream (i.e. A4H010) and closest downstream (i.e. A4H014) gauging stations are therefore approximately 116.1 km. The remote gauging stations presents a major challenge to estimating historical river discharges at the study sites. This is because the lower Mokolo River is characterised by substantial run-of-river losses.

The following aquifers have been identified in the study area:

- The northern region of the study area is underlain by basement aquifers that comprise of deeper fractured (i.e. secondary) aquifers overlain by a weathered horizon of variable thickness. Thick, weathered aquifer zones are expected in areas where the bedrock has been subjected to intense fracturing. The existence of diabase and dolerite dykes forms poor groundwater targets due to the lack of weathering on the margins of these dykes with the basement rocks (gneiss), especially below the static water level. The most noticeable aquifer within the basement rocks are the ENE trending zones of shearing, faulting and brecciation and are usually covered with Quaternary deposits contributing to the aquifer's storage potential.
- The Waterberg aquifer is predominantly of a fractured and weathered type potentially connected to alluvial deposits occurring along the Mokolo River. The main groundwater targets are associated with fractured dyke contacts and fault zones. The Waterberg formation is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. Recharge to the aquifer, often discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.
- The Karoo aquifer shows similar aquifer properties as the Waterberg aquifer comprising of fractured rocks with a porous matrix. However, groundwater resources and especially the development thereof, are limited due to the low recharge to these aquifers.
- Alluvial aquifers are recharged during periods of high stream-flows and discharge events (from the Mokolo dam) as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers.

Based on detailed field work to classify the groundwater-surface water interaction of the Mokolo River as part of the groundwater Reserve determination study for the Mokolo catchment the following conceptual aquifer model is proposed:

- The alluvial aquifer associated with the Mokolo River is in direct contact with the river.
- The alluvial aquifer is generally unconfined.
- The regional aquifers show marginal gradients towards the Mokolo River course and exchange water with the river only indirectly via the alluvial deposits.

[3] Direction along the river

- The surface-groundwater exchange between the alluvium and the Mokolo River occurs on a far shorter time scale in comparison to the interaction between the regional and alluvial aquifers.

2. Field assessment

The field assessment will entail visiting one IUA and collecting the following data:

- Flow in river (if possible)
- Water quality of river
- Cross-section through river
- Groundwater levels (boreholes in the IUA)
- Groundwater quality
- Landuse

3. Modelling

Use PCSWMM to model the IUA and simulate the following scenario where all land use is changed to game farming.

4. Write report

Write a report similar to those in the reference list.

SELF-EVALUATION QUESTIONS

1. Collect all data necessary for hydrological and geohydrological assessment of RDM
2. Run various scenarios with the model.
2. Document RDM results including: Classification, Reserve and RQOs

SUMMARY

At the end of this model the student would have completed a RDM study and be able to implement all study units.

DEFINITIONS

ABIOTIC: not pertaining to living organisms; environmental features such as temperature, rainfall, etc.

ABSTRACTION: the removal of water from a resource, e.g. the pumping of groundwater from an aquifer.

AEROBIC: a process that takes place in the presence of oxygen.

ALLUVIAL: sediments deposited by flowing water.

ALLUVIAL AQUIFER: an aquifer formed of unconsolidated material deposited by water, typically occurring adjacent to river channels and in buried or palaeochannels.

ALLUVIUM: a general term for unconsolidated deposits of inorganic materials (clay, silt, sand, gravel, boulders) deposited by flowing water.

ANAEROBIC: a process that takes place in the absence of oxygen.

ANISOTROPIC: having some physical property that varies with direction.

AQUATIC: associated with and dependent on water, e.g. aquatic vegetation.

AQUATIC ECOSYSTEMS: not defined by the National Water Act (Act No. 36 of 1998), but defined elsewhere as the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and their fringing vegetation.

AQUIFER: a geological formation, which has structures or textures that hold water or permit appreciable water movement through them [from National Water Act (Act No. 36 of 1998)].

ATTENUATION: the breakdown or dilution of contaminated water as it passes through the earth's material.

BACTERIA: a large group of unicellular microscopic organisms lacking chlorophyll and multiplying rapidly by simple division.

BANK STORAGE: water that percolates laterally from a river in flood into the adjacent geological material, some of which may flow back into the river during low-flow conditions.

BASEFLOW: sustained low flow in a river during dry or fair weather conditions, but not necessarily all contributed by groundwater; includes contributions from delayed interflow and groundwater discharge.

BASEFLOW INDEX: the ratio of the annual baseflow in a river to the total annual run-off.

BASIC HUMAN NEED: the least amount of water required to satisfy basic water requirements; this is currently set at 25 ℓ/cap•d.

BENEFICIAL USE: the use of the environment or any element of the environment that is conducive to the benefit of legitimate users.

BIOTIC: pertaining to living organisms.

BOREHOLE: includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer [from National Water Act (Act No. 36 of 1998)].

CATCHMENT: the area from which any rainfall will drain into the watercourse, contributing to the runoff at a particular point in a river system; synonymous with the term river basin.

CHANNEL PRECIPITATION: precipitation that falls directly on to a surface water body during a precipitation event and makes an immediate (but usually small) contribution to stream flow; does not flow over or through land to reach the surface water body.

CLASSIFICATION: The classification system prescribed under the National Water Act (1998) provides guidelines on how to set appropriate levels of protection for water resources.

CONJUNCTIVE USE: combined use of surface and groundwater.

CONSERVATION: to keep or protect from harm, decay or loss; implies wise use of a resource.

CONSERVATIVE POLLUTANTS: pollutants that move readily through the aquifer, with little reaction with the rock matrix, and are unaffected by biodegradation.

CONTAMINATION: the introduction of any substance into the environment by the action of man.

DEGRADABLE POLLUTANTS: pollutants that readily break down.

DESIRED ECOLOGICAL STATUS: the future desired status of groundwater within the resource unit as used in setting the groundwater component of the ecological Reserve.

DETACHED STREAM: see disconnected stream.

DIFFUSE POLLUTION SOURCE: see non-point source of pollution.

DISCHARGE AREA: an area in which subsurface water, including water in the unsaturated and saturated zones, is discharged at the land surface.

DISCONNECTED STREAM: a stream detached from and not in hydrological contact with the groundwater system below; a special case of an influent stream; also referred to as a detached stream.

ECOLOGICAL CATEGORY: The assigned ecological condition by the Minister to a water resource that reflects the ecological condition of that water resource in terms of the deviation of its biophysical components from a predevelopment condition.

ECOLOGICAL WATER REQUIREMENTS: The quantity and quantity of water of that resource that is required to maintain the said water resource in its assigned ecological category.

ECOLOGICALLY SUSTAINABLE BASE CONFIGURATION SCENARIO: The lowest acceptable level of protection required for the sustainable use of the entire integrated unit of analysis.

ECOLOGY: the study of the interrelationships between organisms and their environment.

ECOREGIONS: regions within which there is a relative similarity in the mosaic of ecosystems and ecosystem components (biotic and abiotic, aquatic and terrestrial).

ECOSYSTEM: an organic community of plants, animals and bacteria and the physical and chemical environment they inhabit.

ECOSYSTEM GOODS, SERVICES AND ATTRIBUTES: The goods, services and attributes that ecological systems provide that are critical to the functioning of the earth's life-support system, and which contribute both directly and indirectly to human welfare, and therefore have economic value.

EFFLUENT: liquid waste or sewage discharge, usually discharged in rivers or the sea.

EFFLUENT STREAM: a stream fed directly by groundwater; the surrounding water table or piezometric surface is above the stream surface; opposite of influent stream.

EPHEMERAL RIVERS: these rivers are generally storm-event driven and flow occurs less than 20% of the time; these rivers have a limited (if any) baseflow component with no groundwater discharge.

ESTUARY: a partially or fully enclosed body of water, which is open to the sea permanently or periodically, and within which the sea water can be diluted, to an extent that is measurable, with fresh water drained from the land [from National Water Act (Act No. 36 of 1998)].

EVAPOTRANSPIRATION: the loss of moisture from the combined effects of direct evaporation from land and sea and transpiration from vegetation.

GAINING STREAM: synonymous with effluent stream.

GEOHYDROLOGY: the study of the properties, circulation and distribution of groundwater; in practice used interchangeably with hydrogeology; but in theory hydrogeology is the study of geology from the perspective of its role and influence in hydrology, while geohydrology is the study of hydrology from the perspective of the influence on geology.

GEOMORPHOLOGY: the study of the form of the earth and the changes that take place in the process of developing landforms.

GROSS GEOGRAPHIC PRODUCT: Amounts to the total income or payment received by the production factors – land, labour, capital, and entrepreneurship – for their participation in the production within that area.

GROUNDWATER: water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface of groundwater systems.

GROUNDWATER CONTRIBUTION TO BASEFLOW OR RIVER FLOW: that groundwater that discharges into effluent streams and sustains baseflow.

GROUNDWATER FLOW: the movement of water through openings and pore spaces in rocks below the water table i.e. in the saturated zone.

HABITAT: the environment or place where a plant or animal is most likely to occur naturally.

HEAVY METALS: those elements with atomic numbers greater than 36 in Group III through V of the Periodic Table.

HETEROGENEOUS: refers to materials having different properties at different points; diverse in character or content; opposite of homogeneous.

HYDRAULIC CONDUCTIVITY: measure of the ease with which water will pass through earth material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (in m/d).

HYDRAULIC GRADIENT: the slope of the water table or piezometric surface. It is a ratio of the change of hydraulic head divided by the distances between the two points of measurement.

HYDRAULIC HEAD: the height of a column of water above a reference plane.

HYDRIC SOILS: soils that are saturated or flooded long enough during the growing season to develop anaerobic conditions in their upper layers.

HYDROGRAPH: a graphical plot of hydrological measurements over a period of time, e.g. water level, flow, discharge.

HYDROLOGICAL CYCLE: the continuous circulation of water between oceans, the atmosphere and land. The sun is the energy source that raises water by evapotranspiration from the oceans and land into the atmosphere, while the forces of gravity influence the movement of both surface and subsurface water.

HYDROLOGICAL YEAR: a continuous 12-month period selected to present data relative to hydrological or meteorologically phenomena; usually from 1 October to 30 September.

HYDROLOGY: the study of the properties, circulation and distribution of water.

HYDROPHYTES: plants that take their nutrients directly from water, typically found in water or wet habitats

HYPORHEIC ZONE: the saturated and biologically active zone in the permeable substrate beneath and adjacent to a riverbed.

INFILTRATION: the downward movement of water from the atmosphere into the ground; not to be confused with percolation.

INFLUENT RIVER: water is discharged from the river into the groundwater system.

INFLUENT STREAM: a losing stream above the water table that discharges into the underlying groundwater system; opposite of effluent stream.

INTEGRATED MANAGEMENT: a management approach that serves to co-ordinate management of the environment as a whole, as opposed to individual parts.

INTERACTING STREAM: see intermittent stream.

INTERFLOW: the rapid flow of water along essentially unsaturated flow paths, water that infiltrates the subsurface and moves both vertically and laterally before discharging into other water bodies.

INTERMITTENT RIVER: conditions range seasonally between discharge from the river into the groundwater system and discharge from the groundwater system into the river; not to be confused with an ephemeral river.

INTERMITTENT STREAM: rivers and streams whose interaction with groundwater depends on the fluctuating position of the water table, ranging from effluent streams in the wet season to influent streams in the dry season.

LACUSTRINE: wetlands such as dams and lakes situated in topographic depressions that have a total area greater than 8 ha.

LEACHATE: any liquid, including any suspended components in the liquid that has percolated through or drained from human-emplaced materials.

LOSING STREAM: synonymous with influent stream.

MESOPHYTES: plants that grow under well-balanced moisture conditions.

NON-POINT SOURCE OF POLLUTION: pollution from broad areas rather than from discrete points.

NUTRIENTS: substances that help living things to grow, e.g. nitrogen, phosphate, potassium.

OVERLAND FLOW: flow of water over the land surface usually originating from precipitation or snowmelt; general term used loosely to include all surface runoff.

PALEOCHANNEL: a buried stream channel.

PALUSTRINE: freshwater wetland environments other than those along rivers and lakes, dominated by trees, shrubs, emergent vegetation, mosses and lichens.

PERENNIAL: lasting through a year or several years i.e. a river that flows all year round or a wetland that remains wet all year round.

PHREATOPHYTES: long-rooted plants that habitually obtain water from below the water table or from the capillary fringe directly above the water table.

PIEZOMETRIC LEVEL: the elevation to which groundwater levels rise in boreholes that penetrate confined or semi-confined aquifers.

POINT SOURCE OF POLLUTION: pollution from discrete and definable points as opposed to pollution from broad areas.

POLLUTION: Pollution means the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it –

a) less fit for any beneficial purpose for which it may reasonably be expected to be use;

b) harmful or potentially harmful –

to the welfare, health of safety of human beings;

to any aquatic or non-aquatic organisms;

to the resource quality; or

to property.

POLLUTION PLUME: area of degraded water in a stream or aquifer resulting from migration of a pollutant.

POTABLE WATER: water that is safe and palatable for human use.

PRESENT ECOLOGICAL CLASS: current status of groundwater within the resource unit as used in setting the groundwater component of the ecological Reserve.

PRISTINE: remaining in a pure or natural state.

QUATERNARY CATCHMENT: a fourth order catchment in a hierarchal classification system in which a primary catchment is the major unit.

QUICKFLOW: by convention, that portion of stormflow that is not part of baseflow and includes overland flow; occurs in direct response to rainfall.

RADIUS OF INFLUENCE: the maximum extent of the cone of depression.

RECHARGE: the addition of water to the zone of saturation, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.

REHABILITATION: to restore to a former condition or status.

REMEDIATION: to restore to health; requires that impact is reduced to some acceptable level.

RESERVE: Reserve means the quantity and quality of water required –

to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No 108 of 1997), for people who are now or who will, in the reasonably near future, be –

relying upon;

taking water from; or

being supplied from,

the relevant water resource; and

to protect aquatic ecosystems in order to secure ecologically sustainable development and use the relevant water resource.

RESOURCE: a substance or item available for use. A natural resource is a resource that man can use but not manufacture or create.

RESOURCE DIRECTED MEASURES: A term used but not defined by the National Water Act. The objective of Resource Directed Measures is to facilitate the proactive protection (for use) of the country's water resources, in line with sustainability principles. The National Water Act (NWA) recognises the need to develop and use the country's water resources to grow. However, the Act also recognises that our water resources should not be used to the detriment of future users. RDM hence strives to ensure that the water resources are afforded a level of protection that will assure a sustainable level of development for the future. To this end, RDM comprises three main interrelated components, namely:

- Classification
- Reserve
- Resource Quality Objectives.

RESOURCE QUALITY: the quality of all aspects of a water resource including (a) the quality, pattern, timing, water level and assurance of instream flow, (b) the water quality, including the physical, chemical and biological characteristics of water, (c) the characteristic and condition of the instream and riparian habitat, and (d) the characteristics, condition and distribution of aquatic biota.

RESOURCE QUALITY OBJECTIVE: Resource Quality Objectives are used to put a Classification and Reserve into practice by specifying conditions that will ensure that the Class is not compromised and the Reserve can be met. Resource quality may relate to critical flows, groundwater levels and quality that must be maintained. The objectives are to articulate goals that result from the catchment visioning process, but must be based on DWA policy statements and methodologies and aligned with the National Water Resource Strategy.

RIPARIAN: area of land directly adjacent to a stream or river, influenced by stream-induced or related processes.

RIVER: a physical channel in which runoff will flow; generally larger than a stream, but often used interchangeably.

RUNOFF: all surface and subsurface flow from a catchment, but in practice refers to the flow in a river i.e. excludes groundwater not discharged into a river.

SEASONAL RIVER: these rivers are driven by seasonal rainfall patterns and flow occurs between 20% and 80% of the time. These rivers have a limited baseflow component with little or no groundwater discharge.

SEEP: a diffuse wetland area where interflow and groundwater emerges, usually at a slow rate or small volume, to become surface flow.

SPRING: a point where groundwater emerges, usually as a result of topographical, lithological or structural controls,

STORAGE COEFFICIENT: the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head

STORMFLOW: increased runoff in a river or stream associated with a particular rainfall event or storm; includes contributions from channel precipitation, quickflow and rapid interflow.

STREAM: a small narrow river; often used interchangeably with river.

SURFACE WATER: bodies of water, snow or ice on or above the surface of the earth (such as lakes, streams, ponds, wetlands, etc.).

SURFACE RUNOFF: that part of the total runoff that travels over the ground surface to reach a stream or river channel.

TOTAL RUNOFF: the total volume of water that flows in a stream, including contributions from channel precipitation, quickflow, interflow and the groundwater contribution to river flow.

TRANSMISSIVITY: the rate at which a volume of water is transmitted through a unit width of aquifer under a unit hydraulic head (m^2/d); product of the thickness and average hydraulic conductivity of an aquifer.

UNDERGROUND WATER: not a recognised geohydrological term; used – but not defined – in the National Water Act (Act No. 36 of 1998); meaning is unclear; thought to be a general term referring to subsurface water.

WATER COURSE: a river or spring; a natural channel in which water flows regularly or intermittently; a wetland, lake or dam into which, or from which, water flows; any collection of water that the Minister of Water Affairs and Forestry may, by notice in the Government Gazette, declare to be a water course National Water Act (Act No. 36 of 1998).

WATER RESOURCE: includes a water course, surface water, estuary or aquifer.

WETLAND: land that is transitionary between terrestrial and aquatic systems, where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil [from National Water Act (Act No. 36 of 1998)].

XEROPHYTES: plants that have adapted to dry or arid conditions.

APPENDIX A: CHAPTER 3 OF NWA

PROTECTION OF WATER RESOURCES

The protection of water resources is fundamentally related to their use, development, conservation, management and control. Parts I, 2 and 3 of this Chapter lay down a series of measures which are together intended to ensure the comprehensive protection of all water resources. These measures ate to be developed progressively within the contexts of the national water resource strategy and the catchment management strategies provided for in Chapter 2. Part 4 and 5 deal with measures to prevent the pollution of water resources and measures to remedy the effects of pollution of water resources.

Part 1: Classification system for water resources

Part I provides for the first stage in the protection process, which is the development by the Minister of a system to classify the nation's water resources. The system provides guidelines and procedures for determining different classes of water resources.

Prescription of classification system

12. (1) As soon as is reasonably practicable, the Minister must prescribe a system for classifying water resources.

(2) The system for classifying water resources may —

(a) establish guidelines and procedures for determining different classes of water resources;

(b) in respect of each class of mater resource —

(i) establish procedures for determining the Reserve:

(ii) establish procedures which are designed to satisfy the water quality requirements of water users as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource:

(iii) set out water uses for instream or land based activities which activities must be regulated or prohibited in order to protect the water resource; and

(c) provide for such other matters relating to the protection, use, development, conservation, management and control of water resources, as the Minister considers necessary,

Part 2: Classification of water resources and resource quality objectives

Under Part 2 the Minister is required to use the classification system established* in *Part I to determine the class and resource quality objectives of all or part of water resources considered to be significant. The purpose of the resource quality objectives is to establish clear goals relating to the quality of the relevant water resources. In determining resource quality objectives a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other. Provision is made for preliminary determinations of the class and resource quality objectives of water resources before the formal classification system is established. Once the class of a water resource and the resource quality objectives have been determined they are binding on all authorities and institutions when exercising any power or performing any duty under this Act.

Determination of class of water resources and resource quality objectives

13. (1) As soon as reasonably practicable after the Minister has prescribed a system for classifying water resources the Minister must, subject to subsection (4), by notice in the *Gazette*, determine for all or part of every significant water resource —

(a) a class in accordance with the prescribed Classification system; and

(b) resource quality objectives based on the class determined in terms of paragraph (a)

(2) A notice in terms of subsection (1) must state the geographical area in respect of which the resource quality objectives will apply, the requirements for achieving the objectives, and the dates from which the objectives will apply.

(3) The objectives determined in terms of subsection (1) may relate to —

(a) the Reserve;
(b) the instream flow;
(c) the water level;
(d) the presence and concentration of particular substances in the water;
(e) the characteristics and quality of the water resource and the instream and riparian habitat;
(f) the characteristics and distribution of aquatic biota;
(g) the regulation or prohibition of instream or land-based activities which may affect the quantity of water in or quality of t le water resource; and
(h) any other characteristic,

of the water resource in question.

(4) Before determining a class or the resource quality objectives in terms of subsection (1), the Minister must in respect of each water resource —

(a) publish a notice in the Gazette —
(i) setting out—
(aa) the proposed class;
(bb) the proposed resource quality objectives;
(cc) the geographical area in respect of which the objectives will apply;
(dd) the dates from which specific objectives will apply; and
(ee) the requirements for complying with the objectives; and
(ii) inviting written comments to be submitted on the proposed class or proposed resource quality objectives (a; the case may be), specifying an address to which and a date before which the comments are to be are to be submitted, which date may not be earlier than 60 days after publication of the notice:
(b) consider what further steps. if any, are appropriate to bring the contents of the notice to the attention of interested persons, find take those steps which the Minister considers to be appropriate; and
(c) consider all comments received on or before the date specified in paragraph (a)(ii).

Preliminary determination of class or resource quality objectives

14. (1) Until —

(a) a system for classifying water resources ha: been prescribed; or

(b) a class of a water resource or resource quality objectives has been determined, the Minister may, for all or part of a water resource make a preliminary determination of the class or resource quality objectives.

(2) A determination in terms of section 13 supervise a preliminary determination.

Giving effect to determination of class of water resource and resource quality objectives

15. The Minister, the Director-General, an organ of state and a water management institution, when exercising any power or performing any duty in terms of this Act, must give effect to any determination of a class of a water resource and the resource quality objectives as determined in terms of this Part and any requirements for complying with the resource quality objectives.

Part 3: The Reserve

Part 3 deals with the Reserve, which consists of two parts — the basic human needs reserve and the ecological reserve. The basic human needs reserve provides, for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene. The ecological reserve relates to the water required to protect the aquatic ecosystems of the water resource. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the class the resource. The Minister is required to determine the Reserve for all or part of* any *significant water resource. If a resource has not yet been classified, a preliminary a determination of the Reserve may be made and later superseded by a new one. Once the Reserve is determined for a water resource it is binding in the same way as the class and the resource quality objectives.

Determination of Reserve

16. (1) As soon as reasonably practicable after the class of all or part of a water resource has been determined, the Minister must by notice in the *Gazette* determine the Reserve for all or part of that water resource.

(2) A determination of the Reserve must —

(a) be in accordance with the class of the water resource as determined in terms of section 13; and

(b) ensure that adequate allowance is made for each component of the Reserve.

(3) Before determining the Reserve in terms of subsection (i), the Minister must —

(a) publish a notice in the Gazette —

(i) setting out the proposed Reserve; and

(ii) inviting written comments to be submitted on the proposed Reserve, specifying an address to which and a date before which comments are to be submitted, which date may not be earlier than 60 days after the publication of the notice;

(b) consider what further steps, if any, are appropriate to bring the contents of the notice to the attention of interested persons, and take those steps which the Minister considers to be appropriate; and

(c) consider all comments received on or before the date specified in paragraph (a)(ii).

Preliminary determinations of Reserve

17. (1) Until a system for classifying water resources has been prescribed or a class of a water resource has been determined, the Minister—

(a) may, for all or part of a water resource; and

(b) must, before authorizing the use of water under section 22(5), make a preliminary determination of the Reserve.

(2) A determination in terms of section 16(1)supersedes a preliminary determination.

Giving effect to Reserve

18. The Minister, the Director-General, an organ of state and a water management institution, must give effect to the Reserve as determined in terms of this Part when exercising any power or performing any duty in terms of this Act.

APPENDIX B: REGULATIONS FOR THE ESTABLISHMENT OF A WATER RESOURCE CLASSIFICATION SYSTEM

APPENDIX C: SOCIO-ECONOMIC ASSESSMENT

Taken from:
http://www.lic.wisc.edu/shapingdane/facilitation/all_resources/impacts/analysis_socio.htm

1.1 INTRODUCTION

Community members are constantly challenged by the need to balance fiscal, social, economic, and environmental goals. One aspect of this challenge is deciding how much and what types of new development the community can accommodate without compromising the day-to-day quality of life for residents. Socio-economic impact assessment is designed to assist communities in making decisions that promote long-term sustainability, including economic prosperity, a healthy community, and social well-being.

Assessing socio-economic impacts requires both quantitative and qualitative measurements of the impact of a proposed development.

1.2 WHAT ARE SOCIO-ECONOMIC IMPACT ASSESSMENTS?

A socio-economic impact assessment examines how a proposed development will change the lives of current and future residents of a community. The indicators used to measure the potential socio-economic impacts of a development include the following:

- Changes in community demographics;
- Results of retail/service and housing market analyses;
- Demand for public services;
- Changes in employment and income levels; and
- Changes in the aesthetic quality of the community.

Quantitative measurement of such factors is an important component of the socio-economic impact assessment. At the same time, the perceptions of community members about how a proposed development will affect their lives is a critical part of the assessment and should contribute to any decision to move ahead with a project. In fact, gaining an understanding of community values and concerns is an important first step in conducting a socio-economic impact assessment.

Changes in social structure and interactions among community members may occur once the new development is proposed to the community. In addition, real, measurable and often significant effects on the human environment can begin to take place as soon as there are changes in social or economic conditions.

1.3 WHO SHOULD BE INVOLVED?

Because socio-economic impact assessment is designed to estimate the effects of a proposed development on a community's social and economic welfare, the process should rely heavily on involving community members who may be affected by the development. Others who should be involved in the process include community leaders and others who represent diverse interests in the community such as community service organizations, development and real estate interests, minority and low income groups, and local environmental groups. In addition, local agencies or officials should provide input into the process of assessing changes in the social environment that may occur as a result of the proposed development (e.g., providing estimates and information demographics, employment and service needs).

1.4 HOW TO CONDUCT A SOCIO-ECONOMIC ASSESSMENT?

The following section provides a two-step process for conducting a socio-economic impact analysis. The process is designed to establish a framework for evaluating cur-rent and future proposed developments in a community.

- Defining the scope of the Socio-Economic Impact Assessment

  The most reliable sources of information about community concerns and needs are residents and community leaders. Surveys and interviews are two excellent methods for identifying priority social and economic goals of the community. Interviews with community leaders can also provide valuable information about what social, economic and other issues are important to community members.

  The development impacts associated with a new development will vary depending on the proposed project's type, size, location, socio-economic characteristics of the community. As such it is important to be familiar with both the project characteristics and the social and economic resources of the community. The better one understands the proposed project, the more accurate will be the assessment in estimating potential impacts.

- Identifying and Evaluating Development Impacts

  - Quantitative Changes

    Demographic impacts include the number of new permanent residents or seasonal residents associated with the development, the density and distribution of people and any changes in the composition of the population, (e.g., age, gender, ethnicity, wealth, income, occupational characteristics, educational level, health status). Development invites growth in new jobs in a community and draws new workers and their families into the community, either as permanent or temporary residents. When this occurs, the incoming population affects the social environment in various ways including increased demand for housing and social services (e.g., health care, day care, education, recreational facilities). Because residents' needs depend on a wide range of variables (e.g., age, gender, employment status, income level and health status), the diversity of service needs are determined not only by the absolute size of the incoming population but also by the old and new populations' demographic and employment profiles. As a result, a proposed development may have a significant impact on the community's ability to accommodate new residents and adapt to changes in the social environment for existing residents. Assessing the magnitude and rate of population change has important implications for community infrastructure and service requirements and can play a major role in determining social impacts associated with the proposed development. There are numerous modelling techniques available to aid in assessing population impacts.

    A housing market analysis helps determine whether the proposed development will be beneficial to your community in terms of its effect on your housing market needs. In the case of a residential development, the market study assists in ascertaining whether there is sufficient demand for the type of housing proposed and whether a sufficient number of households in the area can afford to purchase or rent the pro-posed type of housing. The analysis also assists in the examination of the connections between the housing market and employment. To understand the impact of a new residential development or a new employment centre on your housing market (or on the regional market), the initial step of the analysis is to complete an inventory and analysis of existing and projected housing needs—a supply and demand analysis. To better understand whether your community is meeting the needs of residents and workers in terms of affordability, an analysis of housing affordability which includes an examination of typical rents and mortgage payments compared to what households at various income levels can afford is necessary.

Retail market impacts caused by growing communities often attract a variety of new commercial developments including both free-standing stores and neighbourhood or community shopping centres. These developments provide a community with products, services and conveniences important to the quality of life of local residents. The challenge to accommodating these types of new developments becomes one of minimizing losses to existing retailers in the area, such as those downtown, while allowing the market to respond to the wishes of the increasingly demanding consumer. Before an analysis of a particular development can be conducted, the economic health of the local retail community must be assessed. This requires a close look at retail activity, particularly in the central business district. Key indicators of economic health in the retail sector include vacancy levels, property values, store turnover, retail mix, employment, tax revenues, new business incubation, critical mass/concentration of retail, and the availability of goods and services demanded by the community. Second, changes in trade area demographics should be estimated. The trade area is generally defined as the geographic area in which three-fourths of current customers reside. A significant increase in population could signal new opportunities for retail expansion or development. Third, regional retail competition must be assessed. New retail concepts are threatening traditional retail stores. Development directly influences changes in employment and income opportunities in communities. Such changes may be more or less temporary (e.g., construction projects, or seasonal employment) or may constitute a permanent change in the employment and income profile of the community should the development project bring long-term job opportunities for community residents (e.g., establishment of a light industrial, manufacturing, or commercial establishment). Assessing these types of changes is an important component of social impact analysis because growth in employment places additional demands on community services and resources.

- Community Perceptions

The attitudes community residents have toward development and the specific actions being proposed as well as their perceptions of community and personal well-being are important determinants of the social effects of a proposed action. Such attitudes are a reflection of the quality of life residents seek to enjoy and preserve, whether it be limiting growth in order to maintain the rural image of a small community; expanding the boundaries of the village; or providing a variety of housing choices to new, diverse residents and businesses. Changes in a community's social well-being can be determined by asking the individuals and representatives of groups or neighbourhoods in the area to make explicit their perceptions and attitudes about the anticipated changes in the social environment.

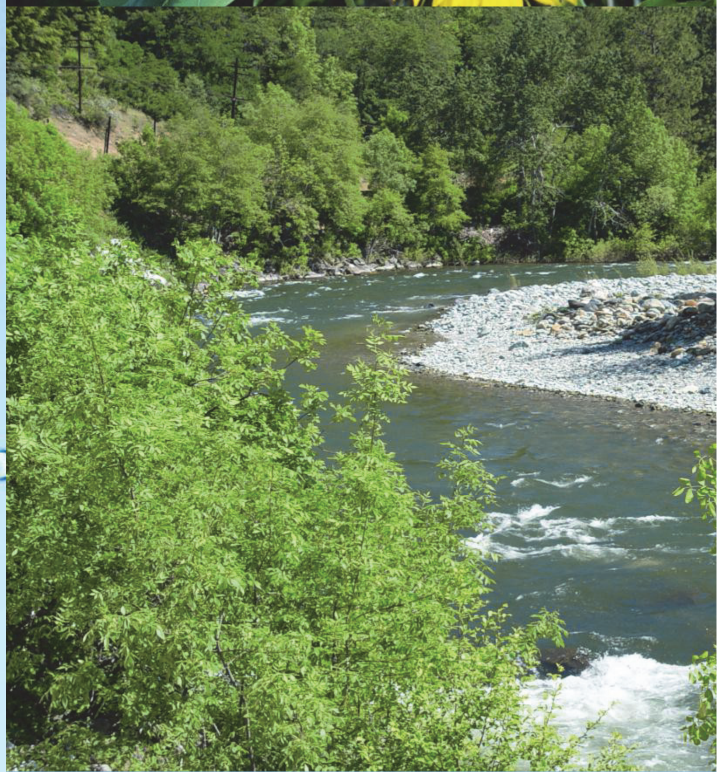
Information about attitudes and perceptions should be gathered from community leaders because their attitudes are important and may lend insight into the overall attitudes of residents if community leaders are perceptive and sensitive to community concerns and interests. However, it is perhaps more important, though generally more time-consuming and costly, to profile the attitudes of the residents living and working in the community and each of the distinguishable social groups because they represent the population in the community most affected by changes in social well-being. The responses may provide an indication of what additional information is necessary and in what detail it should be gathered for a particular proposed development.

MODULE 4
HYDRAULICS AND HYDRODYNAMICS

Tutored MSc in Ecological Water Requirements

Developed by
Prof. Ingrid Dennis

November 2013



LIST OF ABBREVIATIONS

BFI	Baseflow Index
BHN	Basic Human Needs
CMA	Catchment Management Agency
CRD	Cumulative Rainfall Departure
DEAT	Department of Environmental Affairs and Tourism
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Category
ER	Ecological Reserve
EWR	Ecological Water Requirements
GGP	Gross Geographic Product
GRIP	Groundwater Resource Information Project
ICM	Integrated Catchment Management
IFR	Instream Flow Requirements
IUA	Integrated Unit of Analysis
IWRM	Integrated Water Resource Management
K	Hydraulic Conductivity
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MLF	Maintenance Low Flow
NEMA	National Environmental Management Act
NGA	National Groundwater Archive
NGDB	National Groundwater Data Base
NWA	National Water Act (Act 36 of 1998)
NWRS	National Water Resource Strategy
PES	Present Ecological State
PESC	Present Ecological State Category
RDM	Resource Directed Measures
RQO	Resource Quality Objectives
RU	Resource Unit
S	Storativity
SA	South Africa

SDC	Source Directed Controls
T	Transmissivity
UA	Unit of Analysis
WARMS	Water Use Authorisation and Registration Management System
WMA	Water Management Area
WMS	Water Management System
WR2005	Water Resources of South Africa 2005
WRC	Water Research Commission

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RATIONALE

Water is a natural resource and belongs to all the people of South Africa. Sustainability, equity and efficiency are identified by the South African government as central guiding principles in the protection, use, development, conservation, management and control of water resources. These principles recognise the following:

- basic human needs of present and future generations,
- the need to protect water resources (for use),
- the need to share some water resources with other countries,
- the need to promote social and economic development through the use of water and
- the need to establish suitable institutions in order to achieve the purpose of the National Water Act (Act No. 36 of 1998) (NWA).

To be able to implement the NWA, the Minister needs to ensure that the tools and expertise required to implement the Act are available. This module addresses the methods and procedures needed to implement the surface and groundwater hydrology components of Resource Directed Measures (RDM).

In some RDM studies it is necessary to understand the hydraulics of the system in order to improve the results of the hydrological (rainfall-runoff) systems discussed in Module 3. These are usually for higher confidence RDM studies.

Before discusses hydraulics in more detail, a distinction must be made between hydrology, hydraulics and hydrodynamics.

Hydraulics, hydrodynamics and hydrology are three branches of science and engineering that treat the properties and movement of water and other fluids; the distinction among the three is not always clear, particularly regarding water. They are all common to several fields or professions that involve water resources. Hydraulics and hydrodynamics deal with the motion of water and other fluids. Hydraulics studies the laws governing the motion of water and other liquids as well as their engineering applications. Hydrodynamics (also called hydromechanics) is the branch of physical science (specifically fluid dynamics) that studies the motion of fluids (particularly liquids) and the forces acting on them and on immersed bodies. Hydrology is concerned only with water, not the other fluids, and is in fact the study of the hydrologic cycle. Simply put, hydraulics is the study of fluid flow, while hydrology is mainly the study of runoff resulting from precipitation.

Procedures for conducting river hydraulic investigations are presented herein with minimal theory. Hydraulics analyses are an essential component of most riverine projects, and the results from these analyses are often critical to RDM project formulation, design, construction, and operation throughout the project’s life. River hydraulics includes the evaluation of flow characteristics and geomorphic (physical) behaviour of rivers and changes in these due to natural or man-made conditions. Environmental aspects often require the prediction of stage, velocity distributions, sediment transport rates, and water quality characteristics, to evaluate the impacts of proposed actions on future river characteristics.

Hydraulics plays a huge role in aquatic habitats and therefore influences the aquatic component of the RDM assessment. It is also important to note that this module focuses on environmental hydraulics and not engineering hydraulics.

LAYOUT OF THE MODULE

In this course, you will get to know the following aspects of the Resource Directed Measures:

- Provides a detailed discussion of the National Water Act. More specifically it focuses on how hydraulics and hydrodynamics are applied in the sustaining of a certain quantity and quality of water to maintain the overall ecological functioning of rivers. (Study Unit 1) (10%).
- Introduction to hydraulics, including flow dimensionality, water waves, flow classification, regimes of flow, types of flow and flow profiles . (Study Unit 2) (10%).
- Formulating hydraulic studies. This includes initial considerations, analysis of hydraulic components, data requirements and available models. (Study Unit 3) (15%).
- Unsteady and steady flow, including flow analysis, geometry and boundary conditions (Study Unit 4) (15%).
- Flow resistance in rivers including channel bed, vegetation and channel macro-form resistance. (Study Unit 5) (10%).
- Study planning, implementation, reporting and lessons learnt. (Study Unit 6) (10%).
- Case study: Practical implementation of all that has been learnt in study units 1-6. (Study Unit 7) (25%).

NB: The percentages in brackets show the ratio regarding the time you have to spend on the various aspects.

PREREQUISITES

Before attending the course you need to read Chapter 3 of the National Water Act and completed Module 3 of this course.

You need the following resources to complete this course successfully:

- Study material as indicated
- GPS

- Flow metre
- Surveying equipment
- Pocket calculator
- Laptop or computer

STUDY MATERIAL

The following source is needed for this course:

- Department of the Army (1993) Engineering and Design: River Hydraulics. Engineering Manual 1110-2-1416. US Army Corps of Engineers, Washington, United States of America.

HOW TO STUDY

The module is presented by means of study units where the core principles are discussed. At the beginning of each section, a time allocation is given, which is an indication of the extent of the study task. You may use this allocation to plan your study process. The learning outcomes are also indicated at the beginning of each study unit and guide you as learner about what the problems in the particular study unit are and where you have to pay special attention. Make sure that you have the study guide always at hand, so that you can easily add additional notes to reach the outcome set for each study unit. At the end of study units, there are also evaluation questions. It is essential to answer these questions before moving on to the next study unit. By doing so and by making sure that the learning outcomes have been reached, you can make sure that you have completed the study unit successfully. It is expected of you as a senior student that you will have developed the skill (and that you will further develop this skill) to gather additional information independently in books, journals as well as from the internet. The study guide serves as framework to guide you through the learning content.

ASSESSMENT

Continuous assessment will take place in the form of assignments. Note the dates in the study letter on which these assignments should be handed in. Examination opportunities at the end of the module are also indicated in the study letter. Admission to the examination is dependent on an adequate participation mark, obtained from the assignments.

PRACTICALS AND FIELD REPORTS

A case study forms a unit that contributes to the reaching of outcomes. A one day site visit, data collection and interpretation will be included in this case study. The case study will include data collection to improve the confidence of an existing RDM study for the Schoonspruit. A report will be submitted similar to the RDM reports submitted to the Chief Directorate: Resource Directed Measures at the Department of Water Affairs.

MODULE OUTCOMES

At the end of the module, students should be able to:

- show insight, knowledge and skills regarding the river hydraulics;
- collect relevant data for a river hydraulics investigation;
- plot relevant river profiles and classify the river;
- develop analytical/numerical models and calibrate these models
- run various management scenarios based on the economic/social requirements;
- document the results to be implemented by other members of the RDM team.

ACTION WORDS

The following words or verbs are important in understanding what to do in example, test, and exam questions:

Calculate:	Determine using numerical data.
Contrast:	Show differences and similarities through comparison.
Derive:	Establish by deduction.
Describe:	Give the relevant facts, characteristics, properties without any further discussion.
Discuss:	Comment on the topic using your own words.
Define:	Give the precise meaning of something.
Explain:	Make comprehensible/understandable.
Illustrate:	To explain something using examples and/or diagrams.
Name/mention/list:	To make a list of characteristics or facts asked for without giving descriptions or explanations.

WARNING AGAINST PLAGIARISM

ASSIGNMENTS ARE INDIVIDUAL TASKS AND NOT GROUP ACTIVITIES. (UNLESS EXPLICITLY INDICATED AS GROUP ACTIVITIES)

Copying of text from other learners or from other sources (for instance the study guide, prescribed material or directly from the internet) is **not allowed** – only brief quotations are allowed and then only if indicated as such.

You should **reformulate** existing text and use your **own words** to explain what you have read. It is not acceptable to retype existing text and just acknowledge the source in a footnote – you should be able to relate the idea or concept, without repeating the original author to the letter.

The aim of the assignments is not the reproduction of existing material, but to ascertain whether you have the ability to integrate existing texts, add your own interpretation and/or critique of the texts and offer a creative solution to existing problems.

Be warned: students who submit copied text will obtain a mark of zero for the assignment and disciplinary steps may be taken by the Faculty and/or University. It is also unacceptable to do somebody else's work, to lend your work to them or to make your work available to them to copy – be careful and do not make your work available to anyone!

STUDY UNIT 1:

CHAPTER 3 OF THE NATIONAL WATER ACT – HYDRAULICS AND HYDRODYNAMICS

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

- Water Research Commission (2010) Ecohydraulics for South African Rivers: A Review and Guide, WRC Report No. TT 453/10
- Water Research Commission (2008) Environmental flow assessments for rivers: Manual for the building block methodology, Project No. TT 354/08
- Water Research Commission (1998) Development of the Building Block Methodology for Instream flow Assessment and Supporting Research on the Effects of Different Magnitude Flows on Riverine Ecosystems, WRC Report No. 576/1

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about surface water and groundwater hydrology:

- Understand hydraulics within river ecosystems;
- Discuss and understand the role of hydraulics within the South African RDM and more specifically the role of hydraulics in the ecological Reserve;

The study unit will be conducted as follows:

- **Study Unit 1: Chapter 3 of the NWA Hydraulics and hydrodynamics**
  - Hydraulics in river ecosystems
  - Linking water occurrences and ecological functioning
  - Hydraulics with the South African ecological Reserve

INTRODUCTION (Taken from WRC, 2010)

In its passage across the landscape and through time, water gives rise to the distinctive features, and is subject to the recurrent cycles, that are commonly associated with river systems. The change in the quantity of water and in its sediment load from headwaters to sea, the repeated sequences of fast and slow moving water, and the annual advance and retreat of water across floodplains are some of the key processes that contribute to the diversity of landforms found in rivers. Thus, distinctive fluvial features such as meanders, floodplains, cobble bars, sand bars, islands, deltas and beaches, arise from this interaction of water and sediment. These features, together with the water flowing through, over and around them, provide the physical living space – the habitat – for organisms. **It** is important to understand the nature physical aspects of the river in order to be able to predict what types of organisms will occur there.

The relationship between discharge and the availability of physical (hydraulic) habitat within the river ecosystem, coupled with an understanding of the hydraulic conditions that are optimal for different species or communities, constitute the essence of ecohydraulics. Ecohydraulic modelling is employed to predict how hydraulic conditions in a watercourse might change under different development scenarios and thus, how the aquatic habitat of specific species or communities could be affected.

1. Linking water occurrences and ecological functioning (WRC, 2010)

The purpose of environmental river hydraulics is to describe and predict the hydraulic conditions that influence the physical, chemical and biological nature of rivers in order to advance understanding of their ecological functioning and to inform management decisions regarding river conservation and rehabilitation. This requires firstly, establishing which hydraulic variables can best be related to physical and biological processes, and secondly, describing and predicting the occurrence of these variables so that the necessary associations with ecological processes can be made. Riverine flora and fauna respond directly to local hydraulic conditions and only indirectly to streamflow and precipitation. (WRC, 2010; Part III)

2. Hydraulics with the South African ecological Reserve (WRC, 2010)

Changing the natural hydrology of river systems to provide water for human needs, coupled with modified land-use, has resulted in a worldwide trend of deteriorating river ecosystem health. This has spurred the development of the science of environmental flow assessment (EFA), which has become internationally recognised as the means for assessing the quality and quantity of flow required for sustainable use of riverine ecosystems.

Changes in natural flow and sediment regimes of rivers may be due to changes in land-use, the construction of impoundments, flow abstractions (including groundwater) and return flows. In-channel structures (e.g. impoundments, structures for abstractions and return flows, flood and bank protection, construction of artificial habitats) also alter the flow and sediment regimes, but these may have more localised influences depending on their scale. Riverine vegetation both responds to and influences flow and sediment behaviour, resulting in a feedback relationship between vegetation, flow and river morphology. Biota respond to discharge through local hydraulic conditions, such as depth, velocity and inundated area. It is therefore necessary to understand how these flow variables are related, so that management of drivers provides the required ecologically relevant hydraulic habitat. Ecohydraulic analysis is therefore a crucial part of environmental river management. In South Africa, this is undertaken within the context of the Ecological Reserve for rivers (Figure 1).

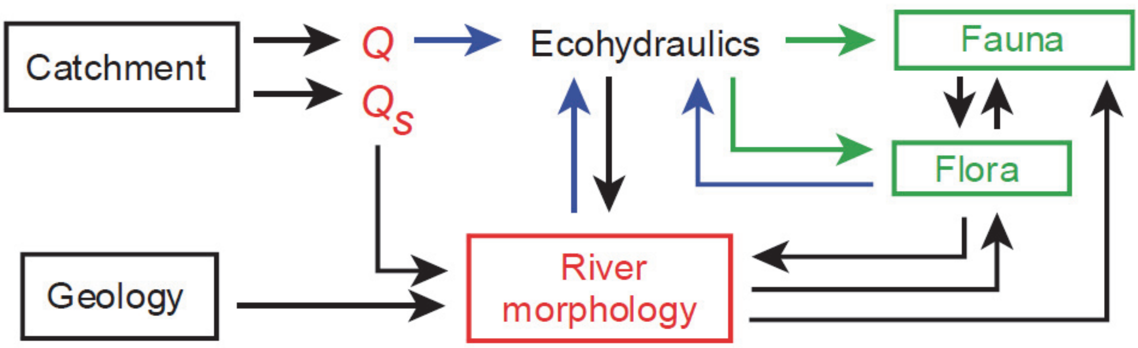


Figure 1: The causal links governing ecohydraulics in the South African Ecological Reserve (Q = discharge; QS = sediment supply; red and green text indicate drivers and biological responses, respectively)

Typical information required for ecohydraulics is listed in Table 1.

Table 1: Data requirements and methods of hydraulic analysis appropriate to different Reserve levels

Reserve level	Data requirements		Methods of analysis	
	Topographic and hydrologic	Habitat hydraulics	Hydraulic	Habitat hydraulics
Comprehensive	Surveys (4) Cross-section(s); and/or 3-DI bed topography; and water surface profiles; and 1:50 000 scale topographical valley slope. Discharge measurements (4) Velocity-area method; or gauge (including rated section	Spatial distributions Composition of substrate-types; position of marginal vegetation, depth and depth-averaged velocity.	1-D (uniform or non-uniform), or 2-D	Statistical or spatially explicit depth-averaged velocity distributions.
Intermediate	Surveys (2) Cross-section(s); and water surface profile; and 1:50 000 scale topographical valley slope. Discharge measurements (2) Velocity-area method; or gauge (including rated section).	Spatial distributions Composition of substrate-types; position of marginal vegetation, depth and depth-averaged velocity.	1-D (uniform or non-uniform)	Statistical depth-averaged velocity distributions.
Rapid	Survey (1) Cross-section; and water surface profile; and 1:50 000 scale topographical valley slope. Discharge measurement (1) Velocity-area method; or gauge (including rated section).	Spatial distributions Composition of substrate-types; position of marginal vegetation, depth and depth-averaged velocity.	1-D uniform	Statistical depth-averaged velocity distributions.

ASSIGNMENT: Read WRC (2010) and relevant documents referenced in the WRC report. Write a 1000 word essay on the role of hydraulics in the protection of water

SELF-EVALUATION QUESTIONS

1. Understand the meaning of hydraulics and ecohydraulics. [ANSWER: WRC (2010)]
2. Discuss the role of hydraulics in the management and protection of South African water resources. [ANSWER: Chapter 3 of NWA].
3. Discuss the ecological Reserve and how it is calculated [ANSWER: WRC (2010)]

SUMMARY (WRC, 2010)

Reliable assessment of ecological flow requirements is based on the relationships between aquatic biota and hydraulic conditions. In South Africa, there is a pressing need to implement Reserves for the equitable (re)allocation of water resources, considering both ecological requirements and human demands. Following Reserve implementation, monitoring is required to assess whether ecological objectives are being attained.

STUDY UNIT 2:

INTRODUCTION TO HYDRAULICS

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

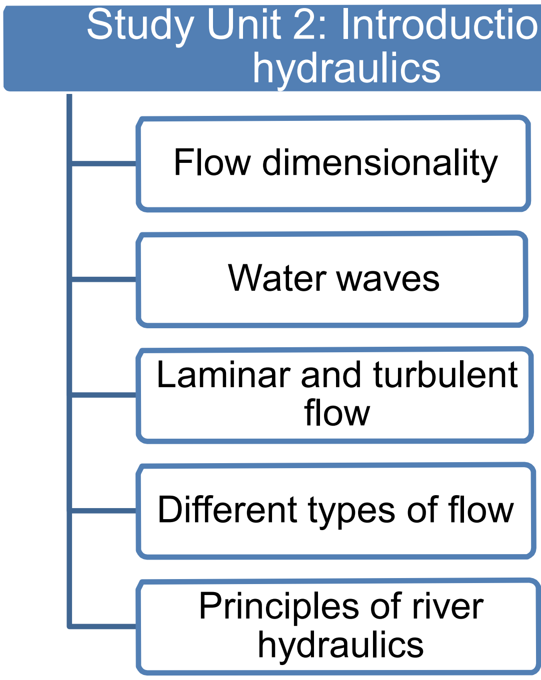
- Department of the Army (1993) Engineering and Design: River Hydraulics. Engineering Manual 1110-2-1416. US Army Corps of Engineers, Washington, United States of America.
- Water Research Commission (2010) Ecohydraulics for South African Rivers: A Review and Guide, WRC Report No. TT 453/10

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about surface water and groundwater hydrology:

- Discuss the importance of dimensionality
- Understand the difference types of water waves (e.g. flood waves)
- Classify flow as laminar or turbulent (etc.)
- Understand the different types of flow (steady, unsteady, uniform and non-uniform)
- Understand and discuss the basic principles of river hydraulics including conservation of mass, conservation of energy and river channel geomorphology)

The study unit will be conducted as follows:



INTRODUCTION

This study unit provides an overview of the principles necessary to perform river hydraulic studies and provides some guidance for selecting appropriate methods for conducting those studies. Topics presented herein include: flow dimensionality, the nature of water and flood waves, an overview of definitions and flow classifications, and basic principles of river hydraulics and geomorphology.

1. Flow dimensionality [Department of the Army (1993); Section 2.2]

Rivers can be thought of as four-dimensional systems, since they vary in space (three dimensions) as well as time (the fourth dimension). The longitudinal (upstream downstream linkages), vertical (river channel and river bed/groundwater interface), lateral (channel-riparian zone/floodplain system) and temporal as seen in Figure 2.

It is not possible to state with theoretical certainty that a given reach can be assumed one-dimensional unless multidimensional studies on the reach have been carried out and compared to the results of a one-dimensional approach. As a practical rule of thumb, however, if the reach length is more than twenty times the reach width, and if transverse flow and stage variations are not specifically of interest, the assumption of one dimensionality will likely prove adequate.

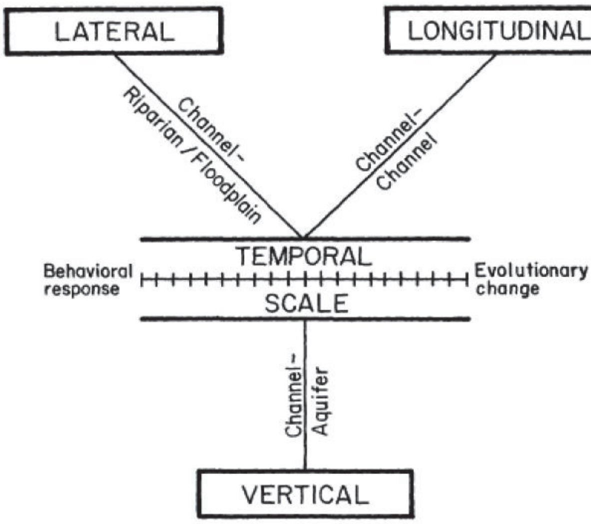


Figure 2: The three spatial dimensions of a river system: longitudinal, lateral and vertical change through different time scales (the temporal dimension) – WRC (2010)

2. Water waves [Department of the Army (1993); Section 2.3]

Water flowing (or standing) with a free surface open to the atmosphere is always susceptible to wave motion. The essence of wave motion exists in the concept of the propagation of disturbances. If a given flow is perturbed by something somewhere within its boundaries, some manifestation of that perturbation is transmitted at some velocity of propagation to other portions of the water body. There are different categories of water waves, many of which are not pertinent to river hydraulics studies.

Photo 1: Flood wave

3. Laminar and turbulent flow [Department of the Army (1993); Section 2.4]

To determine which principles apply to a particular situation in river mechanics, it is necessary to properly classify the flow. Various categories of flow are amenable to different simplifying assumptions, data requirements, and methods of analysis. The first step in the analysis of river hydraulics situations is classification of the state, type, and characteristics of the flow (Figure 3).

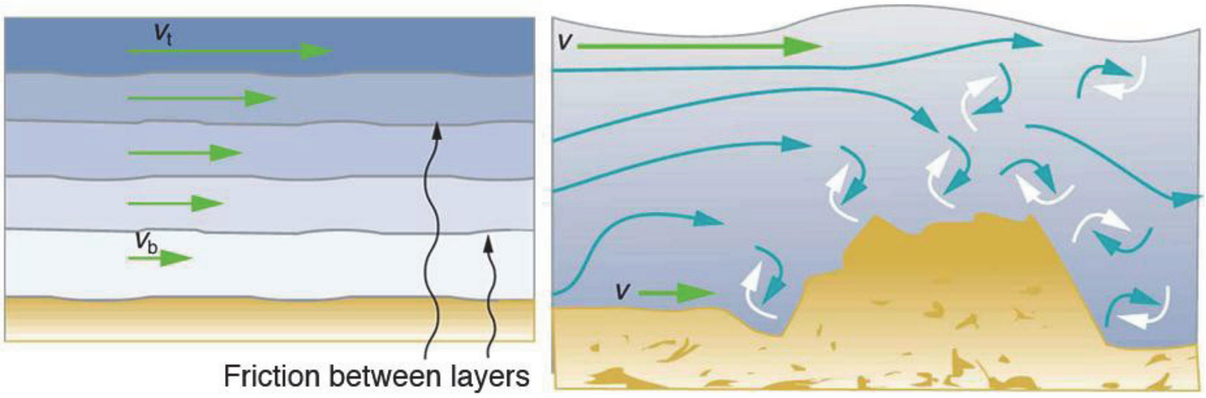


Figure 3: Example of laminar and turbulent flow

4. Different types of flow [Department of the Army (1993); Section 2.6]

The following flow classifications are based on how the flow velocity varies with respect to space and time.

a. Steady flow. A flow is steady if the velocity at a specific location does not change in magnitude or direction with time.

b. Unsteady flow. If the velocity at a point changes with time, the flow is unsteady. Methods for analysing unsteady flow problems account for time explicitly as a variable, while steady flow methods neglect time all together.

c. Uniform flow. Uniform flow rarely occurs in natural rivers because, by definition, uniform flow implies that the depth, water area, velocity, and discharge do not change with distance along the channel. This also implies that the energy grade line, water surface, and channel bottom are all parallel for uniform flow. The depth associated with uniform flow is termed "normal depth."

d. Non-uniform flow. Most flow in natural rivers and channels is non-uniform, or spatially varied flow. Here, the term "spatially varied" is to be taken in the one dimensional sense; i.e. hydraulic variables vary only along the length of the river. Even if the flow is steady, spatial variation can result from changes occurring along the channel boundaries (e.g., channel geometry changes), from lateral inflows to the channel, or both.

5. Principles of river hydraulics [Department of the Army (1993); Section 2.7]

Evaluation of the hydraulic characteristics of rivers and open channels requires analysis of mass and energy conservation. Conservation of mass is often referred to as flow continuity. Continuity is the principle that states that mass (stream flow volume) is conserved (e.g., mass is neither created nor destroyed within the system being evaluated). Mass conservation in a volumetric sense means that the volume passing a given location will also pass another location downstream provided that changes in storage, tributary inflows and outflows, evaporation, etc. between the two locations are properly accounted for.

The second basic component that must be accounted for in one-dimensional steady flow situations is the conservation of energy. The mathematical statement of energy conservation for steady open channel flow is the modified Bernoulli energy equation; it states that the sum of the kinetic energy (due to motion) plus the potential energy (due to height) at a particular location is equal to the sum of the kinetic and potential energies at any other location plus or minus energy losses or gains between those locations.

Even though the same laws of conservation of mass and energy apply to pipe and open channel flow, open channel flows are considerably more difficult to evaluate. This is because the location of the water surface is free to move temporally and spatially and because depth, discharge, and the slopes of the channel bottom and free surface are interdependent.

Flow in a river channel is often considered to be one-dimensional in the direction of flow. As previously discussed, this assumption allows a simplified mathematical analysis of the flow. Multidimensional flows require accounting for the physics (mass and momentum conservation) of the flow in two, and sometimes three, directions.

Natural streams acquired their present forms from long-term processes involving land surface erosion, stream channel incisement, streamflow variation, human activities, and land use changes. The study of these processes associated with land form development is referred to as geomorphology (Figure 4). In a natural river, there is a continuous exchange of sediment particles between the channel bed and the entraining fluid. If, within a given river reach, approximately the same amount of sediment is transported by the flow as is provided by the inflow, the reach is said to be in equilibrium.

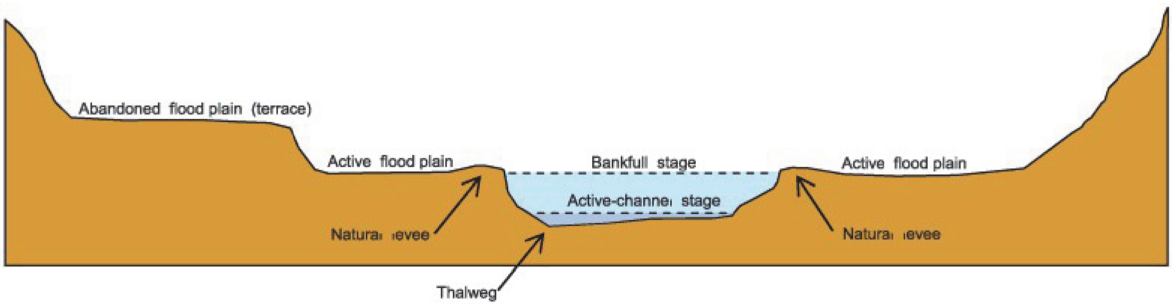


Figure 4: Example of river channel geomorphology

SELF-EVALUATION QUESTIONS

1. Discuss the basics principles of river hydraulics. [ANSWER: In literature provided].

3. Discuss the role of these basic principles in the maintenance of ecosystems. [ANSWER: In literature provided]

SUMMARY (WRC, 2010)

The daily, seasonal and inter-annual variation in flow and its capacity to perform work on the channel is largely responsible for rivers being amongst the most variable and dynamic of ecosystems. To a large extent, the flow regime is responsible for the patterns in channel form as well as the fluctuations in biological communities, which respond both in terms of their composition (the kinds of species present), and structure (the proportions of different types of species).

STUDY UNIT 3:

FORMULATING HYDRAULIC STUDIES

TIME

You will need approximately 15 hours to master this study unit.

REFERENCES

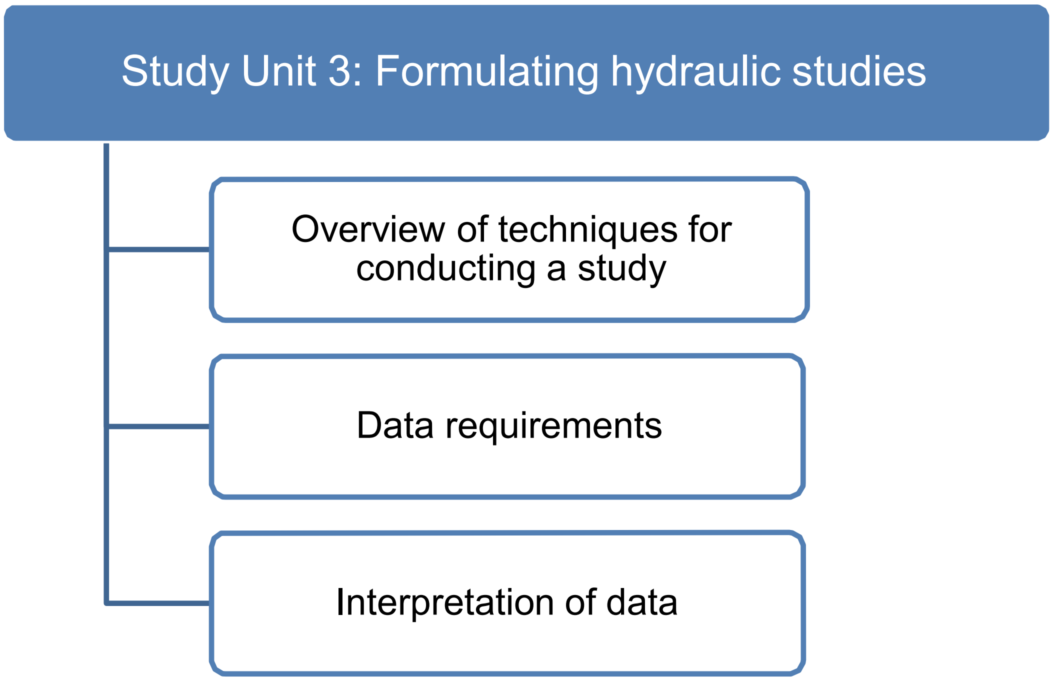
- Department of the Army (1993) Engineering and Design: River Hydraulics. Engineering Manual 1110-2-1416. US Army Corps of Engineers, Washington, United States of America.
- Water Research Commission (2010) Ecohydraulics for South African Rivers: A Review and Guide, WRC Report No. TT 453/10

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Acquire the field data necessary for a hydraulic study
- Determine the level of data interpretation necessary (analytical, physical or numerical model)
- Develop a model based on the requirements

The study unit will be conducted as follows:



INTRODUCTION

Once the project objectives are established, specific elements of the hydraulic analysis can be addressed. Development of the study plan requires establishment of appropriate levels of detail commensurate with the particular study phase. The appropriate level of hydraulic analysis detail is a key issue in most studies affecting, perhaps drastically, both the time and cost of the effort.

1. Overview of techniques[Department of the Army (1993); Section 3.2]

A general overview is given below:

a. Field data. Field (prototype) data collection and analysis serves both as an important aspect of the application of other methods and as an independent method. It is an indispensable element in the operation, calibration, and verification of numerical and physical models. Also, to a limited extent, field data can be used to estimate the river's response to different actions and river discharges using simple computations. Obtaining detailed temporal and spatial data coverage in the field, however, can be a formidable and difficult task.

b. Analytical solutions. Analytical solutions are those in which answers are obtained by use of mathematical expressions. Analytical models often lump complex phenomena into coefficients that are determined empirically. The usefulness of analytic solutions declines with increasing complexity of geometry and/or increasing detail of results desired.

c. Physical models. Analysis of complex river hydraulic problems may require the use of physical hydraulic models. The appearance and behaviour of the model will be similar to the appearance and behaviour of the prototype, only much smaller in scale. Physical scale models have been used for many years to solve complex hydraulics problems. Physical models of rivers can reproduce the flows, and three-dimensional variations in currents, scour potential, and approximate sediment transport characteristics. The advantage of a physical model is the capability to accurately reproduce complex multidimensional prototype flow conditions. Some disadvantages are the relatively high costs involved and the large amount of time it takes to construct a model and to change it to simulate project alternatives

d. Numerical models. Numerical models employ special computational methods such as iteration and approximation to solve mathematical expressions using a digital computer. In hydraulics, they are of two principal types finite difference and finite element. They are capable of simulating some processes that cannot be handled any other way. Numerical models provide much more detailed results than analytical methods and may be more accurate, but they do so with increased study effort. They are also constrained by the modeller's experience and ability to formulate and accurately solve the mathematical expressions and obtain the data that represent the important physical processes.

2. Data requirements [Department of the Army (1993); Section 3.4]

There are three main categories of data needed for hydraulic studies: discharge, geometry, and sediment. Not all of these categories, or all of the data within each of these categories, will be needed for every study.

3. Interpretation of data [Department of the Army (1993); Section 3.5 & 3.6]

The choice of the appropriate model to use during a river hydraulics study is predicated on many factors including (1) the overall project objective, (2) the particular study objective for the project (level of detail being called for), (3) the class, type, and regime of flows expected, (4) the availability of necessary data, and (5) the availability of time and resources to properly address all essential issues.

> ASSIGNMENT: Choose 2 comprehensive RDM studies published on the following webpage: http://www.dwa.gov.za/rdm/Default.aspx and design hydraulic studies for both of them.

SELF-EVALUATION QUESTIONS

1. List of discuss all data needed for a hydraulic study as part of a RDM investigation. [ANSWER: In literature provided]
2. Based on the required information for the RDM study, analyse and choose the correct model. [ANSWER: In literature provided].

SUMMARY

Not all data needs can be foreseen at the start of a study. Consultations with experienced personnel early in the study are often useful in identifying data needs. Some common needs that often surface well into a study include stage and/or discharge duration data, type and gradation of bed material present at different times for movable bed model calibration, measurement of velocity directions and magnitudes at various stages, times, and locations for use in multidimensional model calibration.

STUDY UNIT 4:

UNSTEADY AND STEADY FLOW

TIME

You will need approximately 15 hours to master this study unit.

REFERENCES

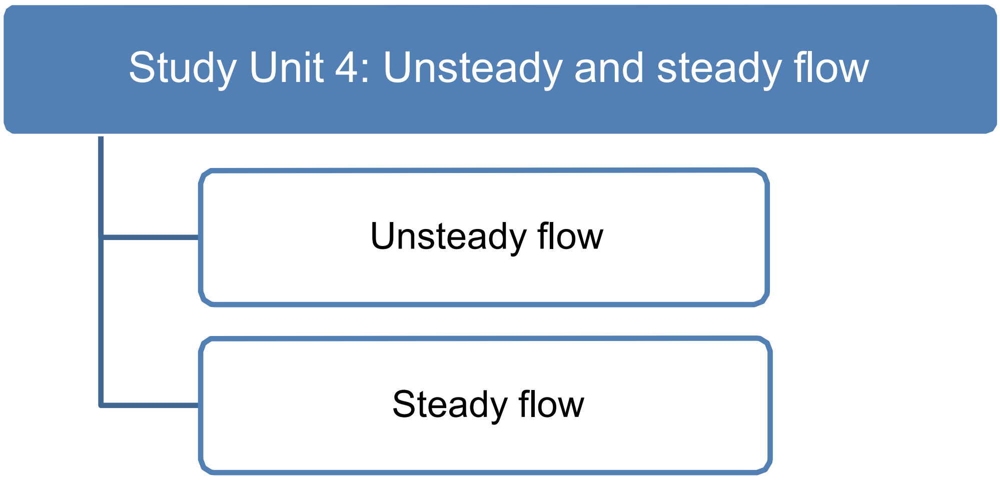
- Department of the Army (1993) Engineering and Design: River Hydraulics. Engineering Manual 1110-2-1416. US Army Corps of Engineers, Washington, United States of America.
- Water Research Commission (2010) Ecohydraulics for South African Rivers: A Review and Guide, WRC Report No. TT 453/10

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Identify steady and unsteady flow in the field
- Discuss the differences between steady and unsteady flow
- Collect the relevant data for steady or unsteady flow studies
- Choose the correct models to interpret the results of data collected for both types of flow

The study unit will be conducted as follows:



INTRODUCTION

The traditional approach to river modelling has been the use of hydrologic routing to determine discharge and steady flow analysis to compute water surface profiles. This method is a simplification of true river hydraulics, which is more correctly represented by unsteady flow. Nevertheless, the traditional analysis provides adequate answers in many cases. This module identifies when to use unsteady flow analysis and when to use steady flow analysis. Guidance regarding the application of models is also provided. The theory regarding various routing techniques is also discussed.

1. Unsteady flow [Department of the Army (1993); Section 5]

Unsteady flow analysis should be used under the following conditions:

a. Rapid changes in flow and stage. If the inflow or the stage at a boundary is changing rapidly, the acceleration terms in the momentum equation become important. The leading example is dam break analysis; rapid gate openings and closures are another example. Regardless of bed slope, unsteady flow analysis should be used for all rapidly changing hydrographs. Any information on events of record, high water marks, eyewitness accounts, and so on can be useful in identifying such conditions. Only an unsteady flow model with all acceleration terms intact is capable of modelling such an effect on downstream hydrographs and water levels.

b. Mild channel slope. Unsteady flow analysis should be used for all streams where the slope is small. On these streams, the loop effect is predominant and peak stage does not coincide with peak flow. Backwater affects the outflow from tributaries and storage or flow dynamics may strongly attenuate flow; thus, the profile of maximum flow may be difficult to – determine. Large inflows from tributaries or backwater from a receiving stream may require the application of unsteady flow. Flow reversals may occur under such conditions, rendering hydrologic routing useless.

c. Full networks. For full networks, where the flow divides and recombines, unsteady flow analysis should always be considered for subcritical flow. Unless the problem is simple, steady flow analysis cannot directly compute the flow distribution. For supercritical flow, contemporary unsteady flow models cannot determine the split of flow. Records of current speeds and directions at different points in a flooded valley and rates of inundation of floodplains help determine whether a one-dimensional approach to a simulation is adequate.

2. Steady flow [Department of the Army (1993); Section 5&6]

Steady flow analysis is defined as a combination of a hydrologic technique to identify the maximum flows at locations of interest in a study reach (termed a "flow profile") and a steady flow analysis to compute the (assumed) associated maximum water surface profile. Steady flow analysis assumes that, although the flow is steady, it can vary in space. In contrast, unsteady flow analysis assumes that flow can change with both time and space.

(1) The typical steady flow analysis determines the maximum water surface profile for a specified flood event. The primary assumptions of this type of analysis are peak stage nearly coincides with peak flow, peak flow can accurately be estimated at all points in the riverine network, and peak stages occur simultaneously over a short reach of channel.

(2) The first assumption allows the flow for a steady state model to be obtained from the peak discharge computed by a hydrologic or probabilistic model. For small bed slopes (say less than 5 feet per mile), or for highly transient flows (such as that from a dam break), peak stage does not coincide with peak flow. This phenomenon, the looped rating curve effect, results from changes in the energy slope.

(3) The second assumption concerns the estimation of peak flow in river systems. For a simple dendritic system the flow downstream from a junction is not necessarily equal to the sum of the upstream flow and the tributary flow. Backwater from the concentration of flow at the junction can cause water to be stored in upstream areas, reducing the flow contributions. Steady state analysis often assumes a simple summation of peak discharges. For steep slopes, once again, the assumption may be appropriate but its merit deteriorates as the gradient decreases.

(4) A more difficult problem is that of flow bifurcation. Hydrologic models and steady state hydraulics cannot predict that division of flow or the flow reversals.

(5) The third assumption allows a steady flow model to be applied to an unsteady state problem. It is assumed that the crest stage at an upstream cross section can be computed by steady flow analysis from the crest stage at the next downstream cross section; hence, it is therefore assumed that the crest stage occurs simultaneously at the two cross sections. Because all flow is unsteady and flood waves advance downstream, this assumption is imprecise. As the stream gradient decreases and/or the rate of change of flow increases, the looped rating curve becomes more pronounced, and the merit of this assumption deteriorates.

(6) The three assumptions are usually justified for simple dendritic systems on slopes greater than about 5 feet per mile. For bifurcated systems and for systems with a small slope, the assumptions are violated and the profiles from a steady flow model are suspected. In general, for large rivers and low lying coastal areas, steady flow analysis is not appropriate.

ASSIGNMENT: Obtain the reaches/profiles of 3 major South African rivers. Assign steady or unsteady flow conditions to all reaches.

SELF-EVALUATION QUESTIONS

1. When is flow in a river steady or unsteady? [ANSWER: In literature provided]
2. What data must be collected to determine if flow is steady or unsteady? [ANSWER: In literature provided]

3. What models must be used to simulate steady conditions? [ANSWER: In literature provided]
4. What models must be used to simulate unsteady conditions? [ANSWER: In literature provided]

SUMMARY

Models can be used to describe both steady and unsteady flow. In most ecohydraulic applications, assuming the temporal variations to be similar to those of the governing discharge time series is sufficient, although unsteady modelling may be necessary for estimating boundary shear stresses in flushing flow determinations. Selection from the many models available, all with different advantages and shortcomings, requires consideration of the output requirements, the levels of accuracy and precision required and the resources of time, money, effort and information available (especially in relation to the level of Ecological Reserve determination being undertaken).

STUDY UNIT 5:

FLOW RESISTANCE IN RIVERS

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

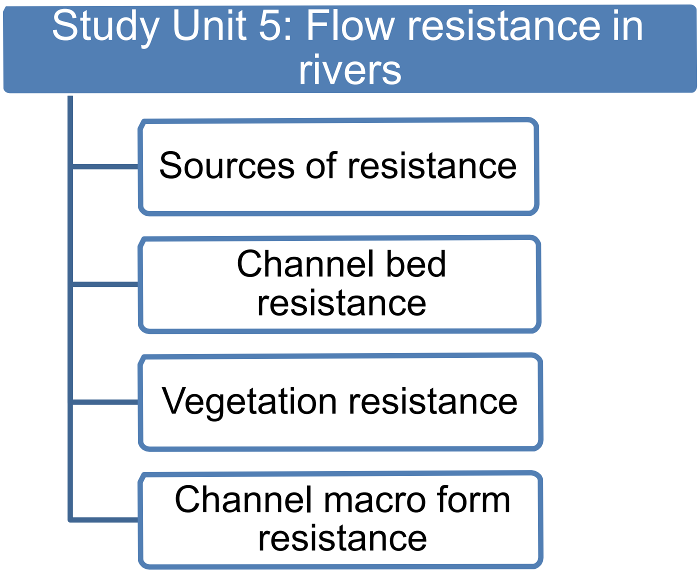
- Department of the Army (1993) Engineering and Design: River Hydraulics. Engineering Manual 1110-2-1416. US Army Corps of Engineers, Washington, United States of America.
- Water Research Commission (2010) Ecohydraulics for South African Rivers: A Review and Guide, WRC Report No. TT 453/10

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- List of describe all sources of resistance
- Describe and calculate the various forms of channel bed resistance
- Describe and calculate the various forms of vegetation resistance
- Describe and calculate the various forms of channel macro form resistance

The study unit will be conducted as follows:



INTRODUCTION [WRC (2010) – Chap 7]

One of the central problems in river ecohydraulics is the determination of flow depths and velocities corresponding to specified discharges. The depths and velocities result from interactions between the flow and the channel boundaries, which take place over a range of spatial scales, and the net effect of the processes induced by these interactions reflects the 'resistance' of the channel.

The relationship between flow depth, velocity and discharge (and hence the resistance) can be described at different levels of resolution, depending on the purpose of the analysis, the amount and type of information available, and the ways in which the underlying processes can be accounted for. For some problems (such as predicting inundation of riparian vegetation) only a stage-discharge relationship is required, while for others (such as describing fish habitat) local flow depths may be required at cross-sections or over two-dimensional plan areas. Similarly, velocities may be required as representative reach values, cross-section averages, cross-section distributions of depth-averaged values, two-dimensional areal distributions of depth-averaged values, or even complete three-dimensional descriptions of local values over area and depth. These requirements indicate the appropriate type of predictive model to be used. In all cases, the model will describe processes at a certain level of resolution and account for the effects of processes at higher levels through empirical input, particularly by specification of a resistance coefficient.

1. Sources of flow resistance and their description [WRC (2010) – Chap 7.3]

Different types of flow resistance have been recognised:

- Surface resistance results from the shear stress at the boundary in contact with the flow, producing shear and associated viscous and turbulent energy dissipation through the flow.

- Form resistance results from the unsymmetrical distribution of pressure and the dissipation of turbulent energy produced by flow separation around submerged or partially submerged boundary irregularities. This type also includes resistance associated with flow patterns induced by the channel form, such as secondary circulation around bends.

- Wave resistance results from the distortion of the free surface by large features, which affects the pressure distribution and dissipates energy by wave motion.
- Resistance associated with local acceleration or flow unsteadiness includes situations of local occurrences of critical flow and subsequent expansions and flow instabilities.

2. Channel bed resistance [WRC (2010) – Chap 7.4]

The effect of the channel bed is the primary consideration when evaluating the resistance in a river. It is important to distinguish between immobile bed and mobile bed conditions (Photo 2). All river beds move during sufficiently high flows and their movement has important ecological implications, but those consisting of gravels, cobbles or boulders may usually be considered to be immobile when assessing hydraulic habitat, while those with sand beds are mobile even under low flow conditions.

Photo 2: Examples of immobile bed (left) and mobile bed (right) conditions

It is important to distinguish between small, intermediate and large scale roughness. Flow resistance associated with various bed forms as shown in Figure 5.

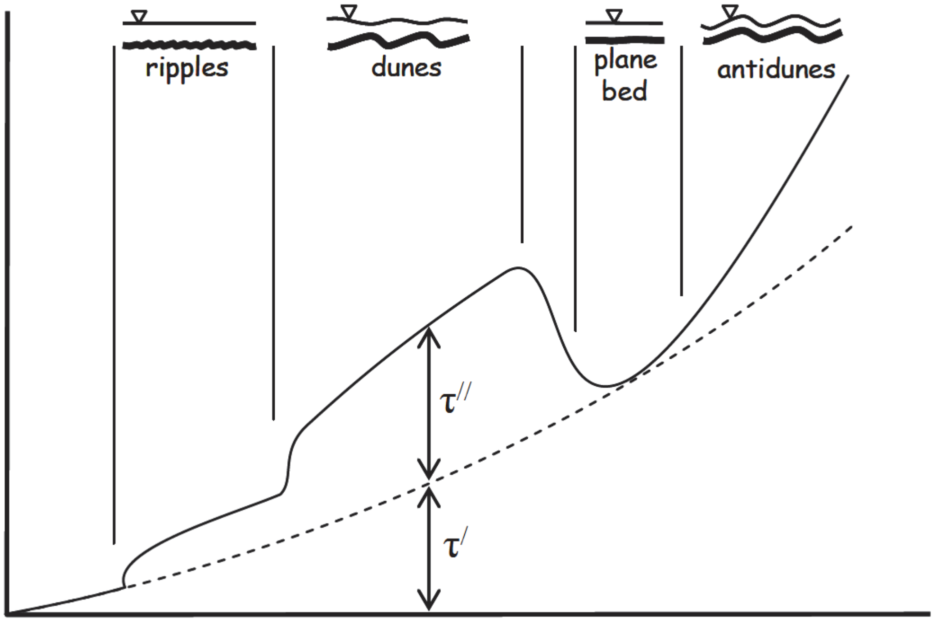


Figure 5: Flow resistance associated with bed forms. The broken line represents the shear resistance associated with grain (surface) roughness and the solid line the total equivalent shear resistance (WRC, 2010)

3. Vegetation resistance [WRC (2010) – Chap 7.5]

Vegetation is common in and along the banks of rivers, and has a significant influence on the resistance to flow. Vegetation resistance is particularly difficult to account for because of the variability of plant morphology and occurrence, which affects the nature of the resistance phenomenon and the values of resistance coefficients. The nature of resistance is determined by the growth habit of the vegetation, which may be one of four types, viz. submerged (the whole plant is below the water surface), free-floating (the plant is unattached to the substratum), floating-leaved (the plants are rooted in the substratum but with most foliage at the water surface), and emergent (rooted plants with leaves and stems protruding above the water surface).

4. Channel macro-form resistance [WRC (2010) – Chap 7.6]

The reach-scale flow resistance in rivers is influenced by form effects at larger scales than bed forms and rocks at low water levels. Large sedimentary bars and channel bends induce flow patterns and secondary circulations that influence resistance coefficients in models that do not describe the corresponding flow processes. These forms of resistance can be divided into:

- Bend resistance (Photo 3)
- Bar resistance
- Compound channels

Photo 3: Bend resistance

ASSIGNMENT: Discuss and quantify the resistance for the Koekemoer Stream, as you see it in the field.

SELF-EVALUATION QUESTIONS

1. Identify and calculate forms of bed resistance. [ANSWER: In literature provided]
2. Identify and calculate forms of vegetation resistance. [ANSWER: In literature provided]
3. Identify and calculate forms of channel macro form resistance. [ANSWER: In literature provided]

SUMMARY (WRC, 2010)

Quantification of flow resistance is a crucial step in the application of hydraulic models for linking the occurrence of water in rivers with their ecological functioning. Selection of an appropriate equation and estimation of a representative resistance coefficient is largely subjective and requires an appreciation of the underlying phenomena and how these are accounted for in the hydraulic model to be used. The resistance coefficient also depends on the physical characteristics of the river channel and the flow condition.

STUDY UNIT 6:

PLANNING, REPORTING AND LESSONS LEARNT

TIME

You will need approximately 15 hours to master this study unit.

REFERENCES

- Department of the Army (1993) Engineering and Design: River Hydraulics. Engineering Manual 1110-2-1416. US Army Corps of Engineers, Washington, United States of America.
- Water Research Commission (2010) Ecohydraulics for South African Rivers: A Review and Guide, WRC Report No. TT 453/10

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:

- Plan a hydraulic study in detail
- Accurately report the results of the study
- Be aware of the "pitfalls" related to hydraulic studies

The study unit will be conducted as follows:

INTRODUCTION

This study unit gives additional details on the preparation of the hydraulic study work plan, a critical step in designing and performing a hydrological study. Also presented are general reporting requirements for presentation of hydrologic/hydraulic studies.

In addition There is much similarity in the geometric data requirements of various river hydraulics models. This module also describes common requirements, points out some differences between models, and presents methods that have been successfully used to model many different situations.

1. Development of a work plan [Department of the Army (1993); Appendix C]

The preparation of a work plan is not intended to be another layer of review guidance or to put additional burden on the scientist. The use of a work plan should be of great value to a scientist in planning and scheduling hydraulic activities, developing and documenting time and cost estimates, and decreasing the supervisory time required to oversee the effort.

The work plan is nothing more than a detailed outline of how the responsible proposes to perform the overall hydraulic study. The detail with which the various activities are described should be sufficient to prepare an adequate time and cost estimate for the entire hydraulic study.

The work plan may be as detailed as desired, in terms of outlining specific hydrologic and

hydraulic work activities.

The analysis of a potential project and its effects on the catchment hydrologic, hydraulic,

and sedimentation regimes is not confined to the physical limits of the project. The work plan must address the total (catchment-wide) effects of the project. The study boundary could well extend for many kilometres upstream and downstream of the project boundaries as well as up tributaries to the project stream. The total work to be performed is largely dependent on the study boundary rather than the project boundary.

The preparation of a work plan should take place over the first days or weeks of initial study planning activities. Information concerning the necessary hydraulic activities and level of detail should be obtained from discussions with interdisciplinary team personnel, local interests, evaluation of available data, and examination of potential alternatives.

2. Reporting and checklists [Department of the Army (1993); Appendix C]

No matter how well the scientist has performed a technical analysis, the lack of a complete and well-written report of the work will cast doubt on its validity. The report is written to document the major steps and findings of the hydrologic work and to convince one or more technical reviewers that the final result is the most appropriate one for the study objectives, level of available data, technical analysis, alternatives possible, and the alternative selected.

Some general guidelines for preparing the report are:

(1) Format. The hydrologic and hydraulic report is usually presented as an appendix to the main report. Avoid duplication of material in the main body of the report or in previous documents that are still accessible to the review authority. Use cross references as much as possible. Don’t use words when the information can be conveyed by tables. Don’t use tables when figures or charts can be utilized. Maximize the use of charts, figures and maps in the report. Ensure that locations discussed in the text are clearly indicated on maps. Reference the appropriate figure or map in the text.

(2) Project description. Clearly describe and show the location of the project, its main features, and its function. Describe the impacts of the project both positive and negative on the system hydrology, hydraulics and sediment regime.

(3) Technical information. Start with the basic data available. Describe the method of analysis selected and why. What key assumptions were made and how were they justified? What are the results of the hydrologic analysis and how do they relate to the plan formulation process? How did you evaluate the sensitivity of results to your assumptions and the consequent effects on project design?

(4) Validity. Remember that you are trying to convince a reviewer of the validity of your technical analysis. An independent analysis should arrive at nearly the same conclusions by following the technical path and thought processes documented in the report.

Hydrologic Scientist Study Checklist includes

a. Safety. Are the levees, channels, spillways, reservoirs, etc. of adequate height, capacity, storage, or level of protection? Are residual problems (such as flooding) well documented?

b. Function. Is the plan conceptually correct? Will it function in an appropriate manner? Are conclusions supported by a logical sequence of data analyses and deductions?

c. Performance. Will the project description, local cooperation, and operation and maintenance requirements ensure that the plan will continue to perform as planned over the project life? Are all the physical features and institutional arrangements well documented?

d. Engineering. Does the engineering analysis appear appropriate for supporting formulation and design objectives? If not, does it appear that an alternate analysis would result in a different conclusion?

e. Economy. Do the major features of plans generally appear to achieve appropriate project purposes in a cost effective manner? Is each component economically justified?

3. Lessons learnt

GEOMETRIC DATA

a. River geometry. It is not feasible to replicate all topographic, land use, vegetative cover, soils types, etc. details in a digital representation of a river system at high resolution for hydraulic analyses. Therefore, key hydraulic features of the channel and floodplains must be identified by the scientist and included in any digital model. The principal features of channel (i.e. in-bank) geometry are harder to detect because they usually cannot be seen on maps; their approximate locations can be found, however, with the understanding of geomorphology. Structures may constrict the flow, changing the hydraulics of the stream. The key to developing representative geometric data is the definition of the features that play significant roles in both the river's behaviour and the numerical model's performance.

b. Cross section locations. Cross sections are located to serve two major purposes in river modeling: (1) to define the geometry of the river and floodplain, including the flow boundaries; and (2) to satisfy the computational accuracy requirements of the analytical method being used. With respect to the latter, for example, most river hydraulics numerical models provide interpolated computation points based on the properties of the input cross sections.

c. Unsteady flow vs. steady flow requirements. Steady flow models and unsteady flow models have different cross-sectional requirements. A steady flow analysis requires definition of only the active flow area (that is, the area which conveys flow), unless storage-outflow data is being developed for hydrologic routing. Unsteady flow simulation requires definition of both the active flow area and the inactive, or storage areas. These storage areas are important because for most rivers, during flood flows, the speed of the flood wave is determined largely by storage rather than wave dynamics. Because steady flow cross sections may only define active flow areas, they may not be sufficient for unsteady flow analysis.

d. Pool-riffle sequence. A river generally forms a sequence of deep pools and shallow riffles. During low to moderate flow, the relatively high invert elevation of the riffle controls the water surface profile, backing water upstream. Pools and riffles are associated with meandering streams in which the flow is predominantly subcritical (although flow can be supercritical at the riffle). The pools occur on the outside of bends and the riffles occur in the straight sections connecting the bends.

f. Storage areas. Storage areas are the regions of the floodplain outside of the active flow area. They may be ignored for a steady flow analysis but are crucial to unsteady flow analysis. Because of the irregularity of the floodplain boundaries, particularly near tributary junctions, the storage indicated by the cross sections is always less than the total actual storage of the floodplain. This underestimation of storage can cause a computed flood wave to arrive too early; consequently, the geometric data may need to be adjusted during calibration.

g. Method of specifying wetted perimeter. The wetted perimeter is defined as the length of the cross section along which there is friction between the fluid and the boundary.

DEVELOPING CROSS-SECTIONAL DATA TO DEFINE FLOW GEOMETRY

a. Flow lines. For floodplain studies, flow lines should be sketched on a topographic map to estimate flow direction and determine cross section orientations.

b. Topographic maps. Cross sections of the overbank areas may be obtained directly from an accurate topographic map, if one is available. Otherwise, cross sections must be obtained by field or aerial surveys. It is necessary to obtain the shape and slope of the channel from soundings of the river channel unless an accurate hydrographic survey is available.

c. Subdividing cross sections based on roughness variation. Cross sections obtained for water surface profile computations on rivers at flood stage should be divided into two or more segments that have different values of the friction coefficient n. These consist of the main channel areas, with relatively low value(s) of n, and one or more overbank areas which, because of vegetation and other obstructions to flow, generally have higher n values. Aerial photographs are valuable supplements to topographic maps and surveyed cross sections for determining the extent of vegetation and portions of cross sections having common values of n.

d. Subdividing cross sections based on depth variation. Parts of a cross section having the same roughness should be subdivided to reflect abrupt changes in depth. The effect of roughness variation tends to be reduced as the depth of flow increases.

e. Checklist for locating cross sections. If cross sections are located according to the criteria discussed in the preceding sections and the list of locations that follows, a reasonable initial definition of river and floodplain geometry should be acquired.

SELF-EVALUATION QUESTIONS

1. Develop a study plan
2. Write a detailed accurate hydraulics report.

SUMMARY

On completion of the study unit, the student should have sufficient knowledge to complete a hydraulic study using basic models.

STUDY UNIT 7:

CASE STUDY

TIME

You will need approximately 30 hours to master this study unit.

REFERENCES

- All references from previous study units.

- Barnard HC. 2000. An explanation of the 1:500 000 general hydrogeological map: Johannesburg 2526. Department of Water Affairs and Forestry.

- Department of Water Affairs and Forestry. 2004. Internal Strategic Perspective: Limpopo WMA. Prepared by Goba Moahloli Keeve Steyn in association with Tlou and Matji Engineering and Management Services (Pty) Ltd and Golder Associates (Pty) Ltd. Report No. P WMA 01/000/00/0304.

- Department of Water Affairs and Forestry. 2005. Mokolo River Catchment WC/WDM Study: Situation Assessment And Business Plan For Lephalale Municipality. Prepared by Tlou & Mallory (Pty) Ltd on behalf of Directorate: Water Use Efficiency. Report No. WUE WMA 1/000/A42/0503.

- Department of Water Affairs and Forestry. 2008. Intermediate Reserve determination study for Selected Water Resources (Rivers and Groundwater) in the Mokolo Catchment. Desktop EcoClassification report. Prepared by Clean Stream Biological Services and Water for Africa. Authored by Louw D, Huggins G P, Kotze P. Report no: 26/8/3/10/14/002

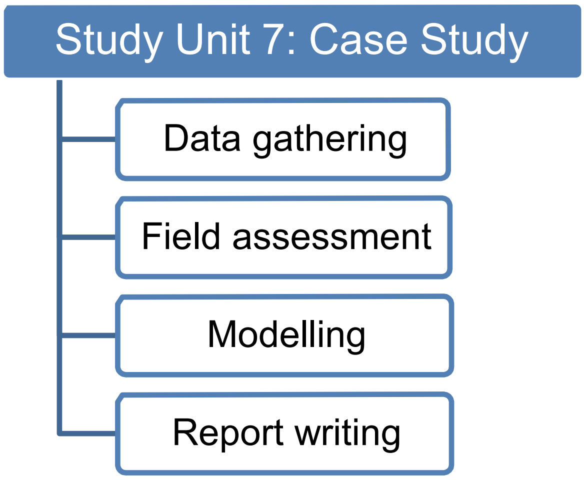
- Department of Water Affairs 2010. Intermediate Reserve determination study for Selected Water Resources (Rivers and Groundwater) in the Mokolo Catchment. Groundwater-surface water interaction report. Authored by Water Geosciences Report no: 26/8/3/10/12/013

- River Health Programme (RHP). 2006. State-of-Rivers Report. The Mokolo River System. Department of Environmental Affairs and Tourism Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight to:
• Use all information from study unit 1-6 to conduct a hydraulic study.

The study unit will be conducted as follows:



INTRODUCTION

In this study unit, students are expected to apply what they have learnt in study units 1-6. The Mokolo River study areas within the Limpopo WMA forming part of the Limpopo Province in the northern part of the Republic of South Africa (Figure 6). The area consists of quaternary catchments A42A-A42J covering an area of approximately 8100 km^2. The two main towns located in the study area include Lephalale (Ellisras) and Vaalwater. The Mokolo River is the major river system flowing through the study area eventually joining the Limpopo River to form the international boundary between South Africa and Botswana.

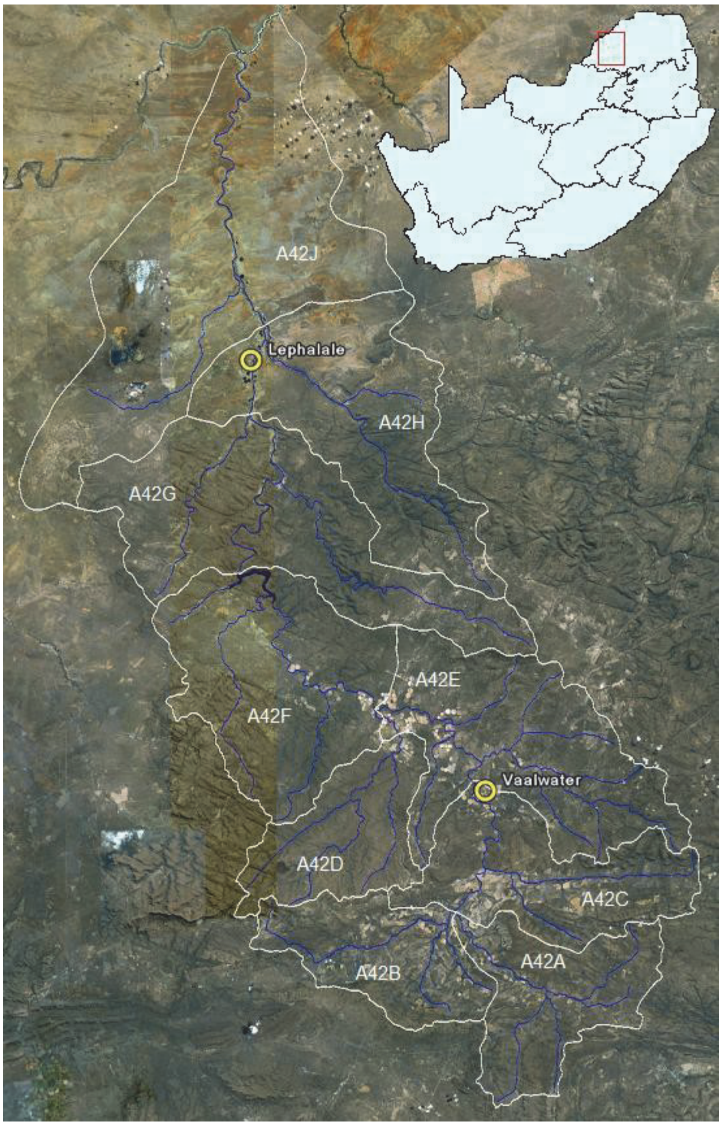


Figure 6: Location of study area

1. Data gathering

All data sets available must be collected and IUA delineated. Some background information is provided below:

The topography (Figure 7) varies depending on the type geological formations present. The northern part of the study area, is typically characterized as relatively flat lying with elevations ranging between 600 to 700 mamsl. Hills are associated with the Bushveld Igneous Complex. The central and southern part of the area is underlain by rocks of the Karoo Supergroup and Waterberg Formation. The mean annual precipitation on average varies between 300 mm and 500 mm. The mean annual potential evaporation is more than twice the amount of rainfall over most of the area. It varies across the Mokolo Catchment from about 1600 mm/a in the south to about 2000 mm/a in the north.

The vegetation of the Mokolo Catchment is characterized by mostly *Bushveld Biomes* in the north, central regions, southeast and southwest. *North Eastern Mountain Sourveld biome* occur in localized areas in the south (Low *et al.,* 1996).

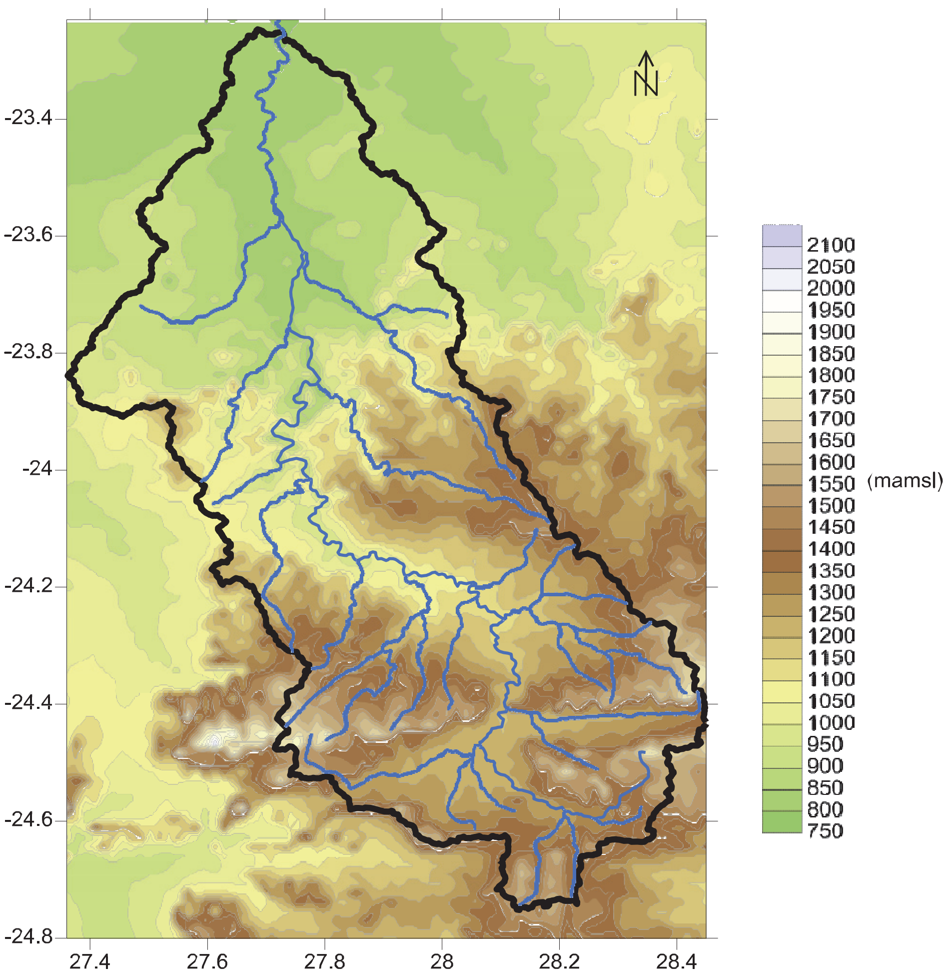


Figure 7: Topography

The geology of the study area is discussed in the following sub-sections:

The north of the study area is underlain by rocks of the Beitbridge Complex and Hout River Gneiss formation forming part of the Basement Complex. The Basement Complex is mainly characterized by granites, granodiorite, migmitites and gneiss but also comprises of metamorphosed sediments, slate, talc schists and sandstone.

Intrusive igneous rocks (Bushveld Igneous Complex) are found to the north, south and east of the study area consisting mainly of the Rustenburg layered suite (Rooiberg Group). This rock formation ranges in composition from ultramafic to acidic rocks and includes an economically (Platinum) important layer comprising mainly of granodoirite, gabbro, norite, anorthosite and granite.

The southern part of the study area is underlain by the Waterberg Formation that consists of three main subgroups; the Setlaole, Makgabeng and Mogalakwena formations. The basal Setlaole Formation is composed of coarse granulestone and is locally conglomeratic. This formation is interpreted to have been deposited in a fluvial, braided river environment. The Makgabeng Formation consists of large-scale trough and planar cross-bedded fine- to medium-grained sandstone. The Mogalakwena Formation consists of interbedded sheets of granulestone and conglomerate.

The Karoo Supergroup, consists mainly of sedimentary rocks. The Waterkloof Formation (Ecca Group), forming part of the Ellisras basin, comprises of diamictite, mudstone and conglomerates. The mudstones are believed to represent glacio-lacustrine deposits whereas the conglomerates and diamictite are believed to have formed as subaqueous outwash deposits formed due to the retreating glacier.

Quaternary deposits cover large portions of the Basement Complex and the northern reaches of the Waterberg Formation. Sediments such as calcrete, ferricrete, gravel red sand and alluvium are found throughout the Mokolo Catchment. Alluvium of up to 5 meters in thickness with a coarse sand base is present along the Mokolo River.

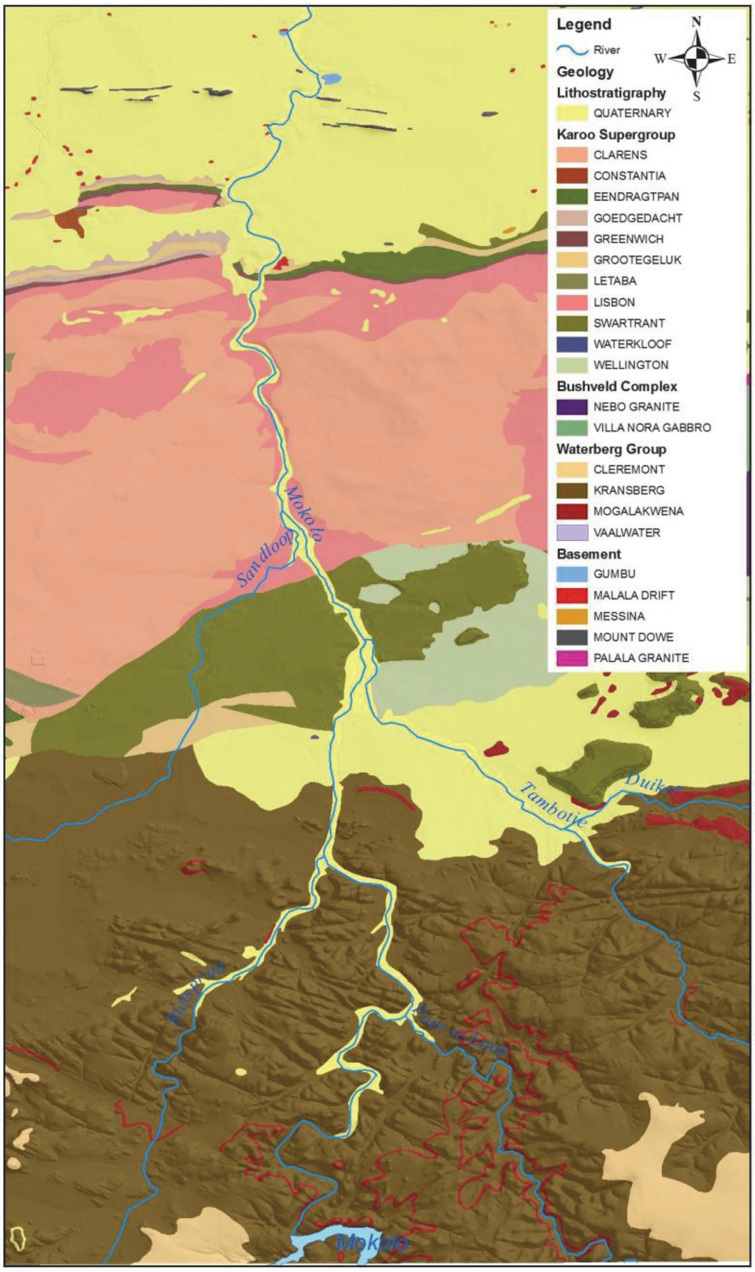


Figure 8: Geology of the study area (taken from DWA, 2010)

There is a State of the Rivers Report for the Mokolo River (2006) which provides an overview of the state of the river for the various sections of the river together with the ecosystems associated with these sections. Impacts on the river are also documented.

In 2010 DWA completed an intermediate Reserve determination for the Mokolo River catchment. The main conclusions taken directly from this report can be summarised as:

- The Mokolo River (upstream) is assumed to be perennial under reference conditions. The Mokolo River (downstream) is presumed to have been near-perennial; only drying up during drought periods. Present day flow modifications to the lower Mokolo have significantly increased the frequency and duration of low and zero flow periods. In future, increased utilisation of the water in the Mokolo Dam is likely to result in further reductions in the size and frequency of high flows coming down the lower Mokolo River. The pools within this lower section of the river are critical for instream biota during times of very low and zero flow. If a viable fish population is to be maintained in the river, and the vegetation of the pools is to be maintained (which provides cover and habitat for biota), then the functioning of the pools themselves must be maintained.
- There are numerous large, deep pools along the lower Mokolo River. Pools within the main macro-channel sit within the coarse sandy matrix of the river bed and are consequently hydraulically well-connected to the water level within the main channel. During dry periods when water levels fall and flows stop, these pools similarly become shallower and eventually dry out.
- In contrast to this, the pools that form in the backwaters of the tributary confluences tend to have higher clay content in their beds and banks and, at low flows, these pools become hydraulically isolated from the main channel.
- . The lower Mokolo River is an alluvial depositional river reach which has, over time, increased its elevation relative the inflowing tributaries The pools that have developed along these backwaters are consequently clay-lined and at low flows largely hydraulically isolated from the river and associated water levels.
- The pools are predominantly maintained by flows from the Mokolo River which backflood into the pools. Some minor inputs from interflow (subsurface seepage) from the adjacent slopes and upstream tributary catchments may also play a role in providing water to the pools, but the hydraulic gradients identified by the groundwater study indicate that these inputs are unlikely or negligible. During critical low flow/dry periods then, it can be expected that the pools are dependent on recharge from high flow events from the Mokolo River.
- The longitudinal river distance between the closest upstream (i.e. A4H010) and downstream (i.e. A4H014) gauging stations are approximately 116.1 km. The remote locations of these gauging stations presents a major challenge to estimating historical river discharges at the study sites. This is because the lower Mokolo River is characterised by substantial run-of-river "losses".
- DWA estimated that the "losses" to the sand bed and surface storage (e.g. pools, weirs and dams) amounted to approximately 5.04 Mm^3
- Present day operation of the Mokolo Dam includes periodic releases (pulses) over a few days for the purpose of supplying surface and subsurface storage that is abstracted for irrigation.
- The gauge data from A4H014 indicates that the releases from the Mokolo Dam do not (generally) produce surface flow into the Limpopo River.
- The typical current day irrigation releases (generally 3 to 4 Mm^3 with a maximum discharge of approximately 10 m^3/s) are unlikely to result in recharge of many of the downstream pools.
- Under natural conditions the Mokolo River (downstream) will be connected during most months (especially wet season) with some isolation during the dry months

(especially end of dry seasons or drought years). Under reference condition the connection would have allowed fish movement between pool and river for ecological processes such as spawning, provision of nursery and feeding habitats.

- Gauging stations are A4H014 – located approximately 48.4 km downstream (approximately 0.7 km upstream of the Limpopo River confluence), and A4H010 – located approximately 67.7 km upstream (approximately 1.8 km downstream of the Mokolo Dam Wall). Tributaries that contribute substantial runoff between these two gauges include Poer se Loop (confluence approximately 29.5 km downstream of the Mokolo Dam Wall), the Rietspruit (confluence a further approximately 14.6 km downstream of the Poer se Loop confluence) and the Tambotie River (confluence a further approximately 15.2 km downstream of the Rietspruit confluence). Of these tributaries, only the Tambotie River is gauged – at station A4H007, which is located approximately 26.5 km upstream of its confluence with the Mokolo River near the town of Lephalale. Details of the gauge stations used in the study for obtaining historical discharge records are provided in Table 2. Table 3 gives the naturalised mean annual runoffs (MAR) at the closest upstream and downstream gauging stations on the Mokolo River, as well as for the intervening tributaries (DWAF, 2007).

Table 2: DWA gauging stations used in this study

River	Station[1] no.	Catchment area (km^2)	Latitude S (dec. deg.)	Longitude E (dec. deg.)	Record length
Mokolo	A4H005	3786	23 45 49.5	27 54 29.9	25/09/62 - 12/01/10
Mokolo	A4H010	4319	23 58 19.5	27 43 33.9	01/08/80 - 13/01/10
Mokolo	A4H014	8431	23 14 08.5	27 43 23.5	23/02/04 - 30/11/09
Tambotie	A4H007	398	24 05 00.5	27 46 21.9	27/08/62 - 12/10/09

1 http://www.dwa.gov.za/hydrology/cgi-bin/his/cgihis.exe/station

Table 3: Naturalised MAR of the Mokolo River and tributaries relevant to this study (DWAF, 2007)

River	Location	MAR (Mm^3)
Mokolo	A4H005	214.4
Mokolo	A4H010	291.9
Tambotie	Mokolo confluence	23.3
Poer se Loop	Mokolo confluence	13.3
Rietspruit	Mokolo confluence	13.1
Sandspruit	Mokolo confluence	5.6

- The longitudinal[1] river distance between the closest upstream (i.e. A4H010) and closest downstream (i.e. A4H014) gauging stations are therefore approximately 116.1 km. The remote gauging stations presents a major challenge to estimating historical river discharges at the study sites. This is because the lower Mokolo River is characterised by substantial run-of-river losses.

The following aquifers have been identified in the study area:

- The northern region of the study area is underlain by basement aquifers that comprise of deeper fractured (i.e. secondary) aquifers overlain by a weathered horizon of variable thickness. Thick, weathered aquifer zones are expected in areas where the bedrock has been subjected to intense fracturing. The existence of diabase and dolerite dykes forms poor groundwater targets due to the lack of weathering on the margins of these dykes with the basement rocks (gneiss), especially below the static water level. The most noticeable aquifer within the basement rocks are the ENE trending zones of shearing, faulting and brecciation and are usually covered with Quaternary deposits contributing to the aquifer's storage potential.
- The Waterberg aquifer is predominantly of a fractured and weathered type potentially connected to alluvial deposits occurring along the Mokolo River. The main groundwater targets are associated with fractured dyke contacts and fault zones. The Waterberg formation is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. Recharge to the aquifer, often discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.
- The Karoo aquifer shows similar aquifer properties as the Waterberg aquifer comprising of fractured rocks with a porous matrix. However, groundwater resources and especially the development thereof, are limited due to the low recharge to these aquifers.
- Alluvial aquifers are recharged during periods of high stream-flows and discharge events (from the Mokolo dam) as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers.

Based on detailed field work to classify the groundwater-surface water interaction of the Mokolo River as part of the groundwater Reserve determination study for the Mokolo catchment the following conceptual aquifer model is proposed:

- The alluvial aquifer associated with the Mokolo River is in direct contact with the river.
- The alluvial aquifer is generally unconfined.
- The regional aquifers show marginal gradients towards the Mokolo River course and exchange water with the river only indirectly via the alluvial deposits.

[1] Direction along the river

- The surface-groundwater exchange between the alluvium and the Mokolo River occurs on a far shorter time scale in comparison to the interaction between the regional and alluvial aquifers.

2. Field assessment

The field assessment will entail visiting one IUA and collecting the following data:

- Flow in river (if possible)
- Cross-sections through river
- River reaches
- Landuse

3. Modelling

Use PCSWMM to model the current hydraulics of the river system.

3. Write report

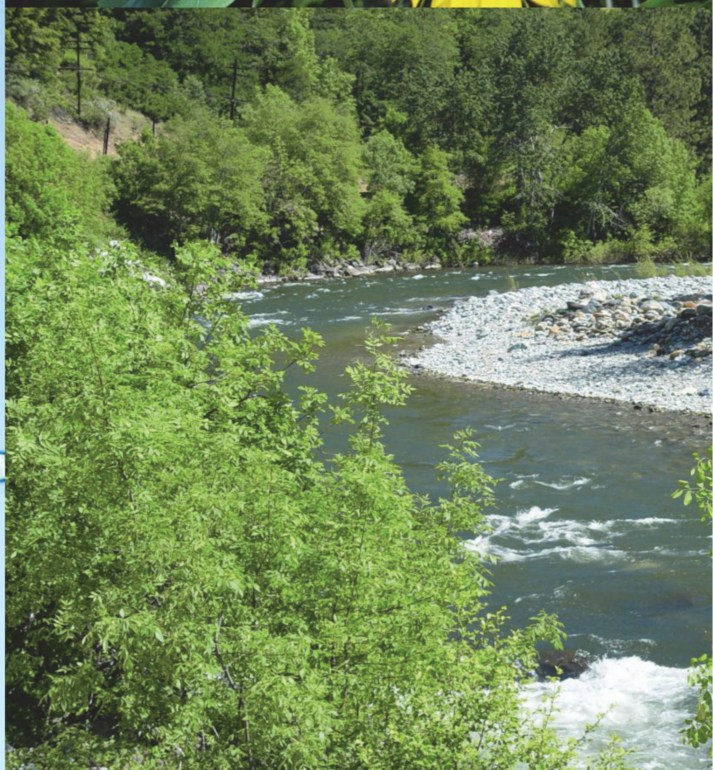
Write a report as discussed in Study Unit 6.

SELF-EVALUATION QUESTIONS

1. Collect all data necessary for hydraulic assessment
2. Write a comprehensive report documenting the hydraulic assessment
2. Relate the hydraulic assessment to the ecological requirements of the Reserve

SUMMARY

At the end of this model the student would have completed a hydraulic study and be able to implement all study units.


MODULE 5

FLUVIAL GEOMORPHOLOGY

Tutored MSc in Ecological Water Requirements

Developed by

Prof. K Rowntree and Prof. V Wepener

November 2013

MODULE 5: FLUVIAL GEOMORPHOLOGY

Purpose:

The purpose of this module is to provide candidates with a working knowledge of geomorphological processes so that they can communicate effectively with a competent geomorphologist, and integrate the specialist output provided by a geomorphologist into an ecological water requirement (EWR) assessment.
The module aims at a basic level of understanding, to provide a conceptual rather than a functional capability.

Outcomes:

On completion of this module learners should be able to:

- explain why geomorphology is an important component of aquatic ecosystems;
- explain the extent to which the spatial and temporal variation in aquatic ecosystems is a response to geomorphological processes;
- demonstrate an understanding of the geomorphological concepts that underpin EWR assessments;
- undertake a basic desktop geomorphological classification of aquatic resources (rivers) within a catchment;
- describe the requirements and likely sources of data needed by geomorphologists in the EWR process;
- present an overview of the practical skills and tools that a geomorphologist can use in an EWR assessment;
- explain the potential and limitations of what a geomorphologist can predict within the EWR process;
- demonstrate a knowledge of the links between geomorphology and other disciplines that make an input into EWR assessments;

The outline of this module is based on: Rowntree, K.M. (2012). Fluvial Geomorphology. In: Southern African Geomorphology: Recent trends and new directions. Eds. Meadows, M and Holmes, P. Sun Media, Bloemfontein. pp. 97-140.

Proposed Timetable:

DAY	1-2	3-4	5-6	7-8
	8h00-10h00	10h00-12h00	13h00-15h00	15h00-17h00
1	Lectures 1 and 2	Lectures 2 and 3	Lectures 3 and 4	Assignments 1/2
2	Feed-back and seminars	Lecture 5	Assignments 3/4	Feed-back and seminars
3	Practical – Practical exercises on classification and zonation. Collection of data for use in GAI model			
4	Lecture 6	Workshop – Populating and running the GAI model		
5	Feed-back – GAI	Seminars and Final examination		

Proposed Assessment:

Assessment will be by means of the following:

- A field trip report;
- A seminar of the candidate's choice on the subject of geomorphology in the EWR;
- Two short assignments to be decided on by the lecturer;
- Final examination.

MARK ALLOCATION:

Field trip report	10
Seminar	30
Assignment 1	5
Assignment 2	5
Final Examination	50

Lectures	**Assignments**
Section 1: Context and fundamentals of geomorphology	
Lecture 1: Introduction to fluvial geomorphology Lecture 2: Regional drivers of river systems in South Africa Lecture 3: Geomorphological classification and zonation of rivers Lecture 4: Abiotic-biotic links: riparian vegetation Lecture 5: Linking the channel to the catchment and concepts of landscape connectivity	Any two assignments based on the lecture topics (examples are provided under the detailed description of the lectures)
Section 2: application of geomorphological principles in river management	
Lecture 6: geomorphology and habitat (link to field work) Field excursion GAI workshop	Practical exercises on classification and zonation The GAI model (level III) – data collection GAI model – running the model Geomorphological RQOs and recommended flow requirements in terms of geomorphology

LECTURE 1

INTRODUCTION TO FLUVIAL GEOMORPHOLOGY

KEY CONCEPTS:

Geomorphology is the study of the processes that shape the surface of the earth. The sub-discipline of *fluvial* geomorphology focuses particularly on the effects of flowing water (i.e. rivers) on the earth's surface. Through the primary processes of erosion and deposition, flowing water creates a dynamic network of channels that transport water and sediment from the earth's surface to the sea as part of the hydrological and sediment cycles respectively.

As sediment makes its way through the channel network, it forms the substrate for various instream and riparian ecosystems. Thus, it can be said that geomorphology forms a template on which these ecosystems exist and function. Along with hydraulic flow conditions and water quality, this template forms an integral part of what is termed "habitat".

Various anthropogenic activities disrupt geomorphological processes and thus stand to result in changes to both instream and riparian habitats. These changes take place at various spatial and temporal scales dictated by the geomorphological system.

OUTCOMES:

By the end of this lecture learners should be able to:

- give an explanation of the broad scope of fluvial geomorphology and
- identify key geomorphological processes and morphology that contribute to the nature of aquatic ecosystems;

RECOMMENDED RESOURCES:

- Freeman, N.M. and Rowntree, K. (2005). *Our Changing Rivers: An Introduction to the Science and Practice of Fluvial Geomorphology.* TT 238/05 Water Research Commission, Pretoria.
- Knighton, D. (1984). *Fluvial Forms and Processes*, Edward Arnold, London.
- Schumm, S.A. & Lichty, R.W. (1965). Time, space and causality in geomorphology, *American Journal of Science*, 263, 110-119.
- Sear, D.A., Newson, M.D. and Thorne, C.R. (2003). *Guidebook of Applied Fluvial Geomorphology* R&D Technical Report FD1914 Defra/Environment Agency. Available online: http://www.defra.gov.uk/science/project_data/DocumentLibrary/FD1914/FD1914_1147_TRP.pdf accessed 31/10/2006.

LECTURE 2

REGIONAL DRIVERS OF RIVER SYSTEMS IN SOUTH AFRICA

KEY CONCEPTS:

Characteristics of rivers are determined by regional and local factors. Catchment run-off and sediment yield are regional factors that provide input into the river channel. The longitudinal profile of the channel determines the potential energy that is available for erosion and transport of sediments. At the local scale the channel is an adjustment of the downstream manifestations of the regional factors. This is further influenced by the local geology and riparian vegetation. This lecture deals with the translation of regional scale factors into flow, sediment yield and changes based on longitudinal profile from a southern African perspective.

OUTCOMES:

By the end of this lecture and related assignments learners should be able to:

- Discuss flow regime and sediment yield as drivers of on the geomorphology;
- Evaluate the short-term and long-term effects of these drivers on channel morphology
- Reflect on the effects of longitudinal channel change on river ecosystems;
- explain how the separate drivers can interact with each other.

ASSIGNMENT 1:

Students work in groups to research techniques for habitat description. Habitat descriptors could include:

- hydraulic biotopes and flow hydraulics
- sediment size distribution
- bed structure
- channel cross section surveys

RECOMMENDED RESOURCES:

- Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J., Nathan, R.J. (2004*). Stream Hydrology: An Introduction for Ecologists*. 2nd Edition. Chichester, Wiley.
- Rowntree, K.M. & Wadeson, R.A. (1999*). A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*, WRC Report No. 497/1/99, WRC, Pretoria.
- du Preez, L. & Rowntree, K.M. (2006). *Assessment of the Geomorphological Reference Condition – an application for Resource Directed Measures and the National River Health Program*, Water Research Commission Report K5/1306, WRC, Pretoria. (CHAPTER 4)
- Freeman, N.M. and Rowntree, K.M. (2005). *Our Changing Rivers: An Introduction to the Science and Practice of Fluvial Geomorphology.* TT 238/05 Water Research Commission, Pretoria.

- Petts, G.E. and Gurnell, A.M. (2005). Dams and geomorphology: research progress and future directions. *Geomorphology*, 71: 27-47.Petts, G.E. and Gurnell, A.M. (2005). Dams and geomorphology: research progress and future directions. *Geomorphology*, 71: 27-47.
- Rowntree, , K M and Dollar, E S J, (1996) Controls on channel form and channel change in the Bell River, Eastern Cape, South Africa. *South African Geographical Journal*, 78(1), 20-28.
- Rowntree, K.M. & Dollar, E.S.J. (1999). Vegetation controls on channel stability in the Bell River, Eastern Cape, South Africa. *Earth Surface Processes & Landforms*, 24, p.127-134.

LECTURE 3

GEOMORPHOLOGICAL CLASSIFICATION AND ZONATION OF RIVERS

KEY CONCEPTS:

Classification is an important process through which we are able to group similar objects, thus enabling description of features and prediction of the outcome of change. Rivers are complex systems and classification of river geomorphology is an inexact science. A hierarchical system has been developed to facilitate classification and is presented here as a framework for describing river systems.

River zonation is one aspect of the hierarchical classification system. It has been adopted as a means to subdivide a river network into uniform stretches that can be expected to have similar geomorphological characteristics and to respond in similar ways to changes in the drivers. River zonation therefore contributes to the definition of Resource Units in an EWR exercise and is one consideration when selecting sites. Identifying river zones is one way in which geomorphologists contribute to the EWR process.

OUTCOMES:

By the end of this lecture and related assignments learners should be able to:

- explain why classification is important;
- explain the concept of a hierarchical classification system;
- describe the SA classification system, define each level of the hierarchy and describe the key characteristics that differentiate rivers at the different levels;
- explain the relevance of each level to ecosystem processes.
- explain river zonation concepts;
- demonstrate how to zone a river;
- apply zonation to site selection.

ASSIGNMENT 2:

Practical exercise classifying river reaches and morphological features from images and video footage. Zoning a river from knowledge of channel gradient, valley form and other relevant information.

RECOMMENDED RESOURCES:

- Rosgen, D.L. (1994). A classification of natural rivers, *Catena*, 22(1), 69-199, Elsevier Science, B.V. Amsterdam.
- Rosgen, D.L. (1996). *Applied River Morphology*, Wildland Hydrology Books, Pagosa Springs, Colorado.
- Rowntree, K.M. & Wadeson, R.A. (1999*). A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*, WRC Report No. 497/1/99, WRC, Pretoria.
- Rosgen, D.L. (1996). *Applied River Morphology*, Wildland Hydrology Books, Pagosa Springs, Colorado.

- Rowntree, K.M. & Wadeson, R.A. (1999). *A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*, WRC Report No. 497/1/99, WRC, Pretoria.
- Rowntree, K.M., Wadeson, R.A. & O'Keeffe, J. (2000). The Development of a Geomorphological Classification System for the Longitudinal Zonation of South African Rivers, *South African Geographical Journal*, 82(3), 163-172.

LECTURE 4

ABIOTIC-BIOTIC LINKS: RIPARIAN VEGETATION

KEY CONCEPTS:

Hydrogeomorphic factors are important in providing suitable habitat for vegetation communities. These in turn provide a key geomorphological control through stabilizing channel banks, bars and beds.

OUTCOMES:

By the end of this lecture and related assignments learners should be able to:

- Provide a critical assessment of how riparian vegetation can be regarded as key in controlling river geomorphology.
- Distinguish between the roles that indigenous and alien vegetation play in determining geomorphological features of a river system.

RECOMMENDED RESOURCES:

- Dollar, E.J.S. & Rowntree, K.M. (1995). Sediment sources, hydroclimatic trends and geomorphic responses in the Bell River, North Eastern Cape, South Africa. *South African Geographical Journal*, 77, 21-32.
- Rowntree, K.M. (1991). An assessment of the potential impact of alien invasive vegetation on the geomorphology of river channels in South Africa. *South African Journal of Aquatic Science*, 17(1/2), 28-43.
- Rowntree, K.M. & Dollar, E.J.S. (1996). Controls on channel form and channel change in the Bell River, Eastern Cape, South Africa. *South African Geographical Journal*, 78(1), 20-28.
- Rowntree, K.M. & Dollar, E.J.S. (1999). Vegetation controls on channel stability in the Bell River, Eastern Cape, South Africa. *Earth Surface Processes and Landforms*, 24, 127-134
- Tooth, S. & McCarthy, T.S. (2004). Controls and transition from meandering to straight channels in the wetlands of the Okavango Delta, Botswana. *Earth Surface Processes and Landforms*, 29, 1627-1649.

LECTURE 5

LINKING THE CHANNEL TO THE CATCHMENT AND CONCEPTS OF LANDSCAPE CONNECTIVITY

KEY CONCEPTS:

The source of both streamflow and sediment is the *catchment*; to understand changes to geomorphological drivers it is important to understand the hill-slope processes in the upstream catchment. These are affected by catchment features such as the climate, topography, geology and soils, vegetation cover, urban developments and other changes to the surface cover.

Connectivity is an important concept that describes the links between the catchment and channel, and between different segments of the channel network. The degree of connectivity determines the flow of water, sediment and other materials through the river system. Changes to geomorphic connectivity can have significant effects on river ecosystems. Different types of connectivity will be explained in this lecture.

OUTCOMES:

By the end of this lecture and related assignments learners should be able to:

- describe key catchment characteristics that impact on channel processes, morphology and habitat;
- explain the different types of connectivity in geomorphological systems;
- explain why the above are important as part of a geomorphological assessment;
- identify the time-scales over which different catchment characteristics can change.

ASSIGNMENT 3:

Use topographic maps and other spatial data bases to derive information about a catchment. This could be the same catchment in which the field site is situated.

RECOMMENDED RESOURCES:

- Dollar. E.S.J. and Rowntree, K.M. (1995). Sediment sources, hydroclimatic trends and geomorphic responses in the Bell River, North Eastern Cape, South Africa. *South African Geographical Journal*, 77(1), 21-32
- Fryirs, K.A., Brierly, G.J., Preston, N.J. & Kasai, M. (2007). Buffers, barriers and blankets: the (dis)connectivity of catchment-scale sediment cascades, *Catena*, 70(1) 49-67.
- Rowntree, , K M and Dollar, E S J, (1996) Controls on channel form and channel change in the Bell River, Eastern Cape, South Africa. *South African Geographical Journal*, 78(1), 20-28.
- Rowntree, K.M. & Wadeson, R.A. (1999). *A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers*, WRC Report No. 497/1/99, WRC, Pretoria.

LECTURE 6

GEOMORPHOLOGY AND RIVER MANAGEMENT: THE GAI MODEL (DATA COLLECTIONAND RUNNING OF THE MODEL)

KEY CONCEPTS:

Since the mid-1990s geomorphologists have played a significant role in developing tools for application in river management in South Africa. This was primarily in response to the requirements set by the National Water Act, which requires the setting of the Ecological Reserve. One such tool is the Geomorphological Driver Assessment Index (GAI) that has been developed to calculate the Present Ecological State of a river reach in terms of its geomorphology. The GAI allows geomorphological input into the EcoStatus model, which forms the backbone of the Ecological Reserve.

OUTCOMES:

By the end of this lecture and related assignments learners should be able to:

- explain the conceptual basis of the GAI model;
- collect desktop and field data to populate the model.
- populate the GAI model with desktop and field data;
- interpret the output of the model in terms of the PES of the site;
- run the model for different scenarios of ecological status;
- critically assess the validity of the model in light of their own knowledge of the site.

ASSIGNMENT:

Collection and analysis of desktop data relevant to a field site. Maps and aerial photographs of the catchment and river reach should be examined. Hydrological time series should be made available for assessment of flood history.

Students should be asked to write a brief report on the geomorphology of the site to be visited the next day.

RECOMMENDED RESOURCES:

- du Preez, L. & Rowntree, K.M., (2006). *Assessment of the Geomorphological Reference Condition – an application for Resource Directed Measures and the National River HealthPrograme*, Water Research Commission Report K5/1306, WRC, Pretoria. (Chapter 4)
- Kleynhans, C.J , Louw, M.D., Thirion, C., Rossouw, N., Rowntree, K.M. (2005). *River EcoClassification: Manual For Ecostatus Determination*, DWAF/WRC, Pretoria.
- GAI manual.

FIELD DAY:

Visit to site to collect data for GAI and to assess evidence for setting flows.

FURTHER RECOMMENDED READING

Text books

Gordon, N.D., McMahon, T.A. Finlayson, B.L., Gippel, C.J. and Nathan, R.J. (2004). *Stream Hydrology: An Introduction for Ecologists*. Second Edition. Wiley, Chichester.

Knighton, D. (1984). *Fluvial Forms and Processes*, Edward Arnold, London.

Rosgen, D.L. (1996). *Applied River Morphology*, Wildland Hydrology Books, Pagosa Springs, Colorado.

Rowntree, K.M. 2000: Geography of drainage basins: hydrology, geomorphology, and ecosystem management. In Fox, R.C., Rowntree, K.M., editor, *The Geography of South Africa in a Changing World.,* Cape Town: Oxford University Press Southern Africa.

Online texts

Sear, D.A., Newson, M.D. and Thorne, C.R. (2003) *Guidebook of Applied Fluvial Geomorphology* R&D Technical Report FD1914 Defra/Environment Agency. Available online: http://www.defra.gov.uk/science/project_data/DocumentLibrary/FD1914/FD1914_1147_TRP.pdf accessed 31/10/2006.

Reports from South African Organisations

Beck, J.S. & Basson, G.R. (2003). The Hydraulics of the Impacts of Dam Development on the River Morphology. WRC Report No 1102/1/03, Water Research Commission, Pretoria

Birkhead, A.L., Heritage, G.L., James, C.S., Rogers, K.H., van Niekerk, A.W. (2000). Geomorphological Change Models for the Sabie River in the Kruger National Park. WRC Report No 782/1/00§, Water Research Commission, Pretoria

Broadhurst, L.J., Heritage, G.L., van Niekerk, A.W., James, C.S., Rogers, K.H. (1997*). Translating Discharge into Local Hydraulic Conditions on the Sabie River: an Assessment of Channel Flow Resistance.* WRC Report No 474/2/97, Water Research Commission, Pretoria.

Dollar, E.S.J. & Rowntree, K.M. (2003). Geomorphological Research for the Conservation and Management of Southern African Rivers. Vol. 2: Managing Flow Variability: the Geomorphological Response. WRC Report No 849/2/03, Water Research Commission, Pretoria

du Preez, L. & Rowntree, K.M. (2006). *Assessment of the Geomorphological Reference Condition – an application for Resource Directed Measures and the National River Health Program*, Water Research Commission Report K5/1306, WRC, Pretoria. (Chapter 4)

Freeman, N.M. and Rowntree, K. (2005). *Our Changing Rivers: An Introduction to the Science and Practice of Fluvial Geomorphology.* WRC Report No. TT 238/05 Water Research Commission, Pretoria.

Heritage, G.L., van Niekerk, A.W., Moon, B.P., Broadhurst, L.J., Rogers, K.H., James, C.S. (1997). *The Geomorphological Response to Changing Flow Regimes of the Sabie and Letaba River Systems*. WRC Report No. 376/1/97, Water Research Commission, Pretoria.

King, J.M., Tharme, R.E. & De Villiers, M.S. (eds, (2000). *Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology*, WRC Report No. TT 131/00, WRC, Pretoria. Kleynhans, C.J , Louw, M.D., Thirion, C., Rossouw, N., Rowntree, K. (2005). *River EcoClassification: Manual For Ecostatus Determination*, DWAF/WRC, Pretoria.

Rossouw, L., Avenant, M.F., Seaman, M.T., King, J.M., Barker, C.H., du Preez, P.J., Peser, A.J., Roos, J.C., van Staden, J.J., van Yonder, G.J., Watson, M. (2005). *Environmental Water Requirements of Non-Perennial Systems.* WRC Report No 1414/1/05, Water Research Commission, Pretoria.

Rowntree, K.M. & du Plessis, A.J.E. (2003). *Geomorphological Research for the Conservation and Management of Southern African Rivers. Vol. 1 Geomorphological Impacts of River Regulation*. WRC Report No 849/1/03, Water Research Commission, Pretoria

Rowntree, K.M. & Wadeson, R.A. (1999). A Hierarchical Geomorphological Model for the Classification of Selected South African Rivers, WRC Report No. 497/1/99, Water Research Commission, Pretoria.

Selected Journal Articles

De Villiers, G. Du T., and Schmitz, P.M.U., 1992: River Channel changes in the Lower Mbokodweni River: a case study of the 1987 flood, *Water Resources Development*, 8(4), 235-243.

Dix, O.R., 1984: Braided-stream deposition in the Mpembeni River, Zululand, *South African Journal of Science*, 80, 41-42.

Dollar, E.S.J. 2002: Fluvial geomorphology. *Progress in Physical Geography* 26(1), 123-143.

Dollar, E.S.J. 2004: Fluvial geomorphology. *Progress in Physical Geography* 28(3), 405-450.

Dollar, E.S.J., James, C.S., Rogers, K.H. & Thoms, M.C. 2007: A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89(1-2), 147-162.

Dollar. E.S.J. and Rowntree, K.M. (1995). Sediment sources, hydroclimatic trends and geomorphic responses in the Bell River, North Eastern Cape, South Africa. *South African Geographical Journal*, 77(1), 21-32

Ellery, W.N., Ellery, K., Rogers, K.H., McCarthy, T.S. and Walker, B.H., 1993: Vegetation, hydrology and sedimentation processes as determinants of channel form and dynamics in the north eastern Okavango Delta, Botswana, *African Journal of Ecology*, 31, 10-25.

Fryirs, K.A., Brierly, G.J., Preston, N.J. & Kasai, M. (2007). Buffers, barriers and blankets: the (dis)connectivity of catchment-scale sediment cascades, *Catena*, 70(1), 49-67.

Le Roux, J.S., 1990: Spatial variations in the rate of fluvial erosion (sediment production) over South Africa, *Water SA*, 16, 3, 185-194.

McCarthy, T.S., Ellery, W.N., Rogers, K.H., Cairncross, B. and Ellery, K., 1986: The roles of changing sedimentation and plant growth in changing flow patterns in the Okavango Delta, Botswana, *South African Journal of Science*, 82, 579-584.

McCarthy, T.S., Stanistreet, I.G., Cairncross, B., Ellery, W.N., Ellery, K, Alephs, R. and Grobicki, T.S.A., 1988: Incremental aggradation on the Okavango Delta fan, Botswana, *Geomorphology*, 1, 267-278.

Petts, G.E., Gurnell, A.M. 2005: Dams and geomorphology: research progress and future directions. *Geomorphology* 71, 27-47.

Rosgen, D.L. (1994). A classification of natural rivers, *Catena*, 22(1), p.69-199, Elsevier Science, B.V. Amsterdam.

Rowntree, K.M., 1991: An assessment of the potential impact of alien invasive vegetation on the geomorphology of river channels in South Africa, *South African Journal of Aquatic Science*, 17, 1/2, 28-43.

Rowntree, K. M. and Dollar, E. . J. (1996). Controls on channel form and channel change in the Bell River, Eastern Cape, South Africa. *South African Geographical Journal*, 78(1), 20-28.

Rowntree K.M. and Dollar, E.S.J., (1999). Vegetation controls on channel stability in the Bell River, Eastern Cape, South Africa, *Earth Surface Processes and Landforms*, 24, 127-134.

Rowntree, K & R. Wadeson, R. (1998). A geomorphological framework for the assessment of instream flow requirements. *Aquatic Ecosystem Health and Management.* 1, 125-141.

Schumm, S.A. & Lichty, R.W. (1965). Time, space and causality in geomorphology, *American Journal of Science*, 263, 110-119.

Tooth, S. and McCarthy, T.S. 2007. Wetlands in drylands: geomorphological and sedimentological characteristics, with emphasis on examples from southern Africa. *Progress in Physical Geography* 31(1), 3-41.

Van Coller, A.L. Rogers, K.H. and Heritage, G.L. 1997. Linking riparian vegetation types and fluvial geomorphology along the Sabie River within the Kruger National park, South Africa. *African Journal of Ecology*, 35, 194-212.

Van Niekerk, A.W., Heritage, G.L. and Moon, B.P., 1995: River classification for management: The geomorphology of the Sabie River in the eastern Transvaal, *South African Geographical Journal*, 77(2), 68-76.

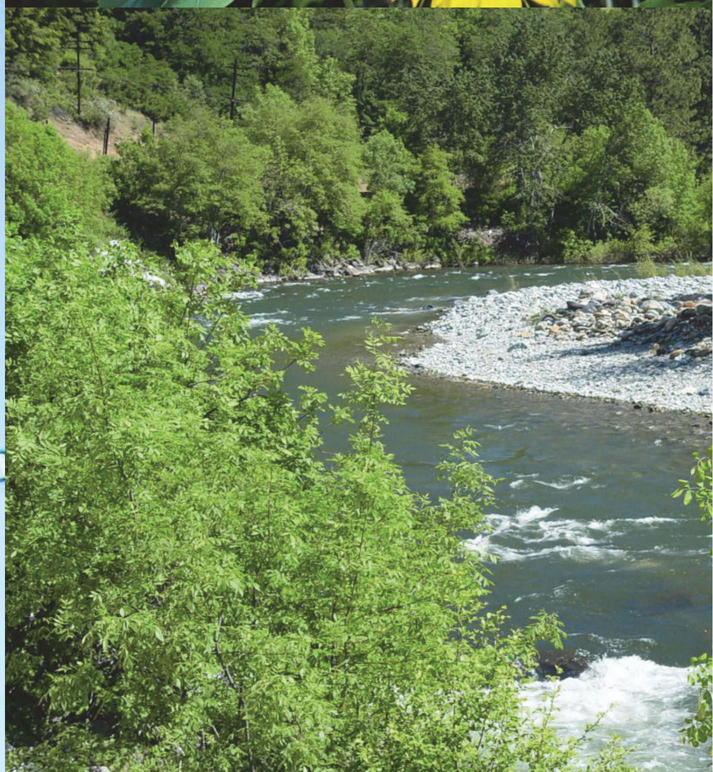
MODULE 6

WATER QUALITY

Tutored MSc in Ecological Water Requirements

Developed by
Dean Ollis and Prof. Jenny Day

March 2014



RATIONALE

Water plays a critical role in our living environment, with a sufficient supply of water of suitable quality being essential to all life forms on our planet. It shapes the landscape, controls our climate, determines the nature of the surrounding environment and is a vital requirement in agriculture, industry, power generation, recreation and tourism, amongst other things. The use of water is limited by its availability *and* by the quality of the water. It is important to recognise that the human use of water for certain purposes can interfere with or constrain its use for other purposes.

The term water quality, in this module, is used to describe the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems.

The purpose of this module is to provide students with an understanding of the various physicochemical constituents in aquatic ecosystems; the effect of these variables on aquatic organisms/communities; and the measurement, monitoring and management of water quality in aquatic ecosystems. The types of aquatic ecosystems that the module is of relevance to include rivers, open waterbodies (lakes and dams), wetlands and estuaries, but excludes marine ecosystems. Groundwater quality is also touched on in this module. The focus of this module is the fundamental principles and concepts that underpin a good understanding of water quality and the main issues relating to this topic, as opposed to specific methods that are used for water quality assessment, monitoring and management in South Africa. The more important methods are, however, introduced in this module and the cardinal knowledge that is gained through this module will equip students to better understand the methods and their limitations.

LAYOUT OF THE MODULE

In this module, the following aspects of water quality will be covered through lectures, discussion sessions, self-study, assignments, a seminar, and a field trip and project report (major assignment):

1. **Study Unit 1: An overview of water quality and its constituents**
    - Includes an overview of water quality, regional differences, categories of water quality variables, effects of altered water quality on aquatic ecosystems
    - Consists of one lecture (2 hours), one group assignment (4 hours), and self-study (6 hours) = **12%** of total time allocated to the module
2. **Study Unit 2: Water quality variables**
    - Deals with the different water quality variables and includes examples of their use
    - Consists of two lectures (4 hours), one assignment (6 hours), one seminar (6 hours), and self-study (12 hours) = **28%** of total time allocated to the module
3. **Study Unit 3: Water quality characteristics of different types of aquatic ecosystems**
    - Compares the water quality characteristics of rivers, wetlands, lakes, estuaries, and groundwater
    - Consists of two lectures (4 hours), one discussion session (2 hours), one field trip (6 hours), and self-study (6 hours) = **18%** of total time allocated to the module
4. **Study Unit 4: Measuring and monitoring water quality**

- Deals with the physico-chemical measurement and monitoring of water quality (pollution), and introduces biomonitoring and the microbiological aspects of water quality
- Consists of one lecture (2 hours), one data analysis session for field-trip data (4 hours), one project report write-up for field trip (12 hours), and self-study (6 hours) = **24%** of total time allocated to the module

5. **Study Unit 5: Biomonitoring and aquatic ecotoxicology**
   - Deals with the use of biomonitoring (or bioassessment) and aquatic ecotoxicology in the assessment and monitoring of water quality
   - Consists of one lecture (2 hours) and self-study (6 hours) = **8%** of total time allocated to the module
6. **Study Unit 6: Management of water quality**
   - Compares the different approaches available for the management of water quality and introduces the way in which the management of water quality is dealt with in South Africa in the context of the National Water Act, Source Directed Control (SDC), Resource Directed Measures (RDM), Environmental Water Requirements (EWR), Resource Quality Objectives (RQOs), and the Reserve
   - Consists of one lecture (2 hours), one discussion/feedback session (2 hours), and self-study (6 hours) = **10%** of total time allocated to the module

NB: The percentages above (in bold) indicate the proportional amount of time you are expected to spend on each Study Unit of the module. A lecture is expected to last for two hours, and three hours of self-study are expected for each hour of lecture time.

PREREQUISITES

You need the following resources to complete this module successfully:

- Study material as indicated.
- Access to a computer with an internet connection.
- Suitable clothing for the field-trip (be prepared to get wet!).

STUDY MATERIAL

There is no specific textbook for this module. Instead, a variety of readings from various sources have been collated to produce the equivalent of a textbook. All the readings are provided in electronic format and form the reference material for the module. Some of these readings are compulsory and others are for supplementary reading. Details are provided in the material for each lecture.

Although the reference material for this module consists of a variety of readings from various sources, the main source of information is the following WRC Report:

- Dallas HF and Day JA (2004). The Effect of Water Quality Variables on Aquatic Ecosystems: A Review. *WRC Report No TT 224/04*. Water Research Commission, Pretoria.

Students are encouraged to obtain a hard copy of the above-mentioned WRC Report (freely available from the Water Research Commission by sending an email to orders@wrc.org.za).

HOW TO STUDY

The module is presented by means of study units where the core principles are discussed. At the beginning of each section, a time allocation is given, which is an indication of the extent of the study task. You may use this allocation to plan your study process. The learning outcomes are also indicated at the beginning of each study unit and guide you as learner about what the problems in the particular study unit are and where you have to pay special attention. Make sure that you have the study guide always at hand, so that you can easily add additional notes to reach the outcome set for each study unit. At the end of study units, there are also evaluation questions. It is essential to answer these questions before moving on to the next study unit. By doing so and by making sure that the learning outcomes have been reached, you can make sure that you have completed the study unit successfully. It is expected of you as a senior student that you will have developed the skill (and that you will further develop this skill) to gather additional information independently in books, journals as well as from the internet. The study guide serves as framework to guide you through the learning content.

ASSESSMENT

Continuous assessment will take place in the form of assignments. Note the dates in the study letter on which these assignments should be handed in. Examination opportunities at the end of the module are also indicated in the study letter. Admission to the examination is dependent on an adequate participation mark, obtained from the assignments.

PRACTICALS AND FIELD REPORTS

Although no practicals, as such, will be completed for this module, there will be a number of group discussion sessions, including a group-work assignment with verbal feedback to the class. In addition, each student will be required to give an oral presentation on a selected topic to the class as one of the assignments.

A one-day field trip will also be undertaken as part of this module, to collect water quality measurements and water samples from a nearby aquatic ecosystem. Students will be responsible for recording and analysing the data that are collected during the field trip (in groups), and an individual project report will need to be completed by each student in which the water quality data are interpreted and discussed.

MODULE OUTCOMES

At the end of the module, students should be able to:

- understand the characteristics of the physicochemical (water quality) variables in aquatic ecosystems (including rivers, wetlands, estuaries and groundwater);
- understand the complexity of the interactions between water quality variables;
- understand the difference between water chemistry and water quality, and the application of water quality guidelines for different users;
- understand the anthropogenic factors that modify water quality variables and the effects on aquatic organisms/communities;
- understand the methods for measuring and monitoring water chemistry and water quality, including the advantages and disadvantages of the different methods;
- understand the issues related to the management of water quality, within the context of the National Water Act and the “Reserve”.

WARNING AGAINST PLAGIARISM

ASSIGNMENTS ARE INDIVIDUAL TASKS AND NOT GROUP ACTIVITIES (UNLESS EXPLICITLY INDICATED AS GROUP ACTIVITIES)

Copying of text from other learners or from other sources (for instance the study guide, prescribed material or directly from the internet) is **not allowed** – only brief quotations are allowed and then only if indicated as such.

You should **reformulate** existing text and use your **own words** to explain what you have read. It is not acceptable to retype existing text and just acknowledge the source in a footnote – you should be able to relate the idea or concept, without repeating the original author to the letter.

The aim of the assignments is not the reproduction of existing material, but to ascertain whether you have the ability to integrate existing texts, add your own interpretation and/or critique of the texts and offer a creative solution to existing problems.

Be warned: students who submit copied text will obtain a mark of zero for the assignment and disciplinary steps may be taken by the Faculty and/or University. It is also unacceptable to do somebody else’s work, to lend your work to them or to make your work available to them to copy – be careful and do not make your work available to anyone!

Study Unit 1

AN OVERVIEW OF WATER QUALITY AND ITS CONSTITUENTS

TIME

You will need approximately 12 hours to master this study unit.

REFERENCES

Compulsory readings:

- Dallas and Day (2004): Chapters 1 & 2
- Davies and Day (1998): Chapter 7, pp. 166-177
- Day and King (1995)

Additional readings:

- DWAF (1996) Water Quality Guidelines – Volumes 1 to 7
- Day *et al*. (1998)
- Dickens *et al*. (2004)

MODULE OUTCOMES

At the end of this study unit, you should have gained an understanding of the fundamentals of water quality and you should be able to:

- explain the difference between 'water chemistry' and 'water quality';
- explain how the concept of water quality relates to the use or users of water;
- discuss the factors that cause regional differences in water quality, and the implications of these differences from a management perspective;
- list the main categories of water quality variables, and provide examples of each; and
- describe some of the possible effects that different physical attributes and chemical constituents can have on aquatic ecosystems.

INTRODUCTION

Water quality can be defined as the combined effect on a 'user' of the physical attributes and chemical constituents of a waterbody or sample of water. The idea of water "quality" is a human construct, implying value or usefulness, with the quality of any sample of water being dependent on the point of view of the 'user'. Water quality differs from continent to continent, and region to region, as a result of differences in climate, geomorphology, geology and soils, and biotic composition. The variables used to measure water quality can be grouped into three categories – physical, chemical, and microbiological. Aquatic ecosystems can be affected in a number of ways by altered water quality. Table 1.1 provides a summary of the effects of major physical attributes and chemical constituents on aquatic ecosystems. This Study Unit includes a group assignment on the application of water quality guidelines for different 'users'.

1. WHAT IS WATER QUALITY AND WHAT ARE THE MAJOR ISSUES?

- Reasons for studying water chemistry:
  - constituents differ naturally from site to site
  - determines which species of faunal and flora occur where
  - modified by pollution
  - crucial for understanding distribution of aquatic organisms
  - NB for relating to ecosystem integrity, understanding ecosystem processes and to better manage the balance between resource use and protection

- Water chemistry versus water quality:
  - Water chemistry = physical attributes + chemical constituents + microbiological
  - Water quality = [physical attributes + chemical constituents + microbiological] + requirements of a particular user
  - Water quality is a human construct – implies value or usefulness; quality of water depends on the point of view of the user, e.g. environment, domestic, agriculture, etc.
  - Human notions of good water quality not necessarily appropriate for natural ecosystems! But, depending on the level of knowledge, what is good for the ecosystem is also a human construct

- Many different users, including:
  - Domestic
  - Recreational
  - Industrial
  - Agricultural – irrigation
  - Agricultural – livestock watering
  - Agriculture – aquaculture

  In addition to aquatic ecosystems – most complex

ASSIGNMENT 1 (GROUP ASSIGNMENT)

Students to discuss, in groups, data provided within the context of DWAF's (1996) water quality guidelines for different users – i.e. domestic, recreational, industrial, agricultural (irrigation), agricultural (livestock watering), agriculture (aquaculture), and for aquatic ecosystems – and to provide feedback to the class.

Aim is to highlight that different "users" have different requirements with respect to the quality of water

- {NB: for definition of pollution see NWA}

  The effects of polluted water on human health, on the aquatic ecosystem (aquatic biota, and in-stream and riparian habitats) and on various sectors of the economy, including agriculture, industry and recreation, can be disastrous.

  Deteriorating water quality may, for example, lead to an increased risk of diseases, reduction in ecosystem integrity, increased treatment costs of potable and industrial process water, and decreased agricultural yields due to increased salinity of irrigation water.

- Major issues in water quality and its management:
  - What substances or attributes?
  - Where do they come from / what causes them?
  - What effect does each have at a particular site or in a specific situation?
  - Importance of interactions and cumulative impacts
  - How do we manage them – Water quality is a multitude of stressors, not a single construct

- Natural processes involved:

Physical

- weathering
- dissolution and precipitation (crystallisation)
- flocculation/deposition
- chemical speciation

Biological

- primary production
- decomposition
- mineralisation

2. REGIONAL DIFFERENCES IN WATER QUALITY – NATURAL VARIATION

- What influences water chemistry? {water chemistry is caused by molecular and atomic interactions and energy of specific magnitude}
- Water quality differs from continent to continent, and region to region, as a result of differences in climate, geomorphology, geology and soils, and biotic composition.
  - **Climate:** amount and origin of rainfall (chemistry of coastal rain different from intertropical convergence zone rainfall); degree of evaporation; seasonality; temperature.
  - **Geomorphology:** gradient (affects the concentration of dissolved oxygen); degree of erosion (affects turbidity and concentration of suspended material).

- **Geology:** lithology (kind of rocks – different chemical composition); total dissolved solids; proportion of major (Na, K, Ca, Mg, Cl, SO_4, HCO_3 /CO_3 $^{2-}$, H^+) and minor ions (trace elements, nutrients, etc.).
- **Biota:** vegetation (organic compounds); rates of photosynthesis and respiration (pH, dissolved oxygen); excretory product (nutrients).
- **Soil type:** weathering and organic content as well as primeval lithology; naturally sodic soil water chemistry differs from, sands and clays; difference in adsorption capacity for cations and anions.

Example: Ecoregion map, mountain stream versus lowland river

- Regional differences in water quality in South Africa – Examples:
  - Igneous rocks – Gauteng, Mpumalanga, Drakensberg – dominated by calcium and/or magnesium cations and bicarbonate anions and has a pH higher than 7. Conductivity is usually low (<50 mS m^{-1} often <20 mS m^{-1}).
  - Cape Supergroup – very little soluble material; major ions are sodium and chloride – waters are "precipitation dominated"; soft, pure and unbuffered.

Examples:

- Maps of TDS in SA; ionic dominance; maucha diagrams

Example: Waters of the Cape Floristic Kingdom – polyphenolics (humic substances)

- summer drought
- oligotrophic (nutrient-poor) soils
- fynbos vegetation: low-growing, fire-adapted, sclerophyllous, produces >secondary compounds
- secondary compounds: complex organics;
  - ❖ phenol-rich (e.g. tannins);
  - ❖ deter herbivory;
  - ❖ reduce rate of microbial decay

→ leaching of secondary compounds into water

= humic substances (= humic acids = flavenoids = fulvic acid, etc.)

3. CATEGORIES OF WATER QUALITY VARIABLES

- Physical attributes:
  - Temperature, turbidity; concentration of suspended solids
- Chemical constituents:
  - pH, conductivity, salinity, TDS, individual ions, dissolved oxygen, organic enrichment , nutrient enrichment, biocides, trace metals
- Microbiological constituents:
  - Bacteria (e.g. total coliforms, faecal coliforms) and other micro-organisms (e.g. *Cryptosporidium*, *Giardia*).
- Interaction among water quality variables – combined effect on aquatic community
  - An aquatic community may be affected by various physical, chemical and biological factors – these factors interact with one another and influence the biota.

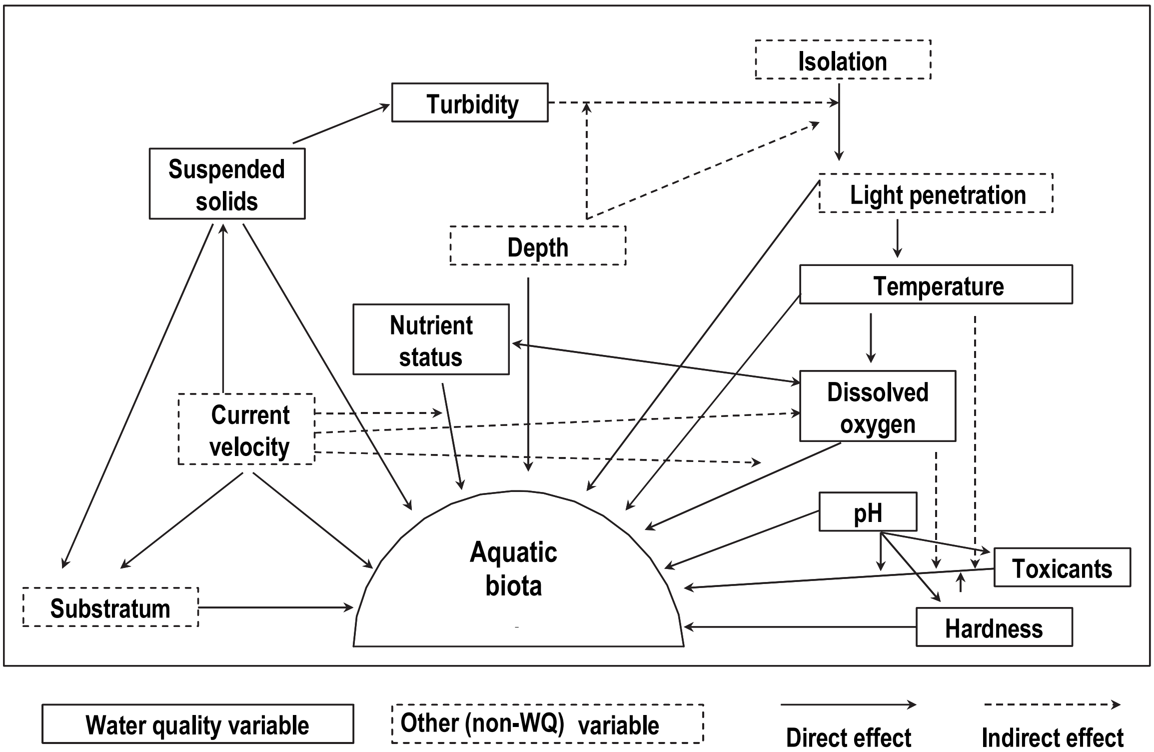


Figure 1.1: Major water quality and other variables potentially affecting aquatic biota, showing both direct and indirect interactions between variables [from Dallas & Day 2004].

- Synergism – When two substances interact to produce a magnified effect (nickel and zinc are 5X more toxic in combination than is either alone) {supra-additivity is probably the more correct term at macro level toxicology}
- Antagonism – When two substances interact to produce a reducing effect (Calcium or magnesium reduce the toxicity of copper and other toxic trace metals) {infra-additivity is probably the more correct term at macro level toxicology}

4. EFFECTS OF ALTERED WATER QUALITY ON AQUATIC ECOSYSTEMS

- Human / anthropogenic activities – affect quality of water in aquatic ecosystems.
- Activities include: agriculture, forestry, aquaculture, engineering and construction, river regulation, environmental flows and inter-basin transfers, industrial effluents, mining, urban runoff, etc.
- Definition of pollution (Holdgate 1979)...

  The introduction by mankind into the environment of substances, or energy liable to cause hazards to:
  - human health
  - harm to living resources and ecological systems
  - damage to structure or amenity
  - interference with legitimate uses of the environment
- Examples of effects on organisms/communities include:
  - a shift in the physical position of a community of aquatic organisms
  - introduction or loss of key species
  - change in diversity
  - altered ecosystem functioning

- Categories of water quality variable as classified in South Africa (DWA):
  - System variables – temperature, TDS, pH, TSS
  - Inorganics – e.g. major ions
  - Organics – e.g. flavones, phthalates, etc.
  - Nutrients – N, P, etc.
  - Toxic constituents (e.g. heavy metals, ammonia)

  {The term 'toxic' here is misleading: Paracelsus' adage that: "All things are toxic depending on the dose" Or "the dose makes the poison" is true for practically all chemical constituents. Even NaCl is toxic, q.v. the use of NaCl as reference toxicant in aquatic toxicology}

- Note: Pollutants are very diverse...
  - Some fall into > 1 category
    E.g. Sewage (suspensoids, nutrients, possibly metals, pathogens)
    - 3000 substances recorded as pollutants of freshwater systems. E.g. River Po (Italy) – and these are only the ones for which sufficient structural information were available to make an identification.
  - Not always xenobiotic substances, e.g. Zn – an essential element, but toxic at high concentrations Rotenone, fish poison, natural plant toxin.

Table 1.1: Effects of major physical attributes and chemical constituents on aquatic ecosystems

WQ VARIABLES	MAJOR EFFECTS
PHYSICAL FACTORS	
Temperature	• determines metabolic rate of aquatic organisms • determines availability of nutrients and toxins • determines oxygen saturation level • changes provide cues for breeding, migration, spawning, etc.
Turbidity and suspended solids	• determines degree of penetration of light; affects photosynthesis, visibility • modify habitat, smother and clog surfaces (e.g. gills); adsorb nutrients, toxins, etc. • adsorbs some toxic substances and nutrients
CHEMICAL FACTORS	
pH	• Involved in the ionic balance {ionic balance is determined by energetic/thermodynamic considerations} • affects chemical species and therefore availability • affects gill functioning
Conductivity, salinity, TDS, individual ions	• affects osmotic, ionic and water balance
Dissolved oxygen	• required for aerobic respiration
Organic enrichment	• reduces oxygen concentration • may increase turbidity and suspended solids • increases nutrient levels • risk of bacterial contamination – faecal coliforms, diseases
Nutrient enrichment	• not toxic per se: causes eutrophication – affects community structure
Biocides	• usually target specific groups (e.g. molluscs, insects, plants) – alter community structure • bioaccumulation
Trace metals	• some essential at low concentrations • some mutagenic, teratogenic, carcinogenic • some metabolic inhibitors

SELF-EVALUATION QUESTIONS

1. What is the difference between “water chemistry” and “water quality”?
2. Discuss the main factors that result in natural regional differences in the physico-chemical characteristics of water resources.
3. Explain the causes and consequences of the natural acidity of Western Cape rivers and wetlands.
4. What are the main effects that a change in turbidity and the concentration of suspended solids can have on aquatic ecosystems?

SUMMARY

In the lecture for this Study Unit, you should have learned about:

- The concept of “water quality”, and the major issues in water quality and its management;
- The natural variation in water quality, which results in regional differences in the water quality characteristics of aquatic ecosystems;
- The various categories that water quality variables can be grouped into, and the ways in which the different variables interact and affect aquatic biota; and
- The effects of altered water quality on aquatic ecosystems.

In the next Study Unit, the different water quality variables will be introduced and explained.

NOTE: It is important to ensure that you have reached the required outcomes for this Study Unit by successfully answering the self-evaluation questions before you move on to the next Study Unit.

Study Unit 2

WATER QUALITY VARIABLES

TIME

You will need approximately 28 hours to master this study unit.

REFERENCES

Compulsory readings:

- Dallas and Day (2004): Chapters 4 to 12
- Davies and Day (1998): Chapter 7, pp. 178-202 (top of page)
- Davies and Day (1998): Chapter 8, pp. 224-239 (Waterborne diseases)

Additional readings:

- Dallas and Day (2004): Chapters 13 to 20

MODULE OUTCOMES

At the end of this study unit, you should have gained an understanding of the main water quality variables of potential concern with regard to aquatic ecosystems and you should be able to explain/describe:

- the key aspects that each variable is providing a measure of, and how measurements are typically obtained for each variable;
- the natural characteristics (and expected fluctuations) of each variable, including an explanation of the primary factors responsible for the natural variability;
- the effect that changes in a particular variable have on water quality and on aquatic biota;
- what the main anthropogenic causes are for changes in a particular water quality variable;
- the potential effects of interactions between different variables; and
- which suites of variables are typically affected by various land-use activities.

INTRODUCTION

There are a number of physico-chemical and (micro-)biological variables that are commonly used to measure, assess and monitor water quality. The material in this Study Unit deals with the more important water quality variables, providing explanations of the main ways in which each variable affects water quality and the biota in aquatic ecosystems. The key anthropogenic causes of change in each water quality variable are also discussed. A summary of the effects of various anthropogenic activities on the water quality of aquatic ecosystems is provided (in a text box) at the end of the Study Unit. As part of this Study Unit, each student will compile a fact sheet and present a seminar on a waterborne disease/pathogen (or another selected topic relating to water quality variables).

NOTE TO LECTURERS:

This module includes TWO LECTURES (each two hours long). The lecturer is to select three or four water quality variables (from those presented below) to discuss in detail during these lectures, with examples. The points highlighted under each water quality variable should be covered for each variable presented. The remaining variables are required reading for the students, based on Chapters 4 to 12 of the WRC Report by Dallas and Day (2004) and the relevant sections of Chapters 7 & 8 of *Vanishing Waters* (Davies & Day 1998).

1. WATER TEMPERATURE

- Natural characteristics:
  - Dependent on hydrological, climatic and structural features of the region, catchment and river
  - Varies naturally – region with seasonal climates: exhibit daily and seasonal temperature patterns + longitudinal changes along a river course

- Effects of temperature changes on water quality:
  - Increase in water temperature – decreases oxygen solubility + increase toxicity of certain chemicals = increased stress to organisms

- Effects of temperature changes on organisms/communities:
  - Organism – temperature or range of temperatures at which optimal growth, reproduction and general fitness occur
  - Elevated temperatures – increase metabolic rate or organisms. Q10 concept, i.e. metabolic rate doubles for every 10°C increase in temperature
  - Modify life cycles – life cycles cued into temperature – e.g. cue for migration, breeding, emergence, etc.) = disruption of environmental cues, e.g. spawning of fish (Clanwilliam yellowfish); accelerate growth, premature hatching asynchronous with environmental parameters, e.g. air temp to cold
  - Result in changes in species composition – tolerant spp. increase in abundance; sensitive spp. decrease = reduction in biodiversity, increase in abundance, e.g. cyanophytes
  - Effects assessed in terms of an organism's lethal limit, sublethal effects or behavioural avoidance preferences.

- Anthropogenic causes of water temperature change:
  - Thermal pollution (heated power station discharges, heated industrial discharges, returning irrigation water)
  - Stream regulation
  - Changes in riparian vegetation
  - Inter-basin water transfers
  - Global warming
  - Releases from impoundments (epilimnetic versus hypolimnetic)
  - Other effluents
  - Reduction in volume

Example: Thermal pollution

Nuclear and fossil fuel-burning: power plants = inefficient in terms of water use relative to energy production

- Large volumes of water used for cooling
- Returned to water body at a higher temperature (also increased NH_3 NO_3^-, Cl_2,TSS).

But **HEAT** = main pollutant
E.g. River Severn: In-take water = 22˚C
2km below outfall =28˚C

2. TURBIDITY AND TOTAL SUSPENDED SOLIDS (TSS)

- **Turbidity** – defined as the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample = physical interference with passage of light; measured as NTUs (nephelometric turbidity units)

- **Total Suspended Solids (TSS)** = inorganics (silt, clay, flocculants) + organics (dead and living); measured as mass per unit volume (e.g. mg l^{-1}) = suspensoids
  - Living particles = phytoplankton (can be measured as chlorophyll), zooplankton, bacterioplankton
  - Dead particles = Particulate Organic Matter (POM): FPOM = fine particulate organic matter + CPOM = coarse particulate organic matter

- Natural characteristics:
  - Natural seasonal variations – governed by hydrology (e.g. flow regime, rainfall) and geomorphology (e.g. weathering, aspect of slopes) of the particular region
  - Short-term elevation in turbidity and TSS occur naturally during flooding

- Effects of increased turbidity on organisms/communities:
  - Light penetration reduced – decrease in the rate of photosynthesis and primary production
  - Smothering of substratum – effect on, e.g. fish spawning
  - Affects respiration of organisms – deposition of silt on respiratory structures
  - Reduction in food availability and quality
  - Decrease in visual cues – interference with predation

- Anthropogenic causes of increases in turbidity and TSS:
  - Agriculture – cropping, erosion
  - Removal of riparian vegetation
  - Mining activities
  - Construction activities
  - Storm water runoff
  - Horticulture, aquaculture
  - Impoundments – rivers below dams – increase in organic (i.e. plankton) and decrease in inorganic suspensoids

3. pH (and alkalinity)

- pH is determined largely by the concentration of hydrogen ions (H^+) [technically, it is defined as the negative $\log_{10}$ of the hydrogen ion *activity*]
  - Since pH is a **log scale**, a change of one unit means a ten-fold change in hydrogen ion concentration (see info in text box below)

A note on the calculation of pH values (prepared by Jan Roos)

The pH scale is a logarithmic one: a solution with a pH of 3.0 is not twice as acidic as a solution of pH 6.0, but one thousand times as acidic (i.e. contains 1 000 times the amount of H^+ ions).

Thus, if the measurement scale is not linear, arithmetic means may give a false value. For example, if three media had values 6, 7 and 8, the appropriate mean pH is not 7 because the pH scale is logarithmic.

To obtain the true mean, convert data into $[H^+]$ values (i.e. put them on a linear scale) by calculating $10^{(\text{-pH value})}$ as shown below.

pH	H^+ (mol/L)
6	1×10^{-6}
7	1×10^{-7}
8	1×10^{-8}
Mean	$= 3.7 \times 10^{-7}$
pH = -log (3.7×10^{-7})	= 6.43

Now calculate the mean of these values and convert the answer back into pH units.
Thus, the appropriate answer is pH 6.43 rather than 7.

- The acid-neutralizing capacity of a water body is known as alkalinity – determined largely by the sum of the concentrations of hydroxyl (OH^-), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions in water

- Natural characteristics:
  - Relative proportions of the major ions – and pH – in natural waters are determined by geological and atmospheric influences
  - Many fresh waters – relatively well buffered; more or less neutral (pH: 6 to 8)
  - NB: well buffered does NOT mean nearly neutral, it is more likely an indication of the balance between weak and strong acids/bases, i.e. the resistance to pH change on acid/base addition
  - Very dilute NaCl-dominated waters – poorly buffered (no bicarbonate or carbonate ions); e.g. in fynbos, pH may drop to 3.9 – influence of organic acids leaching from the vegetation

- Under natural conditions, pH can be low if lots of CO_2:

  $CO_2 + H_2O \leftrightarrow CO_{3(aq)}$

  $CO_{3(aq)} \leftrightarrow H_2CO_3$

  $CO_2 + H_2O \equiv H_2CO_3^-$ (carbonic acid)

- If salts are present in solution, *buffering* occurs: {carbonic acid system buffering depends on the presence of a weak acid (H_2CO_3 or HCO_3^-) and its conjugate strong base (HCO_3^- or CO_3^{2-} respectively)}

  $$CO_2 + H_2O \equiv \underset{\text{carbonic acid}}{H_2CO_3^-} \equiv \underset{\text{bicarbonate}}{HCO_3^-} + H^+ \equiv \underset{\text{carbonate}}{CO_3^{2-}} + OH^-$$

- Equilibrium tends towards CO_3^{2-} in presence of bases (e.g. Na, Ca), at high pH (>8) and as a result of photosynthesis.
- Extreme rates of photosynthesis – natural or as a result of eutrophication – commonly cause very high pH values in standing waters

- Final equilibrium (and final pH) depends on:
  - Quantity of base present
  - Extent of photosynthetic activity
  - Weak organic acids
  - Strong inorganic acids

Example: South-western Cape – polyphenolics: 'humic substances'

- Effects of change in pH on water quality:
  - pH determines the chemical species – availability and toxicity – of metals in water (e.g. silver, aluminium) and non-metal ions in water (e.g. ammonium converted to ammonia at higher pH).
  - Note: this is only true if acid/base is added to the water; any cation/anion added to water will require a new equilibrium which may determine the pH (and not necessarily the other way around)

- Effects of pH on organisms/communities:
  - Freshwater organisms have well developed abilities to maintain ionic and osmotic balance
  - Increased energy requirements – retaining osmotic and ionic balance
  - Indirect effects more important – e.g. mobilization of toxic substances, e.g. aluminium toxicity
  - Numerous *in vitro* toxicity tests and field studies – to ascertain the effects of changes in pH on aquatic organisms

- Anthropogenic influences on the pH and alkalinity of inland waters
  - Acid pollution – industries (chemical, pulp and paper, and tanning/leather industries), mining and acid precipitation ("acid rain")
  - Alkaline pollution – industries (e.g. food canning and textile production), eutrophication (excessive primary production leads to depletion of CO_2 from water in the presence of sunlight). Concrete.

Example: acid deposition

- pH of unpolluted rain ≈ 5.6 (lots of CO2)
- release of sulphur (coal-burning) and nitrogen (combustion engines)
- = strong mineral acids (sulphuric and nitric), pH of rain << 4.0

- Effects:
  - In soils: Ca^{2+} and Mg^{2+} replaced by H^+ → pH decreases
  - In water: HCO_3^- / CO_3^{2-} buffering system lost, replaced by SO_4^{2-}
    → pH decreases, many trace metals become toxic
    → loss of taxa
    → complete sterility

4. CONDUCTIVITY, SALINITY, TOTAL DISSOLVED SOLIDS (TDS), INDIVIDUAL IONS

The amount of dissolved material is measured as:

- **Total dissolved solids (TDS)** = total dissolved salts (mg l^{-1}, g l^{-1}); includes major (Na^+, K^+, Ca^{2+}, Mg^{2+}, H^+, Cl^-, SO_4^{2-}, HCO_{3-}, CO_3^{2-}) and minor inorganic ions (nutrients, minor ions F, Fe, Si, trace elements including metals Hg, Se, Pb, B) + soluble organics (ionic or not)
- Note: always check – in some publications tds refers to "total dissolved salts" = not quite the same if calculated (if measured in the laboratory differences should be minimal).
- **Salinity** – (≡ chlorinity): specific for sea water (ionic proportions unvarying); ∑ major ions in 1 kg of sea water; units originally = g kg^{-1} or parts per thousand; now a dimensionless number, measured as conductivity
- **Conductivity** – a measure of the ability of water to conduct an electric current; units = S (Siemens) per unit distance / ohm^{-1} / mho (e.g. 10 µS cm^{-1}, 9.6 mS m^{-1}); temperature sensitive – always referred to as if at 25°C (specific conductivity).

(Sum of inorganic ions + organic ions)	= conductivity of a sample
+ (non-ionic organics + floccs)	= TDS

- Relationship: TDS (mg l^{-1}) = conductivity (mS m^{-1}) * 6.6
  - (Note: The factor 6.6 is used by way of example – the factor depends on the ionic composition and may vary between 6.2 and 7.5)
- NB: In sea water (or saline inland water), organic content is a minute fraction of TDS, <20 mg l^{-1} vs. 35 000 mg l^{-1} inorganics

  In fresh water, however, organic content represents a significant fraction of TDS, 1-5 mg l^{-1} vs. 100-1000 mg l-1 inorganics

- Natural characteristics – sources of salts and natural variation:
  - Weathering of rocks – majority of ions in natural waters derive from rocks over which they flow
  - Atmosphere – coastal cyclic salt
  - TDS values for natural waters vary from about 1 mS m^{-1} (mountain stream of the Western Cape) through 35 000 mg l^{-1} in sea water to about 330 000 mg l^{-1} in brines in saline lakes reaching NaCl saturation point

- Effects of increase in salinity on organisms/communities:
  - loss of sensitive species
  - overall decrease in diversity
  - estuarine species may move further upstream
  - may lead to change in community structure

- In addition:
  - *rate of change* rather than the final salinity that is most critical
  - in fresh water systems the ionic ratios (analogous to salt composition) is more important than TDS (q.v. differential toxicity of salts)
  - juvenile stages often more sensitive to increased TDS levels than adults

- Anthropogenic causes of salinisation (=mineralisation) of rivers and soil:
  - Irrigation with slightly saline water in arid areas (e.g. in South Africa – Berg, Breede & Fish Rivers)
  - Sewage return flows (e.g. in South Africa – Vaal River)
  - Discharge of industrial effluents
  - Removal of trees where groundwater near the surface in arid areas (e.g. South & Western Australia)
  - Saline groundwater
  - Encroachment of seawater into coastal aquifers

5. DISSOLVED OXYGEN

- Aquatic organisms are dependent on water for their survival – maintenance of adequate dissolved oxygen concentrations is critical for the survival and functioning of aquatic biota.

- Natural characteristics:
  - Dissolved oxygen (as mg l^{-1} or % saturation) fluctuates diurnally – dependent on relative rates of respiration and photosynthesis of aquatic animals and plants
  - Varies longitudinally down a river – response to decreasing gradient (highest in mountain streams, lowest in lowland rivers)

- Effects of decrease in dissolved oxygen concentration on organisms/communities:
  - depends on the frequency, timing and duration
  - continuous exposure to concentrations of <80% saturation is harmful – likely to have acute effects (e.g. fish-kills)
  - repeated exposure to reduced concentrations may lead to physiological and behavioral stress effects
  - if the rate of change is rapid – adverse effects on the biota will increase significantly
  - dependence of an organism on water as a medium determines the extent to which it is affected
  - oxygen requirements of aquatic organisms vary with type of species (warm vs cold-water species), with life stages (eggs, larvae, nymphs, adults) and with different life processes (feeding, growth, reproduction) and size – lethal and sublethal effects
  - Toxic constituents (e.g. ammonia, cadmium) – become increasingly toxic as dissolved oxygen concentrations are reduced.

- Factors causing an increase in dissolved oxygen:
  - atmospheric re-aeration
  - increasing atmospheric pressure
  - decreasing temperature and salinity
  - photosynthesis by plants

- Factors causing a decrease in dissolved oxygen:
  - increasing temperature and salinity
  - respiration of aquatic organisms
  - decomposition of organic material by micro-organisms
  - chemical breakdown of pollutants
  - re-suspension of anoxic sediments
  - release of anoxic bottom water (e.g. from dams)

6. ORGANIC ENRICHMENT

- Dissolved and particulate organic matter (DOM and POM) – characteristically present in aquatic ecosystems.
- Detritivores in streams and in sediment communities of slow-flowing rivers depend upon POM for most of their energy.

- Natural versus anthropogenic organic matter:

  → Main difference between natural organic matter and anthropogenically-derived organic matter relates to size, quantity and texture of the organic matter.
  - natural POM: occurs in larger packets, like leaves, with a low surface-to-volume ratio
  - anthropogenically-derived POM: usually soluble or finely divided and very labile

- An organic discharge is not always directly toxic to aquatic life (depending on the composition of the organic component) but its effects may significantly change biotic community structure and biological processes
- Effects of organic enrichment on water quality and organisms/communities:
  - decrease in dissolved oxygen concentrations – may lead to sudden fish kills
  - increase in turbidity and the concentration of suspended solids
  - increase in nutrient concentrations and possible bacterial contamination of the receiving water body
  - change in species composition of aquatic biotas – increase in taxa tolerant to enrichment; decrease or elimination of taxa sensitive to enrichment

- Anthropogenic sources of organic enrichment:
  - domestic sewage / human waste
  - food processing plants, e.g. dairy and milk processing, breweries and vegetable canning
  - animal feedlots
  - abattoirs
  - cattle grazing

Example: Sewage Treatment in England – see powerpoint presentation (Prepared by Jenny Day)

7. NUTRIENT ENRICHMENT ≡ EUTROPHICATION

- Plant nutrients – any elements required for normal plant growth and reproduction (include carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulphate and silica, as well as other elements, termed "micro-nutrients") – Nitrogen and phosphorus are normally the significant nutrients linked to eutrophication
- Liebig's Law of Minimum: "The growth of plants is controlled by that factor (usually chemical) in the least amount in proportion to requirements"

- Natural sources of nutrients:
  - soil
  - weathering of rocks
  - recycling
  - precipitation (including dust, smoke)
  - birds and other animals
  - Nitrogen binding from the air: N2 → NO_3^- (e.g. Azotobacter species)
  - N only – nitrification

- Nitrogen:
  - inorganic: as nitrate (NO_3^-), nitrite (NO_2^-) and ammonium/ammonia (NH_4^+/ NH_3) ions
  - organic: common; many N-containing compounds; mostly soluble and readily available
  - Kjeldahl nitrogen (≈ organic N): operational quantity (by acid digestion) ≈ total nitrogen (TN) = organic N + inorganic N

- Phosphorus:
  - Inorganic: usually in the form of phosphate salts $Ca_3(PO_4)$ or PO_4^{3-} ions
  - salts usually poorly soluble, immobile or unavailable (e.g. polyphenol-bound)
  - usually transported as particle-bound PO4
  - measured as SRP: soluble reactive phosphorus
  - organic P: a compound of detritus (in 'organic waste', e.g. sewage)
  - total P measured by acid deposition (TP)
  - often the "culprit" and sometime the "scapegoat" in enrichment!

- NB: nutrients are usually not toxic, exception nitrite and ammonia; effects are mostly on community composition
- Effects of eutrophication on water quality and organisms/communities:
  - Increase in algae (e.g. *Cladophora*) and blue-greens (cyanobacteria)
  - some cyanobacteria (e.g. *Microcystis*) – toxic
  - increase in biomass (macrophytes) – encroachment
  - increase in turbidity (a problem for predators)
  - increase in silting-up /clogging of filters due to microbiomass production
  - reduced oxygen levels – anoxia (fish kills)
  - decrease in biodiversity – simplification of the food chain (fewer species, more generalists)
  - problems of taste and odour due to algal blooms

- Anthropogenic sources of nutrient enrichment:
  - sewage return flow (nutrient removal is never complete – especially pit-latrines situated too close to rivers)
  - manure and urine from feedlots
  - untreated organic waste
  - agriculture – fertilisers, N-fixing crops (e.g. soya)
  - industrial effluents and detergents
  - horticulture
  - forestry activities
  - dissolution of NO_xs (atmospheric pollution)
  - wash-off from informal settlements (many other pollutants also)

- Problems for managers of eutrophic systems:
  - water hard to treat (filters block up)
  - decrease in amenity value
  - toxins – e.g. ammonia toxic at pH>~8; nitrosamines may be carcinogenic; toxins from cyanobacteria (blue-green bacteria)
  - blockage of channels (flow of water impeded, boats unable to sail, etc.)
  - death of fish, loss of some species of fish
  - nitrates toxic to infants if concentration >100 mg/l NO3
  - methaemoglobinaemia in infants

- How do we deal with excessive nutrients (particularly P) in aquatic ecosystems?
  - de-stratify lake by aeration
  - ferric sulphate (chemically P in sediments by precipitation of ferric phosphates)
  - remove sediments
  - harvest plants
  - increase rate of through-flow of water
  - manipulate biota (dangerous!): e.g. remove planktivorous fish - increase in zooplankton – decrease in phytoplankton
  - remove at source (reduce loading)

8. BIOCIDES (Bio-active substances)

- Characteristics:

  Biocides are chemicals that kill living organisms and that are used in the control of pests, usually associated with agricultural crops and vector-borne diseases. {Cl_2-derived biocides (e.g. HOCl chloramines) from water treatment processes more common in inland waters than pesticides}

  → commonly used – herbicides, fungicides and insecticides

- Measurement of biocides:
  - methods for detection and quantification are complex and expensive
  - analysis is complicated by the small quantities of biocides found in water and the variety of breakdown products, with variable toxic properties, of most biocides

- Toxic effects of biocides in aquatic ecosystems:
  - nature, modes of action and toxicity – vary considerably
  - low-level chronic effects may be minimal
  - first noticeable effects usually sub-lethal (e.g. reduced fecundity, slower growth rates)
  - gradual loss of sensitive species
  - reduced diversity
  - sterility (e.g. Scandinavian lakes and acid rain)

- Anthropogenic sources of biocides:
  - direct application (for pest control)
  - industrial effluents
  - sewage
  - leaching and runoff from soil
  - deposition of aerosols and particulates

Example: Endocrine Disrupting Contaminants (EDCs)

- Oestrogen mimics
- Anti-androgens
- Anti-oestrogens

Increasing concern over last 10 years – 17-β-estradiol a potent estrogen and metabolite of ethynyl-estradiol (a common synthetic hormone in birth control pills), common in inland surface water.

Reported effects:
- 25-50% drop in sperm count in some countries; dramatic increases in some cancers (testicular, prostate, breast) – exposure during embryo development
- feminisation + decrease in fertility of certain spp, e.g. fish, reptiles (hermaphrodism, vitellogenin, sperm abnormalities)
- increase birth deformities in mammals (e.g. hypospadias in boys)

Note: some metals have also been shown to be EDC

Example: DDT (dichlorodiphenyltrichloroethane)

DDT (and derivatives, e.g. DDD, DDE) + many other pesticides (e.g. endosulphan, kepone) have been identified as EDC culprits (see previous example).

Characteristics of DDT:

- organochlorine insecticide
- most hazardous; banned in many countries
- persistent and widespread in the environment
- concentrates in organisms – food chains – bioaccumulation
- genetic resistance
- weak oestrogenic activity

DDT discovered 1873

- insecticidal properties noted 1930s by P. Muller (Nobel prize)
- used extensively next 30 years

Led to increased crop production; able to combat disease (e.g. malaria, yellow fever, typhus) by killing mosquitoes, lice

- 1950s record use in western countries
- late 1950s reports of impacts humans/wildlife
- 1962 “Silent spring” Rachel Carson – effects on birds;
- oestrogenic effect only recognised in 1990s

Why is DDT so problematic?

- Persistent ($t½$ > 100yrs in soil)
- Bioaccumulates (in fat)
- Biomagnifies (predators)
- Passed on to progeny (e.g. mother’s milk)

Banned in western countries since 1970s. BUT still used in developing countries (and SA) – (USA exported 100tons to Africa in 1991); concentrations of up to 1-10 µg/L in wells, rainwater, groundwater.

BUT: Malaria scourge in Africa? Options?

9. TRACE METALS

- Trace metals can be divided into two groups:
  - those that occur naturally in trace amounts in most waters – cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn); and
  - those that do not usually occur in measurable amounts in natural waters – cadmium (Cd), lead (Pb) and mercury (Hg); these are potentially toxic in low concentrations and have become widely distributed as a result of human activities
- An alternative way to divide them is between those that are necessary for biotic processes and those that aren't (e.g. Hg, Cd, Os, Bi)

- Chemical and physical factors modifying toxicity and uptake of trace metals:
  - chemical species of the metal
  - presence of other metals and organic compounds
  - volume of the receiving water
  - substratum type
  - dissolved oxygen
  - temperature
  - hardness
  - pH
  - salinity

- Effects of metals on organisms/communities:
  - biological factors (e.g. life history stage, age, sex, tolerance levels) – influence an organism's susceptibility to metals, i.e. species specific
  - reduction in species richness and diversity
  - a change in species composition – selective elimination of less tolerant species; increase in the abundance of more tolerant species
  - reduction in competition and predation
  - degree of change – related to the concentration of the metal(s) and the type (chronic, acute, constant, intermittent) and timing (in relation to season and thus flow rate) of exposure

- Anthropogenic sources of trace metals:
  - geological weathering (natural)
  - atmospheric sources
  - industrial effluents
  - agricultural runoff
  - acid mine drainage

10. BACTERIA AND OTHER MICRO-ORGANISMS

- A wide variety of pathogenic viruses, protozoans and bacteria may be transmitted by water. These micro-organisms cause disease such as gastroenteritis, giardiasis, hepatitis, typhoid fever, cholera, salmonellosis, dysentery and eye, ear, nose and skin infections, which have worldwide been associated with polluted water.

- Infections are usually contracted by:
  - drinking contaminated water
  - recreational exposure to contaminated water
  - inhaling aerosols
  - consumption of raw food (e.g. irrigated vegetables and shellfish) exposed to polluted water

- Human and livestock waste contains a large amount of partly digested organic matter (our food and other waste), which enters the environment where it feeds masses of bacteria (e.g. total coliforms, faecal coliforms) and other organisms designed to decompose such matter (e.g. *Cryptosporidium*, *Giardia*).

- Anthropogenic sources:
  - human waste – entering as untreated sewage – informal settlements and/or during high flow events (overflow of storm water drains)
  - livestock waste

- Effects of contamination with human waste:
  - flourishing populations of decomposer organisms use oxygen to survive – reduction in dissolved oxygen
  - loss of more sensitive species – reduction in diversity
  - risk of pathogens – bacterial (e.g. *Salmonella*, cholera) and viral (e.g. hepatitis, polio).
  - risk of infection by parasites e.g. flukes (*Ascaris*, liver fluke is one of the most common; *Bilharzia* fluke)
  - severe health risks for people using water for drinking, washing and recreation

- Assessment of the safety of water by tests for the many pathogens which may be present is impractical to technical and economic reasons – therefore use indicator organisms

- Indicators recommended for assessment of microbiological safety of domestic water, include:
  - Total coliform bacteria – indicator of general hygienic quality
  - Faecal coliform bacteria – indicator of faecal pollution which originates from humans and warm-blooded animal; *Escherichia coli* (*E.coli*) is a highly specific indicator of faecal pollution; most commonly used bacterial indicators of faecal pollution
  - Enterococci – relatively specific indicator of faecal pollution
  - Bacteriophages – detection of bacterial viruses

- Measuring faecal contamination:
  - easiest method is to measure *E. coli* bacterium – serves as an indicator of the likely presence of other more harmful bacteria, viruses and even larger parasites
  - usually enumerated as counts (number of colonies) per 100 ml of water
  - used to indicate the presence of bacterial pathogens such as *Salmonella* spp., *Shigella* spp., *Vibrio chloerae*, *Camphylobacter jejeuni*, *Campylobacter coli*, *Yersinia enterocolotica* and pathogenic *E. coli*.

ASSIGNMENT 2: FACT SHEET

Each student is to produce a fact sheet on one of the following topics, or another relevant topic of their choice that is approved by the lecturer.

Waterborne diseases /pathogens:

- Gastroenteritis
- Giardiasis
- Hepatitis
- Polio
- Typhoid fever
- Cholera
- Salmonellosis
- Dysentery
- Bilharzia

Other topics (relating to water quality variables):

- Cyanobacterial toxins
- Endocrine Disrupting Contaminants
- Nitrates in groundwater
- Fluoride
- Temperature pollution (climate change)
- DDT
- Arsenic
- Aluminium
- Acid precipitation
- Agricultural effects on water quality

ASSIGNMENT 3: SEMINAR

Each student is to present a 10 to 15 minute seminar (i.e. oral presentation) on the topic chosen for Assignment 2.

NOTE TO LECTURERS:

The effects of different anthropogenic activities on the water quality of aquatic ecosystems (see very brief summary in box below) should be covered at a broad level in one of the lectures for this Study Unit or in a discussion session with the students.

Students should also be directed to the following references for more detailed coverage of this topic:

- Davies and Day (1998): Chapter 7, pp. 199-202 (top of page)
- Dallas and Day (2004): Chapters 13 to 20

Summary: The effects of anthropogenic activities on the water quality of aquatic ecosystems

- **agriculture (crops):** nutrients (eutrophication), pesticides, organics, salinisation, suspended solids
- **air pollution**: nutrients, acid deposition
- **aquaculture:** nutrients (eutrophication), organic enrichment, deoxygenation, chemical contamination (anti-microbial compounds, cleaning agents), suspended solids
- **engineering and construction:** suspended solids and sediment
- **forestry:** nutrients (eutrophication), turbidity and suspended solids, change in water temperature
- **horticulture:** nutrients (eutrophication), pesticides, suspended solids
- **industrial effluents:** heavy metals, acids, toxins (e.g. cyanide), salinisation
- **informal settlements:** nutrients (eutrophication), organics, deoxygenation, toxins (e.g. battery acids)
- **invasion by alien plants and animals – loss of native plants and animals:** changes to loads and types of DOM (dissolved organic matter) and to rate of evapotranspiration
- **mining, industrial:** heavy metals, acids, toxins (e.g. cyanide), salinisation
- **power generation:** heated water
- **quarrying:** suspended solids
- **river regulation (rivers below dams):** hypolimnetic discharge: increases in nutrients, DOM, suspensoids; decreases in DO epilimnetic discharge: increase in organic suspensoids (i.e. plankton), decrease in inorganic suspensoids
- **sewage effluents:** nutrients (eutrophication), salinisation, parasite eggs [viruses, bacteria, antibiotics, hormones]
- **untreated sewage, feed-lots:** nutrients (eutrophication), organics, deoxygenation, parasite eggs [viruses, bacteria, antibiotics, hormones]
- **urban runoff (storm water):** nutrients, oils, heavy metals, pathogens, suspended solids

SELF-EVALUATION QUESTIONS

1. What are the main anthropogenic sources of temperature changes in aquatic ecosystems and what are the potential effects of such changes on aquatic biota?
2. What is the relationship between the measurement of salinity, TDS and conductivity?
3. What are the main elements of concern when it comes to the eutrophication of aquatic ecosystems, and what are some of the key characteristics of these elements?
4. Discuss the origin and potential threat posed by Endocrine Disrupting Contaminants in aquatic ecosystems.
5. What indicators are typically used to assess the microbiological safety of domestic water?

SUMMARY

In the two lectures for this Study Unit, and through the completion of a fact-sheet and preparation of an oral presentation, you should have learned about the different variables that are typically used to assess water quality. The following water quality variables were covered:

- Water temperature
- Turbidity and total suspended solids (TSS)
- pH (and alkalinity)
- Conductivity, salinity, total dissolved solids (TDS), individual ions
- Dissolved oxygen
- Organic enrichment
- Nutrient enrichment (eutrophication)
- Biocides (bio-active substances)
- Trace metals
- Bacteria and other micro-organisms

The effects of different anthropogenic activities on the water quality of aquatic ecosystems were also dealt with, at a broad level, in this Study Unit.

The topic for the next Study Unit is the water quality characteristics of different types of aquatic ecosystems.

NOTE: It is important to ensure that you have reached the required outcomes for this Study Unit by successfully answering the self-evaluation questions before you move on to the next Study Unit.

Study Unit 3

WATER QUALITY CHARACTERISTICS OF DIFFERENT TYPES OF AQUATIC ECOSYSTEMS

TIME

You will need approximately 18 hours to master this study unit.

REFERENCES

Compulsory readings:

- Clapham (1973), pp. 137-144 (water and aquatic ecosystems)
- Bartram and Ballance (1996): Chapter 2 (by Meybeck *et al*.), pp. 15-31 (water quality of inland aquatic ecosystems)
- Davies and Day (1998): Chapter 2 (inland waters of South Africa)
- Dallas and Day (2004): Chapter 2, pp. 3-7 (rivers and wetlands)
- Davies and Day (1998): Chapter 6, pp. 142-156 (estuaries)
- Ollis *et al*. (2013): Chapters 1 & 2 (Classification System for inland aquatic ecosystems in South Africa)
- Parsons (2003): Chapter 4 (groundwater)

Additional readings:

- Davies and Day (1998): Chapter 3 (natural standing waters)
- Davies and Day (1998): Chapter 4 (rivers)
- Davies and Day (1998): Chapter 5 (wetlands)
- Malan and Day (2012) (water quality and wetlands)

MODULE OUTCOMES

At the end of this study unit, you should be able to:

- distinguish between the different types of aquatic ecosystems;
- elaborate on the key 'drivers' that determine the water quality characteristics of different types of aquatic ecosystems;
- describe, generically, the water quality characteristics of each type of aquatic ecosystem;
- explain the implications of the differences for the management of water quality; and
- assist with the collection of water quality data from an aquatic ecosystem.

INTRODUCTION

The main types of aquatic ecosystems, at a broad level, are the ocean (marine ecosystems), estuaries, inland ("athalassic") water ecosystems, and groundwater. Inland aquatic ecosystems can be further divided into rivers, open waterbodies (lakes and reservoirs/dams), and wetlands. The different types of aquatic ecosystems have different natural water quality characteristics, due to differences in the key 'drivers' of water quality. The water quality characteristics of the different types of inland aquatic ecosystems, and of estuaries and groundwater are compared in this Study Unit (marine ecosystems are not dealt with). As part of this Study Unit, a field trip to an inland aquatic ecosystem or an estuary is to be undertaken, to collect water quality data for Assignment 4.

1. WHAT ARE THE DIFFERENT TYPES OF AQUATIC ECOSYSTEMS?

- Depends on the classification system that is followed!
- At a broad level, general agreement of a distinction between:
  - **the ocean** (marine ecosystems) [not dealt with in this module]
  - **estuaries**
  - **inland waters** or inland aquatic ecosystems (often referred to as "freshwater ecosystems") {the most accurate term, but one which does not have widespread usage, is probably "athalassic" (i.e. not associated with the sea)}
  - **groundwater** (aquifers)
- Inland waters can be further divided into:
  - **rivers** = 'lotic' (flowing water) systems with distinct channels
  - open waterbodies (**lakes and reservoirs/dams**) = deep (permanently inundated) 'lentic' (standing water) systems
  - **wetlands** = transitional, shallow lentic or slowly-flowing systems (often only seasonally or intermittently inundated, and/or characterised by periodically to permanently saturated soils that support distinctive wetland vegetation)

Table 3.1: Some key differences between the different types of aquatic ecosystem (compiled by Prof JA Day, University of Cape Town)

Type of system	Water movement	Size	Shape	Age	Permanence
OCEAN*	currents	huge	[open]	very ancient	✓
ESTUARY	✓✓✓	[varies]	long	ancient	maybe
RIVER	✓✓	[varies]	long	ancient	maybe
LAKE	×	deep	basin	young	short-term
WETLAND	(✓)	[shallow]	[varies]	young	maybe

* Oceanic water quality is not dealt with in this module

2. WHAT ARE THE KEY ‘DRIVERS’ OF THE WATER QUALITY CHARACTERISTICS IN DIFFERENT TYPES OF AQUATIC ECOSYSTEMS?

- In different types of aquatic ecosystems, there are differences in:
  - **geomorphology**
  - **geology**
  - **water movement**
  - **size and shape**
  - **abiotic processes**
  - **biological processes**
- These differences result in somewhat distinctive water quality characteristics between the different types of systems (for example, marine waters typically have a relatively high and relatively constant salinity with a relatively low concentration of dissolved organic matter, compared to estuarine or inland waters)

- There are a number of *processes* that influence the water quality characteristics of an aquatic ecosystem – distinguish between ‘abiotic’ (non-biological) and ‘biotic’ (related to living things)
- Abiotic processes affecting water quality in aquatic ecosystems include:
  - transport (of water → sculpting; of particulates → scouring; of solutes → dilution)
  - deposition (of particulates → accumulation; of precipitates → aggradation)
  - leaching (of material from rocks → weathering)
- Biotic processes affecting water quality in aquatic ecosystems include:
  - photosynthesis
  - growth and assimilation
  - respiration
  - feeding (including predation)
  - reproduction
  - excretion
  - decomposition
  - mineralisation

- The ‘water quality’ features that may differ between different types of aquatic ecosystems, as a result of differences in the key ‘drivers’, include:
  - concentrations of gases: O_2, CO_2
  - conductivity / TDS
  - turbidity
  - temperature
  - pH
  - ionic composition
  - concentrations of nutrients

3. WATER QUALITY CHARACTERISTICS OF INLAND AQUATIC ECOSYSTEMS (RIVERS, OPEN WATERBODIES, WETLANDS)

RIVERS

- Governed by permanent or periodic, concentrated **flow** of water in a distinct channel
- Fast-flowing rivers (or sections of rivers) have significantly different characteristics to slow-flowing rivers (or sections of rivers)
  - more turbulence
  - more dissolved oxygen (and less CO_2)
  - less suspensoids (lower turbidity)
- Natural water quality of a river (especially in terms of pH, conductivity/TDS, ionic composition, and concentrations of nutrients and trace elements) is very strongly influenced by the lithology (geology) and vegetation of its **catchment**
  - e.g. compare the water quality characteristics of the rivers of the igneous, grassland-dominated Highveld to those of the sandstone-dominated areas of the Fynbos biome where the naturally-occurring vegetation is still intact
- Climate and longitudinal position in the landscape (e.g. mountain headwater stream vs. lowland river) also strongly influence the natural water quality characteristics of a particular river reach
- In a particular river, **longitudinal differences** in natural water quality characteristics (along the upstream-downstream profile) are generally more significant than vertical or lateral differences

OPEN WATERBODIES (LAKES AND RESERVOIRS/DAMS)

- Only one true freshwater lake in South Africa (Lake Funduzi in Limpopo, formed by a natural rock fall that dammed up a river), but many deep reservoirs (dams) that act like lakes and a number of 'coastal lakes' (currently or historically estuarine in nature)
- Deep lentic (standing water) systems – open waterbodies – are governed largely by **vertical mixing processes**

  → this has a strong influence on their natural water quality characteristics
- Most open waterbodies, if they are deep enough, go through cycles of **stratification** (in summer) and being well-mixed (in winter)
- A stratified waterbody has distinct upper and lower layers – the **epilimnion** and **hypolimnion**, respectively, with a **thermocline** (metalimnion) in between
  - epilimnion = warm, oxygen-rich, nutrient-poor water
  - hypolimnion = cold, oxygen-poor, nutrient-rich water
- As temperatures drop in autumn, the water equilibrates → overturn occurs and the waters of the deep open waterbody become mixed (with no stratification)
- The water quality characteristics of an open waterbody that is subject to stratification will vary significantly between **seasons** and, when stratified, the water quality will be strongly dependent on **depth** (with very different characteristics above and below the thermocline)
- In a dam (reservoir), besides influencing the water quality characteristics of the open waterbody itself, stratification (during the warm seasons) will also have major consequences for the water quality of the river downstream of the dam
  - epilimnetic vs. hypolimnetic discharge

WETLANDS

- Note difference in definition of a "wetland" according to the NWA and the Ramsar Convention
  - NWA definition more appropriate = vlei, marsh, swamp, bog, pan, etc. (not rivers, lakes, coral reefs, etc.!)
- There are a **variety of wetland types** (ranging from floodplain and valley-bottom wetlands to seeps, depressions and wetland flats), which have different hydrological and geomorphological characteristics – presumably, there are also differences in the water quality characteristics of (at least some of) the different types of wetlands (in addition to regional differences)
- Availability of water quality data for wetlands, especially long-term datasets, very limited in SA, especially when compared to rivers
- Wetlands typically have **high levels of natural variability** in terms of water chemistry than rivers (and lakes), both spatially and temporally
- Natural water quality '**reference conditions**' of different wetland types in different regions of SA virtually unknown (some preliminary work has been done by Malan & Day)
- Most wetlands function as **sinks** rather than sources of sediment → accumulating systems (sinks/sumps in the landscape), affected significantly by deposition → impacts on water quality characteristics
- Some of the localised factors that influence wetland water quality (in addition to regional factors such as geology and climate):
  - **water source** (e.g. spring/groundwater vs. river floodwater vs. overland runoff)
  - **drainage pattern** (endorheic vs. exorheic) → inward-draining (endorheic) wetland types (mostly depressions) likely to be characterised by higher values of electrical conductivity, pH and nutrients, on average, than outward-draining (exorheic) systems such as valley-bottom wetlands and seeps
  - **residence time** (determined partly by flow regime / hydroperiod, typically longer in lentic vs. lotic systems) → longer residence time of water = more time for evaporation and for salts and other constituents to concentrate AND greater amount of time that water is in contact with vegetation and substrate = typically higher concentrations of dissolved substances in the water
  - **inundation depth** (typically shallow and often non-permanent for wetlands, if inundated at all → water generally well-mixed with no stratification)
  - **vegetation** (wetlands with lots of vegetation, and thus decomposition, often anoxic)
  - **soil characteristics** (soil chemistry, soil texture, etc. – e.g. wetlands with clay-rich substrata will tend to have more turbid water than those on sandy soils or rocky substrata)
- Vegetated wetlands can be used, or constructed, to 'improve' water quality ('**treatment wetlands**'):
  - Vegetation slows water current → particles (including bacteria) come out of suspension → nutrients are sequestered by soils and roots → organic materials decomposed

NOTE TO LECTURER:

A discussion session should be held with the students to talk about the different kinds of inland aquatic ecosystems (rivers – open waterbodies – wetlands) and how the water quality characteristics vary between the different types of systems.

Local examples should be considered and contrasted during this discussion session, as far as possible. Students from other regions/countries should be encouraged to talk about the different kinds of inland systems that occur there, and what they know of the water quality characteristics of the different types of systems in their part of the world.

Discuss the importance of considering 'reference' (minimally impacted) systems/sites when determining the natural water quality characteristics of a particular ecosystem type, and the challenges of this.

4. WATER QUALITY CHARACTERISTICS OF ESTUARIES

- **Definition of 'estuary'**: 'A partially or fully enclosed water body that is open to the sea permanently or periodically, and within which the seawater can be diluted, to an extent that is measurable, with freshwater drained from land' *(National Water Act, 1998)*
- SA has approximately 260 estuaries, distributed across 3 bio-geographical zones

<u>Key Water Quality Variables in Estuaries</u>:

- **System variables:**
  - Salinity
  - Temperature
  - Suspended solids/turbidity
  - pH
  - Dissolved oxygen
- **Nutrients:**
  - Inorganic nutrients (e.g. nitrate, phosphate, silicate)
  - Organic nutrients (e.g. carbon and nitrogen)
- **Toxic substances:**
  - Trace metals
  - Pesticides
- **Microbiological contaminants** (pathogens)

<u>Processes Affecting Estuarine Water Quality:</u>

- **Quality of Source Waters (river and sea)**
  - Estuaries are transition zones between river and sea
  - These sources have distinctly different water quality characteristics (e.g. salinity of seawater ~ 35 ppt and that of river water ~0 ppt)
  - Water quality characteristics are therefore largely determined by water quality of inflowing river water *and* seawater

- **Mixing Processes between Source Waters**

- Water quality characteristics largely influenced by extent of mixing between river and seawater
- Longitudinal (and often vertical) gradient in salinity and other water quality variables are typical

- **Geo- and Bio-chemical Processes**
  - Geochemical processes within estuaries can also alter water quality characteristics
    - ❖ Flocculation, e.g. triggered by changes in pH/salinity at the mixing interface between fresh and saline waters
    - ❖ Adsorption, e.g. trace metals and pesticides adsorbing onto organic or clay particles (often deposited in sediments)
  - Biochemical processes, e.g. nitrification, denitrification and mineralisation of organic matter (nutrient recycling)
  - Biological processes, e.g. nutrients can be altered through uptake by phytoplankton and macrophytes within estuary
  - Above processes typically have a significant influence on water quality characteristics when retention time of water in estuary is longer than process rates

Anthropogenic activities and inputs into Estuaries:

- Anthropogenic activities and inputs into estuaries can also influence water quality characteristics and include:
  - Sewage and industrial wastewater discharges (introducing nutrients, suspended matter and pathogens)
  - Stormwater runoff (introducing organic matter, toxic substances and pathogens)
  - Structures that alter water circulation patterns (e.g. structures such as jetties can create stagnant areas resulting in low oxygen zones)
  - Agricultural return flows (introducing excess nutrients and pesticides)

Assessment of Water Quality in Estuaries:

- A useful technique to assess water quality characteristics in estuaries is to compile **mixing diagrams** (or **property-salinity plots**)
  - plot of concentration of a particular variable of concern (on the y-axis) vs. salinity (on the x-axis)
  - upward (convex) curvature [above 'conservative mixing line'] → implies processes occurring in estuary releasing/increasing concentrations
  - downward (concave) curvature [below 'conservative mixing line'] → implies processes occurring in estuary taking up/decreasing concentrations

Estuarine Water Quality as part of Larger Estuarine Ecosystems:

- Estuaries are **complex, highly variable systems** providing unique habitats that support a wide range of biota
- Estuarine biota are usually capable of tolerating highly variable conditions (including water quality) characteristic of these systems
- Water quality forms key component within complex structure of estuarine ecosystem

5. WATER QUALITY CHARACTERISTICS OF GROUNDWATER

Groundwater in the context of the hydrological cycle and the distribution of water on Earth:

The chemistry (quality) of groundwater reflects natural and anthropogenic inputs:

- Natural: from the atmosphere, from soil and water-rock reactions (weathering)
- Anthropogenic: from pollutant sources such as agriculture, mining, land clearance, acid precipitation, domestic and industrial wastes
- Shallow groundwater quality may also be affected by activities, e.g. landslides, fires, that increase or decrease infiltration
- Residence times in groundwaters are orders of magnitude longer than surface water – slow movement of water through the ground

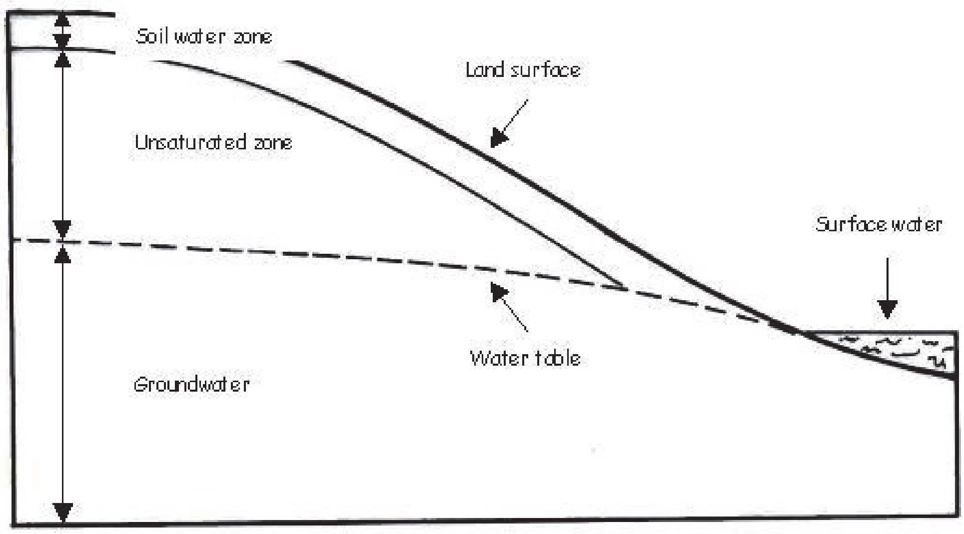


Figure 3.1: Distinction between groundwater and other subsurface waters [from Parsons (2003)]

Why is groundwater important?

- important for human consumption – changes in quality can have serious consequences
- support of habitat and for maintaining the quality of baseflow to rivers
- chemical composition is a measure of its suitability as a source of water for domestic, agricultural (livestock and irrigation), industrial and other purposes
- influences ecosystem health and function

Groundwater dependent ecosystems (GDEs):

- ➢ In-aquifer (and cave)
- ➢ Spring and seep
- ➢ Riverine (baseflow)
- ➢ Riparian
- ➢ Wetlands
- ➢ Terrestrial (flora & fauna)
- ➢ Estuarine and coastal

- Dependency of GDE on groundwater varies:
  - Entirely dependent
  - Highly dependent
  - Proportionally dependent
  - Opportunistic dependence
  - Not dependent

Contamination of groundwater

- **Salinity:**
  - changes in levels of salinity may occur due to natural factors such as interaction with sea water, underlying rock types, evaporation in areas with shallow water tables
  - intrusion of saline water into coastal aquifers can result from over-pumping of fresh groundwater, or when streamflow decreases
  - change due to excessive pumping and irrigation practices that stimulate precipitation of dissolved solids as salts on agricultural lands
- **pH:**
  - increase in acidity of shallow groundwaters, especially in areas deficient in carbonate minerals – as a result of acid deposition
- **Agricultural pollution:**
  - increase in nitrate levels – excess use of fertilizers
  - herbicides and pesticides (insecticides, fungicides) – may also be mobile in groundwaters
- **Mining**
  - sulphate – derived from the oxidation of sulphide minerals – indicates pollution from metal and coal mining, oil and gas production
  - often result in a decrease in pH and an increase in dissolved Fe and other metals – may contaminate both groundwater and surface waters as acid mine drainage
- **Urban and industrial pollution**
  - numerous chemicals are disposed in areas where humans live and via waste disposal – many chemicals enter the ground

NB:
Once groundwater is contaminated it is extremely difficult to decontaminate it!

Human health:

- endemic human diseases (e.g. fluorosis associated with excess F and goitre associated with I deficiency) are related to natural groundwater quality

Monitoring of groundwater:

- shallow wells, springs and major water supply boreholes where flow is active
- changes in groundwater quality – usually detectable on a seasonal or annual scale.

FIELD TRIP

As part of this Study Unit, a half-day to one-day field trip to an inland aquatic ecosystem (river, lake, dam or wetland) or an estuary should be undertaken with the students, to collect data for an assessment of the water quality of the system (**see Assignment 4**). During this field trip, water quality measurements and water samples should be collected from the aquatic ecosystem, using appropriate equipment. Students should be taught about the proper use and calibration of the sampling equipment that is used as part of this exercise, and students should be involved in the measurement and recording of data (and in the collection of water samples, if this is done).

Examples of water quality (and other) parameters that could be measured during the field trip include:

- pH
- Electrical conductivity
- Turbidity (using a turbidimeter) and/or TSS (by means of filtering a water sample through pre-weighed filter paper)
- Water temperature
- Dissolved oxygen concentration (and percentage saturation)
- Water clarity (e.g. using a Secchi disk)
- Water colour
- Water depth (or, preferably, a depth profile across the system)
- Dimensions of the aquatic ecosystem (if relevant)
- Flow rates and discharge (if relevant)
- Substratum characteristics (e.g. relative proportion of different substratum types)
- Vegetation characteristics
- (Water samples can also be collected for lab analyses, e.g. of major ions, nutrients, chlorophyll-*a*, heavy metals, faecal coliforms and *E. coli*, etc, depending on the facilities and expertise available)

After the field trip, students should be shown how to process any water (and/or other) samples that were collected for laboratory analyses, and they should be given responsibility for collating all the data that were collected.

SELF-EVALUATION QUESTIONS

1. What are the different types of aquatic ecosystems that can be distinguished and what are the key differences in their biophysical characteristics?
2. Describe the differences in the physical attributes and chemical constituents (i.e. water 'quality') of hypolimnetic and epilimnetic water in a reservoir/lake.
3. Why is the generic description of the water quality characteristics of wetlands so challenging, especially in South Africa?
4. What are the key water quality variables that are typically considered for estuaries?
5. What are the main factors that determine the groundwater quality at a particular location?

SUMMARY

In the two lectures for this Study Unit, and through participation in a discussion session, you should have learned about the different types of aquatic ecosystems and how the water quality characteristics vary between them. The aquatic ecosystems that were covered during these 'contact sessions' were inland aquatic ecosystems (rivers, open waterbodies and wetlands), estuaries, and groundwater. You should be able to compare and contrast the water quality characteristics of these different types of aquatic ecosystems upon completion of this Study Unit. As part of the Study Unit, a field trip was undertaken to an inland aquatic ecosystem or an estuary, to collect water quality data for Assignment 4.

In the next Study Unit, the measuring and monitoring of water quality is dealt with.

NOTE: It is important to ensure that you have reached the required outcomes for this Study Unit by successfully answering the self-evaluation questions before you move on to the next Study Unit.

Study Unit 4

MEASURING AND MONITORING WATER QUALITY

TIME

You will need approximately 24 hours to master this study unit.

REFERENCES

Compulsory readings:

- Bartram & Ballance (1996): Chapter 1 (by Bartram & Helmer)
- Palmer *et al*. (2004): Chapter 2
- Day (1990)
- Bartram & Ballance (1996): Chapter 14 (by Steel *et al*.)

Additional readings:

- DWAF (2004a): Strategic Framework for National Water Resource Quality Monitoring Programmes

MODULE OUTCOMES

At the end of this study unit, you should have gained an understanding of what the measuring and monitoring of water quality entails, and you should be able to:

- list the possible reasons for monitoring water quality;
- compare the various aspects that could be monitored;
- explain the three core functions of any monitoring initiative;
- describe some of the different measurements that could be collected to monitor water quality and how they could be used in a monitoring programme; and
- understand how to analyse, interpret and report on water quality data.

INTRODUCTION

There are a number of reasons for monitoring water quality and a number of aspects that could be monitored, depending on the purpose of the monitoring. The main types of monitoring are compliance monitoring, performance (audit) monitoring, status and trend monitoring, impact assessment monitoring, and water quality surveys. The three core functions of any monitoring programme should be (1) Data acquisition, (2) Data management and storage, and (3) Information generation and dissemination. Remember the adage that, "you can't manage what you can't measure". For water quality measurement and monitoring, it is important to distinguish between the collection of physico-chemical data and biological data, and to realise the limitations of water quality monitoring programmes that only rely on the collection of physico-chemical data. As part of this Study Unit, the water quality data that were collected during Study Unit 3 will be analysed and interpreted, and a scientific report will be written up, providing a situation assessment of the water quality in the aquatic ecosystem from which the data were collected.

1. MEASUREMENT AND MONITORING OF WATER QUALITY (POLLUTION)

Modes of entry (of pollutants) into freshwater systems:

- Direct discharge as effluent (= point source)
- Run-off from hardened/saturated surfaces e.g. litter, phosphates, sediment (point or non-point source)
- Subsurface flow from rainfall percolating through soil (non-point source e.g. pesticides, nutrients)
- Dust or direct rainfall over a water system (non-point source e.g. spray drift of pesticides)
- Direct application to rivers to control e.g. algae

Control of non-point source pollutants

- Point-sources are (theoretically) much easier to control
- Management practices that can be used to control non-point sources:
  - Reduce pesticide/fertiliser applications (education)
  - Improve sanitation of informal settlements
  - Decrease impermeable surfaces (urban areas)
  - Riparian buffer strips: erosion of banks; decreases surface run-off
  - Flushing of salinised lands during wet season
  - Wetlands (natural and artificial)
    - ❖ effective removal of sediments, nutrients, organic matter, metals and pathogens
    - ❖ How? Sedimentation/filtration/uptake/biotransformation
    - ❖ Sometimes wetlands = sources not sinks
    - ❖ "No net loss" policy
  - Impoundments can act as settling-ponds
    - ❖ (e.g. Buffalo River, Lourens River)

Impacts of pollution on the environment

- What is the concentration of a chemical in the environment?
- What kind of effect do the pollutants have on non-target organisms?

YOU CAN'T MANAGE WHAT YOU CAN'T MEASURE!

What is the meaning of "monitoring"?

- Monitoring can be defined as the periodic measurement, assessment and reporting of specific data and information in a consistent manner that is focused on well-defined objectives.

Monitoring has to include three core functions:

- Data acquisition
- Data management and storage
- Information generation and dissemination

Why monitor water quality?

- "state of the rivers"
- compliance with legislation (e.g. Receiving Quality Objectives)
- effectiveness of rehabilitation actions
- effect of developments (e.g. dams, agriculture)

What aspects would one monitor?

- Potability (drinkability)
- Suitability for various uses (e.g. recreation, aquaculture)
- Maintenance of habitat diversity (habitat integrity)
- Maintenance of biodiversity (biotic integrity)
- Maintenance of ecosystem processes (functional integrity = ecosystem health)

Monitoring programmes can be grouped according to the following criteria:

- compliance monitoring
- performance (audit) monitoring
- status and trend monitoring
- impact assessment monitoring
- surveys

NB: When designing a monitoring programme, ***"begin with the end in mind"***

What measurements might you take?

- Concentration of chemical substances
- Magnitude of physical attributes, e.g. temp, pH
- Biodiversity (what taxa?, where?, etc.)
- Ecosystem functioning
- Habitat integrity

Chemical measurement

- Water quality data collected by DWAF (>1000 sites)
- Continuous, weekly, monthly or less frequently
- Time-series from few months to 30 or more years
- TSS, Temp, DO and toxics usually NOT included

- Eutrophication (Chl a), microbiology, also now monitored
- Available on internet, requested by email and on CD-ROM

Utilising available resources for:

- Defining the Reference Condition
- Assessing the Present State
- Looking at trends in water quality at a site
- Checking compliance
- Setting up and validating water quality systems models

Chemical analysis

- Expensive – but needs to be considered relative to value
- spot samples (one site, one point in time)
- exception, e.g., electronic probes/data loggers
- not possible to analyse all pollutants (unknown pollutants are not detected)

Any alternatives ?

Specific tools related to water quality and biota

- Biological monitoring (biomonitoring)
- Ecotoxicology

see **Study Unit 5**

Physicochemical sampling methods (Prepared by Jenny Day)

Field measurements

- Require portable equipment – usually done with probes
- Necessary for continuous recording
- Necessary for constituents that vary in collected samples
- Examples: gases, pH, redox, alkalinity, turbidity best done on site (probe or colorimeter), conductivity

Particulate material (filter in field)

For water to be returned to the laboratory

- Containers must be chemically clean, washed with water from site
- Choose suitable depth and distance from bank
- Label, freeze, cool and preserve

Analytical – laboratory techniques

TDS	evaporation at <70°C
Salinity	[titration], refractometry (for salinities > 5), conductivity measurements
Conductivity	conductivity probe
Cations	flame photometry, atomic absorption spectrophotometry, ICP (inductively coupled plasma spectrometry), ion chromatography
Anions	titration (Cl^-), wet chemistry (SO_4^{2-}), ion chromatography, ICP (but not for gases: C, Cl, N compounds)
Nutrients	wet chemistry, auto-analyser, ion chromatography (ICP)
Particulates	mass, fractionation (for particle sizes), muffling (for proportion of organics)
Chlorophyll *a*	filtration, dissolution and spectrophotometry
Gases	probes, titrations
pH	probe (or paper)
Toxics	depends on what they are; most organics can be identified using HPLC (high-performance liquid chromatography) – very expensive
Bacteria	culturing on (or in) specific media at particular temperatures
Humics	e.g. polyphenols – colour, phenol content, spectrophotometry

Reporting of results

See Day 1990. Pitfalls in the presentation of chemical data. *South African Journal of Aquatic Sciences* 16(1/2): 2-15. (Copy provided)

Quoting results

- always include units (mmol l^{-1}, mg l^{-1}, etc.)
- indicate limits of detection, precision and accuracy
- use appropriate number of decimal places
- choose appropriate techniques for the job at hand

ASSIGNMENT 4: FIELD-TRIP PROJECT REPORT

Students are to analyse and interpret the data collected during the field trip completed as part of Study Unit 4, and each student is to prepare a **scientific report** on the water quality of the aquatic ecosystem that was visited*.

The terms of reference for the report are to provide:

- An indication of the water quality of the aquatic ecosystem, based on the parameters recorded and visual observations made during the field-trip;
- Recommendations for a water quality monitoring programme for the aquatic ecosystem (including aspects such as parameters to be measured, data collection methods, frequency of sampling, timing of sampling, etc.), bearing in mind the financial cost implications; and
- Overall conclusions and recommendations based on the findings of the investigation.

In terms of report structure, the following sections/headings are recommended:

- Abstract (i.e. summary)
- Introduction
- Description of study site/area (include a map)
- Methods (of data collection and data analysis)
- Results
- Discussion
- Conclusions and Recommendations (can be separate sections)
- Acknowledgements
- References

*NOTE: While the analysis of the data collected during the field trip can (and should) be completed by students working together in groups (during a dedicated data analysis session to be facilitated by the lecturer or course coordinator), each student must **individually** write up their project report. Students who do their write-up together will be guilty of plagiarism!

NOTE TO LECTURER:

A data analysis session should be arranged as part of this Study Unit, during which a lecturer/supervisor/tutor is available to assist students and deal with queries relating to the analysis of the data collected during the field trip

SELF-EVALUATION QUESTIONS

1. What are the main modes of entry of pollutants into aquatic ecosystems? Explain how this influences the measurement and monitoring of water quality.
2. What are the three core functions of monitoring?
3. What are the different types of monitoring programmes that are typically implemented for monitoring water quality in aquatic ecosystems?
4. Discuss the statement with regard to water quality and water resources that "You can't manage what you can't measure".
5. What are the limitations of water quality monitoring programmes that rely solely on the collection of physico-chemical measurements?

SUMMARY

In the lecture for this Study Unit, you should have learned about the possible reasons for monitoring water quality and the different approaches that can be followed, depending on the purpose of the monitoring. The important features of a water quality monitoring programme were examined, and the limitations of relying solely on the collection of physico-chemical data were highlighted. As part of the Study Unit, the data that were collected during the field trip were analysed and interpreted, and a scientific report on the water quality of the relevant aquatic ecosystem was written as Assignment 4.

The use of biomonitoring and aquatic ecotoxicology in the monitoring of water quality is dealt with in the next Study Unit.

NOTE: It is important to ensure that you have reached the required outcomes for this Study Unit by successfully answering the self-evaluation questions before you move on to the next Study Unit.

Study Unit 5

BIOMONITORING AND AQUATIC ECOTOXICOLOGY

TIME

You will need approximately 8 hours to master this study unit.

REFERENCES

Compulsory readings:

- Palmer *et al*. (2004): Chapter 2 (pp. 27-37), Appendix 2 (Biomonitoring in rivers, by Dirk Roux) and Appendix 3 (Ecotoxicology, by Nikite Muller)
- Dickens and Graham (2002)
- Scherman *et al*. (2003)

Additional readings:

- Dallas and Day (2007)
- De la Rey *et al*. (2004)
- Harding and Taylor (2011)
- Matlala *et al*. (2011)
- Kleynhans and Louw (2008)
- Connell *et al*. (1999): Chapters 1 & 6

MODULE OUTCOMES

At the end of this study unit, you should have gained an understanding of the use of biomonitoring and ecotoxicology in water quality monitoring, and you should be able to:

- explain the concepts of biomonitoring and bioassessment;
- list examples of biota that can be used for biomonitoring of aquatic ecosystems, and some of the advantages of using biota for water quality monitoring;
- describe some of biotic indices that have been or are being used for the monitoring of aquatic ecosystems in South Africa;
- explain the fundamental concepts of aquatic ecotoxicology; and
- discuss how physico-chemical monitoring, biomonitoring and aquatic ecotoxicology can complement one another in a water quality monitoring programme.

INTRODUCTION

Physico-chemical monitoring has limitations and it is very expensive to monitor water quality on the basis of physico-chemical parameters alone. Biomonitoring is, therefore, commonly used in combination with physico-chemical monitoring and, although not as common, ecotoxicology is also used to complement these approaches. Using all three approaches in a water quality monitoring programme provides a more holistic 'picture' of the situation, and allows for a better understanding to be gained of the linkages between water quality and the effects of altered water quality on aquatic biota.

1. BIOASSESSMENT AND BIOMONITORING

- **Bioassessment**: the process of determining if human activity has altered the biological properties of an ecosystem
- **Biomonitoring**: systematic use of biological responses to evaluate environmental changes within a quality-control programme

Comparing physicochemical monitoring with biomonitoring

Physicochemical monitoring is:

- limited to period of sample collection
- limited to constituents measured
- expensive to measure all constituents
- sensitivity limitations – low concentrations cannot be detected

Biomonitoring using biota

- continuous monitors – integrate effect of time and multiple pollutants
- account for synergistic (magnifying) and antagonistic (reducing) effects (e.g. pH)

→ physicochemical and biomonitoring – **complementary**

Which organisms to use in bioassessment?

- protozoa /diatoms – identification specialised
- algae / periphyton – identification specialised
- aquatic macroinvertebrates – identification to species-level specialised
- fish
- macrophytes
- riparian vegetation

Aquatic macroinvertebrates – diverse group of sedentary organisms that react strongly, and often predictably, to human influences on aquatic ecosystems – used to give example of value of using a biotic component as a measure of river health.

Advantages of using aquatic macroinvertebrates:

- widespread distribution – common in aquatic ecosystems
- range of sensitivities
- non-mobile, immature, aquatic phase – representative of the location being sampled
- lifecycle is of a suitable length; long enough to assess change over time, but short enough to observe recovery

Disadvantages of using aquatic macroinvertebrates:

- relatively patchy distribution
- sensitive to factors other than water quality – flow, habitat availability and food availability
- they may not respond to all impacts, e.g. certain herbicides

Locally-developed bioassessment tool for rivers based on macroinvertebrates – SASS (South African Scoring System)

- water resource managers needed a quick, cost-effective method to assess water quality
- used as a general index of riverine health
- NB tool in the River Health Programme (RHP)
- yields three metrics: SASS5 Score, No. of Taxa and Average Score Per Taxon (ASPT)
- has been through extensive testing and validation, and has been updated a few times since its initial development (now on Version 5)
- tools for consistent interpretation of results have been developed (taking regional and longitudinal variability into account)

Advantages of using SASS:

- rapid, non-destructive, field-based
- undertaken by technicians providing sufficient training is given
- repetitive sampling enables a quick assessment of the improvement or regression in water quality at a site
- data output is simple – easily interpreted by water resource managers
- wide variety of potential applications

Limitations of SASS:

- does not reveal the cause of the problem – red flag
- based mostly on families of macroinvertebrates – medium-to-course level – effects at species-level not detected
- no abundances – not sensitive to ↑ or ↓ in no. of individuals in a taxon
- data reduced to a score – loss of information
- developed for running waters – cannot be used in ephemeral rivers or wetlands

More recent macroinvertebrate-based bioassessment tool for rivers in SA = Macro-Invertebrate Response Assessment Index (MIRAI)

- part of DWA's suite of "River EcoClassification" tools for "EcoStatus determination"
- developed primarily for Ecological Reserve Determination studies, but also supposed to be applicable to RHP assessments
- based on the diversity and frequency of occurrence of macroinvertebrate taxa (identified to family-level) with different (pre-defined) requirements/preferences in terms of biotopes, velocity and physico-chemical conditions
- method still requires testing and validation, esp. in certain parts of the country (e.g. SW Cape) and in certain types of rivers (e.g. non-perennial streams)

Diatoms – a group of micro-organisms that can potentially serve as reliable indicators of water quality

- abundant, diverse and important components of algal assemblages in freshwater ecosystems
- often represent a large proportion of the periphyton that forms a slimy coating on any stable surfaces in an aquatic ecosystem (periphyton consists mainly of algae, but also includes fungal and bacterial matter)
- mostly less than one millimetre in length (i.e. microscopic), characterised by having a cell wall composed of biogenic silica rather than cellulose as in other plant cells
- have many unique life forms – can be free-living as single cells (motile or attached) or often linked together in a colony
- a number of diatom indices have been developed around the world as bioassessment tools for providing an integrated reflection of water quality – usage typically involves making a list of the taxa present in a sample (identified to species or, at least, to genus level), along with a measure of the abundance of each taxon

Advantages of using diatoms:

- they occur in all types of aquatic ecosystems
- they comprise a large portion of total algal biomass over a broad spectrum of trophic levels
- collectively show a broad range of tolerance along a gradient of aquatic productivity, but individual species have specific habitat and water chemistry requirements
- they have one of the shortest generation times of all biological indicators – reproduce and respond rapidly to environmental change, providing early warnings of both water quality and habitat changes in an aquatic ecosystem
- rapid immigration rates and a lack of physical dispersal barriers ensure there is little lag-time between perturbation and response
- they are especially sensitive to changes in nutrient concentrations, with each taxon generally having a specific optimum and tolerance for nutrients such as phosphate and nitrogen, which can usually be quantified to a high degree of certainty
- assemblages are usually diverse and it is easy to obtain large numbers of individuals, therefore robust statistical and multivariate procedures can be used to analyse assemblage data
- the taxonomy of diatoms is generally well documented
- can still be found on dry substrata, so they can be sampled at most times of the year (NB for seasonal systems)
- collection of samples relatively rapid and easy – can be done by non-specialists (with adequate training in the sampling protocols)

Disadvantages of using diatoms:

- they are primarily photoautotrophic organisms and thus require light – limits their use in dark or heavily shaded environments
- sensitive to factors other than water quality – flow, habitat availability, light availability
- identification and enumeration of samples requires specialised lab work (with microscopes), and is time-consuming – processing and analysis of samples specialised and relatively expensive
- cannot be used for rapid, field-based assessments
- very few diatom specialists or trained technicians (to process samples) in SA [but a number of labs in the country are now providing such a service]
- some statistical knowledge required for proper analysis and interpretation of results

Diatom indices in South Africa:

- **South African Diatom Index (SADI)** for rivers = modified version of the Specific Pollution sensitivity Index (SPI) developed in France
  BUT: not applicable to the Western Cape in its current form
- **Diatom index for wetlands** – preliminary work has been done but further research required (in the interim, has been recommended that existing international indices such as the SPI be used for bioassessment and biomonitoring in SA wetlands)

Other biotic indices developed for aquatic ecosystems in South Africa:

- Mostly (only?) for rivers to date
- **Riparian Vegetation Index (RVI)** – developed for the RHP
  - more recently, replaced/supplemented by **Riparian Vegetation Response Assessment Index (VEGRAI)**
- **Fish Assemblage Integrity Index (FAII)** – developed for the RHP
  - replaced/supplemented by **Fish Response Assessment Index (FRAI)**

The importance of reference sites

Two types of sites: monitoring and reference

- Monitoring site – selected based on objectives of study (assess pollution source, "State of Rivers" assessments, etc.)
- Reference site – selected to represent the natural (or as near to natural as possible) condition, i.e. least-impacted

A reference site -

- acts as a benchmark with which a monitoring site is compared
- is representative of the aquatic ecosystem type for which it provides a reference
- several reference sites used to generate a reference condition (or natural reference state)
- easier to derive a reference condition for sites in upper catchments since pollution often less severe than in lower catchments – often need to derive reference conditions for lowland sites based on "best available" sites

Why do we need reference sites?

- Aquatic ecosystems are complex systems that vary in space and time
  - Regional / catchment differences
  - Longitudinal differences and landscape-setting differences
  - Habitat differences (substrate, hydraulics, hydroperiod / flow regime, etc.)
- Leads to variation in aquatic biota, e.g. invertebrates, fish, plants

Reference sites – allow us to compare "like with like"

Reference (and monitoring) sites are usually selected in the context of a **hierarchical spatial framework** within which biomonitoring is typically undertaken

National Aquatic Ecosystem Health Monitoring Programme (NAEHMP)

- Previously known as the National Aquatic Ecosystem Biomonitoring Programme (NAEBMP) or the National Biomonitoring Programme for Aquatic Ecosystems (NBPAE)
- Long-term vision of the NAEHMP is to "implement, maintain and improve biomonitoring for all inland aquatic ecosystems in South Africa and throughout the southern African region".
- Envisaged that the monitoring programme will eventually cover all surface water resources, including rivers, wetlands and estuaries.
  - **River Health Programme (RHP)** = most advanced component to date
  - **National Estuarine Monitoring Programme** → pilot implementation stage
  - **National Wetland Monitoring Programme (NWMP)** → research stage
- NAEHMP is one of several national programmes coordinated by DWA to monitor various aspects of surface water quality. Other programmes, which are at different stages of development or implementation, include:
  - National Chemical Monitoring Programme (mostly rivers)
  - National Hydrological Monitoring Programme (focus on rivers)
  - National Eutrophication Monitoring Programme (focus on reservoirs/dams)
  - National Microbial Monitoring Programme
  - National Radioactivity Monitoring Programme
  - National Toxicity Monitoring Programme
  - National Sediment Monitoring Programme

2. AQUATIC ECOTOXICOLOGY

- "The effect of toxic substances on aquatic organisms"
- Usually laboratory experiments – variables controlled
  - mesocosm experiments
  - real systems

Link between water quality and effects on the biota

= chemical monitoring ↔ ecotoxicology ↔ biomonitoring

Two common, if confusing, ecotoxicology terms:

- **Acute exposure:** high concentrations, short period of time; effect = usually lethal; e.g. road-spill of benzene
- **Chronic exposure:** low concentrations, long period of time; effect = usually sub-lethal; e.g. reduced growth rate, fecundity, etc.

Case can be made for different terminology: long- and short-term tests using lethality or sub-lethal end-points. Be very careful when reading aquatic and ecotox literature! Older literature still uses some human toxicological terms (due to historical roots) with somewhat different interpretation.

More terminology:

- Cumulative effect: brought about, or increased in effect, by successive doses of a toxin.
- Dose = concentration X length of time of exposure. Note: in Fundamentals of Aquatic Toxicology 2nd Ed (Rand 1995) p941 – Dose: "The amount of material introduced into the animal […] considered to be the exposure dose. The amount of material at the receptor or target sites in the animal that elicits a response is the target dose." → essence is that **dose is an amount of material *in the body* of the target animal**. Dose is sometimes approximated by ambient concentration, e.g. in LC.
- Lethal concentration (LC), e.g. 48hr LC_{50} = concentration of a toxin that kills 50% of a test sample of organisms after 48hr (e.g. 24hr LC_{50}, etc.), i.e. death = criterion of toxicity
- Effective concentration (EC)
  - e.g. growth reduction, fertility
  - Example: 10 day EC50 "Concentration of a chemical that results in a significant reduction in body length in 50% of a test population (relative to control) after 10 days"

Important notes:

- Compare different chemicals (the lower the LC/EC the more toxic)
- Compare tolerances of different spp to a single chemical (or complex effluent)
- BUT very little data on indigenous spp. in SA
- For a single sp., tolerance is variable
  - e.g. larval stages often more sensitive than adults
  - e.g. between males and females

Some examples:

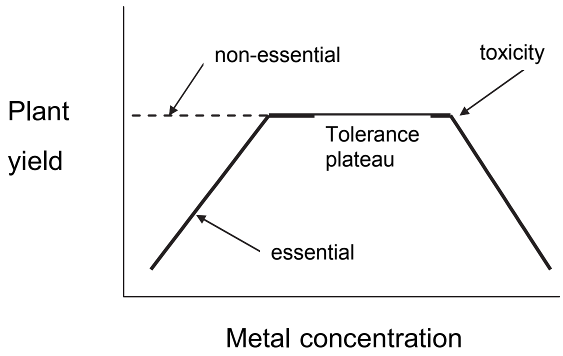


Figure 5.1: Example of a dose-response curve

Table 5.1: Acute toxicity (96-h LC_{50}, mgl^{-1}) of cadmium, phenol and ammonia to several invertebrate species (from Williams *et al.* 1984) [example of results of an LC_{50} test for different species]

	Species	Cadmium	Phenol	Ammonia
Worm	*Limnodrilus hoffmeisteri*	2.9	780	1.92
Snail	*Physa fontinalis*	0.8	70	1.7
Shrimp	*Gammarus pulex*	0.03	69	2.05
Hoglouse	*Asellus aquaticus*	0.6	180	2.3
Mayfly	*Baetis rhodani*	0.7	15.5	1.7
Midge larva	*Chironomus riparius*	>200	240	1.65

Some of the environmental factors that affect toxicity:

Temperature – Increased temperature USUALLY results in increased toxicity

- BUT: phenol in rainbow trout
  - Absorption rate ↑ vs rate of detoxification ↑ when temperature is increased
  - Net effect – phenol less toxic at higher temperatures

pH

- Effect on metal toxicity
- Water hardness [$CaCO_3$] – pollutants (e.g. Pb, Cu, Zn) usually MORE toxic in soft waters (i.e. low concentration of $CaCO_3$)

SO: Need to be careful when extrapolating toxicity results to the field.
BUT: Useful if in combination with biomonitoring + chemical monitoring

Duration of exposure

- The longer the duration, the higher the apparent toxicity (lower LC and EC)
- Effective uptake (dose) depends on difference between uptake rate and excretion rate.
- Toxicity tests are usually designed around constant exposure. If ambient concentrations vary with time, effective toxicity characteristics differ from those measured in toxicity tests.

NOTE: in interpreting all the above environmental factors, the mechanism of toxicity plays a crucial role. Lethality/sub-lethality by itself is often not very useful in estimating the effects on populations. **Life cycle assessment** is needed. Typical life cycle end-points could be net population growth. Like LC50 and NOEC, this is the result of a mathematical model. Life cycle assessment (LCA) becoming increasingly popular in the assessment of chemicals.

Uses of ecotoxicology in managing freshwater systems

- whole effluent toxicity
- deriving guidelines
- interpreting biomonitoring data for resource management

Other ways of assessing water quality with biota

- Bioaccumulators – concentration of pollutants low, e.g. estuaries; potentially: freshwater mussels, bryophytes

- Fish alarms – Distinctive physical + behavioral response to LOW concentrations; fast response linked to automatic alarms
- Biomarkers, e.g. enzymes, vitellogenin

SELF-EVALUATION QUESTIONS

1. What are the advantages of biomonitoring over the monitoring of physico-chemical measurements alone?
2. What organisms can be used for biomonitoring in aquatic ecosystems?
3. What are the advantages and disadvantages of using aquatic macroinvertebrates [and/or diatoms] in a water quality monitoring programme?
4. What is the difference between acute and chronic exposure, and how does this relate to the use of lethal concentration (LC) and effective concentration (EC) in ecotoxicology tests?
5. Discuss the use of biomonitoring, chemical monitoring and ecotoxicology in assessing the effectiveness of pollution control measures in aquatic ecosystems.

SUMMARY

In the lecture for this Study Unit, you should have learned about the use of biomonitoring (and bioassessment) and aquatic ecotoxicology in the assessment and/or monitoring of the water quality of aquatic ecosystems. The differences between physico-chemical monitoring, biomonitoring and ecotoxicology were explained, and the advantages of using a combination of all three approaches were highlighted. The variety of biota that can be used for aquatic bioassessment and/or biomonitoring was introduced, and the advantages and disadvantages of using aquatic macroinvertebrates and diatoms (and biotic indices based on these organisms) were explored. Some of the fundamental concepts of ecotoxicology were covered, and an indication of the potential application of aquatic ecotoxicology in water quality monitoring programmes was given.

The management of water quality, particularly in the South African context, is dealt with in the next Study Unit.

NOTE: It is important to ensure that you have reached the required outcomes for this Study Unit by successfully answering the self-evaluation questions before you move on to the next Study Unit.

Study Unit 6

MANAGEMENT OF WATER QUALITY

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

Compulsory readings:

- Palmer *et al*. (2004): Chapters 1 and 3
- National Water Act (Act No. 36 of 1998) and General Authorisations dealing with water quality

Additional readings:

- DWAF (2008) [RDM water quality methods for rivers]
- DWAF (2004b) [RDM methods for estuaries], pp. 33-56
- Malan *et al*. (2013) [RDM water quality methods for wetlands – Rapid Reserve determination]
- Kleynhans *et al*. (2005) [River EcoStatus methods, incl. PAI – original version]
- DWA (in prep.) [updated PAI Manual for River EcoClassification]
- Malan & Day (2012) [wetlands water quality database]
- Malan *et al*. (2003) [flow-concentration modelling]
- DWAF (2007) [Training Manual for Resource Water Quality Objectives (RWQO) Model]

MODULE OUTCOMES

At the end of this study unit, you should have gained an understanding of the different approaches to the management of water quality and of some of the relevant 'tools' that are available to assist with this task in the South African context, and you should be able to:

- differentiate between the different types of pollution sources;
- compare the different approaches that can be used to manage water quality;
- explain how the management of water quality has been dealt with in the National Water Act, and how the setting of Resource Water Quality Objectives (RWQOs) fits into the processes of water resource "classification" and Ecological Reserve determination; and
- describe some of the 'tools' that have been developed in South Africa to assist with the management of water quality.

INTRODUCTION

The water quality requirements of different water users and the various potential sources of pollution must be taken into account in the management of water quality. In South Africa, following the framework established through the National Water Act (Act No. 36 of 1998), water quality is managed through the application of Source Directed Controls (SDCs) and Resource Directed Measures (RDM). The setting of Resource Water Quality Objectives (RWQOs) is a fundamental component of the "(eco-)classification" of water resources and the determination of the Ecological Reserve. A number of 'tools' have been, and continue to be, developed to assist with the management of water quality in SA.

1. MANAGEMENT OF WATER QUALITY

Managing water quality

- Disposal of effluents in rivers = cheap, efficient
- Cleaning via sewage works = expensive
- Water must be returned to the stream of origin
- Water required for different users including domestic, industrial, agricultural + livestock, aquaculture, recreational/aesthetic; and for aquatic ecosystems

Types of pollution sources

Point sources:

- pipes discharging effluent
- sewage outlets
- stormwater drains

  → manageable (technically at least)

Non-point (diffuse) sources:

- runoff from agriculture (return flows)
- runoff from informal settlements
- suburbian runoff, landfills

  → can be difficult to manage

Groundwater = especially vulnerable

Need to have a **balance** between the cost of pollution abatement and detrimental social and environmental effects...i.e. **management**, rather than total elimination of pollution

Management approaches

Source-directed controls = discharge standards

- registration of sources of impact
- effluent standards for waste discharges = legal limits (general and special standards)
- best management practices
- discharge permits and impact assessments
- pollutant charge system currently under development by DWA

Ok for point sources but what about non-point sources?

Resource-directed controls – receiving water quality standards/objectives

- resource water quality objectives per river reach
- calculate dilution capacity (assimilative capacity)
- calculations depend on the river class
- permit to discharge

What are possible disadvantages to this approach?
What about wetlands?

Are the controls adequate?

- Monitor water quality
- Compare with the Receiving Water Quality Objectives / RQOs
- Depends on the users of the water
- SA Water Quality Guidelines (Aquatic Ecosystems, Agriculture, Aquaculture, Domestic, Industrial use)
- Not mandatory <u>but</u> SAWQG is a technical basis that can be used in setting RQOs that have a legal standing. Controls, or more accurately measures (i.e. licences, economic instruments) always have a legal standing; they are part of the regulatory toolbox of the Minister.

Focus of 1996 SAWQ is **hazard**. For more effective resource management, focus needs to shift to **risk** (part of current SAWQG review).
→ will require a paradigm shift from the *possibility domain* to the *likelihood domain* = a more onerous requirement on both experts and regulators, but with significant benefits.

Question: What are the advantages of a risk-based approach as opposed to a hazard-based approach in sustainable resource management? Disadvantages?

For example Fluoride ≈ 0.1 mg/L in unpolluted rivers

- TWQR ≤ 0.75 mg/L (for aquatic ecosystems)
- CEV = 1.5 mg/L
- AEV = 2.54 mg/L

≥ 1.5-3.5 causes damage to teeth (drinking water < 0.7)

- Guidelines compiled by specialists
- International toxicological data
- water quality issues in SA
- **NOTE**: Don't fall into the trap of looking at lists of figures. Look at the proper context of applying the figures in the guidelines (Where and under what conditions are they applicable? What do the figures represent? How are they to be adapted/amended? etc.)

Problems:

- Acute or chronic values?
- Geographical variation?
- Toxicity tests or application in the real world?

<u>**National Water Act (Act No. 36 of 1998)**</u>

- Commitment to protect water resources – entire ecosystem needs to be protected
- Source-directed controls (effluent standards, management practices for diffuse pollutants)

- Receiving Water Quality Objectives approach was broadened, introducing the concepts of Resource Quality and **Resource Quality Objectives (RQOs)**

Resource Quality means the quality of all the aspects of the water resource, which includes water quality, water quantity, as well as the aquatic ecosystem quality (quality of the aquatic biota, and in-stream and riparian habitat).

RQOs are regarded as a **Resource Directed Measure (RDM)**, which are aimed at the requirements of the water resource. Inherent to this approach are **SDMs or SDCs (Source Directed Measures/Controls)** that must be established in order to ensure that the requirements that were set during the RDM process are not violated. {RQOs reflect the requirements set by catchment visioning, which includes all users, might also reflect socio-economic, cultural, political and catchment management strategic objectives outside of those addressed in RDM.}

The RQOs approach embodies an approach that strives towards a sustainable balance between protection, on the one side, and water use and development, on the other side.

RQOs stipulate **resource water quality objectives** aimed at meeting the water quality requirements of the five water user sectors, and are aimed at ensuring fitness for use of South Africa's surface water (rivers and wetlands), groundwater and coastal estuaries.

NB: Without efficient and effective source directed controls, the water quality objectives set through resource directed water quality management will, in most cases, not be met.

Relationship between different aspects of water resource quality management

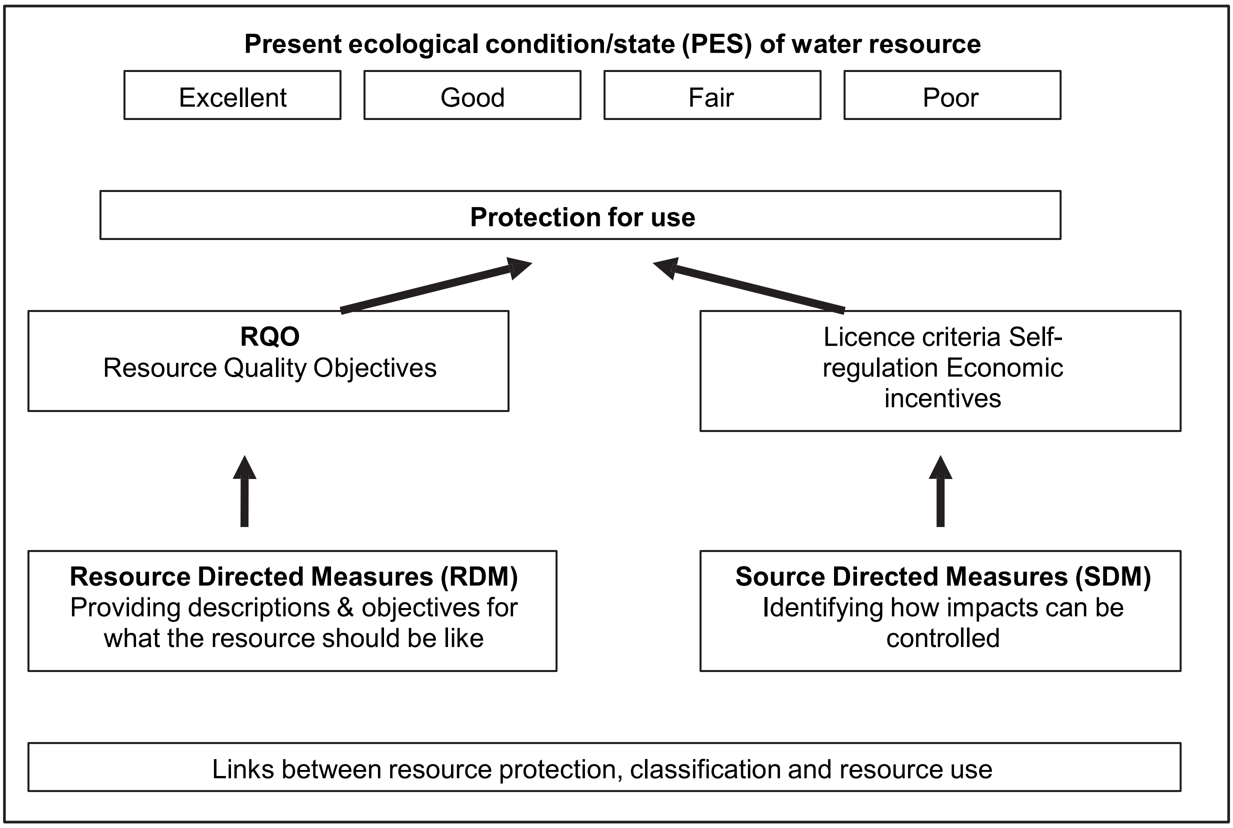


Figure 6.1: Flow diagram showing links between resource protection, classification and resource use [from Palmer *et al*. (2004)]

The Reserve: The quality, quantity and assurance of water needed to protect basic human needs and structure / function of ecosystems so as to secure ecologically sustainable development and utilisation

- Human reserve
- Ecological reserve

The NWA recognises that water resources perform many valuable services other than just providing water, such as:

- Drinking + basic human needs
- Economic development (agriculture and industry)
- Transport + purification of waste
- Subsistence + commercial supply of fish, plants, etc.
- Recreation
- Habitat for plants + animals (ecotourism)
- Retention + storage of water
- Flood water transport

→ **a level of ecosystem functioning** is required to provide many of the above (e.g. purification)

The Ecological Reserve

= the quantity and quality of water required to maintain a water resource as a functional ecosystem; applicable to:

  - rivers
  - wetlands
  - lakes
  - estuaries
  - groundwater

- Environmental Water Requirements (EWR) = water quantity
- Resource (Water) Quality Objectives (RQO/RWQO) = water quality
- Methods have been developed and used for rivers & estuaries; those for other aquatic ecosystems not as well developed
  - Instream habitat (geomorphology)
  - Riparian habitat (vegetation)
  - Biota (fish, macroinvertebrates, sometimes wildlife)

The Human Reserve

- Ending private ownership of the country's water resources
- An allocation of water for everybody (e.g. 25 L per day)
- Reserve (at whatever level it is negotiated to be by the catchment visioning process) is guaranteed as each citizen's right
- Subsistence users of water resources recognised

Legal Process = first allocate Ecological (and Human) Reserve, THEN issue licenses for agricultural, industrial use, etc.

<u>Classification of water resources (in terms of National Water Act)</u>

→ according to what state they are in + what they will be used for, i.e. <u>Classes</u>: Natural, Good, Fair, Poor

→ derive a reference condition = benchmark value (TWQR – target water quality range)

→ set resource quality objectives (RQO) for **water quality** (+flow, biota, instream + riparian habitat)

NOTE: The word "classification" has a very specific meaning in the NWA; different to typical meaning internationally, e.g. "wetland classification" (i.e. implying 'typing')

Process:

- Specialists, stakeholders and resource managers suggest class for a water resource
- Final decision by Minister
- Financial implications (pollution control, abstraction, etc.)

- **Reference water quality condition (what it should be)**
  - Derived for a site by looking at historical data
  - From non-impacted tributaries/systems
  - From non-impacted adjacent catchments
  - Setting a baseline – so we can estimate extent of deterioration (biomonitoring, ecotoxicology, etc.)

- **Present Ecological State (how it is)**

- **Resource quality objectives (how it will be managed)**
  - standards, "ecospecs"
  - for all key water quality variables
  - adjust if reference condition is very different from natural default values

<u>Tools for managing water quality in South Africa</u>

A number of tools have been developed through the years to assist with the management of WQ in SA, including (but not limited to):

- Water Management System (WMS) water quality database
  - suite of computer programs developed for and managed by DWA to provide info for water resource monitoring and management in SA
  - includes data for rivers, dams, springs ('eyes'), groundwater, very few wetlands
  - includes internet-based Geographical Water Quality Data Exploration Tools (via DWA-RQS website)

- Water Quality Guidelines
  - Series of documents produced by DWA(F) in 1996 [for different users, including aquatic ecosystems]
  - More recent guidelines have subsequently been produced (through WRC) for drinking water quality

- Water Quality Standards
  - 'General' and 'Special' Limits for various parameters published in terms of the NWA (applicable to effluent concentrations, not water resource concentrations)

- RDM methods for determining the water quality component of the Ecological Reserve
  - rudimentary methods initially developed for rivers, wetlands and estuaries in 1999

- more refined methods published for estuaries in 2004 (Taljaard *et al*.), for rivers in 2008 (Scherman), and for wetlands (rapid assessment) in 2013 (Malan *et al*.)

- Methods of modelling Flow-Concentration (Q-C) relationships for water quality parameters
  - necessary for predicting water quality under various flow scenarios in a Reserve determination study
  - range from simple numerical techniques (e.g. rating curves) to instream computer models, to catchment runoff models → increasing complexity, and increasing data, time and expertise requirements (leading to increased cost implications)
  - NB to be aware of limitations of method that is used for predicting water quality

- River EcoClassification and EcoStatus suite of assessment tools
  - initially published in draft form in 2005; updated versions of various 'tools' published from 2008 onwards
  - includes the "**Physico-chemical driver Assessment Index (PAI)**" [updated version due to be released in 2014] → requires flow-concentration (Q-C) modelling to predict water quality, which can be done using relatively simple mathematical methods or more complex computerised models

- TEACHA computer software program
  - developed for DWA → desktop tool for generating aggregated salt concentrations from ionic data (i.e. concentrations of individual major ions) within the WQ component of an Ecological Reserve determination process
  - only tool currently available in SA for conducting inorganic salt assessments in context of a Reserve determination process
  - primary output is a recommended water quality Reserve with corresponding ion data to use in resource quality objective setting
  - can also be used in the River EcoStatus assessment for the PAI
  - alternative is to base assessment of inorganic salt concentrations (TDS) on electrical conductivity measurements

- RWQO determination methods and model
  - computerised model (program) and supporting documentation
  - developed by DWA in 2007

- Water quality database for wetlands
  - first version developed in 2005; updated in 2013 (by Malan & Day, UCT)

- Blue Drop assessment system
  - assessment of drinking water quality [national DWA initiative]

- Green Drop assessment system
  - assessment of performance and management of wastewater treatment works (WWTW) [national DWA initiative]

- Others???

NOTE TO LECTURER:

One (or more) of the topics included in this Study Unit should be selected as the focus of a discussion session with the students. During this discussion session, students should be encouraged to highlight linkages between the selected topic/s and material covered in previous Study Units of this module.

SELF-EVALUATION QUESTIONS

1. What are the different types of pollution sources and what are the implications of this for the management of water quality?
2. What is the difference between the SDC and RDM approaches to water quality management?
3. What are RQOs and RWQOs, and what ‘tools’ are available for their establishment?
4. How does the setting of RWQOs fit into the processes of water resource “classification” and Reserve determination?

SUMMARY

In the lecture and through participation in the discussion session for this Study Unit, you should have learned about the approaches used to manage the water quality of water resources in South Africa. The use of Source Directed Controls (SDCs) was contrasted with the use of Resource Directed Measures (RDM) in the management of water quality. The setting of Resource Quality Objectives (RQOs) for water quality, also known as Resource Water Quality Objectives (RWQOs), was introduced and an explanation was given of where the setting of RWQOs fits into the legislative processes of water resource “classification” and the determination of the Ecological Reserve. Some of the ‘tools’ that have been developed to assist with the management of water quality in the context of the National Water Act were explored.

This was the final Study Unit in this module on Water Quality.

NOTE: It is important to ensure that you have reached the required outcomes for this Study Unit by successfully answering the self-evaluation questions.

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MODULE 7

AQUATIC ECOLOGY

Tutored MSc in Ecological Water Requirements

Developed by

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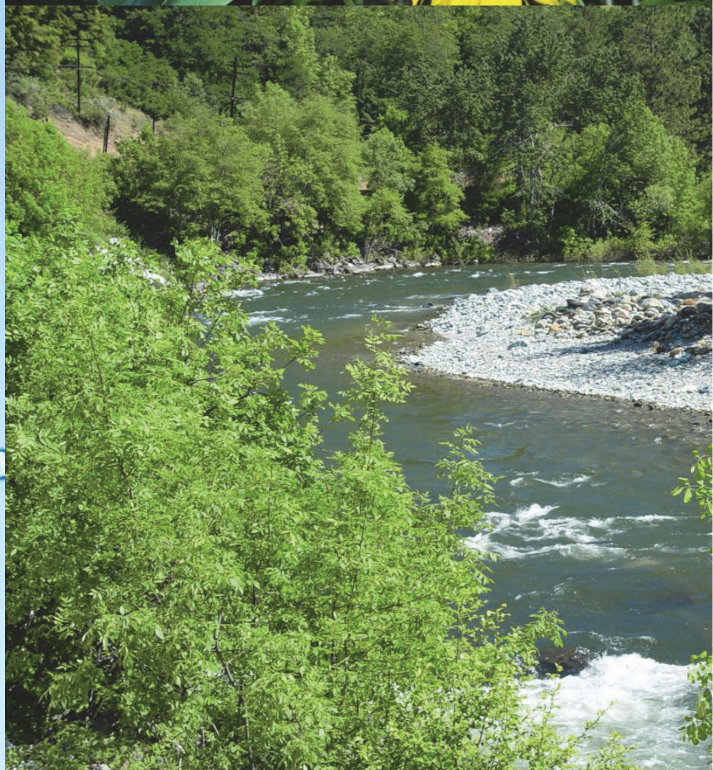


MODULE 7: AQUATIC ECOLOGY

Rationale

The objective of this module is to provide a basic understanding of the ecology of inland waters, particularly for students who intend to become managers of aquatic ecosystems.

Ecology is the scientific study of the interactions that influence the number and distribution of organisms on Earth. It can therefore find application in almost every aspect of society. In particular, the use of resources on Earth can only be sustainable if based on ecological principles.

This module studies mutual interactions between organisms as well as their interactions with the abiotic environment. Attention will particularly be given to the ways in which these interactions determine the number and distribution of organisms.

Ecology is a vast multidisciplinary field of study with three main facets:

(1) interactions between organisms and the abiotic environment (environmental conditions and resources)

(2) interactions between organisms (competition, predation, parasitism, mutualism)

(3) the nature, functioning and dynamics of communities.

Although the principles of ecology are universal, in this module we deal specifically with inland water ecosystems, using examples drawn from these systems wherever possible.

Layout of the module

In this course, we will address the following aspects of ecology. Each lecture topic (i.e. Lectures 1-12) contributes equally to the content of the module. We also have a field trip and three practicals, and you are expected to give a seminar. Details of these activities are provided in a separate electronic folder called “Field trip, seminars and practicals”

Lecture 1 What is ecology? (**r**eadings 2, 3, 7, 8, 18, 32, 36)

What are the basic principles on which the science of ecology is based?

Explanation and prediction of patterns and processes in ecosystems

The practical value of ecology as a discipline

Lecture 2 **Rivers** (readings 15, 19, 28)

What are the physical and biological features of rivers?

In what ways are riverine organisms adapted to life in flowing water?

What 'goods and services' are provided by rivers?

Lecture 3 **Wetlands** (readings 20, 21, 26, 37)

What are the physical and biological features of wetlands?

In what ways are wetland organisms adapted to life in standing water?

What 'goods and services' are provided by wetlands?

Lecture 4 **Estuaries and coastal lakes** (readings 16, 21, 27)

What are estuaries? And coastal lakes?

What are the physical and biological features of estuaries and coastal lakes?

In what ways are estuarine organisms adapted to the varying conditions in estuaries?

What 'goods and services' are provided by estuaries and coastal lakes?

Lecture 5 **Abiotic factors** (readings 5, 7, 15, 33)

Properties of water as the medium of aquatic organisms

Physical features of water

Chemical features of water

The harsh-benign, variable-stable and predictable-unpredictable continua

Lecture 6 **Autecology** (readings 1, 4)

Tolerances and limiting factors

Feeding

Reproduction and life histories; larvae

Places for living

Lecture 7 **(Population &) community ecology** (readings 9, 10, 12, 14, 29)

What are the major kinds of biotic interactions?

Photosynthesis, energy, decomposition

Trophic relations: food chains and food webs

Community structure: keystone species; diversity and stability

Lecture 8 **Systems ecology & biogeochemical cycles** (readings 6, 11, 13, 30, 35)

Ecology of whole systems

Nutrient cycling at local and global levels

Eutrophication

Mention of interference with biogeochemical cycling and global warming

Lecture 9 Biodiversity and biogeography (readings 10, 31)

What are the physical and biological features of rivers?

In what ways are riverine organisms adapted to life in flowing water?

What 'goods and services' are provided by rivers?

Lecture 10 Anthropogenic effects I: physical & chemical effects on organisms and communities (readings 22, 34)

Toxins (e.g. agrichemicals, Persistent Organic Pollutants)

System variables (e.g. pH, salinity)

Organic pollution

Eutrophication

Lecture 11 Anthropogenic effects II: effects of water reduction on organisms and communities (readings 15, 17, 24)

Effects of dams on rivers

Effects of alteration of hyrological régime on wetlands

Effects of increasing water supplied to rivers and wetlands

Lecture 12 Anthropogenic effects III: other effects of human activities (reading 23)

Effects of alien organisms, particularly on native fishes

Effects of physical alteration to rivers and wetlands

Water-borne diseases (e.g. malaria, bilharzia, enteritis, cholera).

STUDY UNITS

NB: The percentages in brackets indicate the amount of time you are expected to spend on each component of the module. A lecture is expected to last for one hour, and four hours of self-study are expected for each hour's lecture.

Study Unit 1: Ecosystems

Lectures 1-4 (4 hours), field trip (6 hours), self-study (16 hours) (26%)

Study Unit 2: Principles of ecology

Lectures 5-9 (5 hours), seminar (2 hours + 4 hours preparation) self-study (22 hours) (33%)

Study Unit 3: Human influences

Lectures 10-12 (3 hours), project (12 hours) self-study (12 hours) (27%)

Study Unit 4: Practicals

Practical work (4 hours), self-study (10 hours) (14%)

Prerequisites

You will need suitable clothing for work in the field (particularly foot-ware that can get wet). Forceps are useful for the practical work.

Study material

There is no specific textbook for the course. Instead, a variety of readings from various sources has been compiled to produce the equivalent of a textbook. These, and the out-of-print textbook *Vanishing Waters* by Davies and Day, are provided on a CD and form the reference material for the module. Some of these readings are compulsory and others are for supplementary reading. Details are provided in the material for each lecture.

How to study

The module is presented by means of study units, where the core principles are discussed and some practice is allowed. At the beginning of each section, a time allocation is given, which is an indication of the extent of the study task. You may use this allocation to plan your study process. The learning outcomes are also indicated at the beginning of each study unit and guide you as learner about what the problems in the particular study unit are and where you have to pay special attention. Make sure that you have the study guide always at hand, so that you can easily add additional notes to reach the outcome set for each study unit. At the end of study units, there are also evaluation questions. It is essential to answer these questions before moving on to the next study unit. By doing so and by making sure that the learning outcomes have been reached, you can make sure that you have completed the study unit successfully. It is expected that you, as a senior student, will have developed the skill (and that you will further develop this skill) to gather additional information independently in books, journals as well as from the internet. The study guide serves as framework to guide you through the learning content.

ASSESSMENT

Continuous assessment will take place in the form of assignments. Note the dates in the study letter on which these assignments should be handed in. Examination opportunities at the end of the module are also indicated in the study letter. Admission to the examination is dependent on an adequate participation mark, obtained from the assignments.

PRACTICALS AND FIELD REPORTS

Please note that practice and theory in ecology form a unit. During the practicals and fieldwork, theory becomes reality. It is therefore important to work systematically during each practical and to record relevant information during the field trip.

OUTCOMES OF THE MODULE

At the end of the module, you should be able to show understanding of the following:

- the basic principles of the science of ecology
- the practical value of ecology as a discipline

- fundamental patterns and processes in ecosystems, including biogeochemical cycling
- interactions between the biotic and the abiotic environment
- the practical value of understanding population dynamics and community ecology
- the physical and biological features of rivers, wetlands and estuaries
- the ways in which aquatic organisms are adapted to their environments
- the ‘goods and services’ provided by rivers and wetlands
- the effects of human activities on water quality, water quantity and the biological composition of aquatic ecosystems

WARNING AGAINST PLAGIARISM

ASSIGNMENTS IN THIS MODULE ARE INDIVIDUAL TASKS AND NOT GROUP ACTIVITIES.

Copying of text from other learners or from other sources (for instance the study guide, prescribed material or directly from the internet) is **not allowed** – only brief quotations are allowed *and then only if indicated as such*.

You should **reformulate** existing text and use your **own words** to explain what you have read. It is not acceptable to retype existing text and just acknowledge the source in a footnote – you should be able to relate the idea or concept, without repeating the original author to the letter.

The aim of the assignments is not the reproduction of existing material, but to ascertain whether *you* have the ability to integrate existing texts, add your own interpretation and/or critique of the texts and offer a creative solution to existing problems.

Be warned: students who submit copied text will obtain a mark of zero for the assignment and disciplinary steps may be taken by the Faculty and/or University. It is also unacceptable to do somebody else’s work, to lend your work to them or to make your work available to them to copy – be careful and do not make your work available to anyone!

Study Unit 1: ECOSYSTEMS

TIME

You will need approximately 26 hours to master this study unit.

The unit includes a day-long field trip and requires you to write an assignment on the data collected during the field trip. Instructions for the field trip and the report are to be found in the electronic folder entitled “Field work, seminars and practicals”.

MODULE OUTCOMES

References, and objectives and outcomes for each lecture (1-4), together with a summary of the content, are provided below.

LECTURE 1: Introduction

1. What is ecology?
2. The history of ecology
3. Explanation, description, prediction and control
4. Emergent properties
5. Smith’s basic principles
6. Ecology and limnology

Lecture 1: Objectives and outcomes

You should understand the following concepts and be able to write about them: explanation, description, prediction and control; emergent properties; Smith’s (1980) basic principles; the concepts ‘ecology’ and ‘limnology’.

Lecture 1: READINGS

3. Brewer 1988: the history of ecology

2. Begon et al. (1996): explanation, description, prediction and control

8. Campbell & Reece (2005): introductory ecology

32. Odum (1983): emergent properties

36. Smith (1980): some basic principles

What is ecology?

Ecology is the study of the relationships between organisms and their environments.

Greek: ‘oikos’ = the household; ‘logos’ = study, thus the study of the ‘natural household’ or the ‘natural economy’.

NB: NOT ‘the ecology’ (the discipline) but ‘the environment’ or ‘the ecosystem’

History of ecology as a science

A relatively new science:

Charles Elton (1927): first quantitative estimates of 'community' structure (Bear Island); food chains and pyramids

Eugene Odum (1953): major textbook; energy flow in Silver Springs, Florida.

Today the 'in' topic is ecosystem modelling (needs large, fast computers)

Description, explanation, prediction and control: what ecologists try to do

- describe a system (e.g. a wetland)
- explain the patterns (which species, where and how long they live, ...)
- identify and quantify the processes (what happens)
- predict what will happen in future (e.g. under conditions of climate change)
- control events (e.g. prevent encroachment of reeds, manage fisheries)

Emergent properties

Organisms represent levels of organization: a hierarchy: biosphere, ecosystems, populations, organisms, cells, genes

At each level, new properties emerge that cannot be predicted just from studying the previous level: e.g. properties of water, nutrient cycling

Some basic principles (Smith 1980)

The major unit is the ecosystem. Ecosystem processes are related to flow of energy and cycling of materials. Energy transfer is only about 10% efficient – i.e. much energy is lost (2nd Law of Thermodynamics). The major functional unit within ecosystems is the population and each plays a particular "role".

When a population reaches the limits imposed by availability of natural resources (the carrying capacity), numbers must stabilize or decline. Changes in environmental conditions represent selective pressures on populations.

Ecology and limnology (the study of fresh waters)

Some terms:

aquatic: relating to water

ecosystem: all factors that interact in a particular place

inland waters: non-marine (but water may be salty)

fresh water: non-salty

athalassic: not associated with the sea

Aquatic ecosystems include

- rivers = lotic systems = running water
- wetlands & lakes = lentic (still-water)
- lakes: permanent, too deep for plants
- floodplains: overtopping river banks
- ponds and pools: small
- reservoirs: man-made ‘dams’
- pans : non-perennial, often large
- estuaries: where the river meets the sea
- the oceans

COMPONENTS OF ECOSYSTEMS

PHYSICAL/ABIOTIC (‘inorganic’) FEATURES

e.g. temperature, altitude, distribution of water in time & space, water chemistry, substratum (the ‘bottom’)…. etc.

BIOTIC (‘organic’) FEATURES

a) PATTERNS in nature: aspects of living organisms and their byproducts, e.g. numbers and kinds of individuals; biomass; numbers and kinds of species; population structure of each species; community composition;

b) Ecosystem functioning: PROCESSES such as production / productivity, turnover etc.

‘BIOPHYSICAL’ refers to ‘the natural world’.

An organism is any living entity (e.g. a bee, a bacterium, a cow, a mushroom).

An animal is any organism that is motile and feeds off other organisms.

The environment is all the factors and conditions that influence an object.

TYPES OF ORGANISMS

- microbes: bacteria, blue-greens, fungi, algae, protozoans
- plants: trees, ferns, reeds, etc.
- animals: birds, worms, sponges, fishes, etc. …

MAJOR BIOLOGICAL PROCESSES in the ‘FUNCTIONING’ OF ECOSYSTEMS

- photosynthesis: capture of energy (CO_2 + H_2O + energy = carbohydrates + O_2)
- consumption: redistribution of energy
- respiration: use of energy: carbohydrates + O_2 = CO_2 + H_2O + energy
- decomposition: breakdown of organic material: carbohydrates + O_2 = CO_2 + H_2O + energy
- mineralisation: nutrient cycling – release of N, P, etc. from organic molecules

LECTURE 2: Rivers

1. An introduction to inland water ecosystems in general
2. Rivers as ecosystems
3. Features of southern African rivers

Lecture 2: Objectives and outcomes

To introduce the subject of rivers as aquatic ecosystems: you should be able to describe features of, functions & processes within, services provided by, rivers & wetlands; longitudinal differences down a river (and why they occur); some fundamental features of South African rivers

Lecture 2: READINGS

Chapter 4 of Vanishing Waters is the reference for this lecture.

Aquatic ecosystems are diverse: standing and running waters
large and small
permanent and temporary
old and young
salty and fresh
thalassic and athalassic (marine and non-marine)
biodiverse and depauperate (species-poor)

Rivers may be seasonal (flow every year, for only one season) or ephemeral (flow only occasionally); old (e.g. Orange/Berg system: >80My) or young (e.g. some highveld streams).

Perennial rivers flow all the time. They consist of upper reaches (usually in mountains); middle reaches (in the foothills); lower reaches (the 'mature' river nearer the sea).

Estuaries occur where the river meets the sea.

Wetlands include large valley-bottom reedbeds; floodplains; swamps with trees; seeps; temporary pools, ponds and pans; coastal lakes (no true lakes* in South Africa). (One definition of a lake is a depression filled with water and having areas too deep for rooted plants to grow.)

Inland waters vary in water chemistry: they may be hypersaline (or very dilute); very acid (or very alkaline); very turbid (or clear); very rich (or very poor) in nutrients.

Rivers as ecosystems

Rivers may be classified in various ways, e.g. by means of geomorphological features, hydrological regime or biotic features.

Some useful terms relating to rivers

benthic pertaining to or living on the bottom (noun = benthos)

emergent of plants, rooted in water but with aerial stems and/or leaves

epilithic living on the surfaces of stones

epiphytic living on the surfaces of plants

hyporheic pertaining to the region below the bed of a river (i.e. the hypothecs)

aerophyte a large, rooted aquatic plant

marginal of the edge of a river or lake

riparian pertaining to the banks of a river

Fluvial geomorphology

fluvial = with regard to flowing (i.e. rivers); geo = the Earth; morphology = (the study of) structure, form; i.e. fluvial geomorphology refers to the study of water-shaped land forms: the physical structure of river beds and banks.

Stream-shaping processes

Stream power (the force of the water) causes sediment transport; suspended sediments (mostly settle out as current speed decreases); bed material (‘hops’ during floods). Headwaters are usually erosive: bed material is usually large boulders & bedrock. Lower rivers are often depositing: bed material is usually fine sediments readily moved by water.

Rivers may be divided into longitudinal zones (Scum 1977): sediment production zone upstream, sediment deposition zone downstream. Pickup (1984): zones reflect variations in the controls of gradient, bed material, stream power potential and ability to move different-sized material.

Rowntree and Wade son (1999) developed a hierarchical model for SA rivers. Two classes of features: aerial and channel.

1. Aerial features

   Catchment: the land surface that contributes water and sediment to the river network

   Zone: areas homogenous with respect to flood runoff and sediment production

2. Channel features

   segment

   reach

   morphological unit: the basic units of channel morphology: erosional (pools) or depositional (hydraulic controls) hydraulic biotope (flow units)

Ecological implications of river zones

High-gradient reaches usually with a narrow belt of riparian trees; few aquatic plants (high shear stress); invertebrates that can withstand/avoid currents

Low-gradient reaches usually with wide, complex belt of riparian trees, instream & fringing plants, some invertebrates belonging to the 'infauna'

Hydraulic features of importance: depth; roughness; presence of boundary conditions: hydraulic 'hideaways'.

NOTE: hydrology is the study of water as a substance: water resources, hydrological cycle, etc.; hydraulics refers to the movement of water in confined spaces (e.g. pipes, river channels, sediments).

Hydrology

Rain does not fall uniformly in time. Rainfall varies in:

timing	(when it falls)
frequency	(how often it occurs)
magnitude	(how much rain falls)
duration	(for how long it falls)
predictability	(whether patterns repeat from year to year).

Other terms:

perennial	= permanent: there all the time
intermittent	= episodic: stopping & starting
seasonal	= varying predictably with the seasons
temporary	= not there all the time
ephemeral	= there for only a short time

Some features of South African rivers

SA is arid with relatively few and small rivers; river flow is exceptionally variable temporally and spatially, and greatly modified by human.

Temporal variability in SA rivers

hour-to-hour e.g. from

evapotranspiration day-to-day e.g. changes

in weather season-to-season dry vs wet

season

inter-annual periods of flood & drought

timing of wet and dry seasons

COEFFICIENT OF VARIATION (%) OF M.A.R. (= mean annual runoff)

USA	38
Canada	20
Europe	22
Victoria (Australia)	53
Australia & N. Zealand	50
Africa	25
Asia	27
South Africa	117

In southern Africa, the most important aspects of flow pattern are

- degree of intermittency
- flood frequency
- flood predictability
- flow variability

NB: systems with very variable/unpredictable flow patterns are abiotically controlled; systems with predictable (thus benign) flow patterns are often dominated by biotic interactions.

So: aquatic ecosystems are diverse in water chemistry (e.g. pH, salinity, organics, nutrients); geomorphology: shape and size; hydrology: frequency, magnitude & predictability of water supply.

Patterns in rivers: the RIVER CONTINUUM CONCEPT (Vannote et al. 1980)

i) longitudinal river ZONES form a continuum of abiotic features that determine the nature of the biota

ii) certain of these features are common to all rivers (well ...)

the mountain stream: steep gradient, turbulent flow; ‘particles’ mostly large; often canopy-covered

the middle reaches: reduced gradient, less turbulent; smaller ‘particles’; canopy confined to banks

the lower reaches: low gradient, ≈ laminar flow; soft bottom; canopy confined to banks

i.e. from upstream down, we see

DECREASES in	INCREASES in
gradient	temperature
'particle' size	[chemicals]
turbulence	discharge
no. of biotopes	stream order
flow-rate	
[O2]	

These trends have consequences for the biota of the river.

allochthonous = from elsewhere (Gr allo = other); autochthonous = from within (Gr. auto =self), chthon = ground, land; FPOM = fine particulate organic matter; CPOM = coarse particulate organic matter

SUMMARY OF THE RCC:

physical differences (gradient, flow ...)

⇓

differences in types & amount of food

⇓

differences in invert. assemblages (taxa, numbers, 'functional feeding groups')

Functional feeding groups

shredders of leaves: feed on CPOM; e.g. amphipods, crabs, stonefly nymphs

grazers: feed on living plants and algae; e.g. snails, some fly and beetle larvae

collectors of particles: deposit feeders (e.g. oligochaetes);
filter feeders (e.g. blackfly larvae, some caddis)

predators: feed on animal flesh (e.g. some beetles, caddis, dragonfly nymphs)

RCC says that the dominant feeding guild depends on the food type in greatest abundance: shredders in upper reaches; grazers in middle reaches; collectors in lower reaches; predators everywhere

Summary of the tenets of the RCC

IN THE HEADWATERS: stream narrow, canopy closed, current speeds high, spates & droughts significant, allochthonous CPOM from riparian trees → FPOM, little primary production

IN THE LOWER RIVER: stream wide, no canopy, current speed low, spates & droughts less significant than upstream, increased instream primary production, decreased allochthonous inputs, little CPOM, much FPOM (from upstream).

Adaptations of riverine organisms (see details in the readings provided)

Major physical constraints:

- currents (thus maintaining position): hooks, suckers, ballast, ...; appropriate positions for eggs
- varying hydraulic biotopes: choice of biotope; moving around the river bed
- scour from sediments: e.g. protection of soft bodies; problem with burrowing
- light: vital for plants, algae

Major chemical constraints:

- availability of oxygen: gills, haemoglobin
- suitable pH, salinity, etc.: often maternal choice of site
- nutrients: significant for plants and algae

Major biological constraints:

- availability of suitable food
- presence of predators
- presence of parasites and pathogens
- presence of competitors (e.g. alien fish)
  - NB: we know too little about these features in SA rivers!

Processes in rivers

Abiotic processes: transport of water & particulates; sculpting of rocks; scouring of the bed; deposition of particulates; accumulation of precipitates (aggradation); leaching of materials from rocks (weathering); dilution of incoming materials.

Biotic processes: photosynthesis, growth and assimilation; biological activities (respiration – e.g. in feeding); death and decomposition: liberation of elements ; nutrient cycling

Because of the abiotic and biotic processes that go on in rivers and wetlands, these systems – if intact – provide services to human beings:

"Ecosystem goods and services" provided by rivers

clean water, periodically renewed by decomposition of organic waste, physical removal of solid & dissolved waste

maintenance of the coastal zone: provision of sediments and nutrients (e.g. Orange River & Namib Desert) flooding of floodplains: provision of nutrients (e.g. the Nile R.)

transport (of water, materials and humans)

bacteria (useful for sewage treatment)

provision of living biomass (biological resources such as rice, fish, timber, reeds, game ...)

provision of water

subsistence agriculture (e.g. on floodplains)

recreation and tourism

conservation values: biodiversity

RIVERS AND CATCHMENTS

The catchment (= drainage basin, = watershed) is the ENTIRE region from which water drains into a stream. The catchment boundary (or watershed) is delimited by the highest points between catchments. So, rivers are 'drains' for the landscape. They are affected by virtually everything that happens in the upstream catchment: thus need for 'catchment management'.

LECTURE 3: Wetlands

1. Physical, chemical and biotic features of wetlands
2. Wetland types
3. Services provided by wetlands
4. Some features of southern African wetlands

Lecture 3: Objectives and outcomes

You should be able to describe features of, functions & processes within, and services provided by, wetlands; differences between different kinds of wetlands (and why these occur); some features of South African wetlands, especially related to aridity.

Lecture 3: READINGS

20. Davies & Day: introduction to wetlands

21. Davies & Day: introduction to coastal lakes

26. Maltby: functions & values of wetlands

37. Westlake *et al.*: introduction to wetlands

LAKES AND WETLANDS

Various definitions: some (e.g. Ramsar) include all aquatic ecosystems: shallow coastal systems, estuaries, rivers, lakes... The South African definition is very wide: any inland systems where soils are affected by water, either permanently or temporarily. Wetlands are usually considered to be inland (i.e. not estuarine) standing waters (i.e. not rivers) where water determines the nature of the soil & types of plants and animals. Soils are usually hydromorphic: affected by water (grey, mottled); emergent vegetation is usually extensive.

Lakes are aquatic ecosystems too deep for rooted vegetation (except at the margins). Ramsar defines lakes as water bodies with <30% of area covered by plants; total area >8 ha (or water >2m); salinity (derived from the sea) <0.5g/l (!!)

NOTE: 1. Wetlands are often a stage in the 'evolution' or aging of lakes!

2. We have only one 'proper' lake (Lake Funduzi, Venda) in South Africa but lots of coastal lakes (most, or al, of which are relict estuaries).

In southern Africa many wetlands are not perennial: they are seasonal, temporary or ephemeral; may be very tiny; often with no wetland plants; soils sometimes not hydromorphic.; such wetlands are of very great biodiversity value.

Physical features of wetlands

Low-lying in the landscape; accumulate water: hydrological régime varies from system to system; fed by rain, groundwater and/or river; aggrading/depositing: accumulate sediments.

Biotopes: open water; benthos (usually soft; may be rocky in temp. wetlands)

Vegetation: marginal, floating and submerged.

Chemical features of wetlands

Accumulation of organics: peat; decomposition extensive; deeper water & bottom sediments usually anoxic (which is why soils become grey, mottled); not always true for temp. systems). Wetlands usually generate methane; nutrients accumulate, usually stored in bottom sediments. Wetlands as 'sinks' for carbon???

Some wetlands are very saline, very acidic or very alkaline.

NOTE: Physical differences within lakes / wetlands are usually **vertical** (not longitudinal, as in rivers): gradients in e.g. light (in euphotic zone only), temperature (bottom water colder in stratified lakes), nutrients more in bottom waters, oxygen less in bottom waters (wetlands are seldom very deep.)

Biological features of wetlands

Types of organisms are (mostly) crustaceans; fewer immature insects than in rivers; lots of adult beetles and bugs (and some immature forms); flatworms; snails and clams.

Invertebrates are adapted to life on marginal vegetation, in the plankton or in sediments. Oxygen tensions are usually low & many small wetlands dry up annually.

Classification (typing) of wetlands

Systems differ from each other in permanence, hydroperiod, degree of water movement, geomorphology, position in the landscape, water chemistry, type of substratum, depth, marginal and littoral vegetation, invertebrate and algal assemblages, size .....

Wetland types include:

swamps (standing water and trees)

marshes (standing water)

floodplains

reedbeds (= 'vleis', dambos)

temporary ponds and pools

pans (large, temporary, often saline)

coastal lakes (mostly relictual estuaries)

bogs, mires (usually with *Sphagnum* – peat moss)

tarns (high-altitude lakelets).

Various classification systems are available e.g. Cowardin (USA), Semenuik & Semenuik (Australia). The South African classification (= wetland typing) system, developed by Ollis *et al.* for use with remote- sensing data, is based on hydrogeomorphic units: land-form and hydrology. (NB: this is NOT the same as the DWAF 'management class' classification for rivers.)

Most significant services provided by wetlands

Hydrological control: reduction of floods, storage of water, recharge of aquifers

Clean water from filtration of suspended particles (including bacteria); removal of nutrients from effluents; loss to sediments; decomposition of organic waste **NB**: constructed wetlands are widely used for sewage treatment.

Some features of southern African wetlands

Evaporation > precipitation: no lakes except L. Funduzi (currently permanent), L. Chrissie etc. (which sometimes dries up and is highly modified by human activities), and many coastal lakes.

The land is old, eroded: few depressions (unlike northern hemisphere: glacial activity).

The Okavango swamps are on associated with African rifting.

Etosha Pan is only ephemerally wet.

W Cape temporary wetlands result from rising water table in winter (soils are generally not hydromorphic).

Coastal lakes (see also lecture 4 on estuaries)

e.g. KZN – L. Nhlanga, L. Sibayi & others

W Cape – upper Wilderness lakes; de Hoop Vlei; Cape Flats vleis; Wadrif Soutpan

Coastal lakes are mostly old estuaries: implies aridification (or abstraction of water through dams or directly), reduced river flow. Other estuarine lagoons have less & less contact with the sea (because of damming): often 'blind' estuary mouths e.g. Bot River, Verlorenvlei.

Biotas of coastal lakes: mostly freshwater zooplankton; some 'trapped' estuarine forms (some from thousands of years ago); 'blind' estuaries, when open, may be nursery areas for marine fish.

LECTURE 4: Estuaries & coastal lakes

1. Physical and chemical features of estuaries
2. Tides.
3. The estuarine biota
4. South African estuaries.

Lecture 4: Objectives and outcomes
You should be able to describe features of, functions & processes within, and services provided by, estuaries; some features of South African estuaries.

READING
16. Clapham (1973): estuaries
21. Davies & Day (1998): introduction to coastal lakes
27. Molles (1999): estuaries

What is an estuary?
Various technical definitions: essentially the area where river and sea meet
- normally confined within a channel
- may extend beyond the land (e.g. the Amazon River; sometimes even the Orange R.)

Features of estuaries
- inland/coastal transitional zone
- tidal: water chemistry varies with the tide:
    - salinity 0-35 g/l (TDS) or PSU (practical salinity units)
    - nutrients higher in river water
  - temperature higher or lower
  - currents vary with the tide in velocity and in direction
    - maintain the channels
  - gradients (tidally moderated) in water chemistry: chemoclines:
    - a longitudinal salinity gradient from river to sea
    - a vertical chemocline: bottom saline water overlain by less dense river water
    - longitudinal & vertical gradients in temperature, turbidity ...

Tides are caused by the moon:
highest ('spring') tides when the moon closest to or furthest away from the earth: new and full moon (i.e. every 14 days); biggest tidal range
smallest tidal range ('neap tides') when moon waxing and waning; smallest tidal range

Vertical tidal reach varies from ≈ 100mm (Med.) to > 10m (Bay of Fundy, Canada)

Timing of tides (NB: important to know timing of tides for sampling in estuaries!)
tides every 12+ hours
advance by approx an hour a tide
full cycle = 2 weeks (14 days).
timing of tides changes up the estuary and around the coast

Estuarine habitats
tidal: sand- and mudflats: infauna (very productive & biodiverse)
salt marshes(halophilic plants) "
deep channels: phyto- & zooplankton, fish

Estuaries are 'nursery' areas for fish, many invertebrates with planktotrophic larvae (larvae that live in and feeding on the plankton).

Some biotic features of estuaries
Organisms must be able to withstand:
changes in salinity from fresh water to sea water and back (0-35 g/l salt)
from inundation to desiccation and back every 12+ hours
changes in direction and speed of current
tidal cycles: not in synchrony with day/night or seasonal cycles
BUT: plants have lots of nutrients
animals have excellent food supply.

Kinds of organisms commonly found:
bacteria and fungi (as always)
phytoplankton (many dinoflagellates)
phytobenthos (many diatoms)
few larger algae (substratum often too soft)
saltmarsh angiosperms (e.g. *Juncus, Spartina*)
infauna: very productive, biodiverse (mostly polychaetes, molluscs, crustaceans)
zooplankton: huge variety
fish, both resident and migratory

Functioning: processes in estuaries

a) Abiotic processes
currents driven by river flow
tidal exchange
deposition of sediments from upstream

b) Biotic processes: as in other aquatic ecosystems

Goods & services provided by estuaries
Natural resources: fish (estuaries are nursery areas for many marine fishes)
shellfish (e.g. oysters, mussels, prawns) harvested and farmed (aquaculture)

Provision of sediments to the coastal zone (maintenance of beaches)

Provision of nutrients to the coastal zone (crucial for inshore fisheries)

Recreation & tourism

Some features of South African estuaries
Knysna the largest, most productive, most biodiverse
Durban Harbour, Richards Bay both severely damaged by modification to form ports
West coast estuaries are very unproductive: why, when the offshore zone is productive? (Maybe because most rivers non-perennial)
The Orange is heavily dammed: little sediment, few nutrients reach the estuary

Effects of dams on estuaries

- less water: mouth tends to close
- less nutrient: estuary & coastal zone less productive
- less sediment: dynamics of channels

Open estuaries usually have rocky headlands (e.g. Knysna) or perennial river flow (many in KZN). As river flow decreases, estuaries tend to become seasonally 'blind':

- they are known as 'temporarily open-closed estuaries' and are common features in SA
- more and more water needed to open the mouth; later the 'open' state becomes unusual. If a lagoon is formed, the water slowly becomes fresher & ultimately a **coastal lake** is formed: e.g. lake Sibaya, Soetendalsvlei, Groenvlei, de Hoop Vlei

Examples of often-'blind' estuaries

- Verlorenvlei (w. coast): also a causeway across the mouth
- Diep River
- Bot River
- Touws River (Wilderness)
- Sundays River ....

NB: think of effects of global warming on estuaries already perturbed by reduced water availability.

SELF-EVALUATION QUESTIONS: Study Unit 1

What is meant by "emergent properties", and how does this concept relate to ecosystems?

What are the major biological processes that take place in ecosystems and how do they relate to each other?

What are the major services provided by rivers & wetlands? Do estuaries provide any additional services (i.e. those not provided by rivers or wetlands)?

Describe the major differences in biophysical conditions in upper, middle and lower reaches. of a river, and explain why these differences occur.

Describe the major different kinds of wetlands, explaining what biophysical conditions cause these differences and what the consequences are for the biotas of each.

Contrast the abiotic conditions in wetlands from arid and mesic areas and explain how these differences are reflected in the kinds of organisms living in each.

It is said that estuaries are ‘driven by the tides’. What is meant by this phrase? Provide examples of ways in which estuaries are ‘driven by the tides’.

SUMMARY: Study Unit 1

Lectures 1-4 describe the different kinds of aquatic ecosystem (rivers, wetlands, coastal lakes and estuaries) and the physical, chemical and biological components that make up these ecosystems. The field trip provides you with practical experience in the field. The next Study Unit looks at the principles of ecology: abiotic features of aquatic ecosystems; how organisms are adapted to their environments; processes within ecosystems; biodiversity and biogeography.

NOTE: it is important to ensure that you have reached the required outcomes for this study unit by successfully answering the self-evaluation questions before you move on to the next study unit.

Study Unit 2: PRINCIPLES OF ECOLOGY

TIME

You will need approximately 33 hours to master this study unit.

MODULE OUTCOMES

References, and objectives and outcomes for each lecture (5-8), together with a summary of the content, are provided below. This Study Unit includes the delivery of a seminar by each student. Details and guidelines are provided in the electronic folder called “Field trip, seminars and practicals”.

LECTURE 5: Physical and chemical features of inland waters

1. Concept of ‘water quality’
2. Physical attributes of inland waters
3. Chemical constituents of inland waters

Lecture 5: Objectives and outcomes

You should understand and be able to describe and discuss the effects on the biota of the major physical attributes of water and aquatic ecosystems and the more important chemical constituents of water in aquatic ecosystems.

Lecture 5: Reading

5. Brewer (1988): abiotic factors
15. Clapham (1973): aquatic ecosystems
22. Davies & Day (1998): Chapter 8, pollution & water chemistry
33. Reed & Wood (1976): water

Physical attributes important in water are: temperature; density; current speed; hydraulic conditions; light; sediments, turbidity and TSS; and dissolved gases

Important chemical constituents of water are:

major ions (Na+, K+, Ca++, Mg++, Cl-, SO4--, HCO-)

hydrogen (and therefore pH)

nutrients (especially N, P, K, Si)

minor ions (e.g. F-, Fex+)

(also numerous organics, both natural and of human origin)

WATER CHEMISTRY ≡ chemical constituents: what? how much (concentration, load)?

'PHYSICOCHEMICAL' CONDITIONS

= physical and chemical conditions

= [chemical constituents] + magnitudes of physical attributes.

Water QUALITY = suitability for use (not the same as water chemistry or physicochemical conditions)

Water itself (see doc 33) has valuable properties relative to other liquids:

- molecules form dipoles: ionic; solvent
- high specific heat: temperature buffer
- high latent heat of vaporization: low evaporation rate
- densest at 4◦C: ice floats
- high surface tension: small objects caught in the meniscus or can walk on water
- transparent: lucky for plants & algae!

Temperature determines

- rates of chemical reactions (most biological reactions double with a 10oC rise in temperature
- cues for spawning, migrating, hibernating
- density of water
- solubility of gases (lower at higher temperatures)

Current, hydraulics determine the amount of energy required to stay in place. Turbulence allows aeration and loss of CO2; suspends sediment particles; provides hydraulic biotopes

Light is necessary for photosynthesis but reduces rapidly with depth It is necessary for animals that search visually for food or that need to escape predators.

Sediments, turbidity and TSS

SUSPENSOIDS: suspended ⇆ sedimented particles

TURBIDITY ≡ physical interference with the passage of light (measured as NTUs: "nephelometric turbidity units")

Particulate material consists of inorganics (silt, clay, floccs, ...) + organics (dead and living) = Total Suspended Solids: TSS. Units: mass per unit volume (e.g. mg l-1)

Dissolved gases

oxygen: product of photosynthesis; (plants AND animals)

carbon dioxide: used up in photosynthesis, produced during respiration ammonia (NH_3): excretory product of many aquatic animals; highly toxic at high pH

Total Dissolved Solids (TDS) (≈ salinity ≈ conductivity) = major & minor inorganic ions + soluble organics (ionic or not)

Major ions = cations Na^+, K^+, Ca^{2+}, Mg^{2+}, H^+ and anions Cl^-, SO_4^{--}, HCO_3^-, CO_3^{2-}

Minor dissolved constituents include Fe, F, Si, ...; numerous organic compounds; trace elements (e.g. heavy metals); nutrients (esp. N, P) and many others.

TDS, salinity & conductivity

TDS = total dissolved solids (mg l^{-1}, g l^{-1}): an operational definition: 'dissolved' substances are those that can pass through a 0.5µm sieve.

Salinity = specific for sea water; units were g kg^{-1} (= parts per thousand: ‰), now a dimensionless number, measured as conductivity and sometimes with the unit PSU (practical salinity units).

Conductivity is a measure of the ability of water to conduct an electric current: proportional to the number of ions in solution; unit is S (Siemens) per unit distance, e.g. µS cm^{-1}, mS m^{-1}; 10 µS cm^{-1} = 1mS m^{-1}. Conductivity measurement is temperature-sensitive.

Conductivity in mS m^{-1} x 6 ≈ TDS in mg l^{-1} (approx. 5.5 in s-w Cape, approx. 6.6 in Gauteng).

Σ inorganic ions + organic ions = conductivity

\+

dissolved non-ionic organics (+ small flocculants) = TDS

Major causes of salinization (sometimes called "mineralization"): irrigation (e.g. Berg, Breede, Fish rivers); sewage return flows (e.g. Vaal River)'; removal of trees (e.g. South and south-western Australia).

pH

pH is the negative $\log_{10} [H^+]$; influenced by (strong) mineral acids and alkalis, (weak) organic acids, buffering system (usually HCO_3^- / CO_3^{2-}). In the Western Cape fynbos-dominated FYNBOS systems: leachates from plants include weak organic acids; natural waters are very unbuffered so in undisturbed systems pH level are very low (as low as pH 3.4!)

pH and buffering in fresh water

Under natural conditions, pH can be low if lots of CO_2:

$CO_2 + H_2O \rightleftharpoons H_2CO_3$
(carbonic acid)

If salts are present in solution, buffering occurs:

$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^{2-} + H+ \rightleftharpoons CO_3^{2-} + OH-$

bicarbonate carbonate

Equilibrium tends towards CO32- in the presence of bases (e.g. Na, Ca), at high pH (>8) and as a result of photosynthesis. The final equilibrium (and final pH) depend on the quantity of base present; the extent of photosynthetic activity; [weak organic acids], [strong inorganic acids].

Alkalinity is a measure of the amount of acid needed to neutralise a sample of water; acidity is the amount of alkali needed to neutralise a sample of water.

Nutrients (more details in Lecture 9)

"Limiting nutrients" are N, P, K (& Si for diatoms). Increased concentrations result from human activities: sewage or purified sewage effluents; fertilisers (agri-, horti-, aquaculture); feed-lots, etc.

Natural concentrations of nutrients in water are at µg l-1 (parts per billion) levels SO CHANGES IN CONDUCTIVITY ARE NOT REFLECTIONS OF CHANGES IN [NUTRIENTS]!!!

What 'causes' water chemistry?

GEOLOGY: lithology (kinds of rocks); age / degree of weathering

CLIMATE: amount of rainfall; rate of evaporation

BIOTA: vegetation: evapotranspiration; uptake of nutrients; leaching from litter;

animals: excretion

LAND-USE: agriculture: nutrients; erosion (turbidity); salinization

urban: stormwater, garden runoff; sewage return flows.

CONTENT OF LECTURE 6: autecology – adaptations to life in fresh water

1. Adaptation to environment
2. Procurement of food
3. Respiration
4. Maintenance of water/salt balance, removal of metabolic wastes
5. Growth, reproduction, dispersal and life cycles

Lecture 6: Objectives and outcomes

You should understand and be able to describe and discuss the following adaptations of freshwater organisms: reproduction and life cycles; dispersal; feeding; osmoregulation and nitrogen excretion; respiration.

READING
1. Barnes & Mann (1980): autecology
4. Brewer (1988): autecology

Autecology is the study of individuals in relation to their environments: the adaptations ('coping mechanisms') that allow them to live where they do.

All organisms must 'solve' the same problems of existence:
Procurement of food and oxygen
Maintenance of water/salt balance
Removal of metabolic wastes
Growth and reproduction
Dispersal

Body 'design' is related to four factors:
The type of environment (*terrestrial*, *marine* or *freshwater)*
The size of the organism
Its mode of existence (e.g. planktonic or benthic; parasitic or free-living)
The constraints of its genome (what its genes allow it to do).

Adaptations particularly important for life in fresh waters
Freshwater ecosystems are variable in time and space:
streams vary greatly in turbidity, velocity, depth, discharge
wetlands fluctuate in oxygen, turbidity and availability of water
large lakes vary with depth and mixing patterns.
drought and flood
Organisms can only survive fluctuating environments if they have the relevant adaptations (e.g. a desiccation-resistant stage in the life cycle; an ability to survive low [DO])

Some other features of freshwater environments make them favourable places to live – e.g.
water aids buoyancy, provides support
desiccation not a problem when water is present (can grow larger: limbs need not be strong, skins need not be waterproof)

Feeding
Adequate nutrition depends on
- availability of suitable food
- ability to find appropriate food
- appropriate mouthparts for manipulating and ingesting the food
- gut adapted to particular type(s) of food.

From an ecological point of view, the concept of functional feeding groups (FFGs) is valuable:
- avoids needing to know details of feeding habits of each species in an ecosystem
- examines trophic relations according to food type (see more detail in lecture 3).

Osmoregulation and excretion
Osmoregulation is the regulation of the concentration of salts and water within the body.

The low salt concentrations in fresh waters create difficulties in maintaining salt/water balance:
- osmotic pressure of body fluids higher than that of the external environment: water tends to diffuse inward – 'leaky ships'
- problem of getting rid of excess water: most freshwater organisms pump out excess water (i.e. they osmoregulate).

The tolerance range of an animal with regard to salt content of the water depends on an organism's physiological ability to cope:
- some animals allow the salt concentration of body fluids to fluctuate with salinity
- some expend energy in pumping out excess water
- fishes have relatively low salt concentrations in the blood (marine fishes swallow sea water and pump out excess salts).

Excretion is the voiding from the body of soluble waste products (i.e. not faeces), particularly nitrogen-containing substances.

Most *aquatic* animals excrete ammonia: it is very toxic, but very soluble.
Terrestrial animals excrete either
urea (not toxic, fairly soluble) or
uric acid (highly insoluble, so does not need much water for voiding): insects, reptiles, birds and mammals).

Respiration
Most aquatic plants and animals respire using oxygen. Oxygen is poorly soluble in water, so aquatic animals increase the surface area of their respiratory tissues (i.e. have gills) and maximise the rate of flow of oxygenated water past them (they may flap their gills, or live in flowing water).
Many aquatic invertebrates take their oxygen directly from the air by coming to the surface and trapping air under wing covers, legs or patches of hydrophobic hairs on their bodies.
Some (e.g. many dipteran larvae) gulp air directly through breathing tubes.

Reproduction, life cycles and dispersal
The variety of reproductive and life-history adaptations is astonishing. The following is a very brief account of some of the more obvious alternative ways in which the next generation is produced by aquatic invertebrates and fishes.

Different taxa may have different immature stages (larva, pupa) which, together with the egg and adult phases, may allow exploitation of different food resources and escape from unfavorable conditions such as ice, floods, desiccation etc.

Life cycles may last for weeks or years:
Slow seasonal *univoltine* life cycles take 1 year to complete (usually in cooler climates);
Several fast life cycles may be completed in a year, usually in warmer climates or where food is abundant.

Eggs may diapause for long or short periods and maturation may be rapid or slow.
Non-seasonal: semi-voltine life cycles are often seen in oligotrophic systems (low nutrients – e.g. western Cape): individuals of several life stages may be present at one time, resulting in a series of overlapping generations.
Reproduction may be asexual or sexual:.

Advantages of asexual reproduction:

- rapid (can take advantage of brief periods of favorable conditions -e.g. water fleas in temporary ponds)
- low cost in terms of time and energy (no courtship, sexual selection, mating)

Advantages of sexual reproduction:
- genetic variability among offspring (asexual reproduction allows very little genetic variation): vulnerable to population crashes / extinctions

Best of both worlds: asexual during good times, sexual under harsh conditions (cladocerans; many ostracods, rotifers, some branchiopods).

Fertilization may be internal or external. External fertilization is commonest in the sea, a favourable environment for eggs and sperm. 'Broadcast' spawning: eggs and sperm released into the sea, where fertilization takes place. It is uncommon in lakes and rivers because of the unidirectional flow of water in rivers, the paucity of planktonic food and osmotic problems in fresh waters. Broadcast spawning usually results in larvae that are planktotrophic, feeding and growing in the plankton before settling down as adults in the benthos. Planktotrophic larvae are a means of dispersal of new generations away from the parental home

The allocation of resources to individual eggs also varies greatly. At the extremes, there may be large numbers of small, poorly protected eggs ("r" selection) or very small numbers of large, well-protected eggs ("K" selection) with considerable parental care (the extreme is the birth of "miniature adults" – e.g. humans).

Dispersal of offspring
Often limited in fresh waters.
- adult (rather than larval) insects
- nauplius larvae in many crustaceans
- many 'K' selected species have very limited dispersal
- decaopd crustaceans (crabs, shrimps, prawns) carry eggs on pleopods
- male belostomatid bugs carry eggs on their backs
- cichlid fishes are mouth brooders (limited dispersal, but much parental care).

Staying in place: living in rivers
Organisms living in running waters may be swept downstream. Adaptations:
behavioural: avoidance (e.g. living under stones or in back-waters)
morphological: body shape (streamlining)
head shaped like a spoiler, decreasing lift
cerci acting as rudders
flattened bodies: less lift, drag, turbulence
attachment devices (e.g. claws, suckers, silk nets, muscular foot)

Staying in place: living in standing waters
Standing waters can be deep – no flow but problems with maintaining vertical position, so buoyancy mechanisms
e.g. swim bladders (fish)
gas / oil bubbles (algae)
gas in lacunae (macrophytes)

Vertical migration is exhibited by most pelagic planktonic species; it is an active process: migrants generally found in deep water by day, migrating upwards as dusk falls.

Adaptive significance of vertical migration:

avoiding predators
following food (usually algae)

Invertebrate drift in rivers

Drift is "downstream transport, by the current, of benthic animals usually living in or on the bottom". Several categories have been distinguished:
catastrophic drift: pulsed, due to disturbance
behavioural drift: periodic, 'intentional'
constant drift = continuous, probably accidental

Adaptive advantages of drift: finding new
resources counteracting upstream
migration dispersal
avoiding competition for food / space
post-flood drift: re-colonisation

LECTURE 7: Community ecology

1. Trophic relations
2. Competition
3. Emergent properties of communities
4. Effects of disturbance on emergent properties

NB: in ecology (as opposed to everyday life), "community" refers to all the species in an ecosystem and "population" refers to all the individuals of a species in a particular area.

Lecture 7: Objectives and outcomes

To provide an understanding of the concepts of trophic relations, competition, biodiversity, persistence, resistance and resilience. You should be able to describe these concepts in simple terms and explain why they are important in understanding the functioning of aquatic ecosystems.

Lecture 7: READING

10. Campbell & Reece (2005): community ecology
12. Clapham (1973): energy, food chains
14. Clapham (1973): communities
19. Davies & Day (1998): community structure in rivers
29. Molles (1999): food webs, keystone species

The goals of community ecology are to understand:

- patterns of species assemblages in nature: composition, diversity, trophic organisation, stability in nature
- the processes that determine these patterns.

Processes at a community level

Trophic relations

Photosynthesis and respiration: production of biomass (i.e. food); requirement for oxygen: plants photosynthesise (take in carbon dioxide and release oxygen) *and* respire (take in oxygen and release carbon dioxide); animals only respire.

Consumption: animals and fungi are *heterotrophs*: they feed on organic material, respire and decompose; plants (primary producers) are fed on by primary consumers (herbivores), fed on by secondary, tertiary, … consumers, etc. **Trophic relations refers to "**who eats whom".

NB: energy transfer from trophic level to trophic level is only about 10% efficient – thus food chains of limited length.

Significance of decomposition and mineralisation**:** removal of dead plants, bodies, etc., 'resetting' of nutrient levels (mineralization) biogeochemical cycling (see lecture on ecosystem processes).

The flood-pulse concept

Focus on biotic response and processes on floodplain: regular pulses of inundation and drying on floodplains are *the* driver of ecosystem structure and functioning. *Lateral* exchanges of water, nutrients & organisms are more important than longitudinal ones: river and floodplain form an ecological unit with high production (large biomasses of plants and animals) thus productive feeding grounds and rich soils for cultivation.

Competition

Competitive exclusion, competitive equilibrium

Competitive exclusion: when 2 or more species or organisms share a resource in short supply relative to requirements, competition may (will?) occur between individuals. Result is reduced survivorship because of increased energy expenditure, decreased intake of resources and thus reduced contribution to future generations.

Interspecific competition of two kinds: exploitation competition (indirect interaction between species / individuals as a result of competition for a limiting resource (e.g. for space on a rock); interference competition (direct engagement – e.g. limpets overturning others).

Intraspecific competition: individuals compete with each other; effects of intra-specific competition are density-dependent.

The competitive exclusion principle: “If two competing species co-exist in a stable environment, then they do so as a result of niche differentiation”; if no such differentiation, one of the two species will eliminate the other.

IS competition actually significant? The “ghost of competition past” is sometimes invoked – but no direct observations. Why? The speed of competitive elimination estimated at ≈ 30-70 generations: studies so far no more than “snapshots”. So ecological and/or evolutionary forces may be at work: elimination of species *vs* changing species traits (niche differentiation). How do we explain the large no. of species in many ecological communities, esp. uniform ones? e.g. the “paradox of the plankton” (Hutchinson) or the ‘consortium’ of microbes decomposing wetland peat.

Emergent properties of communities and effects of disturbance on these

Biodiversity

Why are there so many species – what aspects of the environment encourage diversity? Some combination of environmental heterogeneity, historical effects (dispersal) biotic interactions, intermediate disturbance.

Disturbance

What is disturbance? One definition is “any relatively discrete event in time that opens up space that can be colonized by individuals of the same or different species” (Hm: this is a very specific definition.) The **intermediate disturbance** hypothesis: greatest diversity at intermediate levels of disturbance. *Predictability* is an *attribute* of the disturbance régime: predictable perturbations are not ‘disturbance’. *Evolutionary* adjustments to a type of disturbance may be reflected in biological attributes that confer differential survival and persistence in the face of that régime.

Persistence, resilience and resistance

Persistence: continuation over time (even in the face of disturbance); resilience: ability to recover after a disturbance (depends on biological characteristics and availability of refugia); resistance: capacity to avoid change (i.e. persistence through a disturbance event): depends on ability to tolerate change.

Are communities stable in the face of disturbance?

Persistence in species composition: the extent to which the species complement of an assemblage remains unchanged over a time period encompassing at least one complete population turnover; persistence in species ranking: the relative constancy of species densities (i.e. their ranked abundance relative to other species in an assemblage) over time.

LECTURE 8: Biodiversity and Biogeography

1. Biodiversity: what it is, why it matters
2. Convention on Biological Diversity
3. Biogeographical patterns and how they are formed

Lecture 8: Objectives and outcomes
You should understand the concepts of biodiversity and biogeography, be aware of broad patterns of both in South African aquatic ecosystems, and explain why and how they are important in the conservation and management of aquatic ecosystems.

READING
10. Campbell & Reece: community ecology
14. Clapham: communities
31. Molles: biogeography

Biodiversity
What is biodiversity? It includes all of the following:
- diversity of types (taxa)
- number of types
- genetic diversity
- ecosystem diversity.

Definition of biodiversity by the Convention for Biological Diversity (1992): "the variability among living organisms from all sources including, *inter alia,* terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"

Why study biodiversity? Curiosity; academic interest: as it contributes to ecology and evolution; conservation: management of the biosphere

Why does biodiversity matter (if it does)?
Provides ecological stability (sustainability of the Earth); efficient biogeochemical cycling (e.g. decomposition, production of O_2); useful species (medicines, crops ...); indication of biological integrity ('ecosystem health'); aesthetics (pleasure, beauty); the precautionary principle; heritage (for future generations): also medicines, crops, ...); ethics.

Loss of biodiversity goes beyond loss of species: it includes the loss of functions up and down the hierarchical scale:

"This is the assembly of life that took a billion years to evolve. It has eaten the storms – folded them into its genes – and created the world that has created us. It holds the world steady." (Edward O. Wilson, 1992). Living organisms are the "savings bank" of Earth's successful genes, holding some 3.5 billion years' worth of "solutions" to the "problems" of living on this planet.

'BIOdiversity' as the diversity/variety of life. How do we distinguish living from never-living things? from dead things? How do we define 'life'?

Living organisms exhibit STRUCTURAL PROPERTIES (complexity of structure; organic compounds); FUNCTIONAL properties (energy flow – conversion of sun's energy to complex tissue); sensitivity & response to stimuli; homeostasis (regulation: feedback); assimilation/growth); DEVELOPMENTAL properties (development from egg/seed to adult; reproduction; transfer of information *via* DNA; evolution by natural selection).

Plants and animals
Fundamental characteristics of plants: autotrophic (photosynthetic); sessile (do not move); have cell walls.

Fundamental characteristics of animals: heterotrophic (no chloroplasts); motile (nerves, muscles), often mobile; no cell walls.

NB: Writing species names
Homo sapiens sapiens or *Homo sapiens neanderthalensis* or *Zea mays*
OR
H. sapiens, H. sapiens sapiens, Z. mays.

NB: 1. ALWAYS write the binomial *in italics* or <u>underlined</u>.

2. Scyphozoa, Diptera (Capital first letter and 'Latin' endings) BUT a scyphozoan, a dipteran larva ('common' names with lower-case first letter and 'English' ending).

Species: are they real entities??
Distinguished on the basis of morphology (outer structure), anatomy (internal structure), physiology (internal workings), biochemistry (especially DNA), biogeography. -

How many species are there on Earth? Robert May (1992): no centralised index of species; rate of speciation 'about a million times' slower than rate of extinction.

The Convention on Biological Diversity (CBD) is an international treaty, adopted at the Earth Summit, Rio de Janeiro, 1992 & entered into force Dec. 1993. (The USA has still not signed!)

MAIN GOALS of the CBD
Conservation of biological diversity; sustainable use of its components; fair and equitable sharing of benefits arising from genetic resources – i.e. development of national strategies for the conservation and sustainable use of biodiversity (thus a key document regarding sustainable development).

CBD issues include measures and incentives for the conservation and sustainable use of biological diversity; regulated access to genetic resources, including Prior Informed Consent of the party providing resources; education and public awareness; national reporting on efforts to implement treaty; commitment to implement the promises made when signing the treaty. More recently, also a protocol for transboundary movement of genetically modified organisms.

Keystone species
A keystone species can be defined as "a functional group without redundancy": no 'replacements'; loss may result in major changes in community structure and/or ecosystem functioning. This emphasises the importance of having >1 species capable of carrying major processes or providing important links in the food web (e.g. loss of elephants: bush encroachment; algae in streams).

Biogeography
Biogeography attempts to document and understand spatial patterns of biodiversity over the earth. Three fundamental processes are involved:
1. Evolution: irreversible changes in the genetic composition of a population;
2. Extinction: species becoming permanently eliminated;
3. Dispersal: the movement of organisms away from their points of origin.

Freshwater habitats have probably existed since precipitation (rain) first fell on the Earth. Rivers are much longer-lived than lakes or wetlands. River systems can change radically:

deposition and erosion of the channel; uplift and erosion of uplands. Large rivers rarely disappear: some have been in continuous existence for tens of millions of years (e.g. Berg/Orange system >80 My old). Biological evidence: rivers include representatives of almost all taxonomic groups found in freshwaters; several invertebrate taxa occur only or mostly in running waters (e.g. many insect groups).

Most existing lakes are geologically very young (<0.1 My); occupy basins formed by ice masses or glacial erosion during recent ice ages.

Ancient lakes
About 10 existing lakes are much older (>>1 million years). Most occupy tectonic basins; they are very deep (>1000 m) and are 'hotspots' of speciation. e.g. African Rift Valley lakes: Tanganyika (≈ 20 My); Lake Baikal (≈ 30 My).

Origins of the freshwater biota
Plants and animals evolved in the sea. Two main components of the freshwater fauna and flora: those that entered fresh waters from the sea (e.g. flatworms, oligochaetes, molluscs, crustaceans); those that re-entered from the land (e.g. insects, flowering plants, air-breathing snails, birds, mammals, reptiles. A few groups (e.g. bony fishes) originated in freshwater systems.

Invasion from the sea was along two major routes: direct upstream migration from estuaries, or *via* the littoral zone, onto land, then invading aquatic habitats. Some groups (e.g. bony fish) re-invaded the sea from fresh waters (bony fish have blood salt concentrations lower than expected for marine conditions).

Natural selection
The process whereby organisms have become adapted to their environments: the basic process of evolution.
Charles Darwin's theory of evolution by means of natural selection proposes that:

- individuals in a population are *not identical*: they vary in size, rate of development, response to temperature etc.
- much of this variation is *heritable*
- not all individuals survive to reproduce: individuals better 'fitted' to their environments produce more offspring, who in turn inherit their parent's 'fit' genes and so in turn live to reproduce.

The number of descendants left by an individual depends largely on *the interaction of the individual and its environment* (including other organisms).
NB: organisms are *not designed for*, or *adapted to*, the present or the future – they are consequences of forces ('natural selection') acting in the past.

Some reasons for present-day distribution patterns

Tectonic movements
The curious distribution of organisms between continents led biologists such as Wegener (1915) (and the South African Alexander du Toit) to suggest that the continents themselves must have moved at some stage. This was vigorously denied by geologists until geomagnetic measurements reflected the same apparently wild explanation. We now know that while major evolutionary developments were occurring in the plant and animal kingdoms, populations were being separated and land areas were moving across climatic zones. The last major event was the splitting-up of Gondwanaland in the Cretaceaous:

- South Africa split off from east Antarctica
- then New Zealand split off from west Antarctica
- later, Australia and east Antarctica split off from South America and west Antarctica

- Africa then connected with Laurasia (Europe).

Climate change
Changes in global climates have occurred over shorter periods that the tectonic movements of the Earth's crust. Relatively rapid climatic and geological changes had profound effects on world's biotas. Present distributions of species largely reflect phases in recovery from past climatic shifts. The Pleistocene Ice Ages in particular played an important role.

Change in climate affects the shape and extent of dry land – primarily through changing sea levels. Rates of climatic change varied: accelerated in the Tertiary, culminating in "Ice Ages": cyclic periods in Quaternary of 100 000, 10 000 years and less.

Vicariance
Vicariance is defined as "the separation of a population of organisms by a geographic barrier such as a mountain or a body of water, resulting in differentiation of the original group into new varieties or species."

Allopatric speciation: speciation when physically isolated populations become differentiated to the point that they can no longer interbreed

River capture: vicariance in action
River capture: one river or stream "captures" or intercepts part of another – a natural event.
The two most common causes are:
- a catastrophic geological event (e.g. an earthquake causing large-scale crustal deformations)
- erosion: the course of one river moves laterally and eventually cuts into the course of another.

Present-day patterns of distribution of southern African freshwater forms
Various patterns are shown by examining different groups of taxa. For most taxa, the following biogeographical areas can be distinguished
- Cape / fynbos-related: highly endemic fauna and flora of the Cape Floristic realm (CFR)
- Afro-montane (north to the Ethiopian highlands)
- Afrotropical: sub-Saharan Africa, including the arid west of southern Africa, and the highveld and savannah.

Each student in the class will be expected to present a ten-minute seminar on a relevant topic. Details are provided in the electronic folder entitled "Field trip, seminars and practicals".

SELF-EVALUATION QUESTIONS: Study Unit 2

What is meant by "persistence", "resistance" and "resilience" with regard to biological communities?

What are some of the "emergent properties" of aquatic ecosystems?

What is the relationship between salinity, TDS and conductivity?

What are the major nutrients in fresh waters, and why are they said to be “major”?

Explain why biodiversity is important in the functioning of ecosystems.

What is osmoregulation and why do freshwater organisms need to be able to osmoregulate?

What are tectonic movements and why are they of significance in the study of biogeography?

What is the significance of the Convention on Biological Diversity?

SUMMARY Study Unit 2

Lectures 5-8 discuss the processes that go on in aquatic ecosystems with a view to understanding the dynamics of undisturbed systems. In the next Study Unit (the last unit that includes lectures) we examine biogeochemical cycling, and the ways in which human activities have interfered with natural aquatic ecosystems, and consider how such systems might best be managed.

NOTE: it is important to ensure that you have reached the required outcomes for this study unit by successfully answering the self-evaluation questions before you move on to the next study unit

Study Unit 3: HUMAN INFLUENCES ON INLAND WATERS

TIME

You will need approximately 27 hours to master this study unit.

MODULE OUTCOMES

References, and objectives and outcomes for each lecture (9-12), together with a summary of the content, are provided below.

LECTURE 9: Ecosystems and biogeochemical cycling

1. Trophic relations
2. Carbon cycling
3. Nutrient cycling (N and P)

Lecture 9: Objectives and outcomes
You should be able to describe briefly the basic abiotic and biotic processes at play in inland water ecosystems, the effects of human activities on the cycles of C, N and P, and the causes and consequences of eutrophication.

Lecture 9: READING
6. Brewer: biogeochemistry
11. Campbell & Reece: ecosystems
13. Clapham: biogeochemistry
30. Molles: nutrient cycling
35. Russell-Hunter: biogeochemistry

RECAP
Abiotic processes

transport of water; sculpting and aggradation of substratum; scouring & deposition of particulates; accumulation of precipitates; leaching of materials; weathering; dilution of incoming materials

Biotic processes

sequestration of carbon and energy; incorporation of other elements; growth and assimilation; increased amount of material; use of energy; activity (including feeding, reproduction); use of energy & respiration; death and decay; liberation of elements; loss of energy.

Trophic relations

production (of biomass)	}	
consumption	}	the inter-related effects of living organisms on the biosphere
decomposition	}	

The fundamental equation of life:

$$6CO_2 + 6H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Photosynthesis produces complex carbohydrates; decomposition returns them to simpler molecules in the process of mineralisation.

On a global scale, annual production of biomass ≈ loss.
Mineralisation / regeneration of elements: BIOGEOCHEMICAL cycling.

NB: each round trip of an element is 'paid for' by a one-way trip of energy: where does the energy come from??

NOTE:	mega	=	M	=	10^6	
	giga	=	G	=	10^9	
	tera	=	T	=	10^{12}	
	peta	=	P	=	10^{15}	

1 tonne	=	10^6 g	=	1 Mg
1 teragram	=	10^{15}g	=	1 Tg

CARBON CYCLING ON A GLOBAL SCALE
About 10^{17} Gg organic matter produced per year (= approx. 100 billion tons: 10^{11} gigatons). (About how much of this is respired???)

Under 'normal' circumstances, [CO_2] in equilibrium: C-fixation by photosynthesis = C-mineralisation by decomposers (CO_2 flux approx. 1.13 x 10^{17} Gt per year)

BUT

Burning of fossil fuels adds	5-6 x 10^{15} Gt C per year
Burning trees* adds	10^{15} Gt C per year
Decomposition of agricultural waste adds	2 x 10^{15} Gt C per year

*Currently approx. 140 000 km^2 y^{-1} of tropical forest is being destroyed.

Net gain to the atmosphere ≈ 3 billion tons of C per year: = global warming!
Effects on crops??
Effects on aquatic ecosystems??
The sea as a sink??
Wetlands as sinks or sources of CO2??
Agriculture (e.g. cows) as net sink or source of CO2??

The global carbon cycle: *see diagrams in various of the readings*

Emissions	from burning of fossil fuels	6.4 ± 0.6 Pg C y-1
	from land-use change	1.4 ± 3.0 Pg C y-1
Net uptake rates	from land	1.4 ± 0.7 Pg C y-1
	from the ocean	1.7 ± 0.7 Pg C y-1
Accumulation in the atmosphere		3.2 ± 0.2 Pg C y-1

Wetlands and global warming
Are wetlands net sources (methane) or sinks (CO_2) of carbon? (Methane is a more effective warmer of the atmosphere than CO_2 is).

Tidal marshes are said to store 44 Tg C y-1 but peatlands in the tundra are presently the only significant potential terrestrial sinks for CO_2.

Peat decay (loss of carbon) depends on: temperature
wetness (drying = decay)
'consortium' of microbes
supply of nutrients (esp. N, P, S)

Table: some values for fluxes and stores of carbon

	components	stock (Pg C)	residence time (y)	accumulation rate (Pg y^{-1})
atmosphere	CO_2	750	3-5	3.2 ± 0.2
land organisms	plants	550-680	50	land net uptake 1.4 - 0.7
soil	peat inorganic carbonates microbial biomass particulate organic C amorphous polymers	360 1220 15-30 250-500 600-800	>10^5 <10 <10^2 10^2 - 10^5	
lakes and rivers	sediments	150	10^{-1} - 10^3	?
lithosphere	kerogen methane clathrates limestone	15 x 10^6 11 x 10^3 60 x 10^6	>>10^6 - -	
ocean: surface	DOC POC living biomass	40 5 2	- - 10^{-1} - 10	oceanic net uptake 1.7 - 0.5
ocean: deep	DIC DOC POC sediments	38 000 700 20-30 150	≃2 x 10^3 5 x 10^3 10 - 10^2	

emissions from burning of fossil fuels 6.4 ± 0.6 Pg C y^{-1}
emissions from land-use change 1.4 ± 3.0 Pg C y^{-1}

NUTRIENTS AND NUTRIENT CYCLING

Liebig's Law of the Minimum:
"The growth of plants is controlled by that factor (usually chemical) in the least amount in proportion to requirements."

C, H, O are abundant, so not 'nutrients' (but C can be limiting in the sea)

N, P, K may be present in limiting quantities (μg l^{-1}), thus 'limiting nutrients' or 'key elements'

'Key elements' in order of abundance (availability is usually related to abundance):
Macronutrients: C O H N K P Ca Mg S Cl
Micronutrients: Fe Mn Mo Cu Zn Bo Ni Si Co Na Se I

THE NITROGEN CYCLE *(see readings for a diagram)*

Nitrification & denitrification: nitrogen fixation by bacteria (e.g. *Rhizobium* in root nodules):

$N_2 \rightarrow \rightarrow NH_4^+ [\rightarrow \rightarrow NO_2^- \rightarrow \rightarrow NO_3^-]$

Under anoxic conditions: $2NO_3^- + 10H_2 \Rightarrow 2NH_4^+ + 6H_2O$

Under oxic conditions: $2NH_4^+ + 3O_2 \Rightarrow 2NO_2^- + 2H_2O + 4H^+$; $2NO_2^- + O_2 \Rightarrow 2NO_3^-$

Nitrosomonas *Nitrobacter*

Denitrification by various heterotrophs: e.g. $6NO_3^- + 5CH_3OH \Rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$

(e.g. is methanol)

DNA analyses show a great functional variety of heterotrophs in wetland sediments.

Forms ('species') of nitrogen

inorganic: as nitrate, nitrite, ammonium /ammonia ionized & unionized

NO_3^- NO_2^- NH_4^+ NH_3

organic (very common): hundreds of N-containing compounds, mostly soluble & thus available

Kjeldahl nitrogen (≈ organic N): operational quantity (by acid digestion); ≈ total nitrogen (TN)

THE PHOSPHORUS CYCLE *(see readings for a diagram)*

NOTE that P has no common gaseous form, and salts are usually poorly soluble, immobile or unavailable (usually transported as particle-bound PO_4), so P tends to accumulate in sediments: we are thus running out of P (accumulating in the depths of the sea). In water P is usually measured as measured as SRP: soluble reactive phosphate.

Forms ('species') of phosphorus

inorganic: usually in the form of phosphate salts such as $Ca_3(PO_4)_2$ or PO_4^{3-} ions

organic P: a component of detritus (in 'organic waste' – e.g. sewage)

Total P is measured by acid digestion (TP).

Natural sources of nutrients: soil
weathering of rocks
recycling: mineralisation
N only: nitrification (lightning, microbes, etc.)

Redfield ratios: 'expected' proportions of N and P in living organisms

	C	N	P
in the sea	106	16	1
freshwater phytoplankton	125	19	1
land plants (mostly structural C)	200	13	1

NB: N often limiting in sea, P in fresh waters: N-fixing cyanobacteria like *Anabaena* occur in fresh water while N volatilizes as molecular N_2.

Eutrophication

= "good feeding": conditions of high nutrient concentrations that encourage the growth of plants. 'cultural' eutrophication = involuntary eutrophication of anthropogenic origin

NB: nutrients themselves are usually NOT toxic

BUT nitrates can ➔ met-haemoglobinaemia;

ammonia is very toxic at high pH: NH_4^+ ➔ NH_3 at pH >8

Effects of eutrophication in inland waters
Effects are mostly on community composition:

- increase in algae (e.g. *Cladophora*) and blue-greens (Cyanobacteria)
  some Cyanobacteria (e.g. *Microcystis*) produce toxins
- increase in macrophytes (➔ encroachment)
- clogging of filters (& purification of water)
- reduced oxygen levels (➔ fish kills)
- simplification of food chain (fewer species, more generalists)
- problems of taste and odour

Anthropogenic sources of nutrients in water

- sewage return flows (nutrient removal is never complete)
- manure and urine from feedlots
- untreated organic waste
- agriculture: fertilisers; N-fixing crops (e.g. soya)
- industrial effluents and detergents
- horticulture
- dissolution of NO_xes (atmospheric pollution)

Other human actions that increase rate of accumulation of nutrients:

- damage to soil structure by deep tillage
- biocides (kill off soil-aerating organisms)
- simplification of landscape (destruction of forests and wetlands): unbuffered flow into aquatic ecosystems

Many problems in Africa are different: ancient landscape: most P already leached; little money to buy fertilisers; depletion of nutrients in soil = one of the reasons for carving of 'new' lands from forests; forest soils with little nutrient, so soon depleted also.

Anthropogenic alterations in nutrient fluxes
Nitrogen
Pre-industrial flux from atmosphere to land/water approx 90-130 Tg N y^{-1}, balanced by denitrification; existing flux approx 300 Tg N y^{-1}, additions (approx 200 Tg N y^{-1} above 'natural' levels) not balanced by denitrification. N-fixing crops (e.g. soya) fix ≈ 50 Tg N y^{-1}: but only part of this is denitrified.

Phosphorus
Pre-industrial flux approx 1-6 Tg P y^{-1}, now accumulating at 10-15 Tg P y^{-1}, mostly from mined PO_4 used in agriculture; mostly accumulates in soil, water, sediments. We are running out of sources of P to mine.

LECTURE 10: Effects of physical & chemical perturbations on aquatic ecosystems

1. Causes of impairment of aquatic ecosystems
2. Major effects on living organisms of physical and chemical perturbations in aquatic (and other) ecosystems

3. Predicting the effects of perturbations
4. Eutrophication as an example
5. Effects of different types of land-use on water quality

NOTE: Aspects of this topic is covered in far more detail in the module on water quality.

Lecture 10: Objectives and Outcomes
You should be able to demonstrate an understanding of causes and effects of the major human-induced perturbations to aquatic ecosystems.

Lecture 10: READING
22. Davies & Day, chapter 7: pollution
34. Russell-Hunter: pollution of rivers

Recap:
Functioning aquatic ecosystems provide goods and services, e.g.:
- hydrological control (e.g. flood reduction)
- clean water, periodically renewed
- decomposition of organic waste,
- filtration of sediment particles, bacteria
- removal of nutrients from effluents
- provision to the coastal zone
- production of living biomass
- etc.

These roles are all compromised by human activities, especially 'development' of water resources.

WHAT IS HAPPENING TO OUR WATER RESOURCES (AND TO OUR AQUATIC ECOSYSTEMS)?

- Loss of quality (increasing levels of pollutants)
- Loss of quantity (increasing levels of abstraction)
- Loss of entire ecosystems (especially wetlands)
- Loss of biological resources (species of fish, invertebrates, plants)
- Loss of biological integrity ('health') (and thus of 'services' to humans)

WHAT ARE THE CAUSES?
- Increased agriculture (pollution, soil erosion, irrigation water)
- Urban development (pollution, water use, damage to ecosystems)
- Industrial development (pollution)

ROOT causes:
- drought
- population growth
- poverty and wealth (and greed)
- ignorance and lack of technological know-how

Dilemma: immediate human needs *vs* long-term sustainability of ecosystems, as discussed by John Cairns (U.S. environmentalist, toxicologist, protozoologist):

"Toward the end of this century, two new cultures have emerged with dramatically different views of the relationship that *Homo sapiens* has with natural systems. The 'environmentalists' believe that humans are a part of natural systems and depend on them to keep the planet habitable.

The ‘exemptionalists’ believe that intelligence, creativity and technology can free human society from the biophysical laws of nature that restrict other species.

The general public and political leaders seem mostly unaware of these two cultures, but global practices are dominated by the economic growth of the exemptionalist model. At the very least, literacy on these issues should be raised to the degree essential for an informed choice”

John Cairns Jr (1999)
The Social Contract **9**: 145-151

Major effects on living organisms of physical and chemical perturbations in aquatic (and other) ecosystems

Chemical variable	**Effects on living organisms**
pH	ionic balance chemical species (and therefore availability) gill functioning
TDS	osmotic balance ionic balance water balance
nutrients	eutrophication community structure (composition of assemblages of primary producers) NB: mostly not toxic *per se*
organic enrichment	reduction in oxygen tension increase in nutrients
oxygen tension	respiration chemical species
biocides	mostly affect specific taxa affect community structure
trace elements	some essential at low concentrations but toxic at higher concentrations some are mutagenic, teratogenic or carcinogenic some are metabolic inhibitors

Physical variable	Major effects on living organisms
temperature	metabolic rate determines availability of nutrients and toxins determines oxygen levels in water changes in ambient temp provide cues for events in life cycles
turbidity and suspensoids	determines degree of light penetration suspensoids reduce penetration of light

clog gills
adsorb nutrients, toxins

light — essential for photosynthesis
needed by visual predators

PREDICTING the effects of impacts

GENERAL predictions are easy:

- water moves downstream according to laws of physics (so can be calculated)
- toxins kill living organisms ...
- plant biomass will increase in the presence of nutrients

SPECIFIC predictions are difficult:

- *how much* sediment will be moved?
- *how many* species will be eliminated?
- *how far* downstream will effects be felt?
- *how soon* will trees die?

So, at least some site-specific research is usually needed if we are to make specific predictions: the more accurate the prediction must be, the more time, money and expertise is needed.

Example: eutrophication ('enrichment of water by inorganic plant nutrients.')
See also previous lecture.

Eutrophication may be natural or anthropogenic.

Results from increases in concentrations of N, P, K (and sometimes Si in inland waters, and iron, a major nutrient in the sea)

Effects of eutrophication include
increase in plant biomass (macrophytes, phytoplankton, ...)
turbidity (a problem for predators)
rate of sedimentation (silting-up)
decrease in DO levels (anoxia: fish kills)
decrease in biodiversity

Problems for managers of eutrophic systems

- water hard to treat (filters block up)
- decrease in amenity value (water may look 'dirty'; filamentous algae may grow)
- toxins (not generally a major problem except in specific circumstances:
  e.g. ammonia toxic >ph ≈ 8;
  toxins from blue-greens such as *Microcystis* and *Anabaena*
  nitrates toxic to infants >100 mg/l NO_3: methaemoglobinaemia of infant Hb
- blockage of channels (flow of water impeded, boats unable to sail, ...)
- death of fish, loss of some species of fish.

How do we deal with excessive nutrients (especially P)?

- destratify lakes by aeration
- ferric sulphate ('seals' P in sediments)
- remove sediments
- harvest plants

- increase rate of through-flow of water
- remove at source (reduce loading)
- manipulate biota (dangerous!):

A method that has been used (with some success) has been to remove planktivorous fish, resulting in an increase in zooplankton and consequently a decrease in phytoplankton

EFFECTS OF DIFFERENT TYPES OF LAND-USE ON WATER QUALITY (for reference, not to be learnt – unless you want to!)

agriculture ('agrichemicals')
nutrients (eutrophication),
pesticides
organics
salinization
suspensoids

untreated sewage and feedlots
nutrients (eutrophication)
organics
deoxygenation
antibiotics, hormones

sewage effluents
nutrients (eutrophication)
salinization
parasite eggs, viruses, bacteria, antibiotics, hormones

horticulture
nutrients (eutrophication)
pesticides
[suspensoids]

storm water nutrients
oils
heavy metals
pathogens
suspensoids

air pollution nutrients
acid deposition

mining industrial effluents
accidental spills
heavy metals
acids
toxins (e.g. cyanide)
salinisation
suspensoids

power generation
heated water

squatter camps

nutrients (eutrophication)
organics
deoxygenation
toxins (e.g. battery acids)

LECTURE 11: Effects of hydrological manipulation on aquatic ecosystems

1. Types of manipulation
2. Effects of reduction in quantity of water
3. Effects of increase in quantity of water
4. Effects of dams on rivers
5. Effects of altering the hydrological regime of wetlands

Lecture 11: Objectives and Outcomes
You should be able to demonstrate an understanding of causes and effects of hydrological manipulation on aquatic ecosystems.

READING
24. Davies & Day Chapter 9: the effects of dams on rivers

Manipulation of hydrological regime may be by:
- reduction in quantity of water reaching or in the system
- increase in quantity of water reaching or in the system
- alterations in flow regime or hydroperiod
- stabilization of fluctuating water level
- fluctuation of stable water level
- interbasin transfers

Reduction in quantity of water results from:
- damming: large storage or hydropower schemes (major effects)
- farm dams: cumulative effects in the catchment
- hydropower schemes: stabilize flow
- pumped-storage schemes: predictable but abnormal daily patterns
- abstraction/diversion: unpredictable patterns; reduced quantity of water; timing may be altered (e.g. no irrigation at week-ends)

Effects of **reductions in the amount of water** in a river:
- reduced 'wetted usable area'
- reduced depth
- less water reaches floodplains
- reduction in water quality (less dilution)

NB
1. Reductions in discharge in the upper part of a catchment can affect its river right down to the sea.
2. There is no such thing as 'waste' water in a river! (And water reaching the sea provides nutrients and sediments to the coastal zone)

Effects of **increases in the amount of water** in a river:

- reduction in seasonal differences in flow and habitat (e.g. temperature, TDS)
- altered cues for breeding, migration

Effects of alteration in flow régime:
- unpredictability in the amount of water in a river:
    - reduced biodiversity
    - increased abundance of a few tolerant species – e.g. blackfly larvae below Gariep Dam
- constant flow: no cues for life cycles

Damming rivers affects inundated areas, the river downstream, and the estuary.

Effects on **inundated** areas:
- loss of agricultural land

- drowning peoples' homes and villages, archaeological and grave sites, sites of special scientific interest, terrestrial plants and animals, etc.

- a new shoreline develops (often fluctuating)

- part of the river becomes a lake:
    altered physical conditions (e.g. stratification of the lake)
    altered water chemistry
    altered aquatic communities
    fisheries and recreational potential changes
    may be climatic and tectonic effects

Effects on **the river downstream**:
- physical effects:
    less water
    fewer biotopes (riffles go first)
    less fine organic material
    armouring of the bed
    different temperature regime

- chemical effects (depend on off-take point for compensation flow):
    hypolimnetic water with less oxygen, more nutrients

- biotic effects:
    less plankton (plankton as food)
    changes in community structure, productivity

Effects of reduced flows on **the estuary**:
- reduction in discharge results in modifications in:
    channel shape
    sediment transport
    mouth dynamics (mouth may close more often or even permanently)
- modification in import and exports of POM, nutrients, larvae
- potential for loss of nursery areas for fish

Inter-basin transfers of water
Effects poorly known but include:
- genetic effects
- effects of new species on community structure
- local extinctions (outcompeted by immigrants)

- spread of pests (e.g. weeds, alien fish)
- altered water chemistry

Effects of altering the hydrological regime of wetlands

Wetland characteristics (biota, functions) entirely dependent on hydrological regime: temporary *vs* perennial, seasonal *vs* ephemeral, predictable *vs* unpredictable. Thus changes to the hydrological regime (increased or decreased availability of water) change the character of the wetland.

Reduction in water availability results in modifications in:
- geomorphology (e.g. shape of the basin or channel)
- modifications to accumulation / decomposition of POM
- may lead to loss of 'perennial' biota, including fish.

LECTURE 12: Some other impacts on aquatic ecosystems

1. Physical perturbations
2. Invasive alien organisms
3. Pathogens
4. Cyanobacterial toxins
5. Endocrine disruptors

Lecture 12: Objectives and Outcomes

You should understand and be able to describe and discuss a) the origin and nature of the following perturbations: physical disturbance; invasive alien organisms; pathogens; cyanobacterial toxins; and endocrine disruptors and b) their effects on the biotas of rivers and wetlands.

Lecture 12: READING

22. Davies & Day Chapter 7: Pollution
23. Davies & Day Chapter 8: other perturbations
34. Russell-Hunter: pollution in rivers

Physical perturbations other than water quantity

a) habitat destruction: man-made structures and alteration to channel form (geomorphology)

e.g. canalisation:
total loss of natural habitat
lack of contact with groundwater or hyporheos
loss of biodiversity
reduction or loss of ecosystem processes

e.g. bulldozing
especially important in rocky beds
destabilisation of bed and bank (>> erosion, siltation)
loss of riparian vegetation and associated invertebrates

e.g. sand mining
suspension and loss of sediments
loss of habitat, instream vegetation (usually not many invertebrates)

e.g. infilling (destruction of wetlands)
total loss of biodiversity and processes
e.g. creation of new aquatic habitat (wetlands, streams, lakes)

somewhat unpredictable (especially which taxa appear)
will usually support natural processes (which is often all that is required)

b) modification of riparian vegetation
e.g. removal of riparian vegetation (ploughing to edge of bank, etc.)
destabilisation of banks
erosion, siltation
reduced flood attenuation
reduced adsorption of nutrients
loss of buffering vs inflow of nutrients, pesticides, sediments, etc.

e.g. deforestation
much as above

For invasion by alien plants, see below
,
NB ‘Replacement’ of wetlands (the USA notion of “no net loss of wetlands”)
- somewhat unpredictable (especially which taxa appear)
- unlikely to be a complete mimic of the original

BUT
- will usually support natural processes (often all that is required).

Alien and invasive organisms
(aliens = foreigners; invasives = those that grow to excess; may be native or alien)

floating plants are often aliens (e.g. Kariba weed, Nile lettuce, water hyacinth):
grow exceptionally fast
choke channels
reduce dissolution of oxygen
increase rate of evaporation
may increase diversity but usually decrease it

rooted plants (e.g. reeds, bulrushes, pondweeds)
mostly indigenous but may become invasive

alien fish (in s-w Cape, e.g. trout, bass, bluegill sunfish):
eat larvae of small local fish
compete with adults, many small local species face extinction

Invasion by alien plants and animals, and loss of native plants and animals:
changes to loads and types of DOM (dissolved organic matter) and to rate of evapotranspiration

Pathogens (see Jones, New Scientist, July 1994)

Pathogens can be grouped into:
- those causing disease as a result of drinking contaminated water (usually of faecal origin) (e.g. cholera, typhoid, hepatitis A)

- those causing diseases resulting from lack of personal hygiene (e.g. no water for washing) – as above, plus other forms of diarrhoea
- parasitic diseases where the lifecycle of the parasite includes an aquatic phase (e.g. bilharzia, guinea worm
- parasitic diseases where vectors have an aquatic stage – e.g. malaria, river blindness.

Types of pathogens

a) BACTERIA
Mostly enteric (i.e. in the gut) and mostly derived from
- inadequately treated sewage
- sewage spills
- informal settlements
- stormwater runoff
- recreational waters

Escherichia coli and the 'coliforms'
'Coliforms' are gram negative bacteria with particular biochemical characteristics. Genera include *Escherischia, Klebsiella, Citrobacter, Enterobacter.*

E.coli itself may be non-pathogenic but has pathogenic serotypes (e.g. 'Montezuma's revenge', 'the trots', urinary infections, 0157:H7); found only in human guts and faeces (thus a good indicator of human faecal contamination in water (and therefore of other more pathogenic bacteria and viruses).

Routine analyses to identify *E. coli* itself: grows at 44°C, produces indole from tryptophan. Results as most probable number of cells per unit volume; 90% or more of samples must have < the permissible number.

WHO guidelines for bacterial counts:
In recreational waters: 80^{th} percentile must have ≤ 100 per ml
95^{th} percentile must have ≤ 2000 per ml as *E. coli* or faecal coliforms
In drinking water: zero cells per 100 ml

Measurement of coliforms: as faecal coliforms (best), or *E. coli*, or total coliforms. NB: not all coliforms are of faecal origin, and some of these can multiply in natural waters (thus possibility of false positive results); also, pathogens may be present even if coliforms are not (thus possibility of false negative results).

b) VIRUSES
Probably mostly enteric (affecting the gut) but poorly known. There seem to be more than 100 'species' of enterovirus. They may survive for long periods in water and are not always denatured even by chlorination (problem in recycling water for domestic purposes).

Mostly virusal contamination seems to be from sewage (even if well treated?), informal settlements, stormwater runoff and recreational waters.

Identification and measurement of viruses is difficult! Water may be a (the?) source of many viral infections but little proof is yet available..

c) PROTOZOANS
Mostly cause dysentery e.g. *Giardia* (in many natural waters)

Cryptosporidium (importance increasing worldwide)
Entamoeba (probably not often waterborne).

Possibly all can be found in sources of drinking water but most are killed by purification.
Naeglaria fowleri causes fatal meningitis (recreational waters are normal habitat).

d) METAZOAN (ANIMAL) PARASITES
"Worms": flukes, filarial worms, round worms

Human intestinal worms (e.g. *Taenia* (tapeworm) and *Ascaris* (pig roundworm)):not strictly water-related but eggs extremely resistant to and often found in sewage sludge.

Flukes (e.g. *Schistosoma* – parasite causing bilharzia)
larval stages in freshwater snails
larva actively penetrate human skin
spread encouraged by reservoirs, farm dams

Filarial worms (*Onchocerca* – river blindness – and *Wucheraria* – elephantiasis)
larval stages in insect vectors with aquatic larvae – e.g. blackflies (which also transmit arboviruses) and mosquitoes.(which transmit malaria)

Cyanobacterial toxins
Cyanobacteria = 'blue-greens' (e.g. *Microcystis, Anabaena, Nodularia*) 'bloom' in eutrophic conditions; some contain virulent toxins:
hepatotoxins (e.g. microcystins): stable and toxic cyclic heptapeptides
neurotoxins (e.g. anatoxins): slightly less toxic alkaloids
have caused death of stock animals and dogs
occasional 'rashes' of human deaths
some are implicated in liver cancer at chronic (very low) dose levels.

Endocrine disruptors (leading, some say, to the "feminization of nature")
1. Increasing concentrations of e.g. oestrogen (the main human female hormone) in water supplies (from WWTWs, 'the pill'; men working in 'pill' factories become feminised)

2. Hormone mimics' = 'oestrogen mimics': breakdown products of many organic compounds, especially pesticides (most especially insecticides) mimic the effects of oestrogen on male animals:
- more female reptiles born than males
- deformities of male reproductive systems (many different taxa)
- reduced sperm counts of human males (?)
- dramatic decline in numbers of e.g. frogs (may be one of many causes)

Good bioindicators are being developed – e.g. vitellogenin test.

SELF-EVALUATION QUESTIONS: Study Unit 3

About 10^{17} Gg organic matter is produced per year on Earth. About what proportion of this is respired annually?

Contrast the cycling of nitrogen and phosphorus to explain why we seem to be running out of P (but not N) as a fertilizer.

Outline the arguments for and against building a large hydropower dam on a river.

What are oestrogen mimics, and why are they discussed in relation to a module on aquatic ecosystems?

Explain why *E.coli* is used in assessment of water quality.

SUMMARY Study Unit 3

To complete the lecture component of this module, In lectures 9-12 we discuss the effects of human activities on inland waters.

Study Unit 4: APPLICATION OF AQUATIC ECOLOGY PRINCIPLES IN ASSESSING ECOLOGICAL FLOW REQUIREMENTS (ECOLOGICAL RESERVE)

TIME

You will need approximately 14 hours to master this study unit.

PURPOSE

Since the mid-1990s ecologists have also made significant contributions towards developing tools for application in water resources management in South Africa. This was primarily in response to the requirements set by the National Water Act, which requires the setting of the Ecological Reserve. Two such tools are the Macro-invertebrate Response Assessment Index (MIRAI), Vegetation Response Assessment Index (VEGRAI) and the Fish Response Assessment Index (FRAI) that have been developed to calculate the Present Ecological State of a river reach in terms of the invertebrate and fish community composition. The VEGRAI, MIRAI and FRAI allow for ecological input into the EcoStatus model, which forms the backbone of the Ecological Reserve and Resource Directed Measures.

MODULE OUTCOMES

When you have completed the practical session the students will be able to:

- Be familiar with the sampling of macro-invertebrates and fish for the purposes of inclusion in the VEGRAI, MIRAI and FRAI models.
- Incorporate the macro-invertebrate and fish data in the MIRAI and FRAI models.
- Interpret the VEGRAI, MIRAI and FRAI model outputs in terms of setting of classes for the ecological reserve.

Practical schedules and work sheets to be completed are to be found in the electronic folder called “Field trip, seminars and practicals”. The work sheets will be assessed by lecturing staff, who will give you marks and feedback on your performance in these tasks.

MACRO-INVERTEBRATE RESPONSE ASSESSMENT INDEX (MIRAI)

Aquatic macro-invertebrates have been used to assess the biological integrity of stream ecosystems with relatively good success throughout the world, more commonly than any other biological group. Aquatic macro-invertebrate assemblages and communities offer a good reflection of the prevailing flow regime and water quality in a river. They are important processors of transported organic matter in rivers and serve a vital function in purifying the water in a river and provide a valuable food resource for larger animals within and even outside the system. In order to continue functioning optimally the component species in a river system require regular inputs of nutrients, sediments and water flow. A specific river system supports a particular assemblage of species forming functional communities within reaches. These communities are adapted to the prevailing flow conditions that control temperature, sediment transport and nutrient flows. A reduction or increase in flow, sediment transport or nutrient loads will lead to changes in community structures through loss of certain species and increases in others as well as providing conditions for a range of new or otherwise scarce species to flourish.

The four major components of a stream system that determine productivity for aquatic organisms are: (1) flow regime, (2) physical habitat structure (e.g., channel form and substrate distribution), (3) water quality (e.g., temperature, dissolved oxygen), and (4) energy inputs from the watershed (e.g., nutrients and organic matter). Distribution of an aquatic macro-invertebrate population is ultimately set by physical-chemical tolerance of the individuals in the population to an array of environmental factors. The distribution pattern resulting from habitat selection by a given aquatic macro-invertebrate species reflects the optimal overlap between habit (mode of existence) and physical environmental conditions that comprise the habitat: substrate, flow, turbulence, etc. Thus, the discontinuous, patchy, distribution pattern of an aquatic macro-invertebrate population is the result of interplay between habitat, habit and the availability of food resources.

Information required:

- Establish reference conditions
- Site selection
- Data collection
- Habitat assessment

FISH RESPONE ASSEMBLAGE ASSESSMENT (FRAI)

Fish stress is described and characterized by the following:

- It is viewed as a condition where the response to a stimulus or stressor results in a state where an extension of the physiological condition occurs beyond the normal resting phase.
- Stress is seen as a state of threatened homeostasis that is re-established by a complex of adaptive responses. In this sense then, response to stress is an adaptive mechanism that permits the fish to cope with real or perceived stressors in order to maintain its normal or homeostatic state and is not necessarily detrimental to the fish.

The mechanism of stress response is complex and involves primary (neuroendocrine), secondary (metabolic) and tertiary responses. Tertiary responses involve whole-animal performance characteristics (growth, swimming capacity and disease resistance) and modified behavioural patterns (feeding and aggression). These three levels of stress response are integrated and interregulated.

Information required:

- Establish reference conditions
- Site selection
- Data collection – habitat diversity assessment, habitat condition
- The fish survey
    - The following apparatus are often used for catching fish in the different velocity-depth classes:
        - Slow-shallow: A small seine net (5 m long, 1.5 m deep, mesh size = 1 mm) can be used to sample fish. An electrical shocking apparatus can be used. Capture results are recorded as number of fish caught during each effort with a net, or the number of fish caught per time unit (minutes) with an electro shocker.
        - Slow-deep: A large seine net (e.g. 70 m long, 1.5 m deep, mesh size 2.5 cm) can be used. A cast net, (diameter = 1.85 m, mesh size = 2.5

cm) can used in pools not suitable for beach seining. Capture results are recorded as number of fish caught during each effort.

- Fast-shallow: An electrical shocking apparatus (e.g. AC, 250V, 800W) one operator and two dip net handlers) is used in such habitat types. Capture results are recorded as number of fish caught per time unit (minutes).
- Fast-deep: An electrical shocking apparatus is used in these habitat types. Capture results are recorded as number of fish caught per time unit (minutes).

RIPARIAN VEGETATION RESPONSE ASSESSMENT INDEX (VEGRAI)

It must be noted that this section describes the structure of the Riparian Vegetation Response Assessment Index (VEGRAI) component that determines the Ecological Category. The products of VEGRAI are more than a measure of Ecological Category (EC) as the process and data are valuable in and of themselves. VEGRAI is designed for qualitative assessment of the response of riparian vegetation to impacts in such a way that qualitative ratings translate into quantitative and defensible results. Results are defensible because their generation can be traced through an outlined process (a suite of rules that convert assessor estimates into ratings and convert multiple ratings into an EC).

Information required:

- Determine reference conditions
- Site selection
- Data gathering
- Data interpretation

SELF-EVALUATION QUESTIONS

1. Discuss the impacts of modified flow regimes (increased and decreased) on the ecosystem and its associated biota.
2. Discuss the types of water borne diseases present in freshwater ecosystems.
3. Discuss the importance of the indices used in the RDM process.

READINGS

Kleynhans, C.J. (2008). River Ecoclassification Manual for Ecostatus Determination (Version 2). Module D Volume 1 Fish Response Assessment Index (FRAI). WRC Report No. TT330/08, Water Research Commission, Pretoria.

Kleynhans, C.J. & Louw, M.D. (2008). River Ecoclassification Manual for Ecostatus Determination (Version 2). Module A: Ecoclassification and Ecostatus Determination. WRC Report No. TT329/08, Water Research Commission, Pretoria.

Kleynhans, C.J., Louw, M.D. & Moolman, J. (2008). River Ecoclassification Manual for Ecostatus Determination (Version 2). Module D Volume 2 Reference Frequency of Occurrence of Fish Species in South Africa. WRC Report No. TT331/08, Water Research Commission, Pretoria.

Kleynhans, C.J., Mackenzie, J.A. & Louw, M.D. (2008). River Ecoclassification Manual for Ecostatus Determination (Version 2). Module F Riparian Vegetation Response Assessment Index (VEGRAI). WRC Report No. TT333/08, Water Research Commission, Pretoria.

Thirion, C. (2008). River Ecoclassification Manual for Ecostatus Determination (Version 2). Module E: Volume 1 Macroinvertebrate Response Assessment Index (MIRAI). WRC Report No. TT332/08, Water Research Commission, Pretoria.

MODULE 8

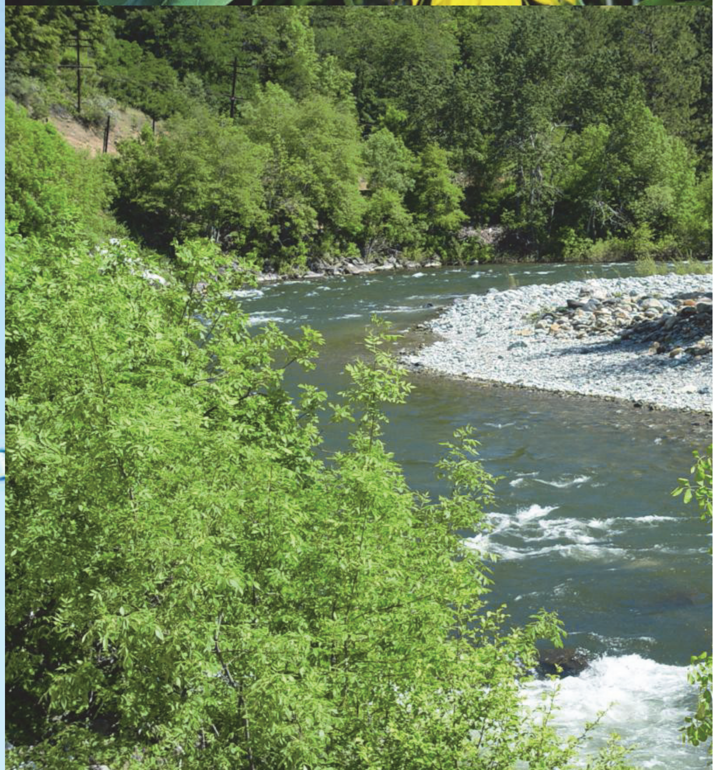
TECHNICAL INTEGRATION (EWR) AND IMPLEMENTATION

Tutored MSc in Ecological Water Requirements

Developed by

D Grobler and T Belcher

November 2013



MODULE 8: TECHNICAL INTEGRATION (EWR) AND IMPLEMENTATION

RATIONALE

Environmental Water Requirements (EWR) methodologies currently in use that relate to the specialist scientific aspects of ecological Reserve determinations, have been developed both locally and internationally over many years, using specialist knowledge and experience in both water resource and aquatic ecology functioning. These methodologies have been adapted where necessary to suit South African requirements and to incorporate the latest information and available knowledge. Each EWR determination requires an inter-disciplinary group of scientists and managers and is never based on the judgement and expertise of one individual or specialist. Typically the team will include ecologists, geomorphologists, water chemists, hydrologists, hydraulic engineers, social scientists and water resource managers.

This module aims to provide the skills and tools required to coordinate quality and quantity EWR determinations separately for river, wetland, estuary or groundwater, as well as how to integrate the various components and implement them. Elements of this module will consist of:

- Understanding the concept of EWR
- EWR methodologies for water resources;
- Data collection, analysis and presentation relating to EWR determinations;
- Integration of EWRs;
- Implementation of EWR within the IWRM framework
- Monitoring and Evaluation of EWRs

LAYOUT OF THE MODULE

In this course, you will get to know the following aspects of the ecology:

1. Background to EWR methodologies. (Study Unit 1) (5%).
2. Water quality and quantity EWR methodologies for rivers. (Study Unit 2 and 3) (30%).
3. Estuary EWR methodologies (Study Unit 4) (15%)
3. Wetland EWR methodologies. (Study Unit 5) (15%).
4. Groundwater EWR methodologies. (Study Unit 6) (15%).
5. Technical Integration of EWRs. (Study Unit 7) (8%).
6. Implementation of EWRs. (Study Unit 8) (12%).

NB: The percentages in brackets show the ratio regarding the time you have to spend on the various aspects.

PREREQUISITES

You need the following resources to complete this course successfully:

1. Study material as indicated.
2. Pocket calculator.
3. Computer with MS Office.

STUDY MATERIAL

The following sources are needed for this course:

- Adams, Janine. 2012. *Determination and implementation of environmental water requirements for estuaries*. Ramsar Technical Report No. 9/CBD Technical Series No. 69. Ramsar Convention Secretariat, Gland, Switzerland & Secretariat of the Convention on Biological Diversity, Montreal, Canada. ISBN 92-9225-455-3 (print); 92-9225-456-1 (web).
- Brown, C., Pemberton, C., Birkhead, A., Bok, A., Boucher, C., Dollar, E., Harding, W., Kamish, W., King, J., Paxton, B. and Ractliffe, S. 2006. In support of water-resources planning – highlighting key management issues using drift: a case study. Water SA. Water Research Commission. Pretoria.
- Davies, B. and Day, J. 1998. Vanishing Waters. University of Cape Town Press, Cape Town.
- Department of Water Affairs and Forestry (1996). South African Water Quality Guidelines (2nd Edition). Volume 7: Aquatic Ecosystem. Department of Water Affairs and Forestry, Pretoria.
- Department of Water Affairs and Forestry, 1999a. Resource Directed Measures for Protection of Water Resources. Volume 3: River Ecosystems Version 1.0. Department of Water Affairs and Forestry, Pretoria.
- Department of Water Affairs and Forestry, 1999b. Resource Directed Measures for Protection of Water Resources. Volume 4: Wetland Ecosystems Version 1.0. Department of Water Affairs and Forestry, Pretoria.
- Department of Water Affairs and Forestry, 1999c. Resource Directed Measures for Protection of Water Resources. Volume 5: Estuaries Ecosystems Version 1.0. Department of Water Affairs and Forestry, Pretoria.
- Department of Water Affairs and Forestry, 1999d. Resource Directed Measures for Protection of Water Resources. Volume 6: Groundwater Component Version 1.0. Department of Water Affairs and Forestry, Pretoria.
- Department of Water Affairs and Forestry. 2002. Methods for Assessing Water Quality in Ecological Reserve Determinations for Rivers. Version 2. Draft 15. Pretoria, South Africa.
- Department of Water Affairs and Forestry. 2003. Resource Directed Measures. Module 1: Introductory Module. Department of Water Affairs and Forestry, Pretoria, South Africa.

- Department of Water Affairs and Forestry. 2007. Development of the Water Resource Classification System (WRCS). Pretoria, South Africa: Department of Water Affairs & Forestry.
- Department of Water Affairs and Forestry. 2008. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 2. Pretoria.
- Department of Water Affairs, 2011. Procedures to Develop and Implement Resource Quality Objectives – Summary. Department of Water Affairs, Pretoria, South Africa
- Ferrar, A.A. 1989. Ecological Flow Requirements for South African Rivers. South African National Scientific Programmes Report No. 162.
- Hughes DA (ed.) 2004 SPATSIM, an integrating framework for ecological reserve determination and implementation: Incorporating water quality and quantity components for rivers. WRC Report No. TT 245/04, Water Research Commission.
- Hughes, DA. Mallory SJL. & Louw D. 2008. Methods and Software for the Real-Time Implementation of the Ecological Reserve – Explanations and User Manual. Report to the Water Research Commission. WRC Report No 1582/1/08, Water Research Commission.
- International Network of Basin Organizations (INBO) and the Global Water Partnership (GWP) 2012. The handbook for integrated water resources management in transboundary basins of rivers, lakes and aquifers.
- James C.S. and King J.M. 2010. Ecohydraulics for South African rivers: A review and guide. WRC Report No. TT 453-10, Water Research Commission.
- King, J and Pienaar, H. (Eds) 2011. Sustainable use of South Africa's Inland waters. A situation assessment of Resource directed Measures 12 years after the 1998 National Water Act. WRC Report Number TT491/11, Water Research Commission.
- King, JM, R Tharme and MS de Villiers. (Eds) 2000. Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Water Research Commission Report No. TT 131/00. Water Research Commission, Pretoria, 339 pp.
- O'Keeffe. J. 2009. Sustaining river ecosystems: balancing use and protection. Progress in Physical Geography. Vol 33(3). Pp.339-357.
- Parsons, R. and J Wentzel. 2006. GRDM Manual. Water Research Commission Project 1427.
- Palmer, C.G. (2003). Further development of methods to quantify water quality aspects of an ecological Reserve assessment and dissemination of information via a Decision Support System: Progress Report to September 2003. Water Research Commission Project K5/1312/0/1, WRC, Pretoria.
- Rossouw, J.N. (2003). Workshop for the water quality component of the ecological Reserve Decision Support System (Draft). Workshop Report. Water Research Commission Project K5/1312. WRC, Pretoria.
- Rountree MW, GC Marneweck, R Tharme and D Kotze. 2006 (Draft). REVIEW OF METHODS FOR DETERMINING ENVIRONMENTAL FLOWS FOR WETLANDS. Wetland Consulting Services (Pty.) Ltd.
- Schreiner B and Hassan R. (Eds) 2011. Transforming Water Management in South Africa. Designing and Implementing a New Policy Framework. Global Issues in Water Policy. Volume 2. Springer Publishers. 278 pp.

- Taljaard, S., Adams, J.B., Turpie, J.K., Van Niekerk, L., Bate, G., Cyrus, D., Huizinga, P., Lamberth, S., Weston, B. 2003. Methodology for the Determination of the Preliminary Ecological Reserve for Estuaries. Version 2. Department of Water Affairs & Forestry, Pretoria, South Africa.
- Turpie, J.K., Adams, J.B., Joubert, A., Harrison, T.D., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. and Van Niekerk, L. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA 28:191-206.
- Tharme, R.E. 2003. Global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. Rivers Research and Applications 19.

HOW TO STUDY

The module is presented by means of study units where the core principles are discussed. At the beginning of each section, a time allocation is given, which is an indication of the extent of the study task. You may use this allocation to plan your study process. The learning outcomes are also indicated at the beginning of each study unit and guide you as learner about what the problems in the particular study unit are and where you have to pay special attention. Make sure that you have the study guide always at hand, so that you can easily add additional notes to reach the outcome set for each study unit. At the end of study units, there are also evaluation questions. It is essential to answer these questions before moving on to the next study unit. By doing so and by making sure that the learning outcomes have been reached, you can make sure that you have completed the study unit successfully. It is expected of you as a senior student that you will have developed the skill (and that you will further develop this skill) to gather additional information independently in books, journals as well as from the internet. The study guide serves as framework to guide you through the learning content.

ASSESSMENT

Continuous assessment will take place in the form of assignments. Note the dates in the study letter on which these assignments should be handed in. Examination opportunities at the end of the module are also indicated in the study letter. Admission to the examination is dependent on an adequate participation mark, obtained from the assignments.

PRACTICALS AND FIELD REPORTS

Please note that practice and theory in EWR form a unit that contributes to the reaching of outcomes. During the practical, theory becomes reality in that the relevant statistical methods and experiments are conducted that supports the outcomes. It is therefore of the utmost importance for work to be done systematically during each practical throughout the programme and for careful recording of exactly what had been done in the form of reports, drawings, etcetera. Try to make sure during each practical that all the outcomes as set have

MODULE OUTCOMES

At the end of the module, students should be able to:

- identify the strengths and weaknesses of different EWR methodologies;
- select appropriate EWR methodology and outline the various processes and activities required for an EWR determination study;
- identify the data requirements and data management for different EWR methodologies;
- analyse and combine specialist data to produce EWR scenarios of interest to stakeholders;
- provide critiques of EWR assessments – case studies;
- understand the role of water resources classification, and the development of EWRs and RQOs in sustainable water resources management; and
- design a monitoring programme to measure compliance with and the adherence of the ecological specifications and other objectives set to protect water resources.

WARNING AGAINST PLAGIARISM

ASSIGNMENTS ARE INDIVIDUAL TASKS AND NOT GROUP ACTIVITIES. (UNLESS EXPLICITLY INDICATED AS GROUP ACTIVITIES)

Copying of text from other learners or from other sources (for instance the study guide, prescribed material or directly from the internet) is **not allowed** – only brief quotations are allowed and then only if indicated as such.

You should **reformulate** existing text and use your **own words** to explain what you have read. It is not acceptable to retype existing text and just acknowledge the source in a footnote – you should be able to relate the idea or concept, without repeating the original author to the letter.

The aim of the assignments is not the reproduction of existing material, but to ascertain whether you have the ability to integrate existing texts, add your own interpretation and/or critique of the texts and offer a creative solution to existing problems.

Be warned: students who submit copied text will obtain a mark of zero for the assignment and disciplinary steps may be taken by the Faculty and/or University. It is also unacceptable to do somebody else's work, to lend your work to them or to make your work available to them to copy – be careful and do not make your work available to anyone!

STUDY UNITS

1 BACKGROUND TO EWR METHODOLOGIES

TIME

You will need approximately 5 hours to master this study unit.

REFERENCES

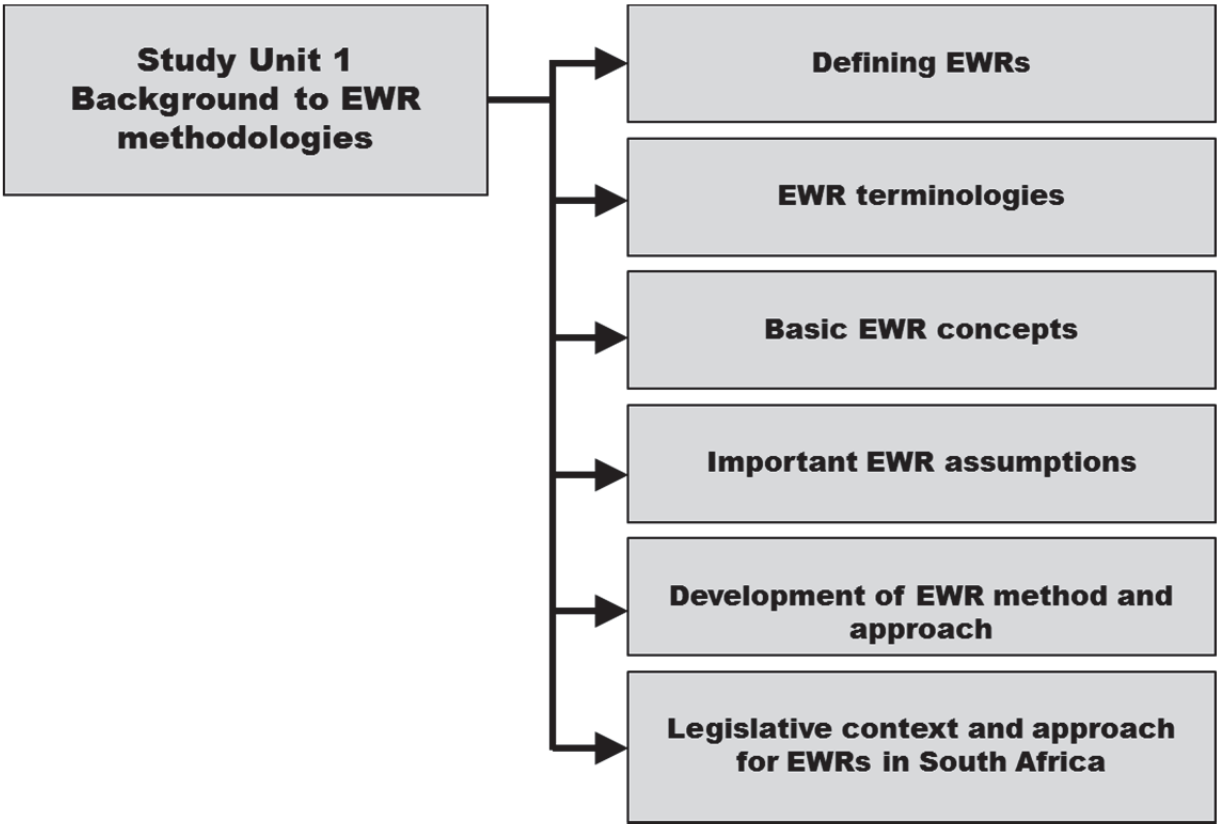
- Department of Water Affairs and Forestry, 2003. RDM module 1: Introductory Module. Department of Water Affairs and Forestry, Pretoria.
- Ferrar, A.A. 1989. Ecological Flow Requirements for South African Rivers. South African National Scientific Programmes Report No. 162.
- King, J and Pienaar, H. (ends) 2011. Sustainable use of South Africa's Inland waters. A situation assessment of Resource directed Measures 12 years after the 1998 National Water Act. WRC Report Number TT491/11.
- King, JM, R Tharme and MS de Villiers. 2000 (ends) Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Water Research Commission Report No. TT 131/00. Water Research Commission, Pretoria, 339 pp.
- Tharme, R.E. 2002. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. Presentation at the 4th Ecohydraulics and Enviro Flows Conference, Cape Town.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR methodologies in general by being able to:

- give a broad overview of the international and national initiatives relating to the development of EWR methodologies;
- explain various terminologies and approaches to EWRs;
- discuss application of EWR determinations; and
- describe the broad approach to and elements of EWR studies.

The study unit will be conducted as follows:



INTRODUCTION

Increasing use of water within water resources has resulted in recognition of the need to establish the extent to which the flow regime or the water quality characteristic of a water resource can be altered from natural, for the purposes of water resource development and management, while maintaining structural and functional integrity, or an accepted level of degradation, of the ecosystem. This provided the stimulus for development of environmental water requirement determination methodologies. Concerted evolution of methodologies for prescribing EWRs began in the late 1940s, in the western United States of America and increased dramatically from the 1970s, primarily as a result of new environmental and freshwater legislation and demands from the water planning community specifically for large instream dams. The result has been varying terminologies as well as methodologies and approaches.

1. DEFINING EWRs (Ferrar 1989 and King *et al.* 2000)

- An environmental (or instream) flow or environmental water requirement = Water of a specific quality and quantity that is **purposefully** left in an aquatic ecosystem, or released into it, to maintain it at a specified level of condition (health) **that will support its direct and indirect use values**.
- Environmental flows are needed for aquatic ecosystems where a basin or water development has occurred or is planned.
- Systems degraded by flow changes could be rehabilitated by introducing environmental flows to support some lost or failing ecosystem functions.
- Environmental flows are a management tool, developed by scientists for use when making decisions about land or water developments that could change the pattern of water movement.

2. EWR TERMINOLOGIES (Ferrar 1989 and King *et al.* 2000)

- Various EWR related terminologies include: 'instream flow requirements', 'ecological water requirements', 'integrated basin flow management', 'environmental flow assessments', 'ecological Reserve'

3. BASIC EWR CONCEPTS (Ferrar 1989 p. 41)

- The concept of flow needs for the ecosystem
- Inclusive theories of river functioning
- Ecological response curves
- RDM is not to make provision for species protection, however the EWR that is decided upon may be set in support of certain biodiversity targets such as the FEPA's, or the recommended ecological categories provided in the estuarine management protocol.
- To ensure maintenance of acceptable water quality and quantity on which users are dependant
- Use biota as surrogates to provide information on the ability of rivers to sustain themselves and the level of use

4. IMPORTANT EWR ASSUMPTIONS (King *et al.* 2000 p. 4-13)

- There is spare water in aquatic water resources (including an assimilative capacity)
- Aquatic systems will recover from most perturbations
- The natural disturbance regime of aquatic systems is important for the maintenance of their biodiversity
- Maintenance of habitat will ensure the persistence of species
- Riverine communities are driven by abiotic rather than biotic processes

5. DEVELOPMENT OF EWR METHODOLOGIES AND APPROACH (King *et al.* 2000 p. 15-16; Tharme 2002)

- Historically EWR methodology has focused on determining the instream flow requirement for rivers that have been triggered by planned construction of large instream dams.

- More than 200 approaches to environmental flow assessments have been reported, and have been used in more than 50 countries as a water planning and management tool.
- Four main types of approaches: hydrological, hydraulic rating, habitat simulation and holistic.
- The decision on which procedure to use is dependent on the sensitivity of the aquatic environment, the complexity of the decision to be made and the increased cost and difficulty of collecting large amounts of information.
- Each method differs in its data requirements, procedures for selecting flow requirements, ecological assumptions and effects on river hydraulics.

6. LEGISLATIVE CONTEXT AND APPROACH IN SOUTH AFRICA (DWAF, 2003. RDM module 1, King J and Pienaar, H. 2011 p. 81-87)

- Inclusion of EWR in NWA (Act 36 of 1998) implies that DWS is the accountable authority for the determination and implementation of EWRs (i.e. it is the departments' responsibility, not individual water users, to ensure compliance to the Reserve through those measures provided in the Act which includes inter alia: control of water use, re-allocation of water, pollution prevention activities and rehabilitation activities).
- A water resource is defined as: a watercourse, surface water, estuary, or aquifer, as well as an ecosystem, including the physical or structural aquatic habitats (both instream and riparian), the water, the aquatic biota, and the physical, chemical and ecological processes which link habitats, water and biota
- Three components of RDM: The determination and setting of the Reserve; the classification of the water resource, and the setting the Resource Quality Objectives (RQOs)
- Methods for different aquatic ecosystems: Rivers, Estuaries, Wetlands and Groundwater
- Methods for the components: Water quality and Water quantity
- EWR determinations are intended to provide results of the highest level of confidence with the best use of the resources available. Within the South African context, levels of ecological reserve determination were initially described in terms of the time it took to carry them out, from Rapid, which could be done in a matter of days, through to Comprehensive, which might take from eight months to two years. This was because it was assumed that the degree of confidence was direct related to the time and cost involved. In practice, it has been found that this is not necessarily the case.
- Desktop, Rapid, Intermediate or Comprehensive refer to the method, whilst the terms low, medium or high refer to the level of confidence, reflecting the integrity of the result.
- RDM adopts an integrated approach to water resource protection and management.

SELF-EVALUATION QUESTIONS

1. Explain what is EWR and the main concepts and assumptions of relevance to the determination of EWR.
2. Define what EWR is and what it is not.
3. Give a broad overview of the international trend in EWR methodology development.
4. Evaluate the differences in the approach and methods applied between the South African and international situations.
5. What are the strengths and weaknesses in the South African approach?
6. Do other government departments have legislative responsibilities in terms of the EWR (i.e. what are the legislative linkages)?

2 WATER QUANTITY EWR METHODOLOGIES FOR RIVERS

TIME

You will need approximately 18 hours to master this study unit.

REFERENCES

- Brown, C., Pemberton, C., Birkhead, A., Bok, A., Boucher, C., Dollar, E., Harding, W., Kamish, W., King, J., Paxton, B. and Ractliffe, S. 2006. In support of water-resources planning – highlighting key management issues using drift: a case study. Water SA. Water Research Commission. Pretoria.
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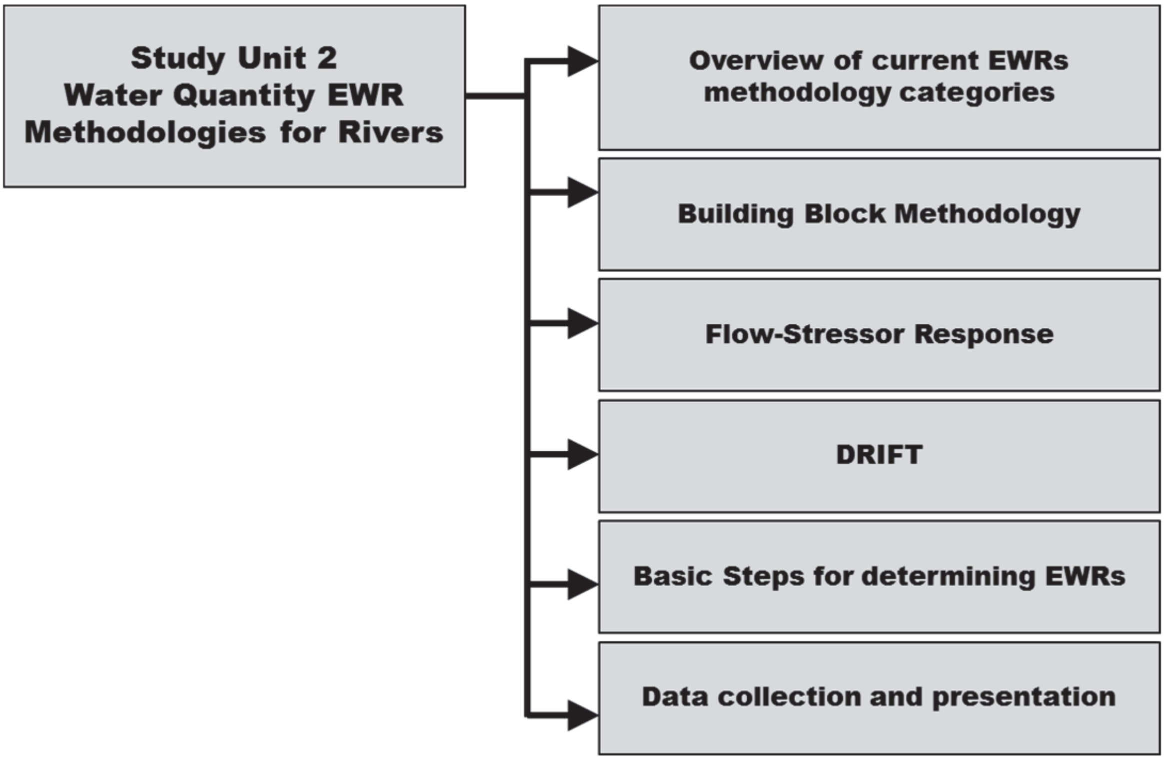
MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR methodologies in general by being able to:

- give a broad overview of the various EWR methodologies currently available for determining the environmental flow requirement in rivers;

- outline the basic steps followed in the BBM and DRIFT methodologies;
- describe the data requirements of these various EWR methodologies; and
- describe the key differences between the methodologies as well as the advantages and disadvantages of each methodology.

The study unit will be conducted as follows:



INTRODUCTION

The majority of EWR methodologies can be grouped into four different categories or hybrids thereof: hydrological, hydraulic rating, habitat simulation and holistic. In South Africa the current methodologies for determination of the ecological flow requirement for South Africa's rivers is the Building Block Methodology (BBM), Downstream Response to Imposed Flow Transformations (DRIFT) and Stressor Response). The data requirements and specialist preparatory work for these three methodologies are similar however the outputs are suited to different applications.

1. Overview of Current EWR methodology categories (King *et al.* 2000 p.17-40; Tharme)

There are four main categories of EWR methodologies:

Hydrological (e.g. Tennant/Montana Method).

- Is the earliest, simplest and most rapid (Desktop approach) method with simple data requirements.
- Uses summary statistics from hydrological data sets (e.g. a percentile from the annual flow duration curve) to set "a minimum flow" for the river – usually for the dry season to ensure, for example, adequate dilution of pollutants or sufficient habitat for fish as well as the range of acceptable variation in flow. The minimum flow required to sustain the aquatic environment is expressed as a percentage of the mean annual flow, with different percentages used for wet and dry seasons (Table 8.1).
- The Tennant (or Montana) Method is based on extensive field observation of habitats used by fish. It was developed in the USA and designed to be applicable to all stream sizes and to warm or cold climates.
- The method is suitable for reconnaissance level assessments and can be upgraded with local input and professional judgement.
- Disadvantages: The method only takes into account flow data (usually monthly) and region specific. It does not address the dynamic nature of the flow regimes such as flow variability or specific flow events. It is also insensitive to the nature of individual rivers and the relationship between flow and the state of the aquatic ecosystem is poorly established.

Table 8.1: Instream flow recommendations based on the Tennant method (Orth and Leonard 1990).

Health of habitat	Recommended minimum flow as a percentage of mean annual flow	
	Wet season	Dry Season
Optimum	60% to 100%	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or degrading	10%	10%
Severe degradation	0% to 10%	

Hydraulic/habitat rating methods (the generic Wetted Perimeter Method is the most widely applied of these approaches**)**

- Relies on the development of various relationships between habitat and discharge.
- Hydraulic variables: wetted perimeter, wetted width or depth is measured at one or more cross-sections at representative sites along the river over a range of flows, as a surrogate for ecological data on habitat.

- The values are plotted against discharge, and thresholds sought where there is a change in the slope of the curve.
- The assumption is that when flow falls below such a threshold, there will be a sharp change in the quality of habitat and thus repercussions for the aquatic life and ecological integrity of the ecosystem.
- Advantage: the use of river-specific data, allows precise hydraulic relationships to be described.
- Disadvantage: the common assumption that arbitrarily chosen thresholds have ecological significance.

Habitat-simulation (most widely used of these approaches is the Instream Flow Incremental Methodology)

- Methodologies link the hydraulic relationships of a river with extensive data on the habitat requirements of aquatic plants and animals in the same river (Figure 8.1).
- Hydraulic data collected at many cross-sections are used to compile a description of representative river sites in terms of the hydraulic habitat they provide over a range of flows.
- The descriptions are linked to known hydraulic-habitat requirements of selected plant or animal species, to provide an output, usually in the form of graphs, of how much habitat is provided for that species at any flow.
- These relationships can be used to identify what are perceived to be optimal flows for the species selected.
- Advantages: strong ecological links and quantitative outputs that can be used in water negotiations.
- Disadvantages: complexity, and focus only on habitat of a target species without recognition of the wider environmental needs of species; on aquatic species to the detriment of riparian species; and on lower flows to the detriment of floods.

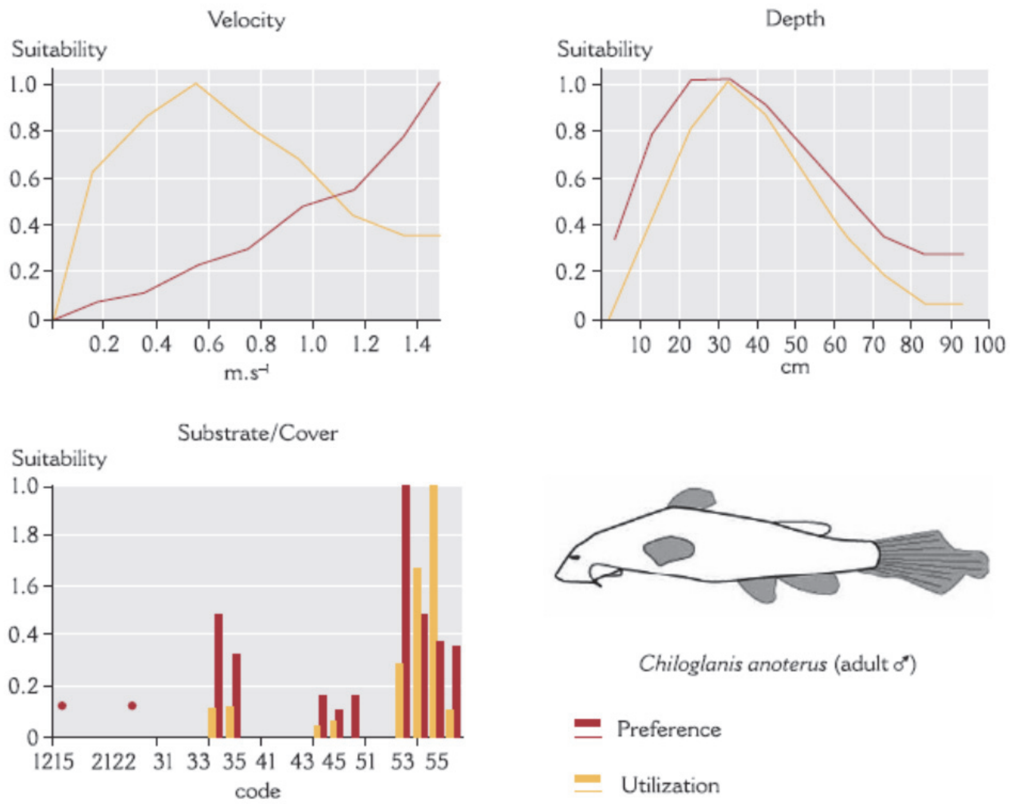


Figure 8.1: Hydraulic habitat requirements of *Chiloglanis anoterus*, a small rock catlet. Numbers on the x axis of the substrate/cover bar chart are indicative of codes which indicate size of substrate and type of instream cover (O'Keeffe 2009)

Holistic approaches (e.g. Building Block Methodology)

- Most advanced and rapidly growing category of methods globally that address all parts of the river ecosystem and all parts of the flow regime.
- Holistic approaches are essentially structured data and information management tools that require and use hydrological, hydraulic, sedimentological, geomorphological, chemical, thermal, botanical (aquatic, marginal and riparian plants), zoological (fish, invertebrates, plankton, water birds, other wildlife), and microbiological data to compile an understanding of the river and develop a consensus prediction of how it would change with flow changes.
- In developing countries they can address the impacts of changing flow on subsistence users and can provide economic information on compensation for resources lost, for instance, downstream of dams. Where subsistence users exist, anthropological, socio-economic and resource economic data can be used to predict the implications for people of the changing river.
- The methodologies can use any relevant data, knowledge or local wisdom, and incorporate any individual discipline methods to derive the relationships needed for predictions.
- Advantages: they contribute toward national databases that enhance understanding of the rivers, and they allow derivation of their own rapid versions based on past applications.
- Disadvantage: the higher cost of large multi-disciplinary teams optimally working over at least one annual hydrological cycle to gather river specific data.

Table 8.2: Summary comparison of the four environmental flow methodologies (King *et al.* 2000)

Type	Ecosystem components addressed	Data needs	Expertise	Complexity	Resource intensity (time, cost, technical capacity)	Resolution of output	Flexibility	Appropriate level of application
Hydrological	Non-specific	Low (primarily desktop): measured or simulated hydrological record	Manipulate hydrological date	Low	Low	Low	Low	Reconnaissance level planning
Hydraulic-rating	General aquatic habitat	Low-medium (desktop and limited field): measured or simulated hydrological record; one or a few hydraulic variables from a cross-section	Manipulate hydrological data; perhaps some hydraulic modelling	Low-medium	Low-medium	Low	Low	Low-conflict water-resource allocations
Habitat-simulation	Aquatic habitat for selected species	Medium-high (desktop and field): measured or simulated hydrological record; many hydraulic variables at many cross-sections; habitat data for selected species	Advanced hydrological and hydraulic modelling; specialist ecological expertise on habitat requirements of selected species	Medium-high	High	Medium-high	Medium	Water allocations for high conservation areas where in-channel habitat is main concern
Holistic	Whole aquatic and riparian ecosystem; can include groundwater, wetlands, floodplains, estuary, delta, and subsistence users	Medium-high (desktop and field): measured or simulated hydrological record; many hydraulic variables at many cross-sections; biological data on flow-related habitat requirements of wide range of species	High: advanced hydrological, hydraulic, and habitat modelling; chemical and thermal modelling if possible; specialist expertise on all ecosystem components; social and economic expertise as required	Medium-high	High	High	High	Developed and developing countries; Flow management in any size river, including ones of high strategic or conservation importance; dam de-commissioning and river rehabilitation

2. Building Block Methodology (King *et al.* 2000 p.53-64)

- In South Africa BBM process have been applied since the early 1990s to determine EWRs.
- BBM includes the determination of Habitat Integrity and Ecological Importance and Sensitivity as well as the consequences of different flow scenarios.
- BBM takes 8 to 12 months to complete with reasonable confidence.
- The method relies on best available knowledge and expert opinion and a key component of the approach is a workshop (specialist meeting) attended by river scientists representing specified fields of expertise.
- The workshop provides a consensus decision on the recommended flow regime required to maintain a river in a desired state.
- Flow magnitudes, timing and duration are decided upon in the BBM workshop.
- The focus is on the natural flow regime of the river i.e. degree of perenniality; magnitude of base flows in the dry and wet season; magnitude, timing and duration of floods in the wet season; and small pulses of higher flow, or freshes, that occur in the drier months.
- Attention is then given to which flow features are considered most important for maintaining or achieving the desired state of the river, and thus should not be eradicated during development of the river's water resources (Figure 8.2).
- The described parts of each flow component are considered the building blocks that create the EWR, each being included because it is understood to perform a required ecological or geomorphological function.
- The first building block, or low-flow component, defines the required perenniality or non-perenniality of the river, as well as the timing of wet and dry seasons. Subsequent building blocks add essential higher flows (Figure 8.3).
- There is a structured process for compiling the workshop material and using the workshop output in further phases of the development.

Table 8.3. Example of a completed IFR table (King *et al.* 2000)

	OCT		NOV		DEC		JAN		FEB		MAR	APR	MAY	JUN	JUL	AUG		SEP		TOTAL X 10^6 m^3	% of MAR
EFR MAINTENANCE LOW FLOWS																					
FLOW (m^3 s^{-1})	0.8		1.1		1.5		2		2		2	1.6	1.1	0.8	0.6	0.4		0.6			
DEPTH (m) section	0.36		0.39		0.41		0.45		0.45		0.45	0.42	0.39	0.36	0.33	0.3		0.33			
FDC% (VIRGIN)	64		79		87		71		78		74	72	76	76	68	73		51			
VOLUME (x 10^6 m^3)	2.1		2.9		4		5.4		4.8		5.4	4.1	3	2.1	1.6	1.1		1.6		38.1	20.6
EFR MAINTENANCE HIGH FLOWS																					
FLOW (Instantaneous peak, m^3 s^{-1})	4	2	2	2	13	3	13	4	45	4	13	4				4	1.2	13	1.2		
DEPTH (m) section	0.53	0.45	0.45	0.45	0.75	0.49	0.75	0.53	1.53	0.53	0.75	0.53				0.53	0.4	0.75	0.4		
DURATION (days)	2	2	2	2	3	2	3	2	2	2	3	2				2	2	3	2		
FDC% (VIRGIN)	28	45	64	64	12	57	12	44	5.8	56	17					6.6	28	3	34		
VOLUME (x 10^6 m^3)	0.5		0.2		2		2		7		1.7	0.3				0.5		3.3		17.6	9.6
	OCT		**NOV**		**DEC**		**JAN**		**FEB**		**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**		**SEP**		**TOTAL X 10^6 m^3**	**% of MAR**
EFR DROUGHT LOW FLOWS																					
FLOW (m^3 s^{-1})	0.3		0.5		0.6		0.6		0.55		0.5	0.7	0.3	0.2	0.15	0.1		0.2			
DEPTH (m) section	0.28		0.31		0.33		0.33		0.32		0.31	0.3	0.28	0.25	0.23	0.2		0.25			
FDC% (VIRGIN)	79		94		100		100		97		98	100	99	95	94	80		51			
VOLUME (x 10^6 m^3)	0.8		1.3		1.6		1.6		1.3		1.3	1	0.8	0.5	0.4	0.3		0.7		11.6	6.3
EFR DROUGHT HIGH FLOWS																					
FLOW (Instantaneous peak, m^3 s^{-1})	0.6		1.2	1	1.5		1.9		13	1.1	1							0.4			
DEPTH (m) section	0.33		0.4	0.38	0.41		0.44		0.75	0.39	0.38							0.3			
DURATION (days)	2		2	2	2		2		3	2	2							2			
FDC% (VIRGIN)	76		78	81	87		74		24	92	87							73			
VOLUME (x 10^6 m^3)	0.02		0.08		0.06		0.09		2		0.03							0.01		2.29	0.01

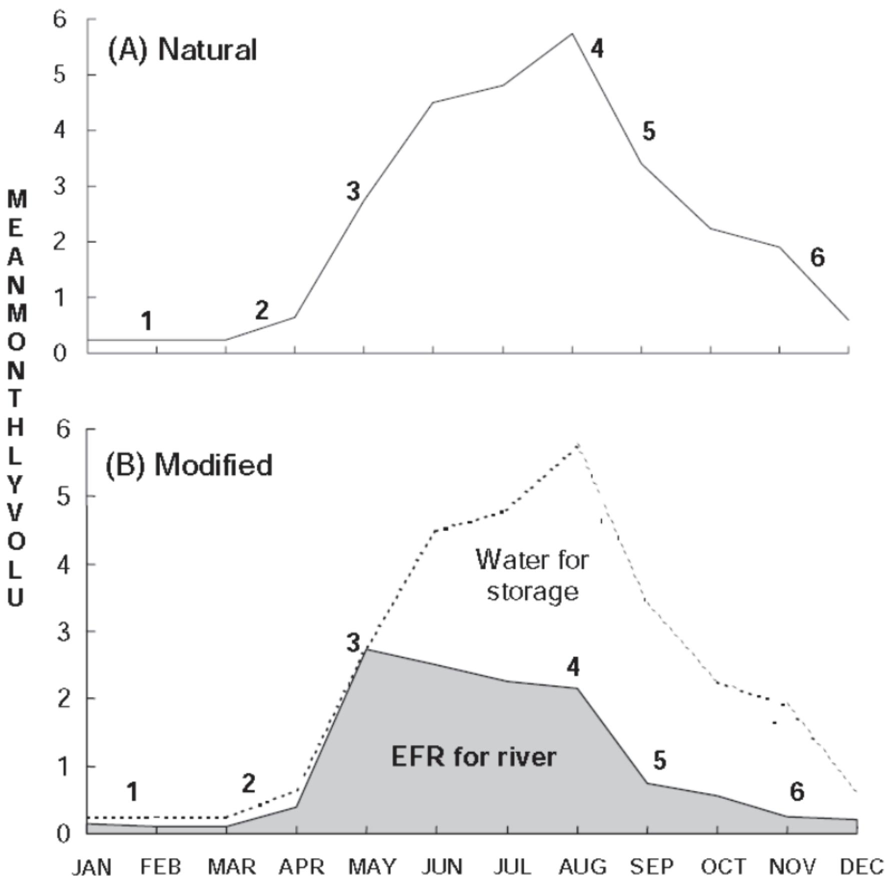


Figure 8.2: (A) is perceived important features of a river's natural flow regime and (B) those features that should be retained in an EFR (e.g. features 1 and 6 may recognise the perenniality of the river (A) and the need to retain this (B); features 2, 4 and 5 may recognise the need to retain the fundamental difference between wet season and dry season base flows; and feature 3 may recognise the timing of the first major flood of the wet season and the need to retain this (King *et al.* 2000)

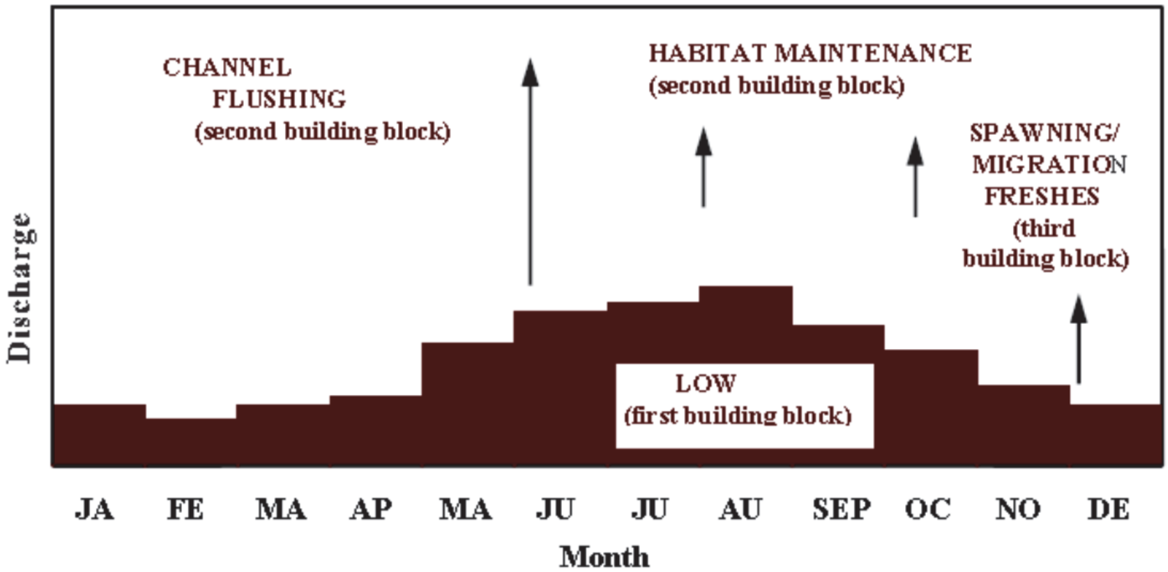


Figure 8.3: A hypothetical EFR created using the BBM (King *et al.* 2000)

3. Flow-Stressor-Response (Hughes 2005, p.59-80)

- This method guides the evaluation of the ecological consequences of modified flow regimes, based on the principles of ecological risk analysis (ERA) (Suter 1993), using an index of flow-related stress.
- It is currently limited to the quantification of the low-flow requirements of rivers, such that alternative approaches are still required to evaluate the high-flow requirements.
- The term "stress" is used to denote the discomfort/damage suffered by the flow-dependent biota as discharges are reduced.
- The severity of stress likely to be caused by any modified flow regime is judged by how much it is increased or decreased from natural levels. Relationships are translated into a stress 'regime' (a description of a time series pattern of stress, similar to a flow regime) for any flow regime, in terms of magnitude, frequency and duration.
- The FS-R method is designed to be used together with holistic methodologies such as the BBM and DRIFT, as a way of consistently capturing specialist knowledge on the relationship between flow, hydraulic habitat, and the responses of instream biota.
- The basis of the method is the application of a generic stress index (from 0 – no stress, to 10 – very high stress) describing the progressive consequences to the flow-dependent biota of flow reduction.
- The stressors, flow hydraulics and associated habitat changes are related to biotic responses in terms of abundance, life stages, and persistence.
- Advantage: Addresses magnitude, frequency and duration of effects and allows for gradual changes, not assumed thresholds.
- Disadvantage: Labour intensive and focuses on the stress responses from low flow conditions.

4. DRIFT (Brown *et al.* 2006)

- Predicts the effects of successive flow reductions on a range of indicators and develops a database of thousands of individual consequences and their severity.

Social and economic costs and benefits are also assessed

- DRIFT is a scenario-based interactive approach in which a database is created that can be queried to describe the biophysical consequences of any number of potential future flow regimes (scenarios). Within DRIFT, component-specific methods are used by each specialist to derive the link between river flow and river conditions (biophysical), or between changing river conditions and social and economic impact (socio-economic).
- The central rationale of DRIFT is that different aspects of the flow regime of a river elicit different responses from the riverine ecosystem (Table 8.3). Thus removal of part or all of a particular element of the flow regime will affect the riverine ecosystem differently than will removal of some other element. Furthermore:
  - It is possible to identify and isolate these elements of the flow regime from the historical hydrological record.
  - It is possible to describe the probably biophysical consequences of partial or whole removal or a particular element of the flow regime, in isolation.
  - Once these biophysical consequences have been described, it is possible to combine them in various ways to describe the overall impact on river conditions of a range of potential flow regimes.
  - Once the potential changes in river conditions have been described, it is possible to describe their socio-economic implications.

Table 8.3: Different kinds of river flow and their importance to ecosystem functioning

The normal flow (flows in the river excluding floods)	Low flows define the basic seasonality of rivers – its dry and wet season, whether it flows all year or dries out for part of it. The different magnitudes of low flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and chemical conditions, which directly influence what the balance of species will be in any season.
Freshes (small floods that occur several times within a year)	Defined here as small pulses of higher flow, freshes are usually of most ecological importance in the dry season. Smaller floods stimulate spawning in fish, flush out poor quality water, mobilise sandy sediments, and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migration of fish and germination or riparian seedlings.
Large floods (floods that occur less often than once a year)	Large, scouring floods dictate the form of the channel. They mobilise sediments and deposit silt, nutrients and seeds on floodplains. They inundate backwater areas, and trigger the emergence of flying adults of aquatic insects, which provide food for fish, frogs and birds. They maintain moisture levels in the banks, which support trees and shrubs, inundate floodplains, and scour estuaries thereby maintain the link with the seas.
Flow variability	Variability of flow is essential for a healthy ecosystem. Different conditions are created through each day and season, controlling the balance of species and preventing dominance by pest species.

- There are eight main activities in DRIFT (post data collection)
  - Preparation of the hydrological data and derivation of summary statistics.
  - Linkage of the hydrological statistics to cross-sectional river features at a number of representative river sites.

➢ Reduction of different flow components in a structured series, and description of the biophysical consequences.

➢ Entry of the consequences into a custom-built database.

➢ Querying the database to describe the changes in river conditions caused by one or more potential flow regimes (scenarios).

➢ Identification of the social impacts of each scenario.

➢ Calculation of the economic cost of compensation and mitigation for each scenario.

➢ Calculation of the impact on system yield for each scenario.

- The disciplines represented vary depending on the requirements of the particular project. In general, the biophysical specialist team will consist of representatives of the following disciplines: Hydrology, hydraulics and physical habitat, water quality, geomorphology/sedimentology, botany, macroinvertebrate ecology, fish. Specialist in aquatic parasites, algae, aquatic and semi-aquatic mammals and birds, and herpetofauna may also be included on the biophysical team, depending on the specific requirements of the EWR.
- Similarly the composition of the socio-economic team is project-specific, and may include specialists in sociology, anthropology, public health, animal health, resource economics, scheme economics and public participation.

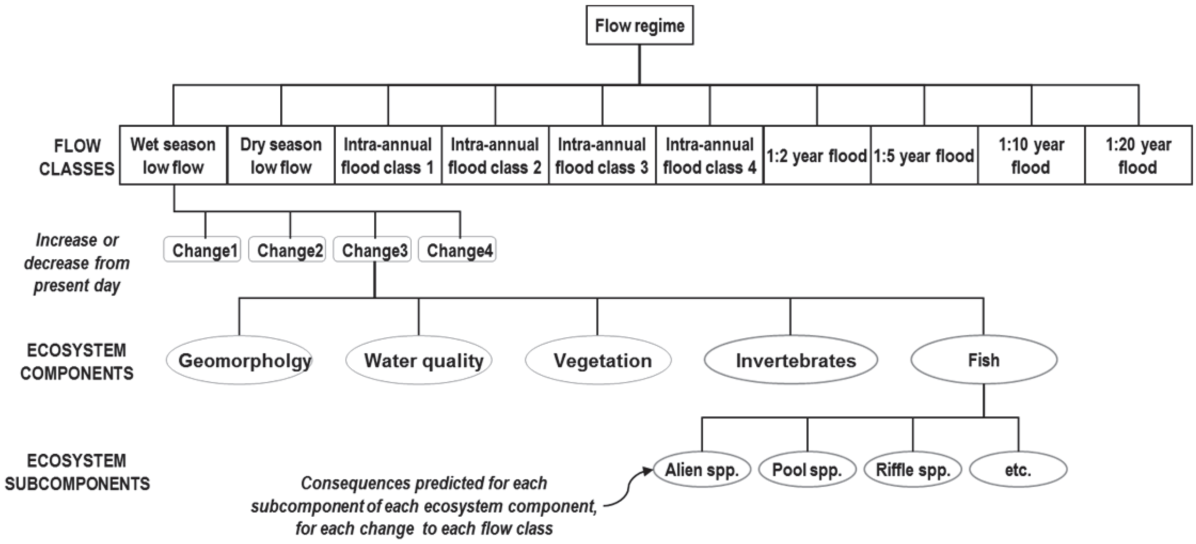


Figure 8.4: Flow classes that are reduced, or increased, in magnitude or number, to produce described consequences, and the five ecosystem components for which consequences are routinely predicted.

5. Basic Steps for determining EWRs (O'Keeffe 2009 and King *et al.* 2004, DWAF 2003)

- For a EWR determination, in which detailed field investigations are undertaken for between one and three years prior to the assessment, there is a complex but clearly defined set of tasks that need to be undertaken by a group of specialists (see Table 1). These tasks may vary depending on the methodology being used, the size and type of river being assessed, the time, resources and information available for the assessment.
- An EWR study would typically require the following specialists: EWR coordinator;

Instream specialists (e.g. macroinvertebrate and fish ecologists); Hydraulician; Hydrologist; Fluvial Geomorphologist; Habitat integrity specialist; Riparian vegetation specialist

Table 8.5: Tasks to be undertaken by specialists in different disciplines during an environmental flow assessment and implementation (O'Keefe 2009)

STAGE A: SCOPING Assess the area of interest, to try to identify issues of particular importance, and to draw up an initial plan for the assessment.
STAGE B: PREPARATION FOR THE ASSESSMENT WORKSHOP **Task 1 Initiate EFA assessment (level of detail, define methodology, appointment of the specialist team)** **Task 2 Zone the study area** Identify reaches of the study river in which physical and ecological conditions are likely to be similar **Task 3 Habitat integrity** Assess the condition of the area of interest by classifying sections of the river in terms of how much they have been modified from natural conditions. **Task 4 Site selection** Select sites within the study area for detailed analysis based on: ease of accessibility; habitat diversity; sensitivity of habitats to flow changes; suitability for modelling; proximity to a flow gauging site; representation of conditions in the river zone; and critical flow locations. **Task 5 Surveys and measurements** These surveys are intended to augment information and fill in gaps that have not been covered in previous studies: • ***Biological surveys –*** To identify flow-sensitive species and define their seasonal habitat requirements in terms of current velocity, depth, substrate type and wetted perimeter. • ***Hydraulic survey and analysis –*** To provide the link between ecological habitat requirements and flows. • ***Hydrological analysis –*** To check that the recommended flows are within reasonable limits of flows experienced in the river, and is therefore a check on the realism of the process, rather than a motivation for recommended flows. • ***Geomorphological survey –*** To assess the sources and types of sediment in the river, analyse the channel morphology in terms of the geomorphic features and their stability, and predict the consequences of changing flows on the sediment input-output and therefore the channel shape and substrate types. • ***Water quality analysis –*** To assess possible problems related to flow modification and to identify point and diffuse runoff impacts. • ***Social survey –*** (1) To identify people who are directly dependent on a healthy riverine ecosystem (e.g., subsistence fishermen, farmers, withdrawers of domestic water, and anglers) and (2) to consult with all stakeholders and identify preferences for the management objectives for the river. **Task 6 Ecological and social importance and sensitivity** Define the priority of the area of interest from an ecological perspective (e.g., number of sensitive and rare species, the resilience of the system to human disturbance, importance as a migration route). **Task 7 Define reference conditions** Define the reference (usually natural, unmodified) physical, chemical and ecological conditions as a baseline against which to judge how much the river has been modified. **Task 8 Define present ecological status** Define present ecological, physical, chemical and ecological status based on available data and expert judgement. **Task 9 Define environmental objectives** Define the most appropriate environmental objectives given the nature of the system, and priority uses.
STAGE C: EFA WORKSHOP Decide upon flow recommendations (including wet and dry season base flows, and floods) using inputs from all of the specialists. Decisions should be made considering all of the identified environmental objectives.
STAGE D: NEGOTIATION **Task 1 Hydrological yield analysis** Calculate the likelihood of being able to maintain the environmental flows and supply the user needs, in wet and dry years. **Task 2 Scenario analysis** Provide the basis for negotiations and decisions where there is insufficient water to meet all requirements. **Task 3 Decision**
STAGE E: IMPLEMENTATION AND COMPLIANCE MONITORING This culminating step in the process lasts indefinitely. Methods of implementation depend on the availability of storage structures, inter-basin transfers, or potential for demand management on any specific river. Initiate long-term monitoring and refinement of flow requirements.

6. Data collection and presentation (King *et al.* 2000)

- Before an EWR study can take place a number of data sets need to be in place (Table 8.5, Stage B). Table 8.6 provides the minimum data set required for each component of a typical EWR determination.

Table 8.6: Minimum data set required for each component of a typical EWR determination.

Task/Component	Minimum data set
Habitat Integrity	The minimum data set for an assessment of habitat integrity would include the following components. • General information on land use in the catchment. • General information on the hydrological character of the river, i.e. general information on the extent of water abstraction and flow regulation. • Videography, or at least low-level aerial photography, for the section of the river under investigation. • Some water quality information, or an informed judgment on the water quality as related to the structure and functioning of the aquatic ecosystem. • Some information on the aquatic biota or at least an informed opinion on the attributes of the biota in the river section.
Ecological Importance and Sensitivity	Information on the presence of rare, endangered or unique species in the river (principally vertebrates, but including riparian plants and aquatic invertebrates). There should also be sufficient information to make at least an approximate evaluation of the biodiversity of the system, and to estimate the sensitivity (or fragility) of the biotic and abiotic components of the system. An estimate is also required of habitat diversity, the importance of the study area as a migration route, and the presence of conserved areas within or adjacent to the study area.
Hydrology	A daily time series of observed flow data measured at, or close, to each site. The data set should be sufficiently long to represent the range of conditions (wet and dry extremes) that naturally occurred. If the observed data represent a flow regime greatly modified from natural, then it may be necessary to simulate parallel data sets of natural and present day conditions.
Hydraulics	An **absolute minimum** data set would be one stage measurement at an appropriate low flow, plus the stage of zero discharge. An **acceptable** data set would be three such stage measurements distributed over the low flow range of interest, plus the stage of zero discharge and some flood-related data. An **ideal** data set would be six data points over a good distribution of discharges, plus the stage of zero discharge and some flood-related data.
Geomorphology	A minimum data set would be derived from the following activities: A desktop study to identify sediment source areas within the catchment; and complete a reach analysis of the river's long profile, based on map and video analysis. A site visit to: verify the reach analysis; survey and classify the channel morphology; identify significant features on the channel cross-sections; survey bed and bank material; survey the types and distribution of hydraulic biotopes. An extended series of field data collection activities could consist of the following components: extension of field surveys within the time frame for the application; repeated surveys of hydraulic biotopes at different discharges; □ refinement of medium to high flow stage-discharge relationships. Additional desk studies using available data: studies of aerial photographs to assess channel change at each site; magnitude-frequency studies of relative bedload transport based on theoretical bedload equations. Long-term field monitoring: field studies of channel dynamics and long-term channel change; bedload monitoring.
Water Quality	The data required for the Workshop are: the physical and chemical water quality conditions associated with the current flow regime; how these conditions change seasonally and yearly; where appropriate, similar data for the system in the non-impacted state. The suites of variables for which data are required, are listed below. Data on those variables shown in bold are essential. Data on the other variables will provide useful additional information.

Task/Component	Minimum data set
	• System variables: **pH**; **water temperature**; dissolved oxygen (DO). • Non-toxic constituents: **electrical conductivity** (EC) or **total dissolved solids** (TDS); TSS; base cations (sodium, potassium, calcium, magnesium); other constituents such as sulphate, silica and total alkalinity (TAL). • Nutrients: **total phosphorus** (TP); **soluble reactive phosphate** (SRP); **total nitrogen** (TN); **nitrate**; **ammonia (proportion of ionised to unionised)**; nitrite; total organic carbon (TOC). • Toxic constituents: **metal pollutants**; pesticides; any other toxins likely to occur in the system.
Vegetation	The minimum data set for a site comprises the data collected during a single visit in the dry season. The data describe the species composition and cover of the dominant and emergent vegetation in the different vegetation zones along one complete transect. However, single transects provide no indication of within-site variability, and give data of unknown reliability for monitoring purposes. On the transect, the exact locations of zone boundaries are related to fixed known points, and the magnitudes of flow that would inundate these points are established. The different levels of inundation typical of wet and dry season flows are illustrated.
Aquatic Invertebrates	The basic data set will be drawn from a survey of the invertebrate fauna of all habitats at all sites, with the animals identified to family level or to more detailed levels. This data set is used to assess the present state of the river, and to recommend flows which will maintain or improve the river according to the Environmental Management Class and objectives.
Fish	A minimum data set would consist of recent historical records of fish species occurring in the river, and a fundamental understanding of the flow-related habitat requirements of the most sensitive species or life history stages. If no or insufficient historical data are available, at least one fish survey should be conducted in each designated geomorphological zone in the study area. This survey should be conducted at the selected sites towards the end of the low flow season, as this usually represents the most critical period for fish survival.
Groundwater	A large amount of geohydrological information is available with which to develop a conceptual understanding of the geohydrological characteristics and functioning of a system. The National Groundwater Database (NGDB), national scale geohydrological maps and regional scale geohydrological maps currently being produced by DWAF represent important sources of information. These may be supplemented with other readily available information (rainfall data, geological maps, WR2005 data), to produce the minimum information required to provide a low confidence geohydrological input into the assessments.

- In the South African RDM approach all methods must provide Reserve scenarios rather than a single Reserve.
- Reserve scenarios are various flow regimes that result in different ecological states.
- This allows flexibility for the decision maker so that implications to other users e.g. socio-economic can be assessed.
- Link planning to the Reserve determination process, i.e. scenarios for future development and the associated water, infrastructure and water quality implications are typically provided through planning studies and it is thus advantageous to run water resource planning and Reserve studies in conjunction.
- The evaluation of different scenarios is now an integral part of the Reserve process and may be generated in response to stakeholder input, or as part of a water resource system analysis where management constraints and other user requirements are accounted for.
- One of the outputs is in the form of a table of flows for each month of the year for different levels of assurance This type of information is compatible with the way in which the WRYM accounts for the ecological Reserve and the WRYM is now the accepted model that is used to integrate Reserve requirements with those of the broad range of water users in a catchment.
- Prior to the quantification of the Reserve scenarios, the Ecological Reserve Categories must be defined.

- This takes place at the EWR specialist meeting.
- Flows are determined for maintenance flows (those flows that will maintain the system at the ERC during years other than drought years) and for drought periods (flows that will only allow for survival of the most critical components of the ecosystem).
  The process during the specialist meeting follows a defined set of procedures:
- The assurances of maintenance and drought flows are determined based on the hydrological characteristics of the system.
- The highest low flow (base flow) month and lowest low flow month on average are selected from the hydrological record. The observed daily hydrological record for the site itself, if available, or from a representative site could be used, or monthly data if daily data is not available.
  - The low flow values specific to the EWR site are determined for these months and the flow rates are used as the upper and lower limits of the range of low flows.
  - The low flows for the rest of the months are interpolated by following the shape of the natural annual hydrograph. This extrapolation is undertaken by the hydrologists and checked by the ecologists. The low flows are specified in cubic metres per second (m3/s).
  - Each river specialist describes the physical parameters (e.g. water level, velocity, depth) required with motivations. Some of the disciplines provide primary and some secondary motivations. Primary motivations are those provided by the disciplines where a lower flow rate than required cannot be accepted. Secondary motivations are those provided by disciplines that could maintain the component with less flows, but for which higher flows required for the other components will not be harmful.
  - After each flow is agreed on, the flows are checked against the hydrological record. Normal or average hydrological years are utilised to check maintenance flows and the driest years to check drought flows.
  - During the wet season high flow events are determined and motivated for. High flows refer to freshes, small, medium and large floods. A fresh is a relatively small increase in base flow. The high flows are specified in m3/s where the specified flow refers to an instantaneous peak. As the hydrological data is provided in mean daily averages, the peaks recommended are converted to slightly lower flows to reflect the mean daily average. Fig 6.3 illustrates an EWR table which is completed during the specialist meeting.
  - The duration of the high flows is specified in days. The shape of the floods is based on the shape of the natural hydrograph. The specified peaks include the low (base) flows. When the total volume of each flood is calculated, it excludes the low flow volume which is already included in the total monthly low flow volume.
  - The high flow or high flows are specified in a specific month. However, all flows recommended are linked to a natural climatic trigger. Therefore, a flood will only be required if the hydrological record indicates that it would have occurred under natural circumstances.
  - A hydrological check of each flood is repeated.
  - These flows constitute the design EWRs which are then converted to the final EWR results.
  - The EWR model or the Desktop Model links the drought and maintenance flows to a natural trigger in a historical time series. The EWR model (which is used

when daily data is available) allows the specialists to view the sequence of occurrence in a historic time series indicating how often drought and maintenance flows occur. This calibration leads to the final EWR results being specified in a format suitable for linking with the Water Resources Yield Model (WRYM). If no daily data is available, the Desktop Model is used to undertake a similar exercise, but based on monthly data. The final format is discussed in chapter 7 and 8.

- Extrapolation for other ERCs: As the Reserve approach is scenario based, a result for a specific river state is insufficient and EWRs for various river states must be supplied. The results determined for the recommended ERC are used to extrapolate to different categories using the Desktop Model. The results are then broken down to the hydraulic parameters and tested by specialists to determine whether it achieves those characteristics which define the, other than recommended, ERCs.
- All EWR results in the correct format are immediately made available to system modellers.

SELF-EVALUATION QUESTIONS

1. Compile a summary of the various EWR methodologies for determining the minimum flow requirements in rivers and list the advantages and disadvantages of each.
2. Discuss roles of the specialists within a EWR determination and where they contribute to the determination.
3. Review a case study of an EWR determination and evaluate it for completeness.

3. WATER QUALITY EWR METHODOLOGIES FOR RIVERS

TIME

You will need approximately 12 hours to master this study unit.

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Rossouw, J.N. 2003. Workshop for the water quality component of the ecological Reserve Decision Support System (Draft). Workshop Report. Water Research Commission Project K5/1312. WRC, Pretoria.

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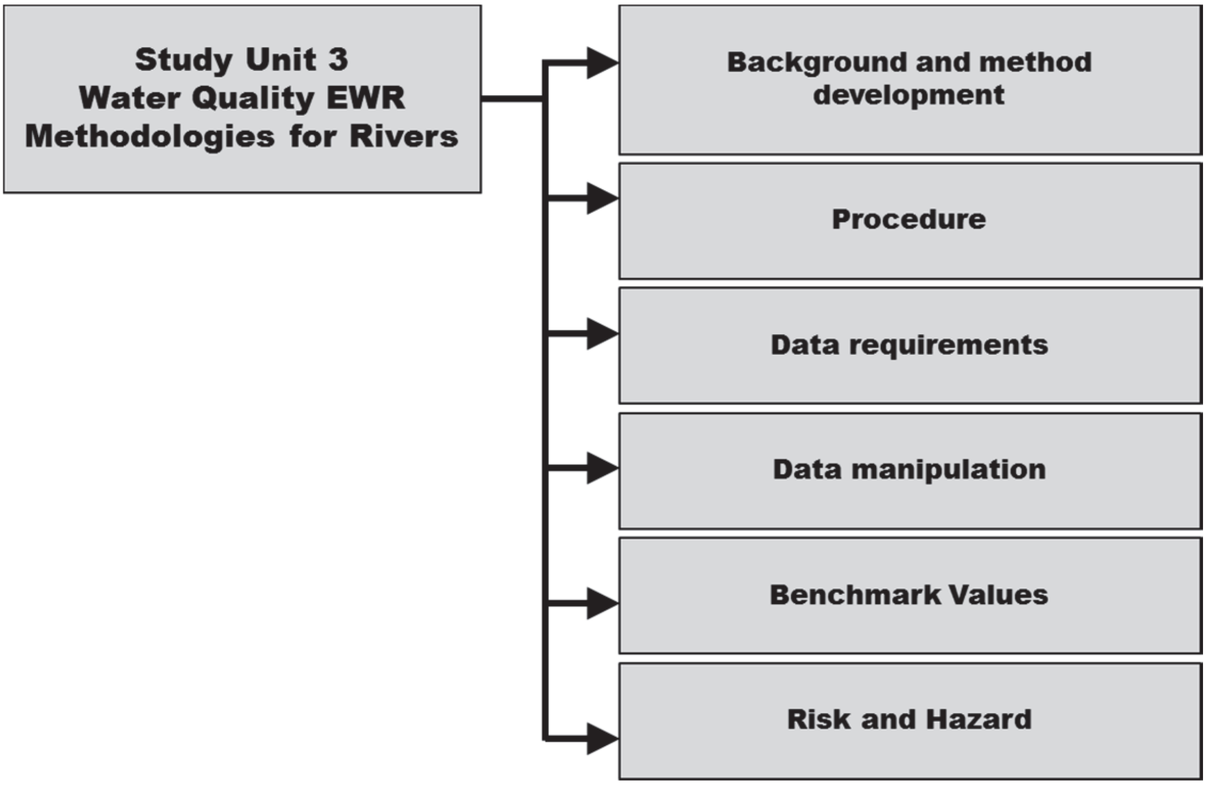
MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR methodologies in general by being able to:

- give an overview of the development of EWR methodologies relating to the water quality requirements for rivers;
- describe the procedure for determining the water quality component of the EWR; and
- indicate the main data requirements for the EWR study for water quality and the manipulation of that data.

The study unit will be conducted as follows:



INTRODUCTION

Methods for determining the quantity component of the environmental water requirements for rivers have evolved over the years into well-developed methodologies such as the Building Block Methodology (BBM) and the DRIFT (Downstream Response to Imposed Flow Transformations). Although water quality was considered in this process as one of the drivers, formal development of a water quality methodology only started in about 1998 with the promulgation of the National Water Act (Act 36 of 1998) as part of an initiative by the South African Department of Water Affairs to formalise methods for the determination of the ecological Reserve, where particular attention was given to integration between water quality and quantity; ground and surface water; and between rivers, impoundments, wetlands and estuaries..

1. BACKGROUND AND METHOD DEVELOPMENT (Hughes 2004 p.82-86, DWA 2008)

- The development of a EWR methodology for water quality in rivers has taken place in South Africa since 1998. The methodology is thus much less refined that that for water quality determinations in rivers.
- An initial methodology was drawn up and described in the original RDM methodologies produced in 1999 (DWAF 1999). Following application of these methods in a number of catchments, they were revised and refined. Shortcomings addressed were sequence of steps, the use of water chemistry data, the approach to salinity, the role of ecotoxicology, and modelling the water quality consequences of flow scenarios.
- A number of Water Research Commission projects played important roles in advancing the understanding of the water quality requirements for aquatic ecosystems.

2. PROCEDURE FOR DETERMINING THE WATER QUALITY RESERVE (DWAF 2008)

- The eight steps procedure for determining the water quality Reserve are as follows: (See DWAF 2008 for detailed descriptions of steps)
    - **Step 1** Initiation of the study and scoping, select water quality variables for the Assessment
    - **Step 2** Delineation of resource units and preliminary water quality site selection,
    - **Step 3** Information collection, site finalisation, water quality boundary values, data manipulation and input to the ERC (Ecological Reserve Category) process
    - **Step 4** Quantification of ecological Reserve scenarios, and
    - **Step 5** Ecological consequences of operational scenarios.
    - **Step 6** Decision making regarding Ecological Category
    - **Step 7** Ecospecs and Monitoring
    - **Step 8** Implementation Strategy
    - Steps 1 through 5 contain the essence of the water quality study.
- These 5 steps were aligned with protocol to determine the water quantity component of the ecological Reserve to ensure timely and appropriate exchange of information between the two processes (Figure 8.5).

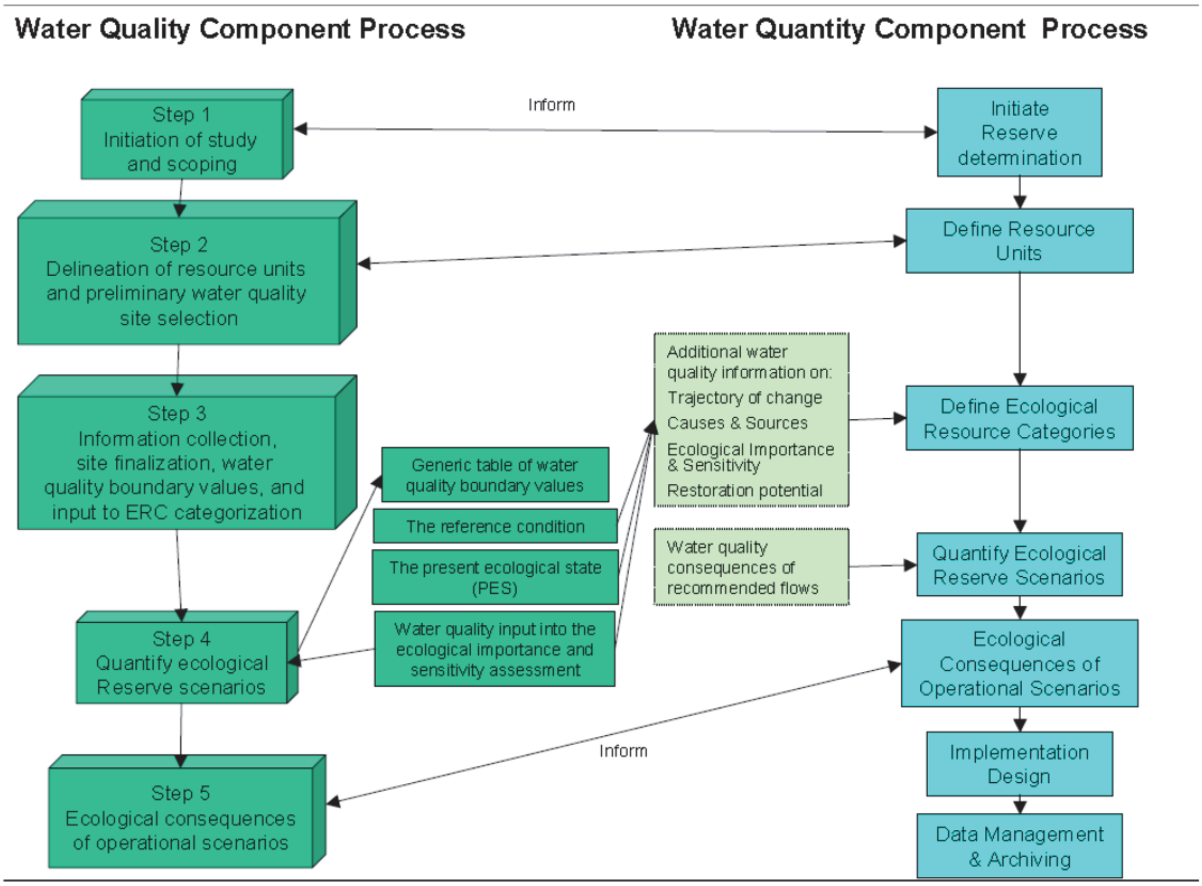


Figure 8.5: Steps for the determination of the water quality and the interface with the water quantity reserve (Rossouw 2003)

3. DATA REQUIREMENTS (DWA 2008)

- All available water quality data needs to be considered for inclusion in the Reserve study. However, not all data are suitable or appropriate – sampling frequency, knowledge of the catchment and professional judgement are used to assess whether data from particular monitoring points are to be included.

Table 8.7: List of constituents considered for the determination of the water quality component of the ecological Reserve (Hughes 2004, Rossouw 2003)

Constituent	Obligatory	Optional	Comment
*Inorganic salts** Sodium chloride (NaCl) Sodium sulphate (Na2SO4) Magnesium chloride (MgCl2) Magnesium sulphate (MgSO4) Calcium chloride (CaCl2) Calcium sulphate (CaSO4)	 X X X X X X		The effects of individual salts would outweigh the effects attributable to TDS – thus individual salts rather than TDS assessed
Nutrients: Phosphate (PO4 .P) Total inorganic nitrogen	 X X		Include algal abundance (response variable) if there is evidence of nutrient enrichment
Physical constituents: Turbidity pH Dissolved oxygen Temperature	 X X X	 X	Include temperature only if there are thermal impacts on the ecosystem
Toxic substances: Those listed in the South African	 X		Include toxic metal ions, toxic organic substances, and/or substances selected

Constituent	Obligatory	Optional	Comment
Water Quality Guidelines for Aquatic Ecosystems (DWAF 1996)			from the chemical inventory of an effluent/discharge
Response variables: Biological indicator of water quality (Diatoms) Algal abundance Toxicity	X	 X X	 Evidence of eutrophication

* Electrical Conductivity is more often than not included as a constituent. In some cases it is used as a surrogate.

- Not all the above listed variables will be available for all water quality monitoring points and not all water quality variables are obligatory for an ecological Reserve assessment for water quality.

4. DATA MANIPULATION (Hughes 2004 p.86-90)

- Note that individual salt ionic data must be run through TEACHA (see Step 3.2) to generate aggregated salts in the most likely combination present at the site under investigation. TEACHA is an acronym for **T**ool for **E**cological **A**quatic **C**hemical **H**abitat **A**ssessment.
- It uses as input, water quality data from a single site and for a reference site. The primary output is the recommended water quality component of the Ecological Reserve with corresponding ion data to use in the setting of resource quality objectives.
- The use of this software presupposes that information is available and reliable. It is not an expert system and requires the availability of expertise to check that the outcome is correct and scientifically valid. It also has strict data input requirements, e.g. all salt ions have to be input or the model will not run.
- SPATSIM also provides a facility for statistically summarising the available water quality data, setting the date range of the data to be used in later analyses and estimating the salt concentrations from the raw water quality data.

5. BENCHMARK VALUES (DWA 2008)

- Present state rating or benchmark values have been specified for the different constituents are presented (Table 8.8) to deriving the present state for each water quality metric.

Table 8.8: Present state rating or default benchmark values specified for the water quality constituents.

Variable group	Variable	Natural	Good	Fair	Poor
Inorganic salts (95th percentile)	MgSO4	16	27	37	>37
	Na2SO4	20	36	51	>51
	MgCl2	15	33	51	>51
	CaCl2	21	63	105	>105
	NaCl	45	217	389	>389
	CaSO4	351	773	1195	>1195
Nutrients (50th percentile)	PO4-P	(mg/l)	0.005	0.025	0.125.
	TIN	(mg/l)	0.25	1	4
Physical variables	Temperature (°C)	See Table 8.9 and description below			
	Dissolved oxygen (mg/l)	6		4	<4
	Turbidity	Deviation from natural background values			
	pH (range)	6.5-8.0	5.75-9.0	5.0-10.0	<5.0 or >10.0
Response variables	Biotic index (ASPT score)	7	6	5	<5
	Algal abundance				
	Phytoplankton Chl a (µg/l)	10	20	30	>30
	Periphyton Chl a (mg/m^2)	3	25	260	>260

- Temperature is only considered when there is evidence of thermal impacts, and is evaluated as a site-specific deviation from the natural temperature range (Table 8.9).

Table 8.9: Benchmark category boundary descriptions for temperature.

Category	Temperature
Natural range	Monthly 10th and 90th percentiles of monthly observed reference data or simulated reference temperature data
Good range	Upper boundary = 90th percentile + minimum(0.1*90th percentile, 2 °C) Lower boundary = 10th percentile - minimum(0.1*10th percentile, 2 °C)
Fair range	Upper boundary = 90th percentile + minimum(0.2*90th percentile, 4 °C) Lower boundary = 10th percentile - minimum(0.2*10th percentile, 4 °C)

Table 8.10: Benchmarks for the toxic substances as listed in DWAF (1996)

Substance	Natural	Good	Fair	Poor
Al	20	85	150	>150
Ammonia	15	58	100	>100
As	20	75	130	>130
Atrazine	19	59	100	>100
Cd soft*	0.2	1	1.8	>1.8
Cd mod**	0.2	1.5	2.8	>2.8
Cd hard***	0.3	2.7	5	>5.0
Chorine (free)	0.4	2.7	5	>5
Cr(III)	24	182	340	>340
Cr(VI)	14	107	200	>200
Cu soft*	0.5	1.1	1.6	>1.6
Cu mod**	1.5	3	4.6	>4.6
Cu hard***	2.4	5	7.5	>7.5
Cyanide	4	57	110	>110
Endosulfan	0.02	0.11	0.2	>0.2
Fluoride	1500	2020	2540	>2540
Pb soft*	0.5	2.3	4	>4
Pb mod**	1	4	7	>7
Pb hard***	2	8	13	>13
Hg	0.08	0.9	1.7	>1.7
Phenol	60	280	500	>500

6. RISK AND HAZARDS (Palmer 2003)

- For water quality variables, most class descriptions are in terms of magnitude (usually concentration) only, with duration and frequency only indirectly considered, if at all. Due to the fact that mainly magnitude is considered, the present method is based on hazard descriptions, whereas future assessments may be risk-based (Jooste et al. 2000). (Hazard is a potentially negative impact, such as a high concentration of a pollutant, whereas risk is the likelihood of the hazard actually happening.)

SELF-EVALUATION QUESTIONS

1. Outline the procedure for the determination of the water quality component of an EWR study and how it links with the water quantity component.
2. Review a case study of a water quality Reserve determination and discuss it in terms of completeness specifically in terms of the data requirements and data manipulation methods.

4. ESTUARY EWR METHODOLOGIES

TIME

You will need approximately 15 hours to master this study unit.

REFERENCE

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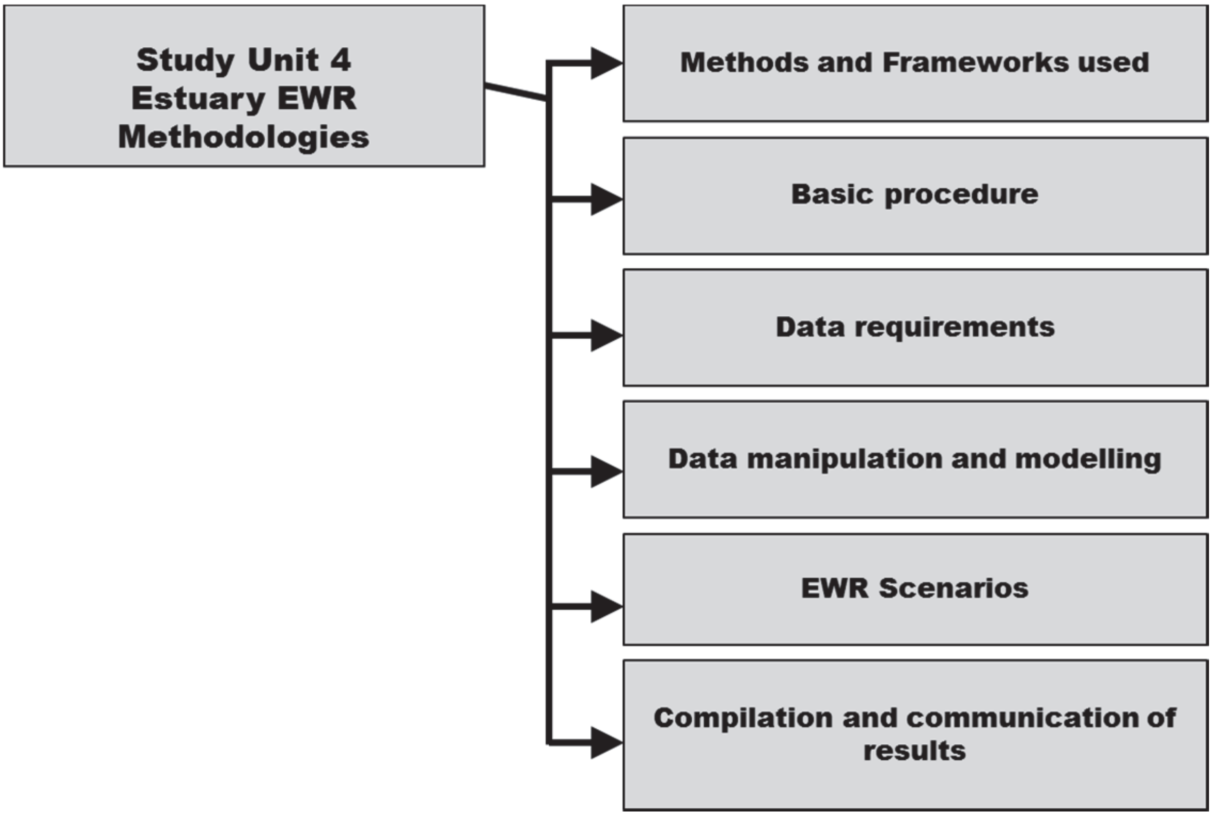
- Taljaard, S., Adams, J.B., Turpie, J.K., Van Niekerk, L., Bate, G., Cyrus, D., Huizinga, P., Lamberth, S., Weston, B. 2003. Methodology for the Determination of the Preliminary Ecological Reserve for Estuaries. Version 2. Department of Water Affairs & Forestry, Pretoria, South Africa.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR methodologies in general by being able to:

- give a broad overview of the methods and approaches relating to EWR methodologies for estuaries;
- describe the procedure for determining the estuarine EWR;
- indicate the main data requirements for the estuary EWR study and the manipulation of that data; and
- interpret the EWR scenarios emanating from an estuarine EWR study.

The study unit will be conducted as follows:



INTRODUCTION

The ecological functioning of estuaries depends on inflows from both coastal marine waters as well as freshwater inflows from rivers feeding the estuaries. The complex relationship between these two inputs determines, to a large extent, the nature of the estuarine ecosystem and associated services which are provided by that ecosystem. Understanding how the relationship between freshwater inflows and marine inflows can be affected by different activities, as well as the flows required to maintain a certain level of ecosystem functioning, is essential to achieving the wise use of estuarine wetland ecosystems. Australia, South Africa, United Kingdom and the USA have made the most significant progress in developing methods for assessment of environmental water requirements for estuaries. These methods have mostly been developed within practical applications, representing a “learning-by-doing” approach.

1. METHODS AND FRAMEWORKS FOR EWR DETERMINATIONS IN ESTUARIES (Adams 2012)

- It has been in general incorrectly assumed that the minimum flows determined for rivers would protect downstream estuary processes and for this reason the development of methodologies for determining the water quantity and quality requirements for estuaries has only really taken place in the last 10 years.
- The need to address the estuarine requirements is still often excluded because of the sectorial management of water resources.
- Current international initiatives have been centred on the determination of features such as: runoff and river flow scenarios; the definition of key biological indicators and components; identification of interactive processes amongst components and holistic ecosystem approaches.
- Estuarine EWR methods require expertise in hydrodynamic modelling, as well as multidisciplinary knowledge of the structure and function of estuaries.
- Each approach has different advantages and disadvantages but most are data rich and emphasize the need for long term monitoring so that the impacts of freshwater inflow alteration and the variable nature of these systems can be understood.
- Environmental flow methods are generally selected relative to the type of management approach applied. Management approaches can be divided into three types:
  - **Inflow-based**: Methodology aims at establishing inflows relative to how much freshwater inflow can be deviated from.
  - **Condition-based**: Methodology aims at establishing inflows relative to what condition the estuary is aimed to be maintained in and the amount of freshwater required for that level of maintenance.
  - **Resource-based**: Methodology aims at sustaining particular resources within the estuary and freshwater inflow requirements are determined according to the amount required by these resources.
- The methods that have been used in various countries to determine the environmental water requirements of estuaries are summarised in Table 8.11.

Table 8.11: Summary of the main international approaches and methods for determining environmental flow requirements of estuaries (Adams 2005).

Approach	Country	Method	Case study
Inflow-based	USA	Percent-of-flow	South-Western Florida estuaries.
Resource-based	USA	TxEMP	Nueces Estuary, Galveston Bay & Trinity-San Jacinto Estuary
	USA	Valued Ecosystem Component Methods 1. Environmental flows for indicator species. 2. Use of SAV to determine minimum and maximum flows. 3. Environmental flows for target habitats.	• Loxahatchee River & Estuary. • Caloosahatchee Estuary • Suwannee River Estuary
	Australia	Determining flows for fisheries	Fitzroy River Estuary
Condition-based	USA	X^2 approach (isohaline position)	San Francisco Bay estuaries
	South Africa	Resource Directed Measures/Ecological Reserve Method	Mdloti, Mhlanga, Tsitsikamma, Thukela, Breede, St Lucia, Orange, and Mtata estuaries.
	Australia	National River Health Programme approach	Richmond River Estuary Emigrant Creek Hawkesbury Nepean River and estuary), and Lower Hastings River

Approach	Country	Method	Case study
	Australia	Benchmarking & risk assessment	FitzRoy River estuary Other Queensland catchments
Risk Assess based	UK	Risk Assessment Approach	
Modeling	USA	Numerical modeling	Pascagoula River & Estuary
	Australia	Numerical modeling	Derwent Estuary
	Australia	Simple Estuarine Response Model (SERM)	Various Australian estuaries?

- Recent studies have taken a holistic and adaptive approach and are mostly presented as frameworks which provide a broad strategy for the assessments of environmental water requirements for estuaries. Methods used in these frameworks are holistic, in that they consider the entire ecosystem and include multi-disciplinary teams and stakeholders.
- Holistic methods have mostly developed from practical applications, a “learning-by-doing” approach.
- **Ecosystem-based approaches** are more holistic, but data requirements are intensive. An ecosystem-based approach generally makes use of experts from a range of disciplines, with knowledge of both living (biotic) and non-living (abiotic) components of the estuarine ecosystem. Studies vary in their selection of parameters that are evaluated and the timeline over which the implications of change are assessed. These types of studies are generally replicable and can transfer to other sites or systems. Good physical, chemical, water quality and ecological data are needed to determine appropriate environmental water requirements.
- **Benchmarking** is a “top down” method that defines environmental water requirements in terms of acceptable levels of change from the natural flow regime. The effects of changes are benchmarked by comparison with similar river reaches that have already been modified. The method can be used to evaluate the consequences of many different scenarios of flow regulation and appears to be suitable for poorly studied areas.
- **Risk assessment approaches** method relies on risk assessment and incorporates levels of uncertainty and prediction of estuarine response to altered freshwater inputs. The approach includes monitoring and adaptive management which allows for updating and re-evaluation of understanding and hypotheses and therefore improves decision making in knowledge-poor environments.

2. Basic EWR Procedure (Adams 2012 and DWA 2004 p. 17-71)

- The South African method for the determination of the ecological reserve for estuaries (Resource Directed Measures (RDM) method) uses a holistic approach. A reference condition is set for an estuary then the Estuarine Health Index is used to assess the present state of the estuary and deviation from the reference condition (Figure 8.6). The health index identifies flow and non-flow related impacts.
- The ecological importance of an estuary together with the present state assessment is then used to recommend an ecological Reserve Category which defines the level of protection afforded to an estuary.
- Resource Quality Objectives are also set to maintain water quantity, quality, habitat and biotic integrity to keep the estuary in the recommended ecological state, and monitoring requirements are identified.
- The method also evaluates different freshwater inflow scenarios. Hydrological specialists provide monthly runoff datasets for each scenario; these are analysed by the hydrodynamic specialists and then presented to ecological specialists for their

assessment. This is an ecosystem approach that requires an understanding of the effect of changes in river inflow on abiotic components (e.g., hydrodynamics, sediment dynamics, and water quality) and, subsequently, the response of biotic components (e.g., microalgae, macrophytes, invertebrates, fish and birds)

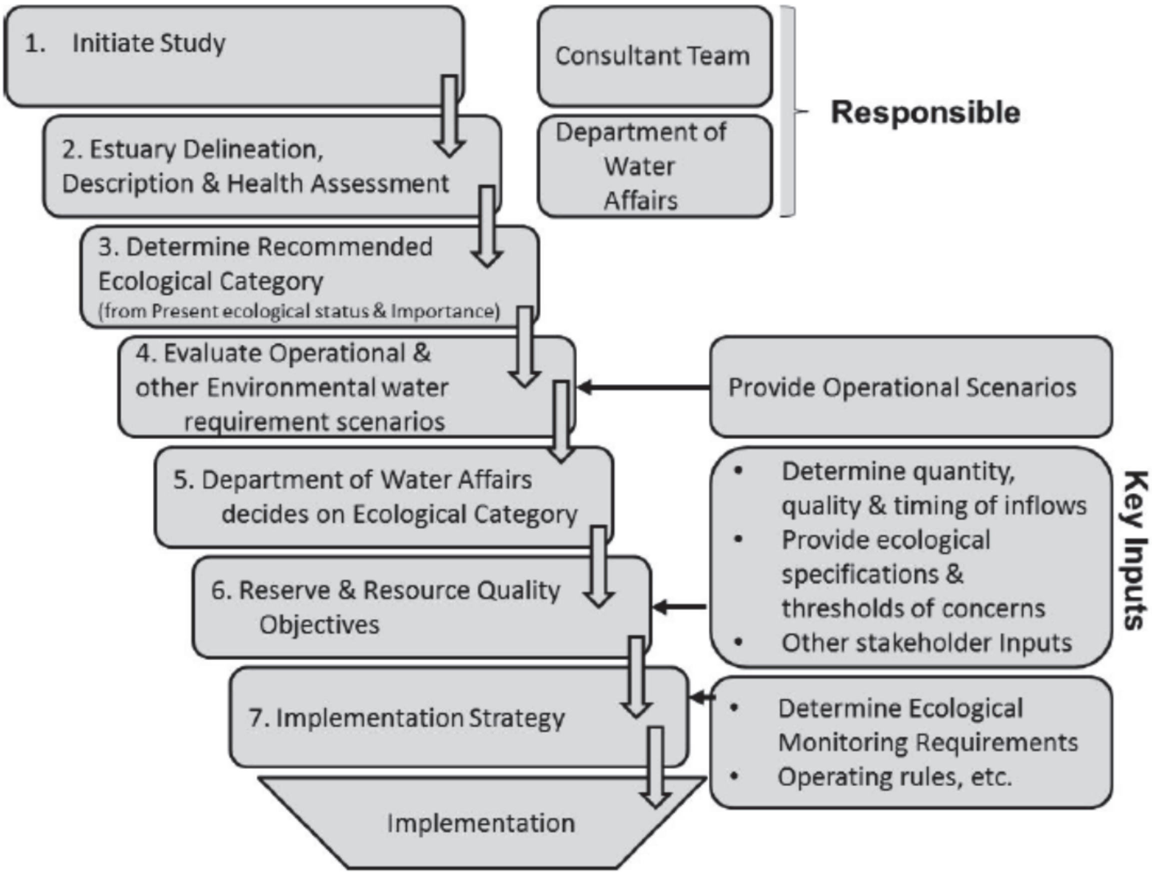


Figure 8.6: Procedure for the determination of the preliminary EWR for South African estuaries (Adams 2012)

3. Data Requirements (DWAF 2004)

- A freshwater requirement study will consist of field surveys, specialist report preparation and a workshop.
- Specialists working on the hydrology, physical dynamics, water quality, flora and fauna would be included.
- A desktop assessment is undertaken to determine the availability and suitability of existing data sets from research projects, impact assessment studies and monitoring.
- Information on rare and endangered species, species with limited populations and habitat diversity is also desirable.
- Data are used that
  - Link flow to abiotic characteristics; and
  - Identify biotic response to changes in abiotic characteristics.
- Basic data sets that are necessary but not always available are for example,
  - permanently open estuaries : relationship between flow and salinity gradients

- ➢ temporarily open estuaries: relationship between flow and mouth condition.

- Data requirements differ for different level ecological reserve studies i.e. rapid versus intermediate versus comprehensive (See DWAF 2004 p.25-42).

4. Data manipulation and modelling (Adams 2012 p.14-16)

- Confidence in the determination of the environmental water requirements of estuaries requires detailed modelling studies linking hydrology, hydrodynamics, water quality, and biotic responses. A number of models have been utilised in EWR studies for estuaries and are discussed in the literature (see Adams 2012).

- The purpose of the study, complexity of the estuary, and available expertise will determine the type of model to be used. For example, there are a number of predictive tools that can be used to assess the hydrodynamics (or water circulation patterns) of estuaries. These range from 3D numerical models, 2D numerical models, 1D numerical models, water balance models, and statistical relationships to conceptual models (Van Ballegooyen *et al*. 2004). Figure 8.7 indicates a decision tree for application of numerical modelling. Numerical modelling can be used to assess the incremental effects of changes in river inflow which are difficult to derive from a number of once-off sampling surveys.

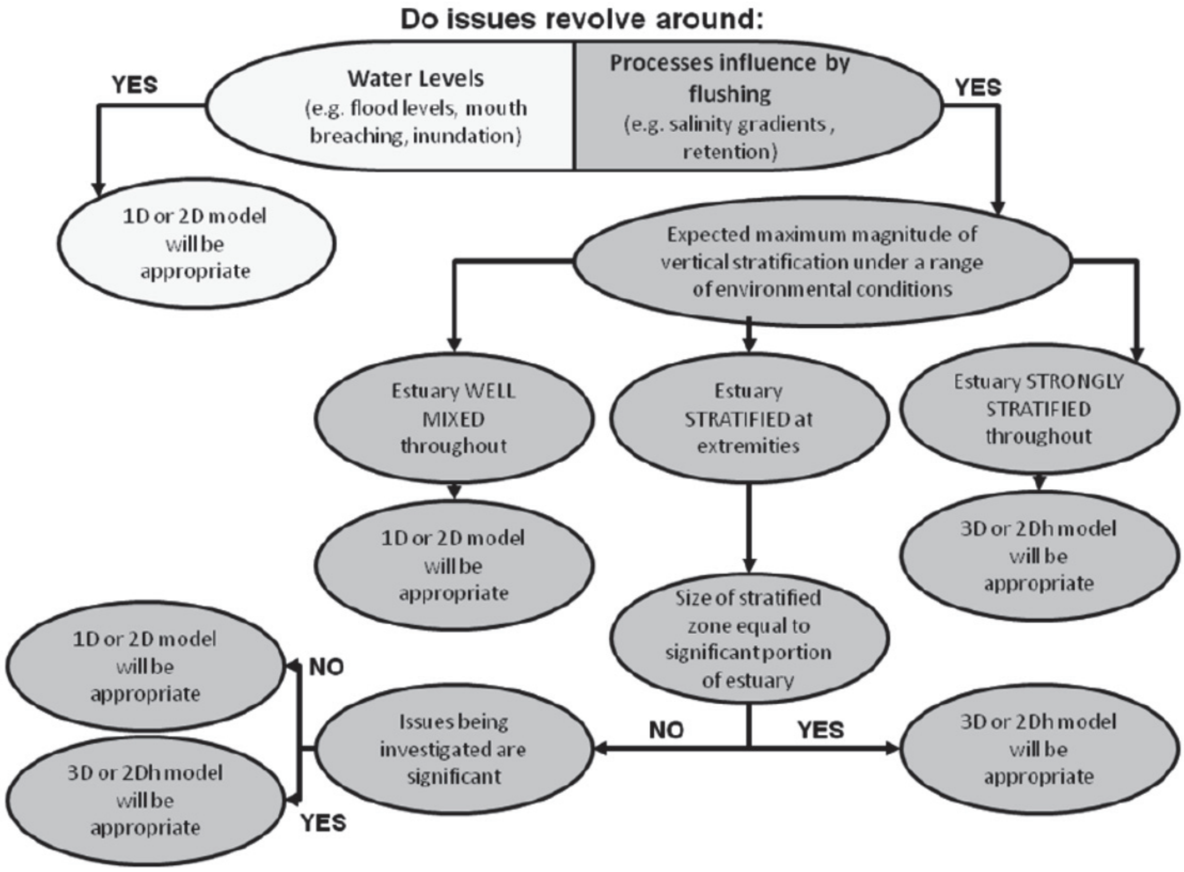


Figure 8.7: A decision tree used to determine the type of numerical model most suited to estuaries (Adams 2012)

5. EWR Scenarios

- Simulated runoff scenarios are used to derive the Ecological Water Requirement Scenarios. Simulations should be carried out as a collaborative effort between water resource planners/managers, a hydrologist (with experience in generation of such scenarios) and an estuarine hydrodynamic specialist (to stipulate specific output requirements).

- These scenarios are typically simulated over a 50-70 year period and presented as average monthly flows that represent inflows at the head of the estuary.
- They can represent the Ecological Categories of the river reach just upstream of the estuary (e.g. Category B, C and D) (this facilitates integration between the river and estuarine components).
- The confidence in the accuracy of these simulations must be provided since they form the basis for the quantification of the preliminary Ecological Reserve.
- The response of an estuary to different freshwater inflow scenarios and the freshwater allocation for the desired future state of a particular estuary is set in a multi-disciplinary workshop environment.

6. Compilation and Communication of results (DWAF 2004)

Compilation of results:

- The response of an estuary to different freshwater inflow scenarios is summarized using an estuarine health index.
- The freshwater allocation is set as a scenario (over a 50-70 year period), rather than single flow values so as to take into account natural variability in river flow patterns.
- This scenario represents the largest modification in river inflow, but where the estuarine health index scores still falls within the category allocated to the desired future state.

Combining water quantity and quality assessments

- Water quality changes associated with different freshwater inflow scenarios are considered in the Estuarine Health index.
- The water quality data are obtained from the river resource unit just upstream of the estuary.
- The quantity of river water entering an estuary and the state of the tide determine the water quality characteristics along the length of the estuary.
- Longitudinal salinity distribution profiles are typically used as primary indicators of water quality.

Communication of results

- The EWRs of an estuary are presented as a scenario of flows.
- In estuaries, river inflow patterns show strong correlation with important hydrodynamic and sediment characteristics, such as state of the mouth, amplitude of tidal variation, water circulation patterns and sediment deposition/erosion. However, the relationships between these characteristics and river inflow are generally complicated to interpret, owing to the influence of the sea, i.e. state of the tide and associated seawater intrusion. The manner in which these characteristics are influenced by river flows is often not the result of a single flow event, but rather that of characteristic flow patterns occurring over weeks or months. In estuaries there is also a much larger buffer or delay-effect between river inflow patterns and their effect on abiotic parameters than in rivers (DWAF 2004).

SELF-EVALUATION QUESTIONS

1. Compile a summary of the various EWR methodologies for estuaries and list the advantages and disadvantages of each.

2. Outline the procedure currently being utilised in South Africa for the determination of an estuary EWR and discuss the specialist roles within the study.

3. Review a case study of an EWR determination and evaluate it for completeness.

5. WETLAND EWR METHODOLOGIES

TIME

You will need approximately 15 hours to master this study unit.

REFERENCE

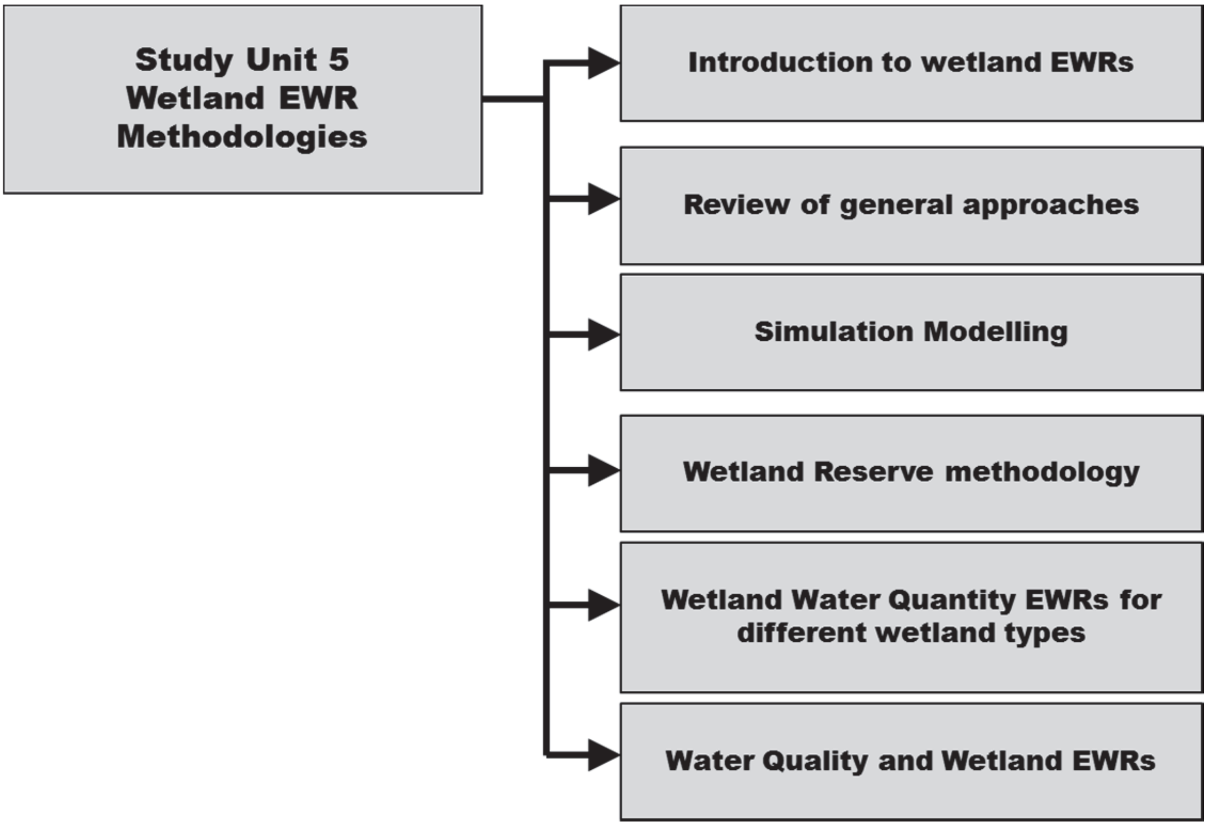
- Department of Water Affairs and Forestry. 1999. Resource Directed Measures for Protection of Water Resources, Volume 4: Wetlands (Version 1.0). Pretoria, South Africa.
- Malan HL and Day JA. 2005. Wetland Water Quality and the Ecological Reserve. WRC Report No. 1311/1/05
- Rountree MW, GC Marneweck, R Tharme and D Kotze. 2006 (Draft). Review of methods for determining environmental flows for wetlands. Wetland Consulting Services (Pty.) Ltd.
- Rountree, M.W., H. Malan and B. Weston (editors). 2012. Manual for the Rapid Ecological Reserve Determination of Inland Wetlands (Version 2.0). Joint Department of Water Affairs/Water Research Commission Study. Report No 1788/15. Water Research Commission, Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR methodologies in general by being able to:

- Give a broad understanding regarding the complexities of EWR assessments for wetlands and need for the difference in approaches;
- explain various approaches to EWRs assessments for the different wetland types; and
- indicate the approach to dealing with the water quality component of the EWR for wetlands.

The study unit will be conducted as follows:



INTRODUCTION

Due to the complexity of wetlands as well as the fact that wetlands are less targeted for larger water supply schemes, there has been little development of EWR methods for wetlands. This was the situation in South Africa in 1999 when the DWA published their first manual of Reserve Determination methods, and this partially constrained the development of wetland EWR assessments, since more data over longer time periods were required to develop an adequate understanding of the wetlands. Although there has been only limited development of EWR methods for wetlands since this time (for a review see Rountree *et al.* 2006), research undertaken by the Water Research Commission and others in aspects of wetland functioning and the hydraulics of vegetated channels has enabled some refinement and streamlining of the earlier methods.

1. Introduction to wetlands EWRs and their complexities (Rountree *et al.* 2005)

- 'Wetland' is a broad term that covers a range of aquatic systems. The Ramsar classification of wetlands recognises over 40 types. Wetland types range from open to closed (endorheic) systems with poor, and highly variable, partitioning between the surface and sub-surface water inputs. A range of approaches to wetland environmental water determination studies are needed to deal with the diversity of wetland types.
- The diversity of wetland types has diverse hydrological drivers. There is seldom easily measurable drivers of the system (groundwater seepage is more difficult to measure than channelised river flows), nor is it easy to provide flows in order to manage these drivers.
- For environmental water allocations, wetlands are usefully grouped by water source/s: precipitation, surface water, interflow and groundwater. However wetland species may be reliant on more than one source: e.g. riparian trees on floodplains utilise water from all three sources at different times. The "catchment area" of a wetland can also be difficult to define where deep groundwater inputs make a significant input to the system.
- In wetlands the link between discharge, ecological and geomorphic processes is less direct than in river systems. Rivers are well-defined, linear systems wherein water flow is confined, but wetlands are often poorly defined/delineated, open systems. In addition, in river systems releases from large dams and control of direct abstraction (pumping) offer relatively easy, measurable and direct cause-effect management options for river flow.
- Environmental water allocations protect only those wetlands where the dominant water source is surface-water or groundwater. Wetlands where precipitation is the main water source are not protected in this way. Surface-water wetlands are generally river-influenced wetlands; these are considered separately from groundwater wetlands.
- The sheer number of different wetland types in South Africa adds to the complexity of determining the EWRs.

2. Review of general approaches

Approaches applied to floodplain systems (Rountree *et al.* 2005)

- The general approach to determining the EWR for wetlands has primarily been for extensive floodplain complexes including end-of-system wetlands that are typical of low gradient rivers in semi-arid climates due to the fact that these systems function similarly to rivers. The EWR for these wetlands can be estimated in two ways: top-down or bottom-up, corresponding to hydrology-hydraulics or ecology-driven.
- Hydrological-physical:
  - ➢ The volume of water required to meet a specified target (e.g. wetland filling) can be measured or estimated from wetland dimensions and expressed in terms of required inflow at a relevant upstream gauging station.
  - ➢ Time series of river flows (simulated natural or historic as appropriate) can then be used to establish frequency, timing etc. of the flow conditions.
  - ➢ Volume and in-flows can be refined using a water budget approach incorporating gains and losses.

- Ecology:
  - Ecological approaches use specific knowledge of water regime requirements for a particular species, community or process, to estimate storage volume for the whole wetland.
  - This specific knowledge may be informed observation, experiments or accumulated information.
  - The water requirements may be expressed as depth x duration x season.
  - Estimates of river-inflows are then derived from storage volume and can be refined to allow for wetland losses and inputs, transmission losses, antecedent conditions.

Approaches applied to Groundwater-fed systems

- These are probably the least understood systems in environmental flow determinations studies. Many wetlands depend on a stable influx of groundwater throughout the year. Others (e.g. the hill slope seepage systems in the Highveld Regions of South Africa) depend on seasonal fluxes in perched groundwater and interflow in the landscape (Kotze et al. 2005).
- The assessment of the environmental flow requirement is complicated by the absence of a single flowing channel for gauging within the wetland. Alternative methods to that used in rivers is required especially in unconfined springs and hill slope seepage systems where decant occurs over a seep face rather than a point source (Rountree et al. 2005).
- One potential approach could be the use of a combination of groundwater level measurements linked to precipitation and groundwater recharge estimates. This requires an understanding of the influence of geology, landscape setting, soil form and sub-surface stratigraphy in groundwater flow and dynamics.

3. Simulation modelling (Rountree *et al.* 2005)

- This is used to explore impacts of water resource management or scenarios.
- Central to these is the use of hydrology-ecology relationships. The four methods (below) are distinguished by the type and complexity of hydrological modelling, and the degree to which ecological responses are incorporated into the model.
- Hydrologic/expert opinion:
  - Hydrologic modelling and ecology are linked in simple ways, such as rule of thumb, logic rules, or index values.
  - The ecology-hydrology relationship may be based on diverse forms of knowledge, formal and informal.
- Hydrologic/empirical:
  - Hydrologic modelling (water balance) and ecology are linked by empirical relationships incorporated into the model as regression or probabilistic models.
  - These are based on data describing an ecological response to a specific set of hydrologic circumstances, which may derive from the target wetland or a comparable site.
  - Experimental data is particularly relevant because the availability of long-term

field data is usually limited to either vegetation attributes or records of water bird breeding.

- Hydraulic/empirical:
  - ➢ Wetland water regime is modelled in greater detail using hydraulic models.
  - ➢ This gives additional variables such as water depth and velocity, hence allowing better representation of plant growth or flow-related processes such as dispersal and migration.
  - ➢ It also gives spatial representation; hence ecological responses can be incorporated in much greater detail.
- Hydraulic/process:
  - ➢ Hydraulic modelling combined with modelled physiological or ecological responses makes models in these categories the most complex to build and run.
  - ➢ The physiological or ecological response that is being modelled is most likely to be plant-based, as there are already a number of plant growth models that can be adapted for use.
  - ➢ Computational demands mean that the area represented by the model is more limited.

4. Wetland Reserve methodology (Rountree *et al.* 2012 p.3-5)

- To facilitate easier linkages between RDM studies of different water resource types (rivers, estuaries, groundwater and wetlands), a generic 8 step procedure (Figure 8.8) is used for all Reserve determination studies. The Ecological Reserve Determination of Inland Wetlands manual for rapid reserve studies (Rountree 2012) provides the detailed technical information for the assessments.

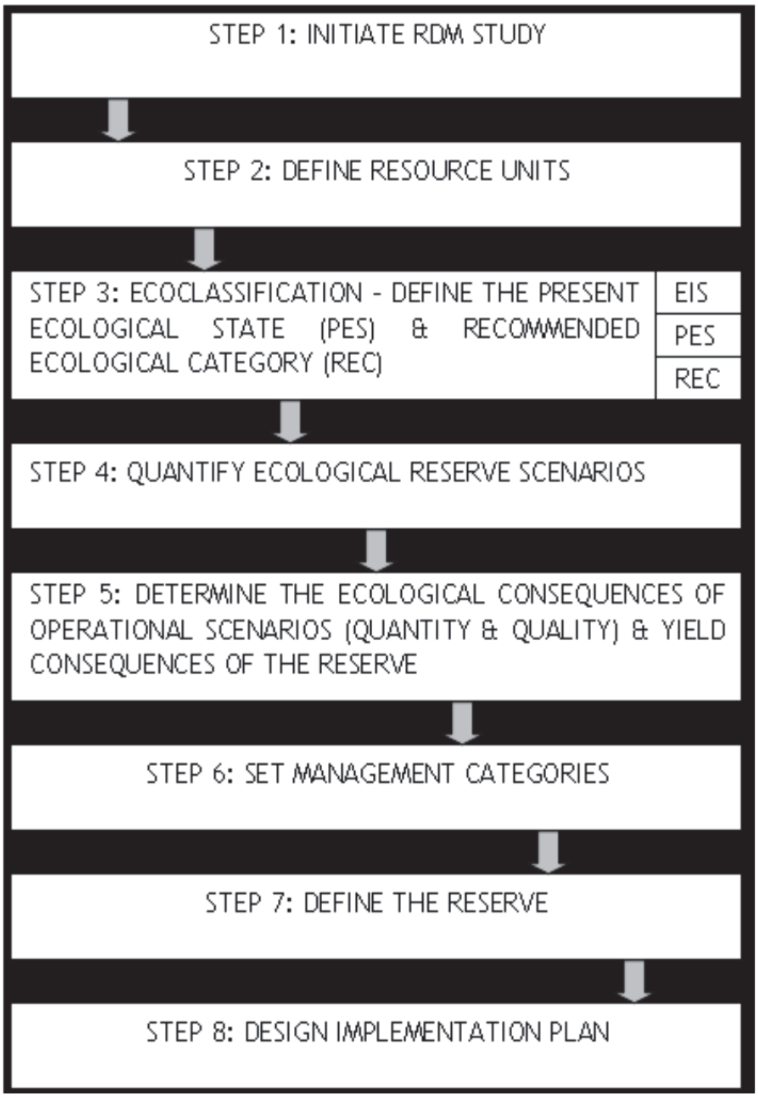


Figure 8.8: Generic 8 step procedure for Reserve Determination studies

5. Wetland Water Quantity EWRs for different wetland types (Rountree *et al.* 2012 p.21-27)

- The simplest way to assess the quantities of water flowing into, through and out of a wetland is to use a Water Balance model – a modelling exercise which balances inflows, outflows and losses from the system.
- Several different types of wetlands have been identified, but many aspects of the water balance approach will be the same regardless of the wetland type. The water balance methodology has therefore been described firstly in generic terms which apply to all wetland types (as well as rivers and estuaries) and then the methodology is refined for each identified wetland type.
- The following information is proposed to be developed for the Rapid level of Reserve studies for wetlands:
  - ➢ An indication of natural inflows (surface flow and interflow where necessary)
  - ➢ Current day inflows
  - ➢ Water use within the wetland: Storage-volume relationships; Vegetated versus

open water areas; Permanent versus seasonal wetland areas; Evapotranspiration losses and rainfall gains;

- ➢ Evaluation of scenarios and how these may impact upon factors such as extent of permanent wetted areas, and reduction in the frequency of flooding.

- For each wetland type, a conceptual hydrological model and water balance model are generated to describe the reference state, present day and scenario hydrology. The ecological specialists then translate the hydraulic and hydrological information into ecological responses and provide the ecological requirements of the different ecosystem components in order to identify the ecological water requirements linked to a specific EcoStatus.
- The hydrological approach adopted for wetland Reserve studies depends on the underlying drivers of the wetland, and is specific to each wetland type:
- **Seepage wetlands**: A seep is generally associated with a perched water table and hence located on a hill slope with little or no upstream influence. Due to the generally small size of seepage wetlands, subsurface inflows, through flows and often subsurface outflows, the recommended approach for the assessment and protection of seepage wetlands would be through Present Ecological Status assessments and the setting of Resource Quality Objectives (RQO"s).
- **Unchannelled valley bottoms**: An unchannelled wetland can be modelled in the same manner as a reservoir, the only difference being that it is necessary to distinguish between the areas of open water and the areas of vegetation. The relationship between discharge and inundation depth/extent within the wetland will be determined by a stage-discharge relationship which needs to be provided by the hydraulician. The influence of aquatic vegetation on flow resistance is determined by the morphology of the individual vegetation stems and characteristics of the whole wetland bed.
- **Channelled Valley bottoms** would (hydraulically) function similarly to rivers with terraces or flood benches. The more traditional river-based hydrology and hydraulic approaches would apply to this wetland type. The procedure for channelled valley bottoms will be the same as for unchannelled valley bottoms, the only difference is that the stage-discharge relationship will indicate that below a certain flow rate the wetland is not inundated.
- **Meandering floodplains** would function (hydraulically) similarly to rivers, although the overbank features are unique and this makes these wetland types more complex than river studies. With some adaption, traditional river-based hydrology and hydraulic approaches would apply to this wetland type. The water balance procedures for floodplains are the same as for a channelled valley bottom, and hydraulic approaches similar as for the traditional river-based approaches. However special attention would need to be paid to floodplain features such as cut-off meanders and backwater swamps.
- **Pans** are depressions in the landscape that tend to have relatively small catchments. Groundwater (including shallow groundwater or interflow) is usually an important hydrological variable. This is however difficult to account for using traditional river-based approaches for EWRs. An accurate area-capacity relationship is required for a depression. An abstraction will reduce the surface area of the depression and the decision on whether to allow the activity will be based on reduction in area that could be allowed.
- **Lakes:** Methods for Intermediate Reserve Determination for freshwater lakes were developed as part of the 1999 RDM Reserve methods, and these methods have been successfully applied in previous Reserve studies. Most lakes in South Africa are coastal lakes thus if the lake is connected to an estuary, and salinity is the driving

process in the system, then the lake should be considered as an extension of the estuary and the estuarine RDM methods applied.

- **Flats:** Groundwater plays a critical role of in wetland flats and therefore these wetlands merely reflect the condition of the groundwater resource. Whilst such wetlands could be monitored as an indicator of the groundwater resource, the Reserve quality and quantity components would need to be assessed by a dedicated Groundwater Reserve study and not as part of an EWR assessment of the wetlands per se.

Table 8.12: Summary of wetland types and specialist work required (Rountree *et al.* 2012 p.10)

Landscape Position:	**Valley Bottom**				**Slope**		**Crest**		**Flat**
Flow/inundation pattern:	standing water	diffuse	channelled (parallel to the valley)	channelled (meandering across valley)	diffuse to diffuse	diffuse flow to surface/ channel	diffuse flow to standing water	standing water	standing water
HGM wetland type:	***Lake*** [1]	***Un-channelled Valley Bottom***	***Channelled Valley Bottom***	***Meandering Floodplain***	***Seepage wetlands***			***Pan***	***Wetland Flat*** [2]
Essential Experts for Rapid Reserve study	n/a	Hydrologist Hydraulician Botanist Geomorphologist [4] Diatomologist	Hydrologist Hydraulician Botanist Geomorphologist Diatomologist	Hydrologist Hydraulician Botanist Geomorphologist Diatomologist Fish	Single wetland expert to undertake PES assessments and provide EcoSpecs			Hydrologist Botanist Diatomologist	Geohydrologist Botanist Diatomologist
PES outputs	n/a	Hydrology Vegetation Geomorphology Diatom	Hydrology Vegetation Geomorphology Diatom	Hydrology Vegetation Geomorphology Diatom Fish	Hydrology Vegetation			Hydrology Vegetation Diatom	Hydrology Vegetation Diatom
Additional expertise that could be considered [3]	n/a	*Water Quality* *Fish Geohydrologist*	*Water Quality* *Fish* *Geohydrologist*	*Water Quality* *Geohydrologist*	*Water Quality* *Geohydrologist*			*Water Quality* *Geohydrologist*	*Water Quality*

1: Only assessed at Intermediate Reserve Level – refer to DWAF (1999) methods
2: The reliance of these wetlands on complex groundwater inflows , which cannot be assessed at a Rapid Level, precludes EWR assessments from being undertaken. PES and RQO's will be set for these wetlands. Wetland flats can be used as indicators of the condition of the groundwater resource upon which they are dependent.
3: Additional experts may be added to the core team according to the wetland and scope of WULA's being considered by Reserve study.
4: Geomorphologist or soil scientist will be required to identify wetting zones.

6. Water quality and wetland EWRs (Malan and Day 2005, Rountree *et al.* 2012)

- Generally little water quality data are likely to exist for wetland areas, meaning that many water quality studies in wetlands will be low confidence unless the studies are undertaken over many years and with intensive data collection. However, often the catchment sizes for the wetlands are small and therefore the likely impacts on water quality can usually be characterised by the surrounding land use activities. A rapid method for assessing the PES of water quality, linked to diatom assessments, in the same way that macro-invertebrate studies have been widely used in river Reserves, has been developed to improve confidence and verify results.

SELF-EVALUATION QUESTIONS

1. Compile a summary of the various EWR approaches for wetlands and list the advantages and disadvantages of each.
2. Outline the procedure currently being utilised in South Africa for the determination of wetland EWR and how it is applied to the various wetland types.
3. Review a case study of a wetland EWR determination and evaluate it for completeness.

SUMMARY

- Inundation or soil saturation duration is often a stronger driver in wetland determination and maintenance than flow volumes. These inundation patterns are often related to perched (near-surface) groundwater and occasionally deep groundwater. However it is difficult to correlate these characteristics with actual flow discharges.
- Hydraulic relationships between flow volumes; wetland physical habitat (e.g. floodplains) and wetland biota are extremely complex and poorly understood (Rountree *et al*. 2005).
- In the South African context while river Reserve requirements can be easily translated into flow volumes (since the requirements are based on depth, velocity and energy components of flow), the findings for wetland water requirements may often need to remain as Resource Quality Objectives (depth or saturation duration requirements). The links between inundation depth and flow rate in wetlands is often very poorly understood, and not easily translated by hydraulicians to a flow volume.

6. GROUNDWATER EWR METHODOLOGIES

TIME

You will need approximately 15 hours to master this study unit.

REFERENCE

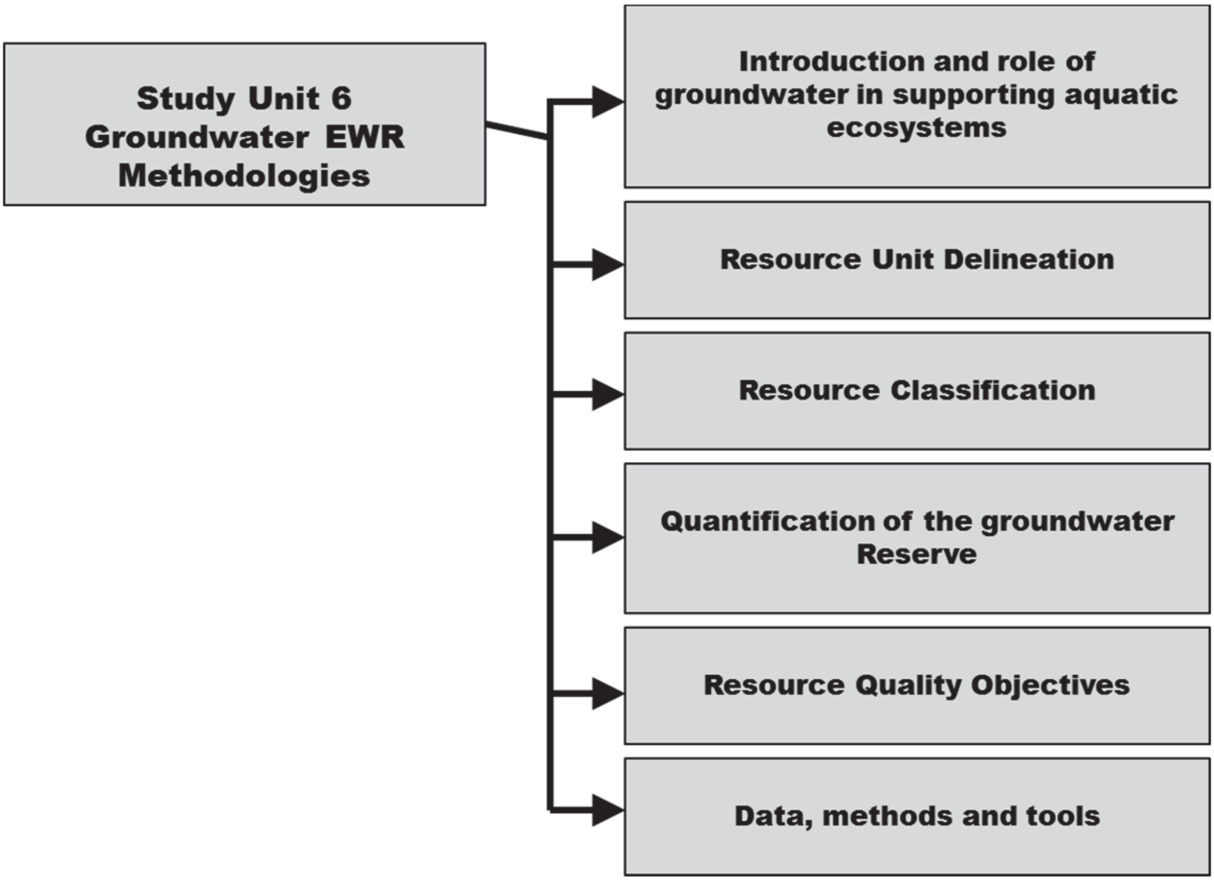
- Parsons, R. and J Wentzel. 2006. GRDM Manual. Water Research Commission Project 1427.
- Department of Water Affairs and Forestry 1999. Resource Directed Measures for Protection of Water Resources. Volume 6: Groundwater Component Version 1.0. Department of Water Affairs and Forestry, Pretoria.
- Flanagan LE, Parsons RP, Munch Z, Basson FC, Conrad JE and Wentzel J. (2006) A Pilot Study for Setting Resource Directed Measures for Groundwater – Groundwater Atlas of the E10 Catchment. WRC Project 1427, Water Research Commission, Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR methodologies in general by being able to:

- give a broad overview of the role of groundwater in supporting other aquatic ecosystems;
- describe how groundwater resource units are delineated and classified;
- provide a summary of the groundwater quantification process;
- provide examples of groundwater RQOs; and
- describe some of the tools used in groundwater RDM determinations.

The study unit will be conducted as follows:



INTRODUCTION

Initially, the generic eight-step process described for surface water Reserve studies was also proposed for the determination of the groundwater component of the Reserve determination (DWAF 1999). More recent revisions of the methodologies for groundwater have however moved away from these steps and proposed different approaches. While most revisions follow the same basic approach, the steps within that approach are not uniform. Implementation of the groundwater Reserve is also still under development. The Reserve for groundwater is considered as only that part that sustains basic human needs and aquatic ecosystems. As the ecological component is only that groundwater which contributes towards base flow in surface water resources and, as groundwater is far more widespread than surface water resources, the groundwater Reserve alone cannot afford adequate protection of aquifers and needs to be implemented in conjunction with the RQOs. In addition, the interpretation of the ‘Groundwater Reserve’ and the integration with surface flows is poorly defined and understood.

1. Introduction and the role of groundwater in supporting other aquatic ecosystems (Parsons and Wentzel 2006)

- The unique characteristics of groundwater (e.g. wide geographic extent and slow rate of movement) require different methods of assessment compared to other components of the hydrological system (rivers, wetlands, estuaries). A number of assumptions are made relating to the assessment of groundwater:
  - Groundwater systems are generally resilient and can normally recover from most perturbations. However, groundwater contamination can persist over decades and centuries.
  - The sustainable rate at which groundwater can be abstracted is a function of the average long-term annual recharge, while the volume of groundwater held in storage acts as a buffer during dry periods.
  - The use and protection of the entire groundwater resource needs to be addressed holistically.
  - If the water table is lowered too much, groundwater discharge to surface water bodies will diminish or cease altogether.
- The current Groundwater RDM methodology consists of the following basic phases or steps:
  - Step 1: Preparatory phase (Study initiation, define study area and level of confidence);
  - Step 2: Description of study area;
  - Step 3: Delineation of groundwater resource units;
  - Step 4: Resource classification (define present status and water resource category);
  - Step 5: Quantification of Reserve (Recharge, groundwater inflows and outflows, basic human needs, groundwater contribution to base flow);
  - Step 6: Setting of Resource Quality Objectives (Water levels and gradients, abstraction volumes, water quality and exclusion zones); and
  - Step 7: Review by panel of experts (DWAF 2004b).
- Groundwater plays an important role in sustaining many rivers, lakes, wetlands, and estuaries as well as the marine environment. (Table 8.13 and Figure 8.9 provide a summary). Where sensitive ecosystems have been identified that are groundwater dependant, protection measures need to be put into place to ensure that groundwater abstraction does not impact negatively on these ecosystems. These measures need to take into account the degree of dependence and the risk of impact.

Table 8.13: Summary of the role of groundwater and activities likely to impact on groundwater-dependent ecosystems.

Role of Groundwater
• Discharge of base flow into rivers • Discharge of base flow into wetlands • Discharge to springs • Discharge into estuaries • Discharge into the marine environment • Supporting terrestrial vegetation

Potentially Impacting Activities
• Large-scale groundwater abstraction • Infestation by alien vegetation • Planting of forests and other plantations • Contaminated groundwater discharging at surface • Modification of surfaces in recharge areas • Lowering of the regional water table

2. Resource Unit Delineation (Parsons and Wentzel 2006)

- A map is used to demarcate groundwater resource units and the name and aerial extent (in square kilometres) of each groundwater unit is recorded.
- In delineating groundwater resource units, consideration must be given to the role groundwater plays in the environment.
- Estuaries, wetlands and rivers must be considered to assess possible interdependency and promote integrated water resource management.
- A 'groundwater resource unit' (or 'groundwater unit') is defined as a groundwater system that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit.
- <u>Example:</u> In the case of the Crocodile River, it was found that groundwater discharge from the dolomitic aquifer system accounted for about 60% of base flow (DWAF 1999). Because of the unique role groundwater played in the hydrological system, the dolomitic aquifers needed to be delineated as a distinct water resource unit.
- Quaternary catchment boundaries are used to delineate groundwater units at a primary level.
- The second level of delineation is based on aquifer type (i.e. primary aquifer, secondary aquifer, dolomitic aquifer).
- When required and where sufficient data exist, further delineation can be based on physical (e.g. geology, climate, recharge), management (property, water user association, catchment management, water management and political boundaries) or functional criteria (i.e. maintaining system integrity, discharge integrity or ecological integrity).
- Exclusion zones are used to maintain <u>system integrity</u> and drawdown limitations used to promote <u>ecological integrity</u>.
- General guidelines for determining the extent of exclusion zones and calculating drawdown limitations are:
  - A distance of 1 km from a particular feature can be used to demarcate exclusion zones, with the exact distance based on prevailing conditions and risk of impact.
  - Exclusion zones or groundwater abstraction limitation zones can be demarcated around sensitive rivers and springs, if groundwater abstraction from such zones could significantly impact flow.
  - Normally the entire low maintenance flow is assumed to be derived from groundwater, but this may be reduced in the case of influent streams.
  - Drawdown and groundwater level limitations need to be based on site specific considerations.

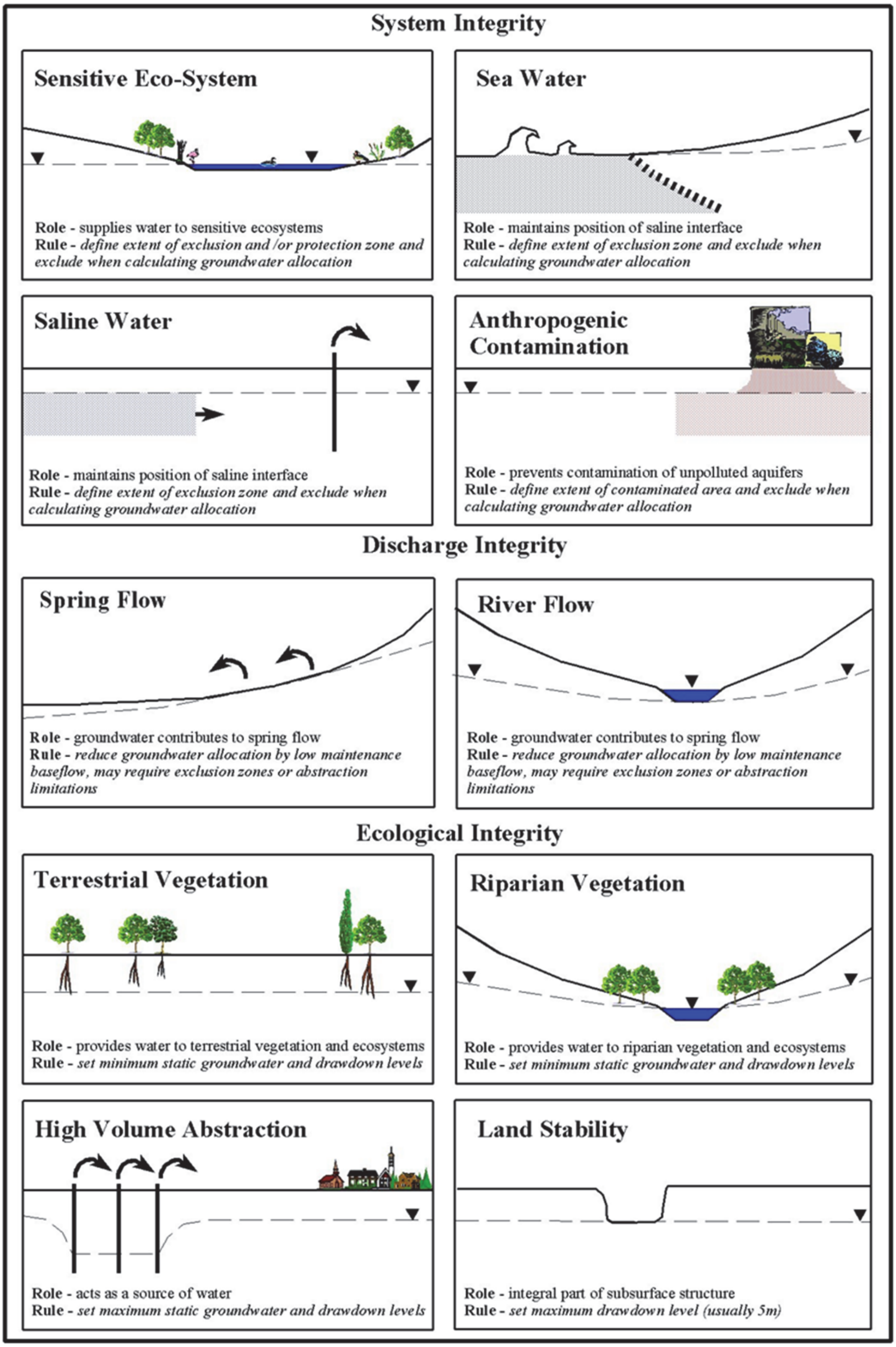


Figure 8.9: Groundwater resource unit delineation tool based on the role groundwater plays in sustaining the environment (DWAF 1999).

3. Resource Classification (Parsons and Wentzel 2006)

- The purpose of resource classification is to determine the present status and water resource category of each groundwater resource unit delineated for the study area.
- In order to determine that class of a water resource the reference conditions and present status of the resource need to be assessed. The degree of modification from natural defines the present status category. The limit of sustainable water use is an important consideration in this process.

Groundwater stress (used to assess what level of detail to include in an assessment)

- The groundwater level in a stressed aquifer may behave in a manner similar to that displayed in Figure 8.10.
- A number of indicators can be used to assess the level of stress on a groundwater system:
  - Groundwater level – a decreasing or downward trend in groundwater levels can reflect groundwater stress
  - Groundwater quality – a deterioration of groundwater quality – as indicated by an increasing or upward trend in chemical concentrations of typical contamination indicators such as EC, K, P, N and others – can reflect groundwater stress
  - Groundwater use – an increase in groundwater use within a catchment may imply increased stress on the groundwater resource
  - Disputes – an increase in the number of legal cases or disputes around groundwater use can reflect groundwater stress
  - Boreholes – an increase in the number of boreholes within a catchment or an increase in the number of boreholes drying up can reflect groundwater stress
  - Ecosystems – collapse of groundwater-dependent ecosystems or a reduction in base flow can reflect groundwater stress
  - Pollution sources – an increase in the number of potential groundwater pollution sources, for example mining and industry, can reflect groundwater stress.

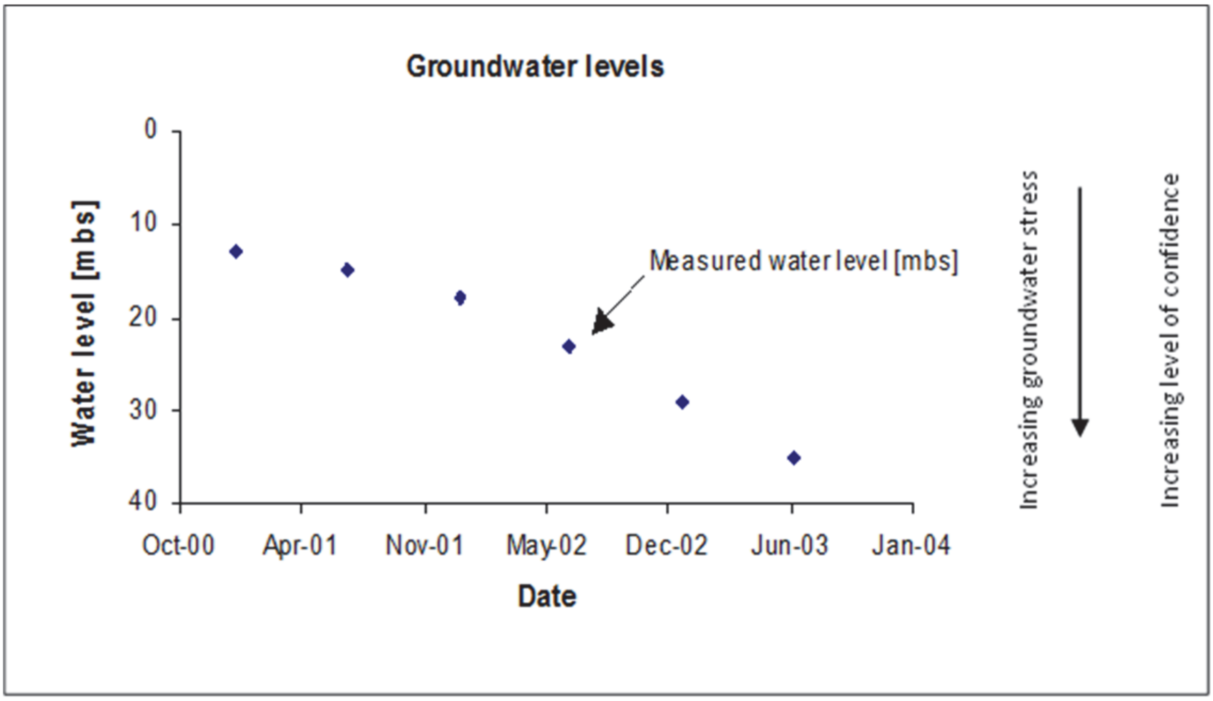


Figure 8.10: Using monitored groundwater level data to assess stress.

4. Quantification of the Groundwater Reserve – South African approach (Parsons and Wentzel 2006)

- Where groundwater contributes to or supports basic human needs or aquatic ecosystems, groundwater forms a component of the Reserve and has to be considered.
- The outcome of a groundwater Reserve the quantity of groundwater that can be abstracted from each resource unit without significantly impacting that unit's ability to sustain the Reserve and meet the Resource Quality Objectives.
- No method is provided to address the groundwater quality component of the Reserve. These issues are generally addressed under source directed controls, Classification and Resource Quality Objectives.
- Calculation of the groundwater allocation is undertaken by a suitably experienced groundwater specialist, and the outcome is presented in a data sheet documenting recharge to a groundwater resource unit, the base flow requirement met from groundwater and the basic human needs to be satisfied from groundwater supplies. This information is used to calculate the groundwater allocation.
- **Quantification process:** To be able to quantify the groundwater component of the Reserve, the following relationship has to be solved:

  $GW_{allocate} = (Re + GW_{in} - GW_{out}) - BHN - GW_{Bf}$

  where: $GW_{allocate}$ = *groundwater allocation*
  Re = *recharge from rainfall*
  GW_{in} = *groundwater inflow*
  GW_{out} = *groundwater outflow*
  BHN = *basic human needs*
  GW_{Bf} = *groundwater contribution to base flow*

- The Groundwater Allocation is the volume of groundwater that can be abstracted from a resource unit without impacting the ability of groundwater to sustain the Reserve.

- **Recharge** is the most important parameter in assessing the sustainable volume of groundwater that can be abstracted from an aquifer system. Recharge is defined as the addition of water to the zone of saturation which generally, only includes precipitation, but leakage into the subsurface from rivers, dams and wetlands can be substantial. Recharge is difficult to quantify because of rainfall variability and aquifer heterogeneities. The geohydrologists must provide the best possible estimate of recharge within the scope and level of the groundwater assessment being undertaken.
- **Groundwater inflows and outflows:** subsurface inflows and outflows are often small in relation to recharge to a quaternary catchment, but may be significant when dealing with smaller groundwater resource units or when dealing with artificial recharge. For detailed assessments, consideration of subsurface inflows and outflows is required.
- **Basic human needs:** The BHN component of the Reserve is calculated by multiplying the number of people living within the confines of a resource unit by 25 ℓ/d. To be correct, this volume should be multiplied by the ratio of people dependent on groundwater for their water supply. However, because the BHN component is generally very small (in relation to recharge), this correction is seldom necessary.
- Because the basic human needs component is generally very small, use of the latest available census data will suffice when estimating this component of the Reserve.
- The majority of the 10 million South Africans that have been provided with water since 1994 have been supplied from groundwater resources.
- **Groundwater contribution to base flow:** Base flow is a non-process related term for low amplitude, high frequency flow in a surface water body during dry or fair weather periods. It is not a measure of groundwater discharged into a river or wetland, but it is recognised that both groundwater and interflow contribute to base flow.
- The base flow component of flow is determined using a variety of base flow separation techniques. It may be possible to determine the groundwater contribution to flow by examining river flow characteristics during the latter part of the dry season. This approach was used on the Hex River (Papini *et al*. 2001) and Thukela River (Parsons 2003.
- A groundwater component has been included into SPATSIM and may provide a tool for quantifying the groundwater contribution to flow. The GRDM Assessment Software includes a base flow separation routine using the Herold method (Herold 1980) and requires monthly flow data.
- While geohydrologists should be able to address the groundwater contribution to base flow, it is strongly recommended that this be done in consultation with an experienced hydrologist.
- The following approach can be used to assess the groundwater contribution to base flow and the quantification thereof:
  - Using Figure 8.11, assess whether the base flow in a river is likely to be fed by groundwater. Ephemeral or highly seasonal streams and those streams with a low base flow index are unlikely to be groundwater fed.
  - If the river has a low probability of being groundwater-fed, then no further assessment of base flow is required.
  - If the river has a moderate to high probability of groundwater sustaining base flow (perennial rivers with a moderate to high base flow index, say above 0.2) or significant perennial springs exist in a resource unit, then a base flow separation assessment is required. In the case of intermediate and comprehensive assessments, this should be undertaken by an experienced hydrologist.

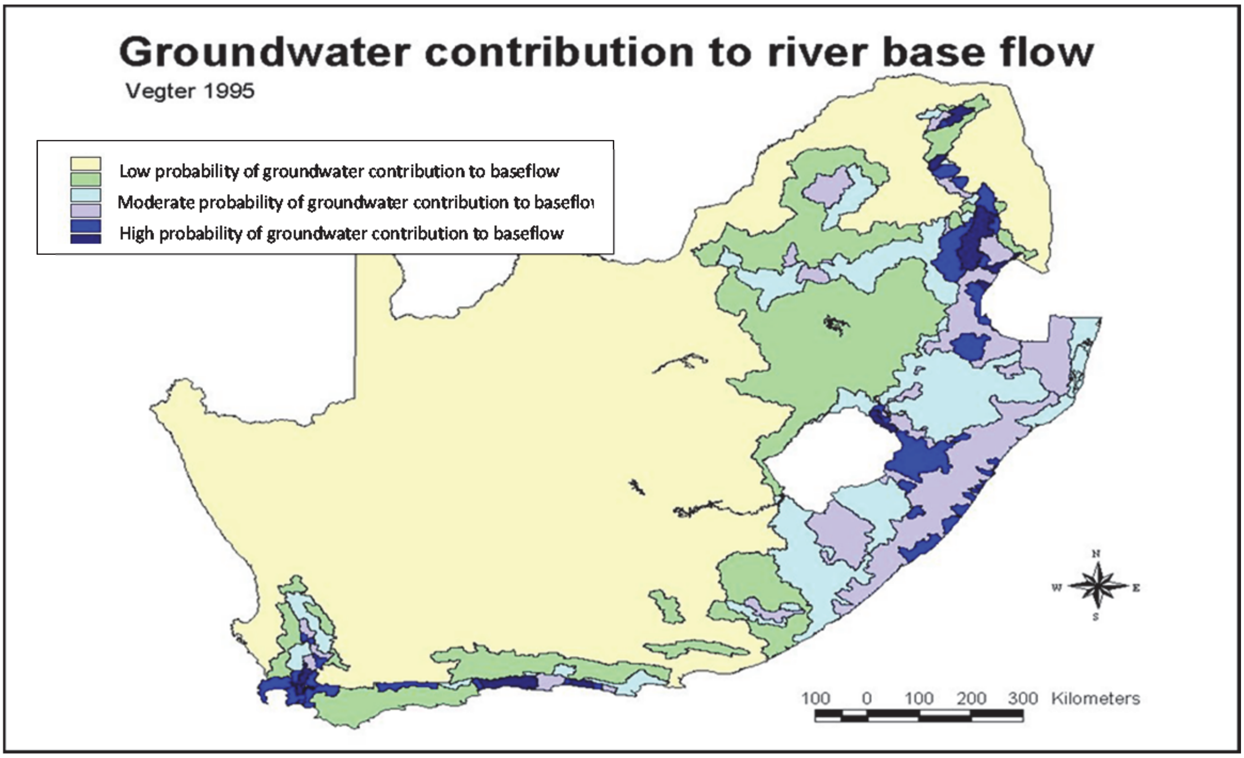


Figure 8.11: National scale map showing the relative probability of groundwater contributing to base flow (Parsons and Wentzel 2006).

5. Resource Quality Objectives (Parsons and Wentzel 2006)

- RQOs include objectives/goals that need to be met to ensure that the groundwater resource is maintained in a desired and sustainable state.
- RQOs include any requirement – numeric or descriptive – required to ensure a water resource remains in a desired state. It is specifically noted RQOs must be set in consultation with stakeholders.
- They cannot be set on a regional scale.
- Detailed RQOs needed to be set on a site specific basis and may have to set per license application.
- RQOs relate to:
  - Groundwater levels and gradients
  - Groundwater quality (the presence and concentrations of particular substances in water)
  - Groundwater abstraction volumes
  - Land use activities that may impact the quantity or quality of a groundwater resource
  - Aquifer structure and integrity (see Figure 8.1).
  - RQOs are merely a new way of considering and articulating aquifer management goals and objectives.

- **Examples of groundwater Resource Quality Objectives:** The following are some examples of RQOs drawn from actual case studies:
  - The groundwater level within 50 m of the river should not be lowered by more than 0.5 m during summer (October-March). Continuous monitoring (hourly) must be implemented by the abstractor to ensure that this RQO is not breached. Monitoring is to have an accuracy of ± 10 cm.
  - The sustainable volume of groundwater abstractable from the significant water resource is 300 000 m^3/a. Abstraction is to be evenly distributed in both time and space. This RQO was based on low-confidence estimates of recharge and it was assumed 65% of the annual average recharge could be abstracted without inducing impacts that negatively influence the functioning and structure of the aquifer system.
  - No groundwater abstraction is permitted within 150 m of the wetland. Furthermore, no land-based activity that could result in groundwater contamination is permitted in this zone.
  - If mining is to lower the groundwater level, then the volume of groundwater discharging into the river during the dry season needs to be maintained by artificially discharging groundwater into the river. Ambient quality groundwater must be discharged into the river at a rate of 100 ℓ/s between April and November.

6. Data, methods and tools (for further details see Parsons and Wentzel. 2006, Section 12)

- **Quantifying recharge:** Recharge is one of the most critical parameters of quantifying the groundwater Reserve but is also one of the most difficult. Usually the method used to quantify recharge is dependent on the data available on which to base the assessment. It is recommended that more than one method be used. Some recharge estimation tools and techniques are described below, but commonly used approaches include:
  - recharge maps
  - expert opinion
  - chloride mass balance method
  - springflow technique
  - hydrograph or base flow separation techniques
  - saturated volume fluctuation method
  - water table function method
  - cumulative rainfall departure method
  - isotope-based methods
  - EARTH model
  - numeric groundwater flow models.

- **Quantifying other inflows and outflows:** Darcy's Law can be used to approximate groundwater inflows into and outflows from groundwater units. Darcy's Law states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path.
- **Quantifying the groundwater contribution to base flow:** The following resources can be used to determine the groundwater contribution to base flow:
  - Base flow map (Vegter 1995);
  - Herold method of base flow separation – Monthly flow data are required for the separation process. Naturalised monthly flow data from the WR2005 data set is included in the GRDM Software for each quaternary catchment. Measured flow data can be downloaded from the DWAF website (www.dwaf.gov.za). The method has been included in the GRDM Assessment Software and is easy to use. However, the fitting of the separation curve is subjective.
  - Rainfall-runoff modelling – Hughes (2004) and Sami et al. (2005) have being developing techniques to more accurately consider the groundwater contribution to base flow using modified versions of the Pitman model.
  - Darcy's Law
  - Numerical groundwater flow models
  - Low maintenance flows from the surface water EWRs
- **Resource Quality Objectives**: A number of tools and simple flow equations can be used when setting resource quality objectives. These include: delineation of protection zones; calculating the radius of influence of a borehole; quantifying drawdowns; and determining the rate at which a borehole can be pumped so that it does not influence groundwater levels near protection zones.

Table 8.14: Methods for calculating the components of the water balance (Parsons and Wentzel 2006)

Component	Definition	Method	References/software
Groundwater inflow (I) and outflow (O) across catchment boundaries	Areas along the boundary where groundwater enters or leaves the catchment. Usually the catchment boundary acts as a groundwater water divide, and it is only in low-lying areas that groundwater will enter or leave the system.	Groundwater levels in an aquifer usually (in more than 95% of aquifers studied in South Africa) follow surface topography. As a result, Bayesian interpolation techniques can be used, and a groundwater contour map can be plotted. After constructing the Bayesian groundwater level contour map, there are two methods that can be used to estimate I and O, namely numerical flow models and Darcy's Law.	***Reference*** Darcy's Law can be obtained from Kruseman and De Ridder (1991). The transmissivity or hydraulic conductivity needed in the flow calculations can be obtained from literature (e.g. Kruseman and De Ridder, 1991) or pumping test data. ***Software*** TRIPOL (Van Tonder *et al.*, 1996) can be used to perform the Bayesian interpolation. It is available on the IGS website: www.uovs.ac.za/igs PMWIN version 5 (Chiang and Kinzelbach, 1999), a numerical flow model, can be downloaded from the IGS website.
Groundwater abstraction	Withdrawing water from the aquifer, normally by means of a borehole	Databases, such as the National Groundwater Database (NGDB) and Water Resource Management System (WRMS), can be used. A hydrocensus would also give an indication of abstraction rates. If a useful database does not exist, information, such as land use maps (for estimating irrigation) and population maps (for estimating drinking and industrial uses) can be used to estimate the existing abstraction rates.	For more information concerning databases, refer to the DWAF website, www.dwaf.gov.za.
Recharge	Recharge is defined as the process by which water is added from outside to the zone of saturation of an aquifer, either directly into a formation, or indirectly by way of another formation.	Chloride method, saturated volume fluctuation method, cumulative rainfall departure method, isotopes and maps. For more information concerning the most commonly used methods, refer to Appendix A.	***Reference*** Bredenkamp *et al.* (1995) and Xu and Beekman (2003) discuss these methods in detail. ***Software*** An EXCEL-spreadsheet programme, RECHARGE (Van Tonder and Xu, 2000) can be used to determine the net groundwater recharge. Available from the IGS website, www.uovs.ac.za/igs. ***Maps*** Vegter's (1995) groundwater recharge map can be used

SELF-EVALUATION QUESTIONS

1. List the various roles that groundwater contributes towards aquatic ecosystems and how activities can impact on this role.
2. Explain how ground water resources are classified.
3. Outline the procedure for quantifying the groundwater Reserve.
4. Give examples of groundwater RQOs.
5. Review a case study of a groundwater Reserve and evaluate how the groundwater component is compiled and communicated.

7. TECHNICAL INTEGRATION OF EWRs

TIME

You will need approximately 8 hours to master this study unit.

REFERENCE

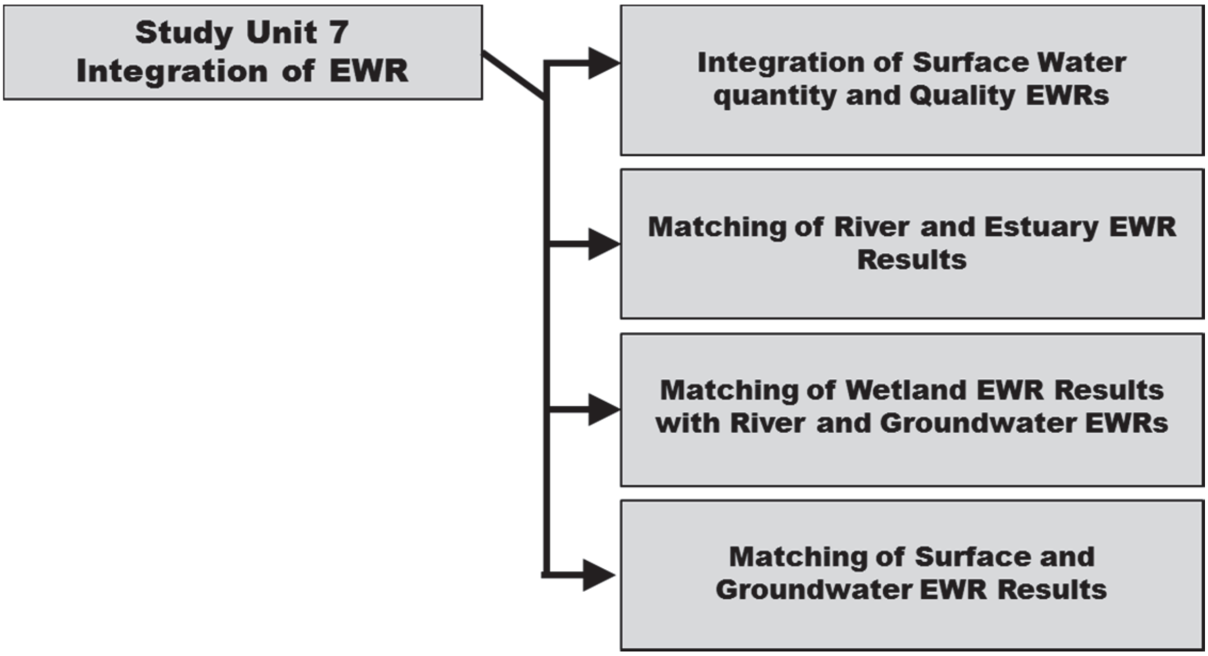
- King, JM, R Tharme and MS de Villiers. 2000 (Eds) Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Water Research Commission Report No. TT 131/00. Water Research Commission, Pretoria, 339 pp.
- O'Keefe J. 2009. Sustaining river ecosystems: Balancing use and protection. Progress in Physical Geography 33(3) p.339-357.
- Parsons, R. and J Wentzel. 2006. GRDM Manual. Water Research Commission Project 1427.
- Rountree, M.W., H. Malan and B. Weston (editors). 2012. Manual for the Rapid Ecological Reserve Determination of Inland Wetlands (Version 2.0). Joint Department of Water Affairs/Water Research Commission Study. Report No 1788/15. Water Research Commission, Pretoria.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight as to:

- Why integration of the results from EWR is necessary; and
- How the integration of EWRs from the various water resources is undertaken;

The study unit will be conducted as follows:



INTRODUCTION

Managing water resources is not a matter of separately managing the rivers, lakes, wetlands, estuaries and groundwater components. It's all about integrated water resource management, in other words dealing with the landscape and its drainage as one interrelated system, whilst considering the water needs of all the stakeholders within the catchment. That's why national water policy requires a holistic and integrated approach involving both specialists and stakeholders. ***Integration*** is a vital word in the context of RDM. Integrated assessment of water resources involves: water quality *and* quantity; surface *and* groundwater, and rivers, lakes, wetlands *and* estuaries. A holistic approach is required on the part of the specialists who are undertaking both the Reserve determination and the associated public participation process.

One of the consistent lessons of the environmental flow process has been the issue of integration of disciplines in water management. It is increasingly obvious that little can be achieved in terms of sustainable management of water resources without a multidisciplinary approach. It has certainly been a developing theme for environmental flows that little can be achieved by ecologists alone, or, for that matter, by hydrologists, geomorphologists or water chemists on their own. The emerging theories of Integrated River Basin Management (IRBM) and Integrated Water Resource Management (IWRM) testify to the desire of water professionals to move beyond the one-solution-fits-all management practices that characterized water resource management in the mid-1900s. (Jay O'Keeffe 2009).

1. Integration of Surface Water quantity and Quality EWRs (King *et al.* 2000)

- In the RDM approach water quality and quantity are assessed independently and then integrated.
- The integration provides the decision maker with information on instream water quality conditions under a variety of flow scenarios.
- This is typically done using a database and model which relates instream concentrations and flow.

2. Matching of River and Estuary EWR Results (Adams *et al.* 2004 Appendix B)

- Previously the results as a % of MAR for the downstream river EWR site (i.e. closest to the estuary) were compared to the estuarine flow requirement results. The comparison usually indicated a marked difference in requirements, mostly a much larger requirement for the estuary. The estuary and river results were provided as different outputs and were therefore not comparable as a % of the MAR.
- Estuaries are driven by both catchment-derived runoff and seawater intrusion, unlike river that are only influenced by catchment-derived runoff. The responses to stressors such as decreased freshwater flows are therefore vastly different between estuaries and rivers.
- In estuaries, river inflow patterns (i.e. water quantity) do show strong correlation with important hydrodynamic and sediment characteristics, such as state of the mouth, amplitude of tidal variation, water circulation patterns and sediment deposition/erosion. However, the relationships between these characteristics and river inflow are generally not linear, but often rather complicated to interpret, owing to the influence of the sea.
- The manner in which these characteristics are influenced by river flows is often also not the result of a single flow event, but rather that of characteristic flow patterns occurring over weeks or months.
- Marked differences exist between the chemistry (or water quality) of river water and seawater, particularly in terms of system variables (e.g. salinity, temperatures, oxygen levels, pH and suspended solids) and nutrients (e.g. nitrate, ammonium, phosphate). As a result, river inflow also has a strong influence on water quality characteristics of estuaries (in addition to the water quality of river inflow). The water quality characteristics along the length of the estuary therefore are often driven by the quantity of river water entering the estuary during that period.
- In the RDM approach the river water quantity and quality results are used as input flow scenarios for the estuary assessment.
- The river state (ERC) is compared with that of the estuary and changes are made to the EWR model to supply the results in the correct format to the yield modeller.
- The matched flow regime as modelled will then result in the desired ERC for river and estuary.
- If the results are significantly different then a scenario is provided that will supply Reserve scenarios to the river or estuary with an associated description of the consequences on either.

3. Matching of Wetland EWR Results with River and Groundwater EWRs (Rountree et al. 2012)

- Integration of wetland results has not been extensively tested but in most cases a similar approach to that described for the estuaries would apply for valley bottom wetlands.
- Wetlands such as wetland flats and pans are wetlands where groundwater plays a key role and in such cases wetlands merely reflect the condition of the groundwater resource. Whilst such wetlands could be monitored as an indicator of the groundwater resource, the Reserve quality and quantity components would need to be assessed by a dedicated Groundwater Reserve study.
- Modifications of the river EWR methods for floodplains have been undertaken as part of EWR studies where floodplain sites where encountered: i.e. floodplains dictate the flood requirements of Rivers.

4. Matching of Surface and Groundwater EWR Results (Parsons and Wentzel 2006)

- In Study unit 6, Section 1, the role of groundwater in sustaining rivers, lakes, wetlands, estuaries and the marine environment is described. In addition to addressing the groundwater components of RDM, one of the key roles of a geohydrologist in the RDM process is to provide insight to other specialists about how the groundwater system functions and the role it plays in supporting other components of RDM. For example, groundwater plays a key role in sustaining many wetlands. If Resource Quality Objectives for groundwater are set without considering the requirement of a wetland that is groundwater driven, the RQOs may be altogether ineffective for protecting that wetland.
- The integration of the groundwater component requires an understanding of the hydrological processes that are associated with the generation of base flows in the river.
- If the groundwater is targeted for use this would affect the base flow contribution to surface water systems and in particular, rivers. The groundwater assessment would then have to take into account the low flow requirements of the river.
- River base flows are not normally quantified on the basis of any assumed hydrological process they are merely the low amplitude, high frequency component of the total flow regime.
- Unfortunately the relationship between surface water and groundwater are not always clearly understood.

SELF-EVALUATION QUESTIONS

1. Evaluate why integration of EWR results is necessary and when.
2. Discuss the various approaches as well as challenges in integrating the EWR results from surface water bodies as well as from groundwater.

8 IMPLEMENTING EWRs: ROLE IN IWRM

TIME

You will need approximately 5 hours to master this study unit.

REFERENCE

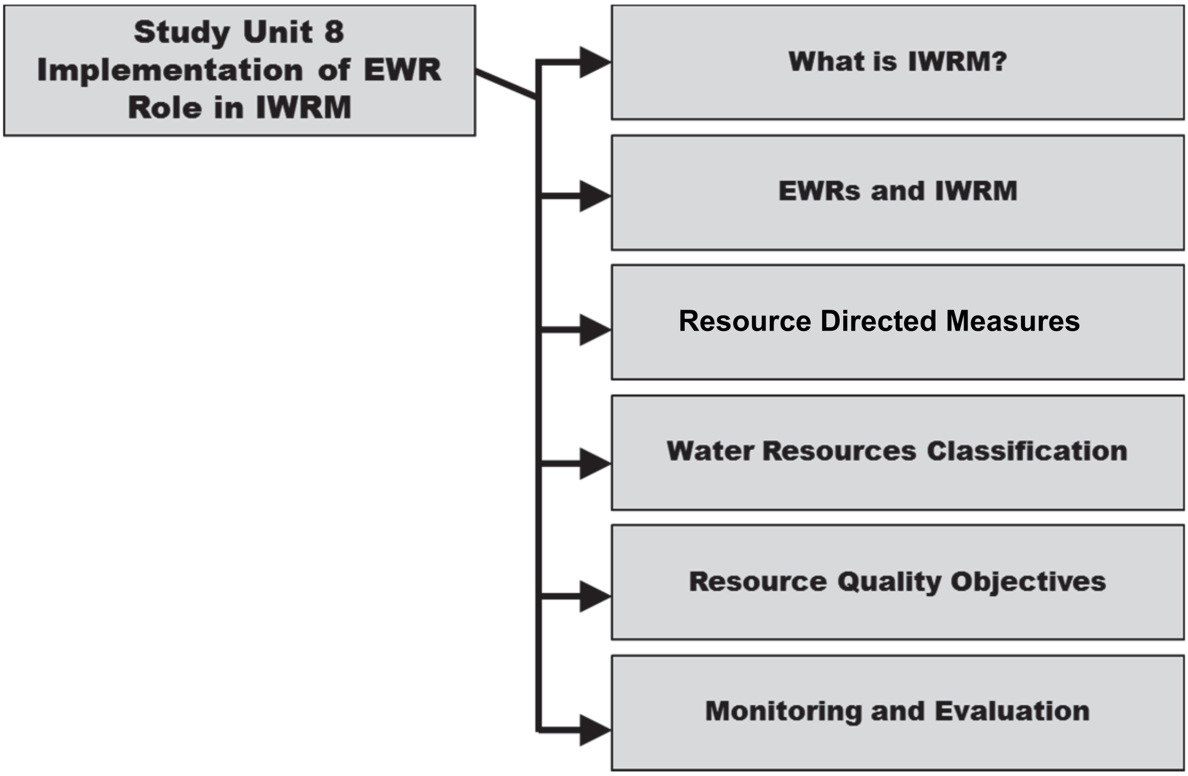
- Department of Water Affairs and Forestry. 2007. Development of the Water Resource Classification System (WRCS). Pretoria, South Africa: Department of Water Affairs & Forestry.
- Department of Water Affairs, 2011. Procedures to Develop and Implement Resource Quality Objectives – Summary. Department of Water Affairs, Pretoria, South Africa
- Hughes DA (ed.) 2004 SPATSIM, an integrating framework for ecological reserve determination and implementation: Incorporating water quality and quantity components for rivers. WRC Report No. TT 245/04, Water Research Commission.
- International Network of Basin Organizations (INBO) and the Global Water Partnership (GWP) 2012. The handbook for integrated water resources management in transboundary basins of rivers, lakes and aquifers.
- King, J and Pienaar, H. (Eds) 2011. Sustainable use of South Africa's Inland waters. A situation assessment of Resource directed Measures 12 years after the 1998 National Water Act. WRC Report Number TT491/11. Water Research Commission, Pretoria.
- King, JM, Tharme R and de Villiers MS. (Eds) 2000. Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. WRC Report No. TT 131/00. Water Research Commission, Pretoria.
- Palmer CG; Griffin NJ; Scherman P-A; Du Toit D; Mandikiana B; Pollard S. 2013. A Preliminary Examination of Water Quality Compliance in a Selected Lowveld River: Towards Implementation of the Reserve. WRC Report No. KV 306/12 Water Research Commission, Pretoria.
- Schreiner B and Hassan R. (Eds) 2011. Transforming Water Management in South Africa. Designing and Implementing a New Policy Framework. Global Issues in Water Policy. Volume 2. Springer Publishers. 278 pp.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR in general by being able to:

- give a broad overview of the role of in EWRs within IWRM; and
- describe the resource protection tools within the South African context; and
- understand the monitoring, evaluation and revision component of EWR implementation.

The study unit will be conducted as follows:



INTRODUCTION

Defining the environmental river flow forms only part of the procedure for ensuring that the environmental water requirements are achieved within aquatic ecosystems. The EWR is also only one tool in water resource management and lies within an integrated water resource management (IWRM) framework. Implementation of EWRs also cannot take place in isolation and requires integration with all other disciplines in water resource management. The function of EWRs within resource protection and IWRM is discussed within this study unit, as well as the importance of monitoring and evaluation within an adaptive management approach to the implementation of EWRs.

1. What is IWRM? (INBO and GWP 2012)

- "IWRM is a process that promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." (Global Water Partnership 2000).
- The purpose of the National Water Act (Act 36 of 1998) is to ensure that South Africa's water resources are protected, used, developed, conserved, managed and controlled. This requires an IWRM approach.
- Key aspects of the NWA are (Figure 8.12):
  - ➢ Resource Protection – reserve (basic human needs + ecological), classification & RQO
  - ➢ Establish Water Management Strategies and Water Management Institutions
  - ➢ Allocating and managing water use
  - ➢ Establishing a National Monitoring System and a National Information System

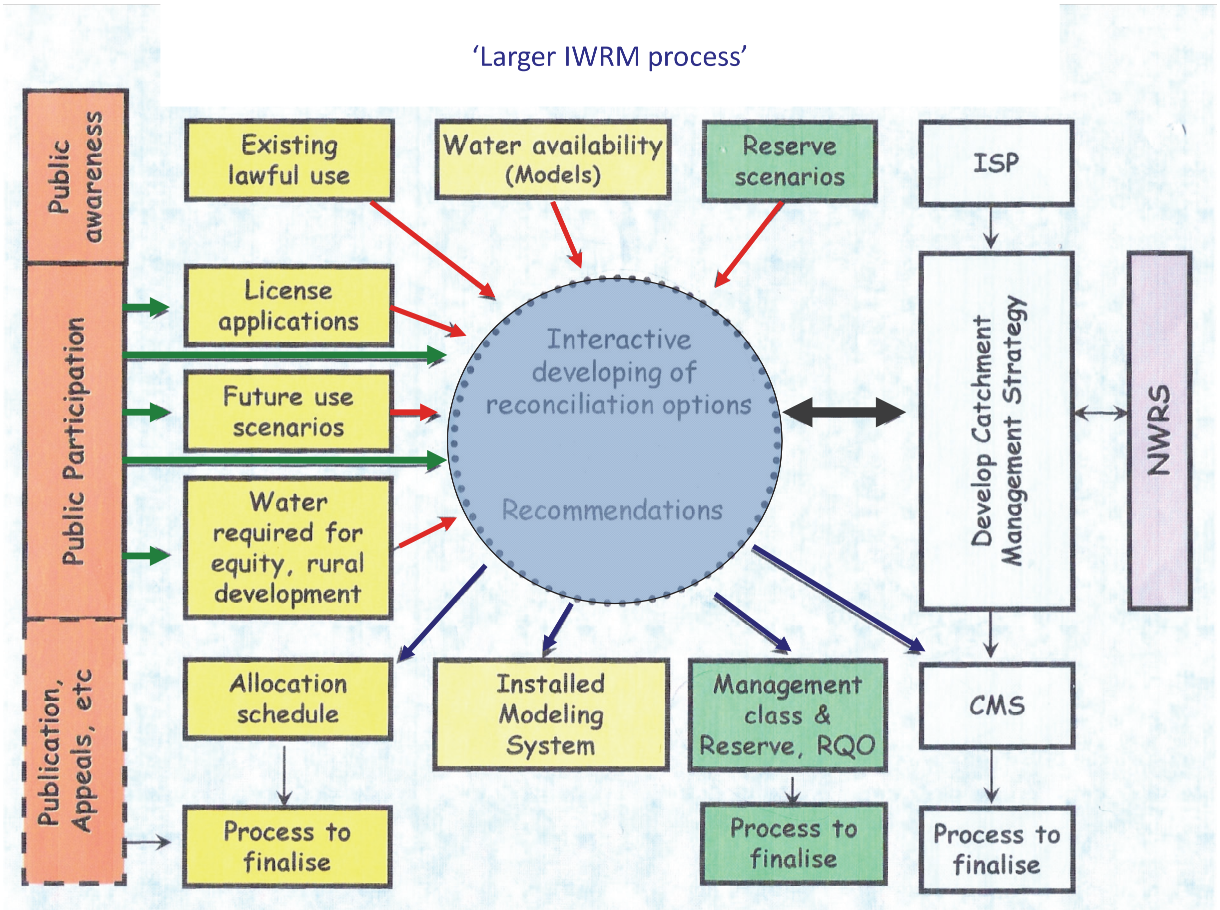


Figure 8.12 DWA's approach to integrated water resource management, showing the positioning of the Management Class, Reserve and RQOs. NWRS = national water resource strategy. ISP = internal strategic perspectives. CMS = Catchment Management Strategy

2. EWRs and IWRM (INBO and GWP 2012)

- Environmental Flows is an essential part of IWRM. In IWRM, there are three overriding criteria/guiding principles for decision-making (GWP 2000):

- **Economic efficiency** in water use: Because of the increasing scarcity of water and financial resources, the finite and vulnerable nature of water as a resource, and the increasing demands upon it, water must be used with maximum possible efficiency;
- **Equity**: The basic rights for all people to have access to water of adequate quantity and quality for the sustenance of human well-being must be universally recognised. Thus water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels and recognising that women play a central part in the provision, management and safeguarding of water;
- **Environmental and ecological sustainability**: The present use of the resource should be managed in a way that does not undermine the life-support system thereby compromising use by future generations.

- In IWRM, EWRs serve to represent water allocation for ecosystems. As ecosystems, in turn, provide services to people, providing for environmental flows is not exclusively a matter of sustaining ecosystems but also a matter of supporting human wellbeing, in particular in developing countries. One of the most promising ways of placing ecosystems on the water agenda is by economic valuation of such services. (**Millennium Ecosystem Assessment 2005**). In this way ecosystems can be compared to other water using sectors and internalized in decision-making processes.

3. Water Resource Protection Measures

- Both long- and short-term protection of water resources is necessary to ensure the sustainable development and use of water. Managing a water resource so that it can continue to function sustainably is the science of determining and working within the limited ability of a water resource to recover from human disturbances.
- Simply managing water resources to ensure that they maintain only the most basic level of sustainable ecosystem functioning in order that the remaining water is made available for use, is not being protective enough. For a sustainable level of aquatic ecosystem functioning to be ensured, a whole range of levels of ecosystem integrity and functioning needs to be managed for.
- The protection principles for achieving sustainable water use, as contained in Chapter 3 of the NWA are: The Reserve; the Water Resource Classification System (WRCS); and RQOs. These measures as collectively referred to as Resource Directed Measures (RDM).
- Through the IWRM process the RDM and Source Directed Controls (SDCs) water resources are protected against over utilisation and poor land use practices.

4. Water Resource Classification System (WRCS) (DWAF 2007)

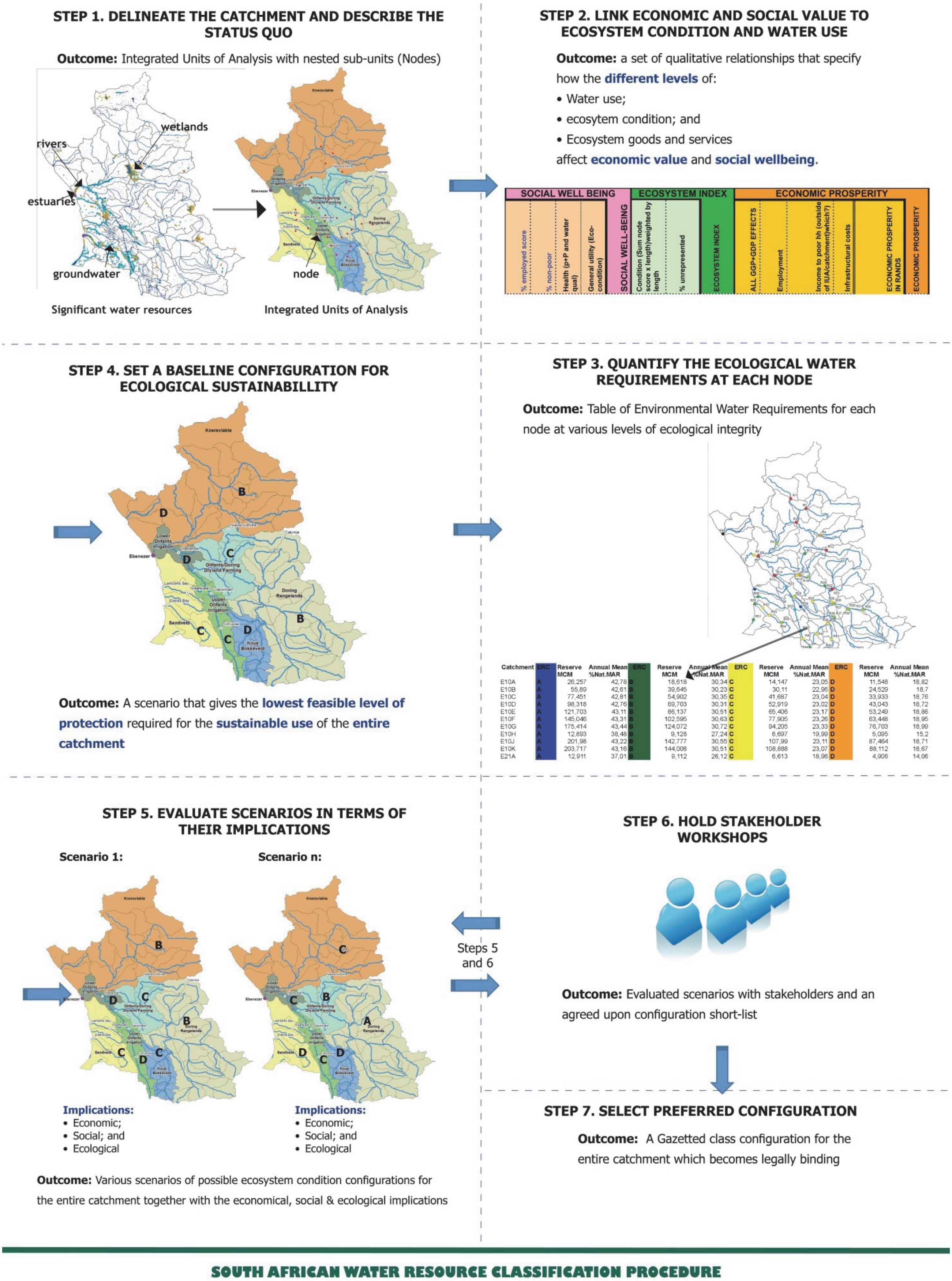
- Water professionals agree that water management should take place at catchment level due to the fact economic, social and ecological processes operate at different scales. In line with this, EWRs, which are determined according to a deemed acceptable level of ecosystem functioning that is based on economic, social and ecological needs, should also not be determined in isolation but rather within the context of the larger catchment.
- In support of this thinking, NWA requires that all significant water resources in South Africa be classified to determine the quantity and quality of water necessary for

ecosystem functioning, and to ensure that they are maintained in a minimum state of health related to an acceptable level of functioning. Classification, however, goes beyond identifying the minimum requirements for ecosystems and human needs, and involves choosing a level of protection between this minimum and complete protection. The final selection of the minimum requirements however needs to ensure that there is a balance between the social, economic and environmental needs.

- The classification system in particular allows for a configuration of water resource classes to be selected that will ensure the long term ecosystem functioning of the entire integrated water resource system. For example for the base level of ecosystem functioning to be met in the lower reaches of a river, some of the upper reaches would need to remain in a relatively unimpacted state. The selection of the configuration is a public participation process that is designed to ensure that a balance is achieved between the social, economic and environmental water needs in a catchment.
- The WRCS was promulgated in the Government Gazette in September 2010 and is being implemented in a number of catchments (e.g. Western Cape Olifants-Doorn WMA, Mpumalanga Olifants WMA and the Vaal River System).
- Water resources are classified through a consultative process, where the WRCS provides the guidelines and procedures for determining the class of a water resource. Each class represents a different level of protection and therefore utilisation. The economic, social and ecological implications of choosing a Management Class (MC) need to be clearly understood as part of the process. The MC ranges from Natural to Heavily Used/Impacted (Table 8.15), and essentially describes the desired condition of the resource, as well as the degree to which it can be utilised, which may have considerable economic, social and ecological implications. The "Unacceptable degraded resources" class is considered an unsustainable condition and will only be utilised to describe present status. In such cases, management will aim to rehabilitate the resource to the desired state.

Table 8.15: Water resource classes

Natural (Management Class I)
The Natural class will provide a reference condition for other resources classified at greater levels of impact, that is, resources in other classes will be defined in terms of the degree of deviation from the Natural class
Moderately used/impacted (Management Class II)
This class represents resource conditions that are slightly to moderately altered from the Natural class reference conditions due to the impacts of human activity and water use
Heavily used/impacted (Management Class III)
This class represents resource conditions that are significantly changed from the Natural class reference conditions due to the impacts of human activity and water use, but that are nonetheless ecologically sustainable
Unacceptably degraded resources (Not considered a management class)
As a result of over-exploitation or major alteration to their physical structure, some resources are already in a condition that can be described as unacceptably ecologically degraded.



Catchment	ERC	Reserve MCM	Annual Mean %Nat.MAR	ERC	Reserve MCM	Annual Mean %Nat.MAR	ERC	Reserve MCM	Annual Mean %Nat.MAR	ERC	Reserve MCM	Annual Mean %Nat.MAR
E10A	A	26,257	42,78	B	18,618	30,34	C	14,147	23,05	D	11,548	18,82
E10B	A	55,89	42,61	B	39,645	30,23	C	30,11	22,96	D	24,529	18,7
E10C	A	77,451	42,81	B	54,902	30,35	C	41,687	23,04	D	33,933	18,76
E10D	A	98,318	42,76	B	69,703	30,31	C	52,919	23,02	D	43,043	18,72
E10E	A	121,703	43,11	B	86,137	30,51	C	65,406	23,17	D	53,249	18,86
E10F	A	145,046	43,31	B	102,595	30,63	C	77,905	23,26	D	63,448	18,95
E10G	A	175,414	43,44	B	124,072	30,72	C	94,205	23,33	D	76,703	18,99
E10H	A	12,893	38,48	B	9,128	27,24	C	6,697	19,99	D	5,095	15,2
E10J	A	201,98	43,22	B	142,777	30,55	C	107,99	23,11	D	87,464	18,71
E10K	A	203,717	43,16	B	144,006	30,51	C	108,888	23,07	D	88,112	18,67
E21A	A	12,911	37,01	B	9,112	26,12	C	6,613	18,96	D	4,906	14,06

Figure 8.13: The classification procedure (as shown for the Western Cape Olifants-Doorn WMA example, DWA 2010)

- Classification of water resources forms an integral component of Integrated Water Resource Management (IWRM). Accordingly, the Classification Process cannot occur in isolation, but is fundamentally linked to other processes in the integrated planning of water resource protection, development and utilisation, and in the management and control of water use. In particular, the Classification Process and the Catchment Management Strategy (CMS) are iterative, while the proposed MC has significant implications for water allocation, Compulsory Licensing and the Waste Discharge Charge System (WDCS).
- A key component of IWRM is therefore an iterative process of evaluating water use and protection scenarios with stakeholders where the economic, social and ecological trade-offs will be made, and out of which will emerge the MC, Reserve, RQOs, allocation schedule and the CMS.

5. Resource Quality Objectives (DWA 2011)

- Resource Quality Objectives capture the Management Class of the Classification System and the ecological needs determined in the Reserve into measurable management goals that give direction to resource managers as to how the resource needs to be managed.
- The National Water Act states that:
    - the purpose of RQOs is to establish clear goals relating to the quality of the relevant water resources and stipulates that in determining RQOs a balance must be sought between the need to protect and sustain water resources and the need to use them (Chapter 3 part 2).
    - the RQOs may "*relate to the Reserve; the instream flow; the water level; the presence and concentration of particular substances in the water; the characteristics and quality of the water resource and the instream and riparian habitat; the characteristics and distribution of aquatic biota; the regulation or prohibition of instream or land-based activities which may affect the quantity and quality of the water resource; and any other characteristic*".
    - "*once the Class of a water resource and the Resource Quality Objectives have been determined they are binding on all authorities and institutions when exercising any power or performing any duty under this Act*."
- The RQO determination procedure works to balance the requirements of the environment with those of the ecosystem within the framework of the Water Resource Classification. RQOs can be more protective than EcoSpecs if there is a particularly sensitive user need, but normally the EcoSpecs defines the level of protection. The RQOs are gazetted and are thus supported by law.
- The outputs of the RQO determination procedure include both descriptive statements (e.g. "the water quality from this Resource must be acceptable for irrigation of crops" or "the endemic yellowfish in this river should be maintained as a viable population to support the ecosystem and also for recreational angling") or numerical values (e.g. electrical conductivity concentration of less than 40 mS/m, or at least 20 yellowfish of >300mm in length collected in a two hour collection effort using an electro-fishing apparatus).
- A seven step procedure (Figure 8.14) has been provided for the determination of Resource Quality Objectives. The RQO determination procedure has been designed in such a way that it can be used to develop RQOs for rivers, wetlands and estuaries. The process of determining the RQOs remains constant, but the prioritisation of components and indicators will vary as different variables are of significance to rivers,

wetlands and estuaries. Groundwater is dealt with separately as not only are the Resource Units completely different to the surface water systems, so are the variables of concern.

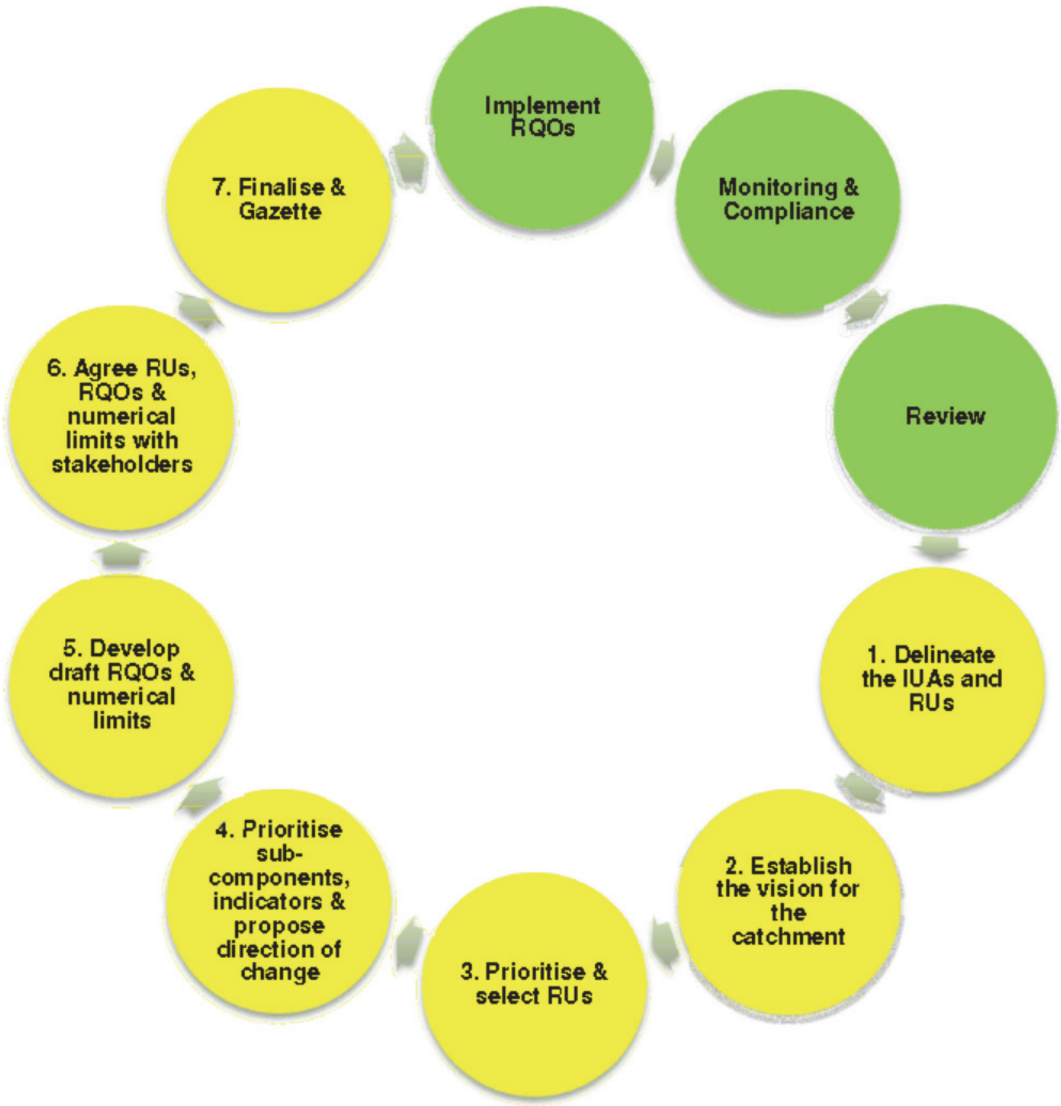


Figure 8.14: The RQOs seven steps procedure and the three additional steps to implement the Adaptive Management Cycle

- After gazetting of the RQOs comes the process to complete the Adaptive Management or 'learning by doing' Cycle. Monitoring and compliance entails a systematic process to measure and manage performance in management of the water resource towards RQOs. Compliance with RQOs would be achieved when the resource is equal to or in a "better" condition than indicated by the RQOs or Numerical Limits.

6. Mechanisms for the implementation of EWRs

- Water use authorisation (licencing) is but one of a number of SDCs used to control water use. Therefore the Reserve, which is an in-stream requirement in many cases cannot be met by a single user.
- Source Directed Controls (SDC) are the measures primarily designed to control water

use activities at the source of impact and are thus an important measure in giving effect to RDM. RDM therefore guides SDCs in both a proactive and reactive manner:

  - Proactive measures to prevent or minimise future water quality problems and the over allocation of water (e.g. licencing, development of self-regulating incentives such as Waste Discharge Charge system, implementation of buffer zones, improving dam operating rules, etc.), and
  - Reactive management of existing water resource problems to achieve the MC, Reserve and RQOs (e.g. rehabilitation-related activities, compulsory licencing, review of water use licence conditions, directives, etc.).

- Once the water user requirements and EWRs have been determined, they can be used to provide RQOs, which inform the allocable water quantity and quality of a water resource.
- Compliance monitoring will need to be included in water use authorisations when appropriate and closely aligned with RQOs relating to water quality, quantity and source management objectives. Such monitoring provides an important information base for subsequent well-focussed corrective actions in cases where non-compliance is evident.

7. Monitoring and Evaluation of EWRs

- The final and crucial aspect of implementing EWRs is the evaluation of success. This is necessary at two levels: to determine that effectiveness or appropriateness of the EWR in achieving the desired level of ecosystem functioning; and to evaluate compliance of the implementation of the EWR against the required objectives. In addition, monitoring of water use and operating rules for dam operators is also required to assist with assessing compliance with EWRs.
- In the absence of predictive ecological models, an adaptive management approach is required where the EWR is adjusted based on the outcome of monitoring of the EWRs.
- At present, although some monitoring of water-use licences occurs, there is no formal RDM monitoring, only monitoring of the quality and flow/water levels of water resources and the ecological state of aquatic ecosystems. Without RDM related monitoring however, there is no means of knowing if the agreed Management Classes are being maintained and also no assurance that the agreed level of protection is being sustained.
- Compliance monitoring of Reserves and the evaluation of whether recommended EWRs attain the desired ecological functioning that they were set to achieve, requires a long term data collection over a period of five years or longer. Some of the ecological variables utilised to assess the integrity of water resources respond slowly and monitoring programmes need to collect relevant data for periods of five years or more before the trend and change in the ecosystem can be observed.

SELF-EVALUATION QUESTIONS

1. Provide an overview of IWRM and explain where resource protection measures and EWRs occur within IWRM.
2. Explain why monitoring and evaluation is critical to the implementation of EWRs and how it should take place.
3. Evaluate a case study where classification of RQOs have been determined for a catchment and identify the challenges still facing the implementation of these components of resource protection in South Africa.

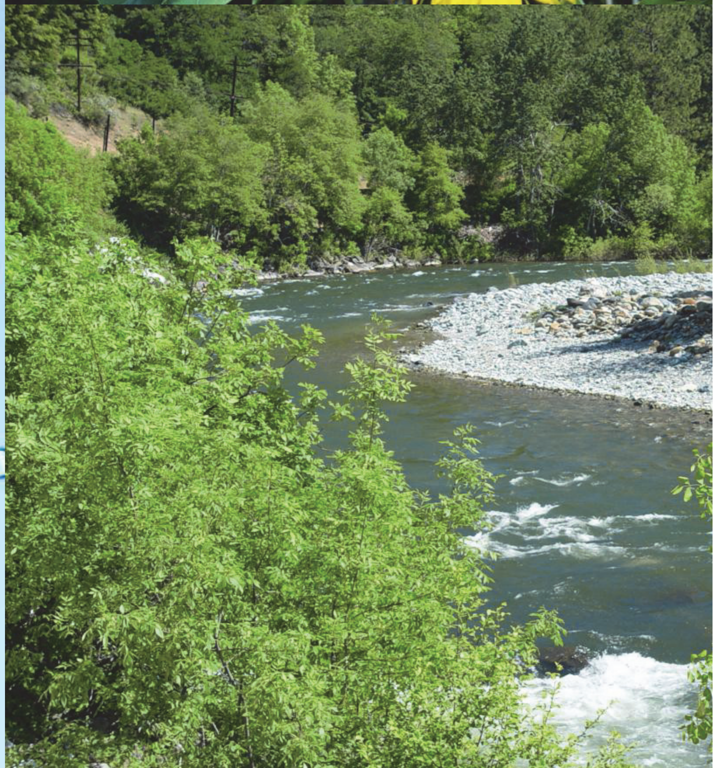
MODULE 9

IMPLEMENTATION AND MANAGEMENT OPTIONS FOR WATER SUPPLY AND SYSTEM OPERATIONS

Tutored MSc in Ecological Water Requirements

Developed by
D Grobler and T Belcher

November 2013



MODULE 9: IMPLEMENTATION AND MANAGEMENT OPTIONS FOR WATER SUPPLY AND SYSTEM OPERATIONS

RATIONALE

The purpose of this module is to provide candidates with an overview of the planning of water resource management options used to determine the needs of users and to ensure sustainable resource use. This will enable students to contextualise environmental water requirements within the realm of water resource management, and to develop an appreciation for the various aspects of water resource management that needs to be considered in order to integrate and implement environmental flow requirements and the alternatives mechanisms to achieve water resource protection.

Students undertaking this module will develop a general understanding of the water resources planning and operational aspects of water resource supply schemes, which will assist them in communicating effectively with water resource engineers and managers.

Topics are covered at a moderate level of detail, to provide a **conceptual rather than a functional capability**. Elements of this module will consist of:

- Water resource planning and the relation with environmental water requirements;
- Alternative water supply options to reduce the level of demand on water resources;
- Water demand management as a key strategy to achieve sustainable water resource use;
- Implementation of environmental water requirements;
- System operations and management to ensure supply of water to users and to give effect to environmental water requirements;
- Understand the role of system yield analysis in water resource management and implementation of EWRs;
- Design system operating rules for meeting the EWR; and
- Detailed case study to integrate water resource planning and execution.

LAYOUT OF THE MODULE

9.1 Water resource planning processes (10%)

9.2 Alternative supply options to augment water resources (15%)

9.3 Water demand management and water resource protection (20%)

9.4 Implementing EWRs: Incorporating into Water Resource Planning and Systems Operation (25%)

9.5 Case study of integrated planning and resource protection (30%)

NB: The percentages in brackets show the ratio regarding the time you have to spend on the various aspects.

PREREQUISITES

It is a prerequisite that you have completed modules 1-8 before you start with module 9. In particular it is essential that you have successfully completed Module 3: Surface and Groundwater hydrology. It is also important that you study and understand the regulatory processes that are used by the South African Department of Water and Sanitation and the standard planning processes and documentation that are used. This includes the National Water Resource Strategies (2004 and 2012), the internal strategic perspectives (ISP), catchment management strategies and implementation plans (which are localised and catchment specific), the reconciliation strategies developed for large water supply systems/metros as well as the All Towns Reconciliation Strategies.

Summary of modules in relation to module 9

Module
Module 1: Background and context
Module 2: Resource Economics
Module 3: Surface and Groundwater Hydrology
Module 4: Hydraulics / Hydrodynamics
Module 5: Geomorphology
Module 6: Water Quality
Module 7: Aquatic Ecology
Module 8: Technical Integration (EWRs)
Module 9: Implementation and management options for water supply and system operations

You need the following resources to complete this course successfully:

- Study material as indicated (electronic documents and articles from scientific journals which are in some instances **not included** in the electronic reference list);
- Access to the internet to access the web references and websites as referred to in this module; and
- Pocket calculator.

STUDY MATERIAL

The following sources are needed for this module:

- Adams JB 2012. A review of methods and frameworks used to determine the environmental water requirements of estuaries. *Nelson Mandela Metropolitan University, PO Box 77000, Port Elizabeth, 6031, South Africa.* Janine.adams@nmmu.ac.za. Published in the Hydrological Science Journal, special edition on Environmental flows.
- Adams, Janine. 2012. Determination and implementation of environmental water requirements for estuaries. Ramsar Technical Report No. 9/CBD Technical Series No. 69. Ramsar Convention Secretariat, Gland, Switzerland & Secretariat of the

Convention on Biological Diversity, Montreal, Canada. ISBN 92-9225-455-3 (print); 92-9225-456-1 (web).

- CGS 2012. Report to the Inter-Ministerial Committee on Acid Mine Drainage Mine Water Management in the Witwatersrand gold fields with special emphasis on acid mine drainage. Prepared by the Expert Team of the Inter-Ministerial Committee under the Coordination of the Council for Geoscience. December 2010.
- City of Cape Town 2007. Long-term Water Conservation and Water Demand Management Strategy. Final draft April 2007, City of Cape Town.
- DWAF 2004. The National Water Resource Strategy (NWRS).
- DWAF 2004. Breede River Water Management Area: Internal strategic perspective. Version 1. October 2004.
- DWAF 2004. Western Cape Water Supply System. Guidelines for water conservation and water demand management in water management areas and in the water services sector, South Africa volume 1 a Planning Framework for Water Conservation and Demand Management at Water Management Area Level. Full Guidelines Version. Danida, March 2004.
- DWAF 2007. Overview of Water Conservation and Demand Management in the City of Cape Town. Western Cape Water Supply System Reconciliation Strategy,
- DWAF 2007. Western Cape Water Supply System Reconciliation Strategy. Overview of the Water Conservation and Water Demand Management in City of Cape Town, June 2007. Report No. 4 of 7.Department of Water Affairs, Directorate National Water Resource Planning.
- DWAF 2008. Water resource protection and assessment policy implementation process. Resource directed measures for protection of water resources. Methodology for the determination of the Ecological Water Requirements for Estuaries. Version 2. Pretoria 2008.
- DWA 2012. The National Water Resources Strategy (NWRS).
    - NWRS 2012 – Presentation Mr. Seef Rademeyer
- DWA 2013. Manual for the rapid ecological determination of inland wetlands (version 2). Resource directed measures for the protection of water resources, March 2012.
- Grobler DF, 2008. Berg River Dam environmental flow releases. PowerPoint presentation made at public meeting 2008.
- Grobler, DF and Rossouw N, 2008. Berg River Dam: Designed with rivers in mind. SA Water Wheel, WRC August 2008.
- Hughes DA (ed.), 2004. SPATSIM, an integrating framework for ecological reserve determination and implementation: Incorporating water quality and quantity components for rivers. WRC Report No. TT 245/04, Water Research Commission.
- Hughes, DA, Mallory, SJL & Louw, D. 2008. Methods and Software for the Real-Time Implementation of the Ecological Reserve – Explanations and User Manual. Report to the Water Research Commission. WRC Report No 1582/1/08.
- James C.S. and King JM. 2010. South African Handbook on Environmental River Hydraulics. WRC Project No. K5/1767.
- King, J and Pienaar, H. (eds) 2011. Sustainable use of South Africa's inland waters. A situation assessment of resource directed measures 12 years after the 1998 National Water Act. WRC Report Number TT491/11.
- King, JM, Tharme, R and de Villiers, MS. (eds) 2000. Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Water Research Commission Report No. TT 131/00.
- Locher P, and Wasdorff, P 2009. Environmental management plan for the Berg River Dam operational phase. TCTA Draft 17 November 2009.
- Mills, L. 2008. Impact of the IFR on the engineering design of the Berg River Dam. PowerPoint presentation made at public meeting 2008.

- Schreiner, B and Hassan, R. (eds) 2011. Transforming Water Management in South Africa. Designing and Implementing a New Policy Framework. Global Issues in Water Policy. Volume 2. Springer Publishers. 278 pp.
- Shand M. 2008. Berg Water Project. Operations and reserve releases. PowerPoint presentation made at public meeting 2008.
- UNU 2003. International waters in Southern Africa. The United Nations University 2003, edited by Mikiyasu Nakayama. ISBN 92-808-1077-4.
- WRC 2006. A desalination guide for South African Municipal Engineers. Department of Water Affairs and WRC. Du Plessis JA, Burger AJ, Swartz CD and Musee N. WRC TT 266/06, July 2006.
- WRC 2007. The status and use of potable water efficient devices in the domestic and commercial environments in South Africa.0 Report to the Water Research Commission by David Still, Su Erskine, Nick Walker and Derek Hazelton on behalf of Partners in Development. WRC K5/1606, July 2007.

Additional reading:

CASE STUDIES

In order to optimise the knowledge transfer and skills acquisition it is important to use the following regulatory documents and use either the Berg River catchment or the Inkomati River catchment as a case study to gain and understanding from a broad-scale planning perspective to the detailed implementation of the water resource management options and its implications. They are (in order of broad-scale planning to detailed implementation documents) the following:

- NWRS First Edition 2004
- NWRS Second Edition 2013
- ISP Breede River catchment DWA 2004
- Catchment management strategy documents (BOCMA – Breede Overberg Catchment Management Agency):
- Berg River Dam development documents (be specific, there are hundreds of documents spanning 20 years' work!!)
- Demand management in the City of Cape Town

Berg River catchment in relation to the Western Cape system analysis and water supply to the City of Cape Town – Planning water demand, determine best options for water supply and integrate environmental water requirements into system operations.

Van den Berg, E, Brown, C, and Sparks, A. 2007. Consequences and implications of meeting ecological needs for a raised Clanwilliam Dam. 13th SANCIAHS Symposium, Waterfront, Cape Town, South Africa (6-7 September, 2007).

- This article provides a summary of the planning infrastructure development within the constraints of existing use and infrastructure limitations.

HOW TO STUDY

The module is presented by means of **six study units** where the core principles are discussed. At the beginning of each study unit, a time allocation is given, which is an indication of the extent of the study task. You may use this allocation to plan your study process. The learning outcomes are also indicated at the beginning of each study unit and guide you as learner about what the problems in the particular study unit are and where you have to pay special attention. Make sure that you have the study guide always at hand, so that you can easily add additional notes to reach the outcome set for each study unit. At the end of study units, there are also evaluation questions. It is essential to answer these questions before moving on to the next study unit. By doing so and by making sure that the learning outcomes have been reached, you can make sure that you have completed the study unit successfully. It is expected of you as a senior student that you will have developed the skill (and that you will further develop this skill) to gather additional information independently in books, journals as well as from the internet and even interviews with experienced professionals. The study guide serves as framework to guide you through the learning content. Additional reading references are provided to guide your self-study process but should not be limited to the suggested list.

ASSESSMENT

Continuous assessment will take place in the form of assignments, which will consist of a group assignment and individual assignments to be prepared and handed in. Note the dates in the study letter on which these assignments should be handed in. Examination opportunities at the end of the module are also indicated in the study letter. Admission to the examination is dependent on an adequate participation mark, obtained from the assignments.

PRACTICALS AND FIELD REPORTS

Please note that practice and theory in the implementation, planning and system operations and management of water resources form a unit that contributes to the reaching of outcomes. During the practical (case studies), theory becomes reality in that the relevant information must be integrated that supports the outcomes. It is therefore of the utmost importance for work to be done systematically during each study unit throughout the programme and for careful recording of exactly what had been done in the form of reports.

Try to make sure during each assignment that the outcomes as set have been achieved.

MODULE OUTCOMES

At the end of the module, students should be able to:

- Demonstrate insight, knowledge and skills regarding the water resource planning process and the relation between water resource planning and environmental water requirements;
- Discuss the procedures and mechanisms to protect water resources in terms of strategic planning and the implementation and use of alternative water supply and

management options to augment water resources and to ensure sustained economic development;

- Describe and explain water demand management as a process to ensure sustainable use of water resources to meet an ever growing need with specific reference to the economic implication of the decisions;
- Demonstrate your ability to use hydrology data and the requirements of the ecological Reserve to undertake a basic assessment of compliance with the ecological Reserve;
- Describe system operations as a necessity in South Africa to ensure water supply and compliance with environmental water requirements, and
- Describe and demonstrate the mechanisms that can be used to delay continued and further water resource development to address current and future water needs with specific reference to environmental water requirements. A case study should be used to demonstrate your knowledge and skills obtained.

WARNING AGAINST PLAGIARISM

ASSIGNMENTS ARE INDIVIDUAL TASKS AND NOT GROUP ACTIVITIES (UNLESS EXPLICITLY INDICATED AS GROUP ACTIVITIES)

Copying of text from other learners or from other sources (for instance the study guide, prescribed material or directly from the internet) is **not allowed** – only brief quotations are allowed and then only if indicated as such.

You should **reformulate** existing text and use your **own words** to explain what you have read. It is not acceptable to retype existing text and just acknowledge the source in a footnote – you should be able to relate the idea or concept, without repeating the original author to the letter, to illustrate your understanding of the concepts.

The aim of the assignments is not the reproduction of existing material, but to ascertain whether you have the ability to integrate existing texts, add your own interpretation and/or critique of the texts and offer a creative solution to existing problems.

Be warned: students who submit copied text will obtain a mark of zero for the assignment and disciplinary steps may be taken by the Faculty and/or University. It is also unacceptable to do somebody else's work, to lend your work to them or to make your work available to them to copy – be careful and do not make your work available to anyone!

STUDY UNITS

1 WATER RESOUCRES PLANNING PROCESSES

TIME

You will need approximately 10 hours to master this study unit.

REFERENCES

- DWA 2004. The National Water Resources Strategy First Edition (NWRS).
  - Chapter 2: SA water situation and strategies to balance supply and demand
  - Introduction pages D.1 and D.2 in appendix D
  - Pages D19.2-D19.4 Berg River WMA
- DWA 2012. The National Water Resources Strategy Second Edition (NWRS).
  - Page 255-259 Berg River catchment
  - NWRS 2012 – Presentation Mr Seef Rademeyer
- UNU 2003. International waters in Southern Africa. The United Nations University 2003, edited by Mikiyasu Nakayama. ISBN 92-808-1077-4. Pages 5-37 Chapter author P. Heyns).
- WRC 2011. Sustainable use of South Africa's inland waters. A situation assessment of Resource Directed measures 12 years after the 1998 National Water Act. King & Pienaar (editors). Pages 1-14. **Chapter 1: Water supply and demand**.

Additional reading:

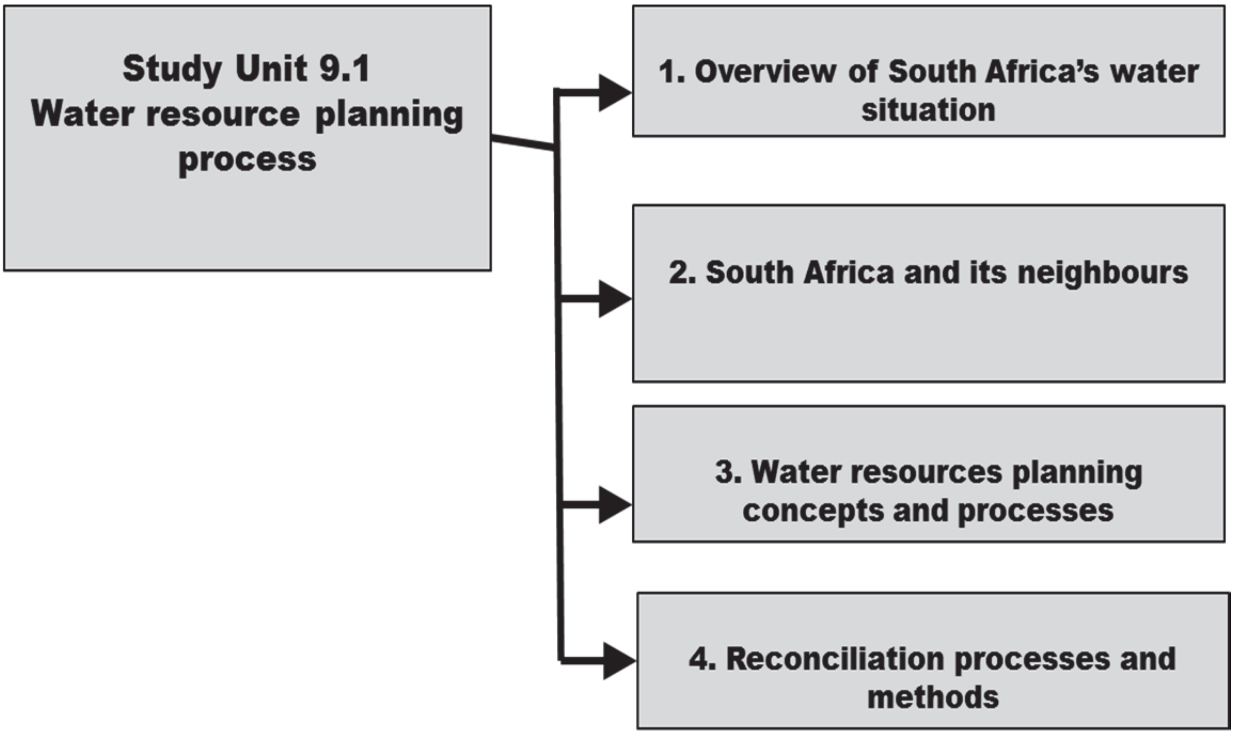
- WRC 2011. Sustainable use of South Africa's inland waters. A situation assessment of Resource Directed measures 12 years after the 1998 National Water Act. King & Pienaar (editors). Pages 19-42. **Chapter 2: Water law in South Africa**: From 1652 to 1998 and beyond.

STUDY UNIT 9.1 OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about water resource planning by being able to:

- Provide an overview of the South African water situation in terms of rainfall runoff and distribution of available water across South Africa;
- Provide an overview of the inter-dependency between South Africa and its neighbours in terms of shared water resources and runoff from these resources;
- Describe the terminology that is used to plan and summarise water demand and availability of water and the factors that influence availability, including the following: yield, MAR, assurance of supply, run-of-river use of water; and
- Describe the process that is used to undertake a reconciliation of requirements within a particular area and the factors that influence the reconciliation process.

The study unit will be conducted as follows:



INTRODUCTION

Water resource development and management in South Africa have continuously evolved over the years to meet the needs of a growing population and a vibrant economy. Considering the constraints imposed by a limited resource, these developments have largely been made possible by recognising water as a national asset, which permits its transfer from where it is available to where the greatest overall benefits for the nation can be achieved. South Africa is today recognised internationally for its progressive water legislation and its sophistication in water resources management. Water resources planning are essential to ensure long-term sustainable use of the limited water resource in Southern Africa. The planning process in South has been refined over many years and can be considered a vital component to undertake planning for the next 30 years. More than 3 500 large dams have been built in South Africa and have secured the establishment of an economy. The available resources to developed are now limited and building dams are not always the most effective way to supply water for continued economic prosperity.

The NWA has brought in new concepts such as the ecological Reserve, adding specific measures to ensure resource protection, but also adding to the complexity of water resources planning. Environmental water requirements are determined and the required rules should be implemented to protect water resources to ensure long-term sustainable use and health of the water resources. This has influenced the planning for, and use of, alternative resources and the selection of management options which were not feasible or financially viable 20 years ago. This already includes but will not be limited to the following measures (now and in the future):

- Increased groundwater use;
- Reuse of water (including treating acid mine drainage);
- Conjunctive use;
- Desalinisation of seawater and naturally saline waters;
- Hydro-electricity generation as an alternative to coal-fired power stations; and
- Re-allocation of water between sectors.

In order to achieve the required supply within complex supply and requirement constraints within South Africa, many river systems and water supply options can only be successful if operational rules and system operations are in place and maintained. These would amongst others require the meeting of environmental water requirements and curtailing user allocations in years of low rainfall and runoff.

1. Overview of South Africa's water situation

- South Africa is 31st on the list of driest countries with uneven distribution of rainfall and water requirement areas;
- Population growth and the need to keep the economy growing places pressure on the water resources and requires continued planning and reconciliation between the needs of the different water use sectors and the available water resources;
- The increase in yield has been achieved in the past by the construction of storage facilities to capture run off from high rainfall events and store the water for use in low rainfall periods. South Africa is now reaching a stage where most available resources have been fully developed and the only option remaining is the implementation of other management mechanisms to reduce water requirements and use alternative sources of water.

2. South Africa and its neighbours

- Approximately 60% of the catchment areas in South Africa are shared with its neighbouring countries and about 40% of the total runoff from these catchments is shared.
- The collaboration between neighbouring countries in the SADC block is essential to ensure the optimal use of development opportunities and peaceful co-existence.
- Lesotho and South Africa have signed a collaboration agreement already in 1985 to address augmentation of the growing water requirements emanating from the economic activities in Gauteng and the return flows and treated effluent generated in Gauteng are becoming crucial water sources for use in the North West and Limpopo provinces.
- Rivers in the SADC regions can be utilised for hydro power generation which will reduce the pressure on South African water resources.
- Various treaties have been signed between the SADC countries and the joint system operations for rivers such as the Senqu/Orange and Komati and Lomati rivers are essential to ensure environmental protection of the rivers in South Africa and its neighbouring countries.

3. Water resources planning concepts and processes

- Integrated water resource planning is essential to ensure long-term sustained economic growth and a sustainable water resource use.
- Detailed knowledge of water resources are required in order to undertake and refine water resource planning. This includes knowledge of the following aspects of a particular water resource: mean annual run-off (MAR), yield determination, assurance of supply required by each water user sector, water requirements of each water user sector and future population and water requirement growth projections. Options to reconcile available supply with the requirements of all user sectors need to be identified and evaluated to determine their feasibility and costs and the impact on the water resource itself, in order to find the best solution to ensure a water balance for a rolling 25-year planning horizon.

4. Reconciliation processes and methods

- Different methods to determine future water requirements must be used to obtain a good estimate and the risks and economic implications of failure to meet water needed for economic growth needs to be assessed. Standardised procedures are therefore required to determine future water requirements.
- The current water use situation needs to be known, future needs must be determined and this is influenced by economic and development objectives and prioritising between sectors in terms of economic output and long-term strategic use of water.
- Reconciliation methods can include demand-side management, reduction of losses and wastage, re-allocation of water (in which case detailed impact assessments must be undertaken), groundwater resource development, construction of new storage (instream and off channel dams) and unconventional augmentation interventions, such as desalination or re-use of water.
-

SELF-EVALUATION QUESTIONS

1. Why is water resource planning important and what are the main considerations that should be included in any water resource planning study?
2. How does South Africa, water resource planners address the imbalance between water availability and rainfall distribution?
3. How much of the South African water resources are shared with its direct neighbours? Express your results in both relative catchment sizes in each country and percentage runoff allocated to each country and explain the reasons for the apparent discrepancies.
4. Provide an overview of the inter-dependency between South Africa and its neighbours in terms of shared water resources and runoff from these water resources.

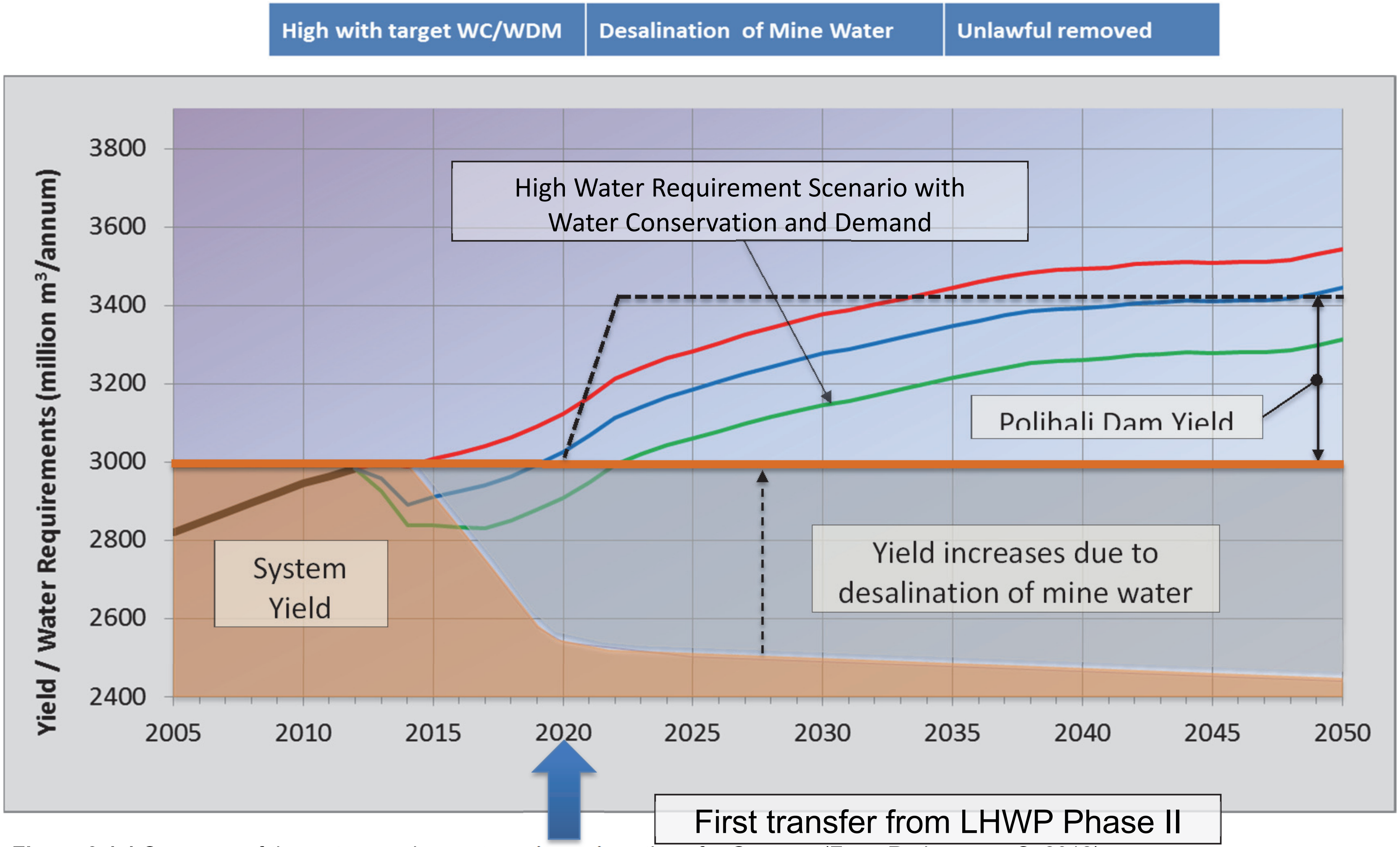


Figure 9.1.1 Summary of the water requirements and supply options for Gauteng (From Rademeyer, S. 2012)

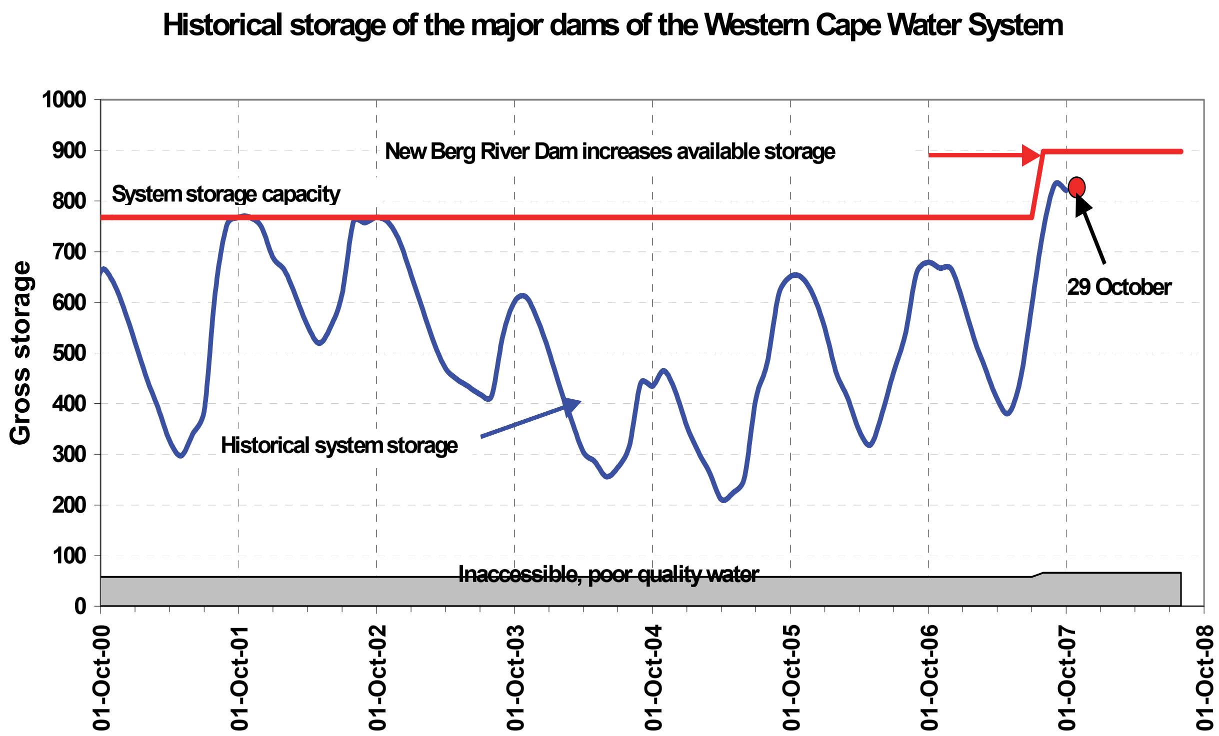


Figure 9.1.2: Berg water project increases storage and yield of WCWSS (from Shand 2008).

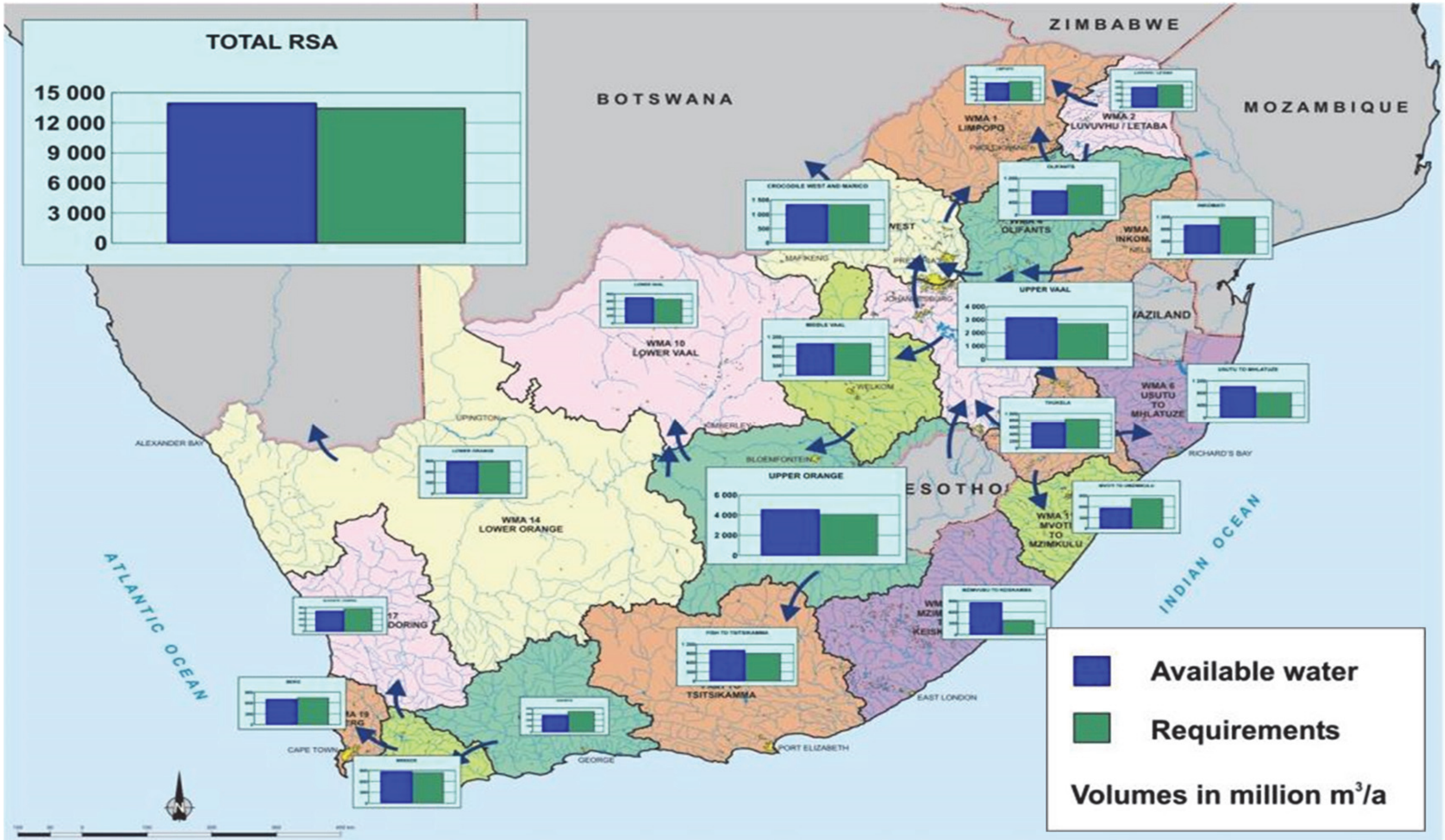


Figure 9.1.3: Water reconciliation (year 2000) for South Africa NWRS 2012.

2 ALTERNATIVE SUPPLY OPTIONS TO PROTECT WATER RESOURCES

TIME

You will need approximately 15 hours to master this study unit.

REFERENCES

- DWA 2004. The National Water Resources Strategy First Edition (NWRS).
  - Chapter 2:
  - Appendix D: Introduction pages D.1 and D.2 in appendix D
  - Pages D19.2-D19.4 Berg River WMA
- DWA 2013. The National Water Resources Strategy Second Edition (NWRS).
  Page 255-259 Berg River catchment
  - NWRS 2012 – Presentation Rademeyer S. 2012.
- WRC 2006. A desalination guide for South African Municipal Engineers. Department of Water Affairs and WRC. Du Plessis JA, Burger AJ, Swartz CD and Musee N. WC TT 266/06, July 2006.
- WRC 2011. Sustainable use of South Africa's inland waters. A situation assessment of Resource Directed Measures 12 years after the 1998 National Water Act. King & Pienaar (editors). Pages 1-14. Chapter 1: **Water supply and demand**.

Additional reading:

- WRC 2007. The status and use of potable water efficient devices in the domestic and commercial environments in South Africa. Report to the Water Research Commission by David Still, Su Erskine, Nick Walker and Derek Hazelton on behalf of Partners in Development. WRC K5/1606, July 2007.

STUDY UNIT 9.2 OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about alternate supply options in context of water resource planning by being able to:

- Provide an overview of the alternative supply options and its use in South Africa and provide a summary of each option's relevance;
- Describe the specific constraints to implement the use of each of the alternative supply options and describe the broad economic implications of failing to implement these water resource management options;
- Explain the relation between alternative supply options and compliance with environmental water requirements and complying with the ecological Reserve; and
- Described the regulatory mechanism that the Department of Water and Sanitation can use to reduce water use.

The study unit will be conducted as follows:

INTRODUCTION

The water situation in South Africa has reached a stage where appropriate and timeous interventions are urgently needed to avert water deficits and associated negative impacts on socio-economic development and ecosystems. The quality of water resources is generally deteriorating, in particular through marked increases in nutrients and microbiological contaminants and is also threatened by acid mine drainage. The ecological component of the Reserve that specifies the quantity and quality of water required for the protection of aquatic ecosystems is not yet fully implemented in most water management areas. Surface water resources have been almost fully developed and utilised and opportunities for siting new and economically viable dams are few. Groundwater resources have not been developed to the same level as surface water resources. Furthermore, treatment of return flows from irrigation, mining, urban and bulk industrial water use could be improved and re-use could be enhanced as a means to increase the availability of water.

The NWRS 2004 included a number of core strategies to address the management challenges. These include Core strategy 6: Implementing water use efficiency, conservation and water demand management.

Accessibility to alternative water resources is conditional and comes at a cost: Except for water losses, alternative water resources are not always readily available or accessible. The critical success factor to supply water to all depends on the ability to mobilize these resources, and to ensure sustainable management thereof. This will require extended effort (in the form of timeous planning, applied research, and developing appropriate technologies (appropriate solutions)), improved governance, leadership and management models, extended funding models and effective financial management, as well as timeous development and implementation, with adequate provision for proper operation and management, both in available budgets and appropriately skilled personnel.

These developments will come at high cost, both in initial capital outlay as well as operation and maintenance over the full life cycle of the project, which will have major impacts not only on the funding thereof, but also on the viability of the development and needs of specific potential users, e.g. agricultural development.

This approach has extensive implications for water resource management. By broadening the narrow traditional focus on surface water resource development as the solution to augment water supplies, a more inclusive business and systems management approach, including efficient water use, use control and regulation, appropriate research and technology, as well as identifying and implementing creative solutions, need to be adopted.

The alternative supply options can be, but is not limited, to the following:

- Water conservation and water demand management
- Surface water resource management (operation of dams)
- Management and use of groundwater resources
- Re-use of water (including treatment of acid mine drainage to a usable standard)
- Eradication of invading alien plants
- Re-allocation of water
- Development of surface water resources (e.g. dams)
- Transfer of water between water use sectors
- Desalination of seawater and brackish water, and
- Conjunctive use.

Other alternatives may not directly make more water available for economic use but will indirectly assist with management of demand and impacts on water resources. This can include the following:

- Hydro-power generation as an alternative to coal-fired power stations which will make water available to other sectors; and
- Transfer of water from other river basins in the SADC region.

These options will not be limited to South Africa but could be a SADC solution and the need for larger-scale integrated planning and long-term strategic considerations are essential.

The deteriorating quality of our natural water resources, both in terms of water quality, as well as river habitat and bio-diversity, is a major and growing concern. The situation regarding acid mine drainage and municipal wastewater pollution has reached unacceptable levels. In terms of river health, almost 60% of river ecosystem types are threatened, with 25% of these critically endangered. Wetland ecosystem types are of even more concern with 65% identified as threatened, including a staggering 48% critically endangered. This situation demands drastic intervention. The DWS has conducted a national review of the water quality status (Figure 9.2.1) and trends that measure, assess and report on the current state and appropriate temporal trends of selected groups of water quality indicators in South African surface water resources.

Results of the review showed that the levels of nutrients in the country's water resources are of major concern. Only 10% of the monitoring sites showed compliance with the prescribed tolerance range of RQO (>0.015 mg/l to <0.025mg/l) for phosphate (11). Levels of noncompliance at national scale are currently 88%. A key contributor to the deterioration of water quality in South Africa's water resources and the marked increase in nutrients and microbiological contaminants with associated health risks are the result of untreated or partially treated wastewater discharges from municipal sewage treatment works (11). The resulting eutrophication in major dams poses health threats to livestock and humans downstream, apart from damaging the ecosystem. Also, water treatment costs increase with higher nutrient loads.

Acid mine drainage (AMD) has been reported from a number of areas within South Africa, including the Witwatersrand Gold Fields, Mpumalanga and KwaZulu-Natal Coal Fields and the O'Kiep Copper District. The Western, Central and Eastern Basins of the Witwatersrand have been identified as priority areas requiring immediate action because of the lack of adequate measures to manage and properly control the problems related to AMD, the urgency of implementing intervention measures before problems become more critical and their proximity to densely populated areas. There is also an estimated 62 Mℓ/day post-closure decant from coal mines in the Highveld Coalfield and around 50 Mℓ/day of AMD discharging into the Olifants River Catchment, reducing the quality of water allocated to irrigation and to municipalities for domestic and industrial supplies, as well as damaging freshwater ecosystems (11). An inter-ministerial committee was set up which made recommendations to address problems associated with AMD. Effective interventions are urgently needed.

The re-use of water could partially address some of these water resource quality challenges.

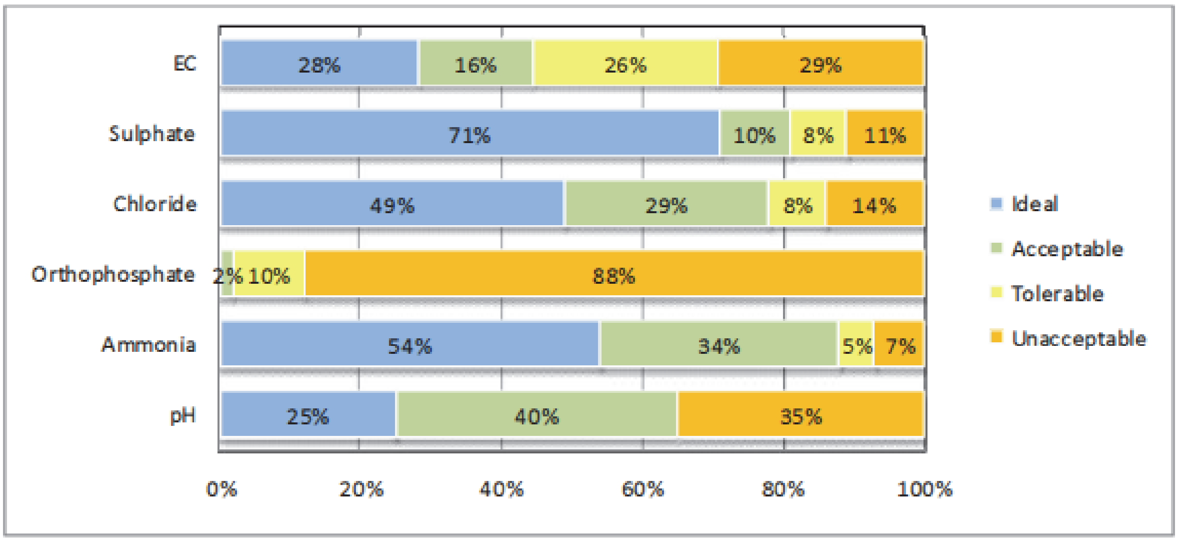


Figure 9.2.1: National percentage compliance of current in-stream water quality with Resource Quality Objectives

1. Alternative supply options

- Various alternative supply options can be considered to augment existing water supply. These option are not equal in terms of the scale and location and economic implications associated with its implementation;
- Alternative supply options can include any or a combination of the following:
  - Increase water use efficiency
  - Management of water demand through reduction of water losses and wastage
  - Water re-use
    - Domestic waste water use (grey water system at home)
    - Treated waste water use from waste water treatment facility for irrigation of sports fields and parks
    - Rainwater harvesting from roofs of houses for garden irrigation, etc. and reduction on formal supply dependence
  - Prevention of the contamination of the water resource with the added cost of treatment and human health impacts on users directly dependant on the resource and directly using water from the resource
  - Desalinisation of seawater and groundwater which can be naturally saline
  - Water conservation by preventing evaporation
  - Recharging groundwater aquifers,
  - Use of groundwater as an alternative to surface water
  - Surface water resource management (efficient operation of dams)
  - Re-use of water (including treatment and use of treated Acid Mine Drainage)
  - Eradication of invading alien plants and replacement with indigenous vegetation that would consume less water and prevent soil erosion and catchment degradation
  - Re-allocation of water between catchments, sectors and even SADC countries

- Transfer of water between water use sectors and even SADC countries, and
- Conjunctive use, which could be a mixture of water use source and double water supply infrastructure (treated waste water for industrial use and garden irrigation and potable water for human consumption).

2. Implementation constraints for alternative water supply options

- Economic considerations. The unit price for the treatment of water from alternative sources can vary widely and will remain a challenge in terms of affordability, but the economic implications of non-supply still outweigh the cost.
- The international target of non-revenue water can be set as 15% of annual water use. A large number of South African supply schemes loose between 30 and 60% of treated water and is most likely one of the most cost-effective ways of addressing the reduction in water requirements. In combination with implementing grey water systems and re-use of water this can have an immediate effect on supply problems.
- Methods for the compilation of information to allow for the comparison between supply option alternatives, Unit Reference Values (URV) and comparison between sectors. See figure 9.2.2 and the NWRS examples.
- Economic consideration of water resource classes and its impact on water use sectors and ecological goods and services. See the Desalination guidelines (page 7) (WRC, 2006).
- Consider the available data from existing operational desalination and re-use facilities in South Africa.

3. Relation between alternate supply and water resource protection

- The reduction in surface water dependence and the need to develop and store surface water will ensure the protection of aquatic resources and the restoration of water resources in areas already deteriorated beyond the acceptable level.
- In a number of river catchment areas in South Africa the limit of potential water resource development has been reached and the implementation of alternative sources and alternative management options is not a luxury any longer but an economic necessity. Specific reference can be made to the upper Olifants River basin where the development of platinum mines is potentially negatively affected by the shortage of water in a catchment where power generation and other water use sectors are competing for the same limited resources.

4. Regulatory mechanisms to implement alternate water supply options

- Compulsory licensing (possibly the least preferred mechanism unless conflicting needs or over-allocation of the resource leaves no alternative).
- Tariffs and economic incentive schemes to reduce the use of sectors that are economically not contributing in proportion to the cost to supply water.
- Implementation of catchment management strategies (CMS) through the development of catchment management plans and long-term planning at various scales: catchment, water management area (WMA), regional, national and SADC.
- The planning and implementation cycle will provide an opportunity to bring these alternatives in at a NWRS and catchment management agency level. The focus should

now be on implementation of these alternatives.

- Water use licensing as a mechanism to entrench the use of alternative sources and is a mechanism to protect water resources.

SELF-EVALUATION QUESTIONS

1. List the possible alternative water supply options that can be used to improve water resource sustainability and protection in South Africa;
2. Provide an overview of the economic implication of alternative water supply methods and their impact on the demand from traditional water supply options;
3. Rank supply options from a case study and supply the Unit Reference Value for each option to provide a comparison between the options;
4. List the regulatory mechanisms that can be used to implement and enforce alternative source management options.

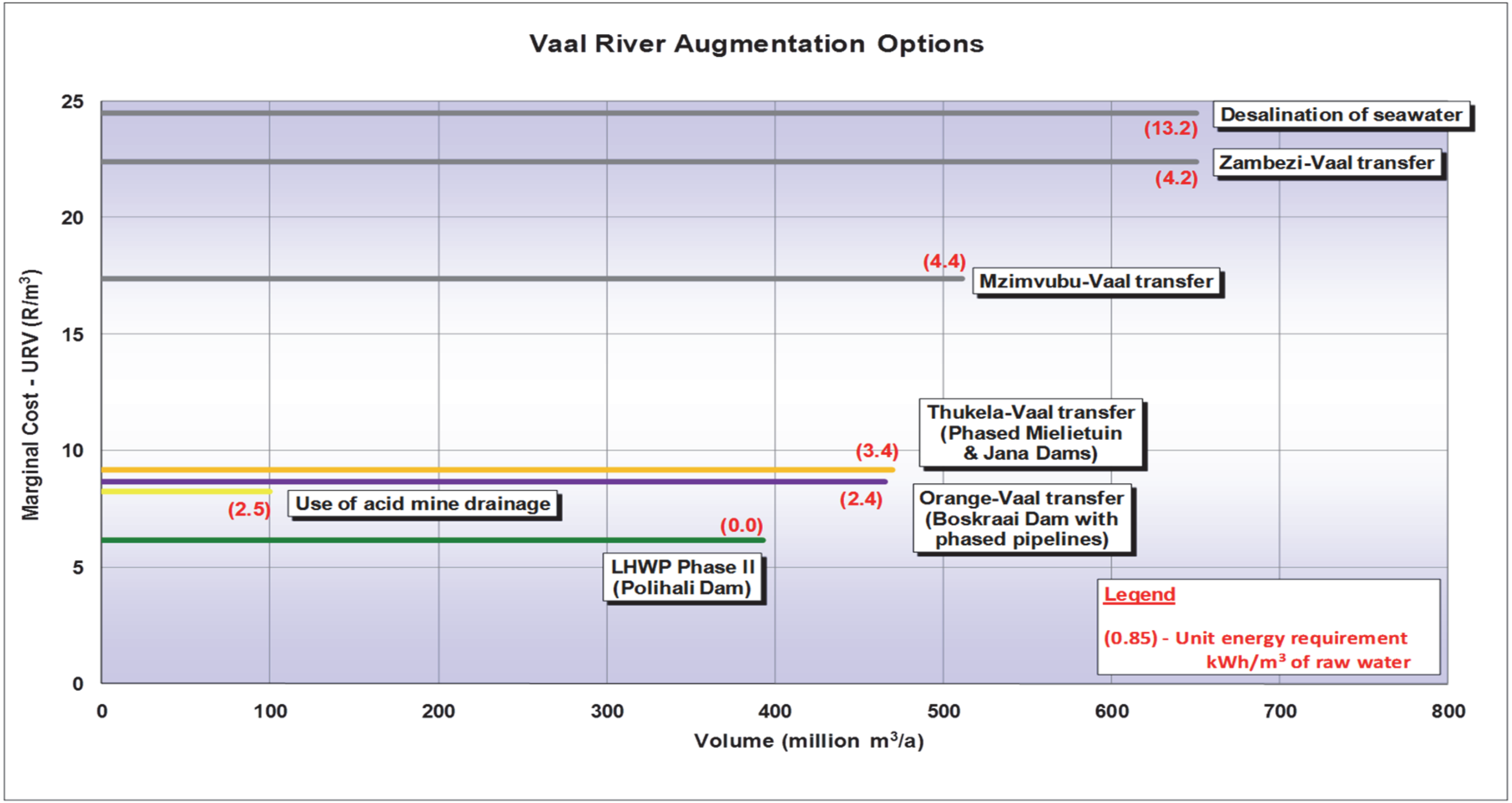


Figure 9.2.2: Unit reference value (rand per cubic meter) for water supply options for supplementation of Vaal river system (Rademeyer S NWRS 2012)

3 WATER DEMAND MANAGEMENT AND WATER RESOURCE PROTECTION

TIME

You will need approximately 15 hours to master this study unit.

REFERENCES

- DWA 2004. The National Water Conservation and Demand Management Strategy
- DWA 2004. Resources Strategy First Edition (NWRS).
    - Chapter 2 page 37.
- DWA 2004. Guidelines for water conservation and water demand management in water management areas and in the water services sector, South Africa, Volume 1: A Planning Framework for Water Conservation and Demand Management at Water Management Area Level. Full Guidelines Version. Danida, March 2004.
- DWA 2007. Overview of Water Conservation and Demand Management in the City of Cape Town, Western Cape Water Supply System Reconciliation Strategy, June 2007. Report No. 4 of 7.
- DWA 2012. The National Water Resources Strategy Second Edition (NWRS).
    Page 255-259 Berg River catchment

Additional reading:

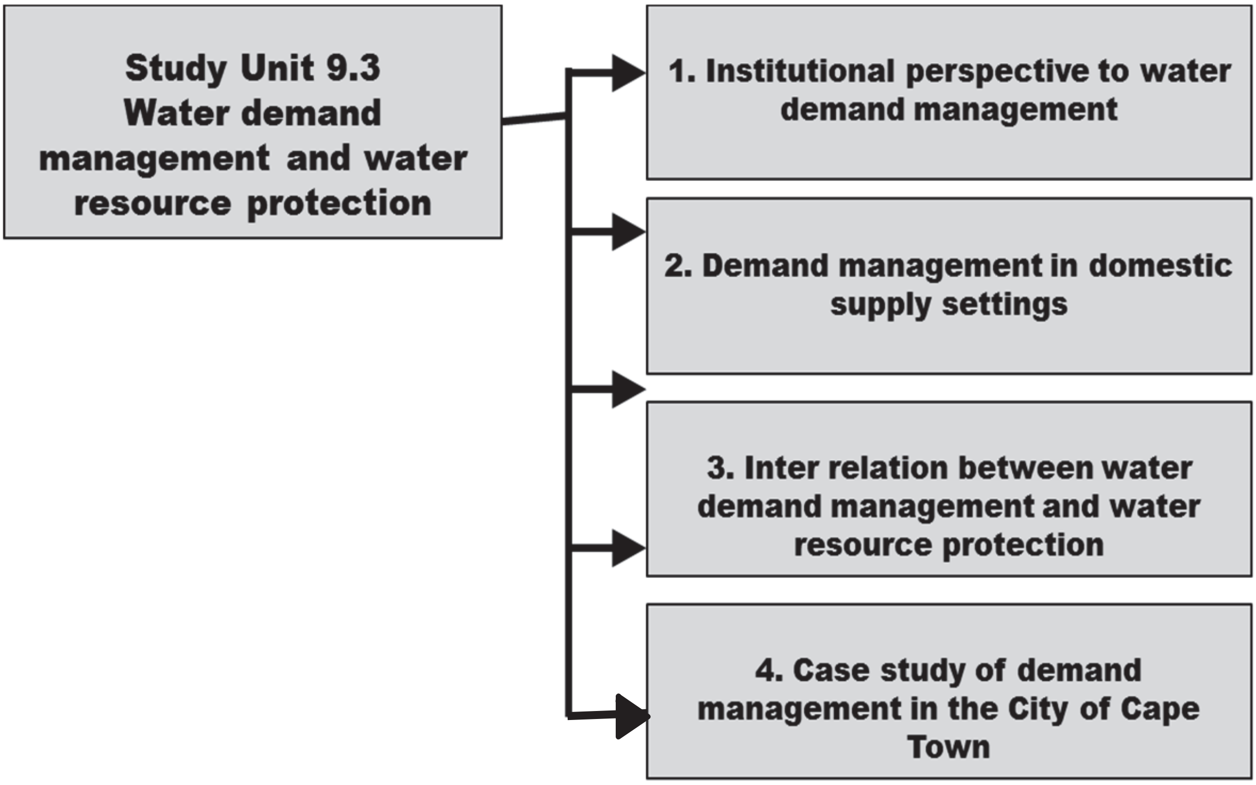
- WRC, 2007. The status and use of potable water efficient devices in the domestic and commercial environments in South Africa. Report to the Water Research Commission by David Still, Su Erskine, Nick Walker and Derek Hazelton on behalf of Partners in Development, WRC K5/1606. July 2007.

STUDY UNIT 9.3 OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about water demand management and its role in improving water resources management and giving effect to environmental water requirements, and be able to:

- Provide an overview of the water management institutional mandate and responsibility to determine and implement water demand management measures;
- List and described each of the domestic water demand management mechanisms that can be used to give effect to water demand management;
- Analyse a water demand management plan and advise on the procedure to measure the success of implementation of such a water demand management strategy; and
- Explain the link between the protection of water resources and water demand management.

The study unit will be conducted as follows:



INTRODUCTION

Water demand management

For many years the tendency in South Africa has been to resort to constructing additional infrastructure where the need for water exceeded the supply. As water use approaches its full potential however, the cost of resource development increases and the environmental impacts become more pronounced. Management of the demand for water is an obvious option for reconciling imbalances between requirements and availability, and has been applied with great success by some users. If in some catchment areas a 10 per cent saving in user requirements could be achieved then a current water deficit can be changed to a surplus situation.

Compared with supply-side management, the management of water requirements in South Africa is relatively under-developed, although there are world-class examples of water use efficiency in some areas of industry and agriculture that will help to set benchmarks. Some quantitative data is available on water savings resulting from demand management programmes, notably in some of the metropolitan areas and the larger municipalities, but in general insufficient information exists to make reliable estimates of the potential savings in each water management area.

More information will become available as the effects of implementing the Department's water demand management programme become evident, and these will be accounted for in the water availability and requirements data in future editions of the NWRS.

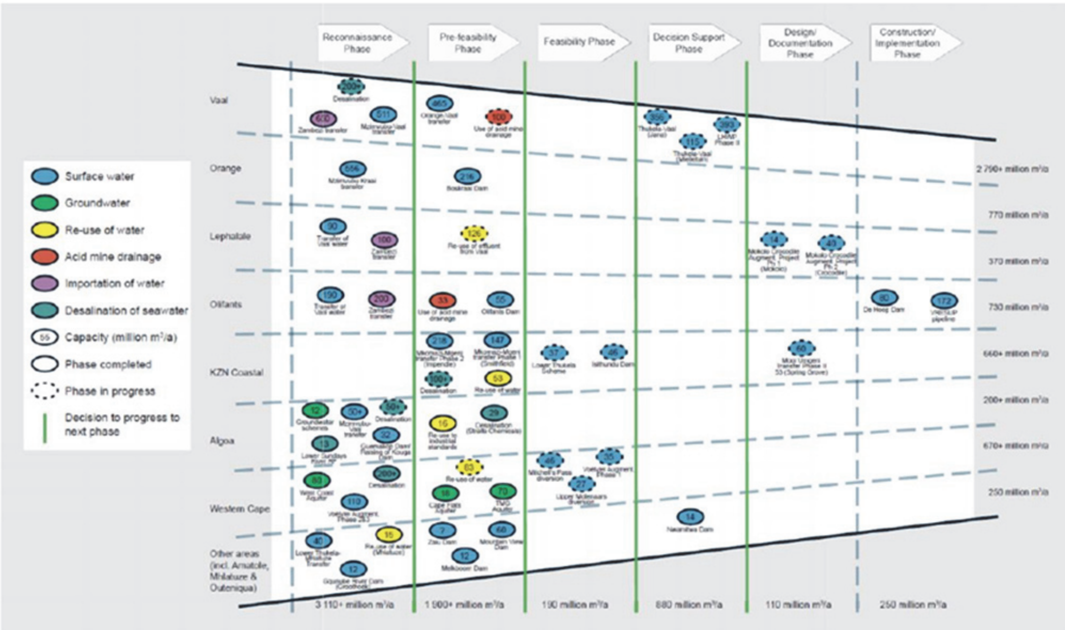


Figure 9.3.1: Water resource project funnel/filter (NWRS 2012 page 35)

Water conservation can be defined as the minimisation of loss or waste, care and protection of water resources and the efficient and effective use of water (national WC/WDM strategy definition). Water demand management can be defined as the adaptation and implementation of a strategy to influence water demand and usage in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, political acceptability (national WC/WDM strategy definition).

Water conservation and water demand management are entrenched in the National Water Act through the commitment to water conservation and the promotion of sustainable and equitable use of water resources in South Africa. Institutions responsible for water resource management must therefore adhere to and promote these goals through their functions and activities. As the institutions delegated with water resource management functions at a catchment level, catchment management agencies (CMAs) are the key bodies for the promotion and implementation of WC/WDM within their WMA.

In conjunction with the drought mitigation measures various other WC/WDM measures should be utilised to reduce water requirements from water resources. The collective use of these measures can result in a significant increase in public awareness concerning the scarcity of water in the area and the need to use it more efficiently.

1. Institutional perspective to water demand management

The generic framework for the development of a CMS makes clear reference to the need to consider and incorporate WC/WDM in the CMS. Water conservation strategies are one of the six “Supporting Strategies” of the CMS, deemed as essential in order to effectively manage water resources in the WMA.

There are both constraints and opportunities to the implementation of WC/WDM in WMAs. These are largely dependent on the institutional capacities, resources, infrastructure, level of awareness and knowledge base available within the water management areas and CMAs. The main barrier to implementing WC/WDM is noted in the WC/WDM National Strategy Framework:

“The key challenge for WC/WDM is its integration into the water resource planning process. In the past, initiatives have been considered only as strategies associated with environmental or communications initiatives, which often led to inefficient water supply planning. “Integrated least-cost planning” or “Integrated Resource Planning” (IRP)…emphasises WC/WDM as potential alternatives to increasingly expensive supply-side management options” (DWAF, 1999:18). However, one of the obstacles DWA identifies to implementing IRP, and by implication, WC/WDM, is resolving whose costs are supposed to be the ‘least’: the institutions, current customers, future customers, secondary customers or society? Resolving these and other issues, as well as creating an understanding of the benefits in the broadest, long-term sense, of implementing WC/WDM, is one of the largest and most pressing challenges to be addressed before WC/WDM will be socially acceptable, and therefore effective.”

The WC/WDM National Strategy Framework goes on to list several other generic constraints to the implementation of WC/WDM in South Africa, most of which are relevant to CMAs:

Bias towards supply-side measures

- Funding is more readily available for supply-side interventions
- Supply-side management options appear easier to implement

- Consultants often promote the development of infrastructure without adequately reviewing WC/WDM measures as alternatives.

Perceptions and lack of understanding

- Resistance to change within institutions
- Water conservation measures are perceived only as drought relief mechanisms
- Demand management strategies are often incorrectly perceived and implemented as punitive measures to the consumers
- Lack of understanding of the principles, scope and potential of demand management
- Lack of knowledge of consumer and water usage patterns
- Lack of adequate knowledge of the factors causing the growth in water requirements
- Misdirection of WC/WDM measures (e.g. conveying "use the shower not the bath" messages to households that have no such facilities).

Payment for services

- Low level of payment or non-payment for services by a significant number of consumers
- Low relative price of water, particularly in the agriculture sector, relative to the real cost of supplying and treating the water.

Sectorial issues

- Officials and industry sectors protect their own interests
- Lack of integration and cooperation between the various institutions in the water supply chain, particularly in the water services sector
- Lack of ring-fencing of the water services functions or the lack of integration and cooperation within the different departments of local authorities.

Skills and capacity

- Lack of skills in South Africa to implement demand management
- Lack of capacity within institutions to implement WC/WDM.

Allocation of water based on efficient use

- Allocation of water to all users that do not take account of efficient use by consumers

Although the constraints appear significant, there are also promising opportunities for implementing WC/WDM through CMAs and by WSAs. To a large extent, mind-sets are beginning to change in the South African water resource management environment. We have policies at the highest level that explicitly promote and encourage the implementation of WC/WDM, they just need more aggressive implementation.

2. Demand management in domestic supply settings

Demand management in domestic supply setting is dependent on the magnitude of the supply problem and the specific circumstances in which water supply and waste water services are provided. Demand management measures can include any or a combination of the following:

- Pressure management
- User education
- Elimination of automatic flush urinals
- Leakage repair projects
- Tariffs, metering and credit control
- Water-efficient fittings
- Boreholes and well points
- Grey water use and
- Rain water harvesting tanks.

3. Inter relation between water demand management and water resource protection

- The higher the water resource class or present ecological condition of a supply source (either groundwater or surface water) the higher the need for environmental water requirements will be to maintain the sustainable use from the resource. This would imply that protection measures which should include demand management should be implemented in resources with a class and present ecological condition that demand protection. The end result is that demand management is not a measure that can be implemented when the resource has reached its last drop to be supplied and is also therefore not uniform across water management areas and supply sources.
- Freshwater biodiversity conservation in conjunction with the conservation of water resources for high quality domestic water supply can be implemented to be a conjunctive protection measure that will ensure the aquatic ecosystem is protected and at the same time associated biodiversity and good quality water can be supplied (refer to the former mountain catchment policy).

4. Case study of demand management in the City of Cape Town

- As part of the conditions set for the water use licence issued abstracting water from the Berg River Dam the City of Cape Town (CCT) was obligated to determine and implement water demand management measures to reduce their requirements from the Western Cape Water Supply Systems.
- The successful implementation of this condition is confirmed through preliminary investigations, which indicate that winter water requirements have remained almost constant since 2000, whilst the summer water requirements indicate a decline.
- Consumer surveys conducted to date indicate that some 57% of residential consumers have changed their water use behaviour, the primary reasons being:
  - Price (41%)
  - Restrictions (32%); and
  - Awareness campaigns (20%).
- The CCT has implemented a number of WC/WDM projects to date:
    - **Pressure management projects**
    - **User education**
        - Implemented as part of specific projects or drought mitigation interventions. The water requirement reduction attributed directly to user education can not readily be determined. However, the media campaign linked to the restriction won the Green Trust Award in 2000; and
        - Programmes/initiatives to enhance in-house awareness.
    - **Elimination of automatic flush urinals**
        - Undertaken as part of specific projects and drought mitigation interventions on municipal property and through the promulgation of by-laws for private property – savings and effectiveness cannot readily be determined.
    - **Leakage repair projects**
    - **Tariffs, metering and credit control**
        - Rising block tariffs – price elasticity not determined
        - Volumetric based sanitation tariffs – impact not determined
        - Adopted policy of universal metering
        - Meter audits of high water use consumers
        - Programme to replace all "gallon" meters
        - Programme to establish zones and install zone meters
        - Instituted systems to facilitate the management of meters and the collection, assimilation and analysis of consumption data; and
        - Actively pursued credit control.
    - **Water-efficient fittings**
        - Installed water-efficient fittings in council buildings
        - By-laws and engagement with certain standard authorities to promote the use of water-efficient fittings in private properties.

- **Boreholes and well points**
  - Promoted and regulated their installation and use, following the dramatic increase in demand for these during the last drought;
  - Did not impose water restrictions on groundwater use during the drought, subject to certain conditions; and
  - Initiated a study to assess the current extent of groundwater use and the impact of the collective use of all boreholes and well points on the aquifers in the area.
- **Grey water use and rain water tanks**
  - The extent and success of this is unknown.

SELF-EVALUATION QUESTIONS

1. Provide your interpretation of the constraints that are often preventing the implementation of demand management and water use efficiency provisions;
2. Provide a list and describe the nature of demand management options within a domestic supply environment and provide the methods that could be employed to measure the success of the demand management measures;
3. Why is water resource planning important and what are the main considerations that should be included in any water resource planning study; and
4. Compile a water balance for your own home and indicate which measures you can implement to reduce your water requirements at a household level.

4 IMPLEMENTING EWRS: INCORPORATING INTO WATER RESOURCE PLANNING AND SYSTEMS OPERATION

TIME

You will need approximately 25 hours to master this study unit.

REFERENCE

- Hughes DA (ed.) 2004. SPATSIM, An integrating framework for ecological Reserve determination and implementation: Incorporating water quality and quantity components for rivers. WRC Report No. TT 245/04, Water Research Commission.
- Hughes, DA, Mallory, SJL, and Louw, D. 2008. Methods and Software for the Real-Time Implementation of the Ecological Reserve – Explanations and User Manual. Report to the Water Research Commission. WRC Report No. 1582/1/08.
- James, CS and King, JM. 2010. South African Handbook on Environmental River Hydraulics. WRC Project No. K5/1767.
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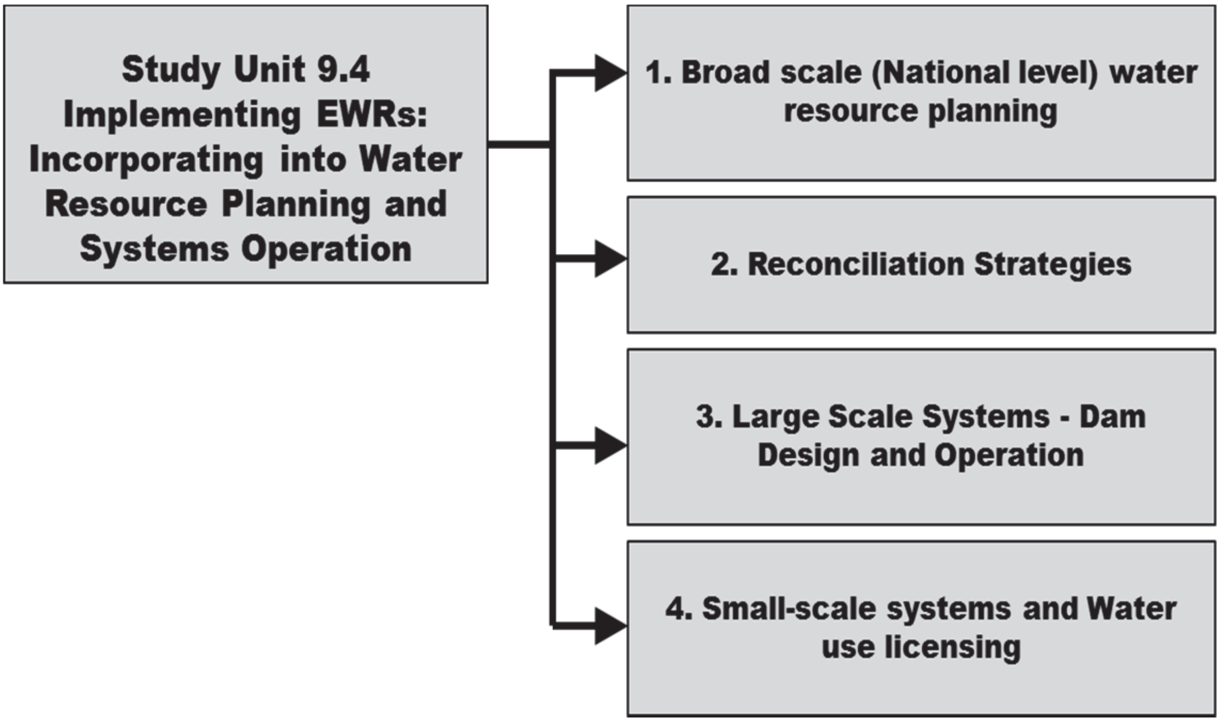
- King, JM, Tharme, R and de Villiers, MS. (eds) 2000. Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. WRC Report No. TT 131/00. Water Research Commission, Pretoria, 339 pp.
- Schreiner, B and Hassan, R. (eds) 2011. Transforming Water Management in South Africa. Designing and Implementing a New Policy Framework. Global Issues in Water Policy. Volume 2. Springer Publishers. 278 pp.

MODULE OUTCOMES

At the end of this study unit, you should be able to demonstrate knowledge and insight about EWR methodologies in general by being able to:

- Provide an overview of how EWRs are taken into account in national and catchment level water resource planning;
- Explain how EWRs are implemented for water resources with large instream dams; and
- Explain how EWRs are implemented for run-of-river abstractions.

The study unit will be conducted as follows:



INTRODUCTION

There are a number of levels at which EWRs can be implemented within water resource management. These range from broad level planning assessments of the availability of water that are carried out at a catchment level or even a number of catchments to those relating to a specific application for water use. The approach to incorporating the EWR into these assessments as well as the way in which the EWR is implemented following the assessments varies substantially. Differences between implementation situations notably occur where there is storage that can be used to control flows and where there is no storage and all 'users' are reliant upon run-of-river flows. This section emphasises the need for operational rules in all situations, where these rules can include patterns of releases from reservoirs (the conventional understanding of the term 'operating rules'), water user supply curtailments based on the current state of storage, as well as supply curtailments based on the estimated natural flow conditions in the river. This study unit describes the various applications and approaches taken to 'give effect' to EWRs.

1. Broad scale (National level) water resource planning (Hughes 2004)

- In 1999, a water situation assessment model (WSAM) was developed by DWA to determine the water availability in water resources in South Africa for broad-scale planning purposes. A national evaluation of ecological data for the river mainstems in all 1946 quaternary catchments in the country was undertaken to determine the ecological importance and sensitivity class (EISC) and present ecological status class (PESC) for each quaternary catchment. This informed preliminary classes that were set for each quaternary catchment. The preliminary class was utilised to calculate the ecological Reserve requirements for each catchment, by means of the Reserve decision support system (ResDSS). The method used in this low confidence ecological Reserve determination assessment for river quantities was referred to as the Desktop method and was also utilised for the National Water Resource Strategy (NWRS) and the Internal Strategic Perspectives (ISPs) – a predecessor to catchment management strategies.
- The ResDSS is based on the extrapolation of the environmental flow requirements that have been determined as part of high confidence Reserve determination studies undertaken across South Africa. The ResDSS were only intended for planning purposes as it was felt that the model was not conservative enough for more detailed decision making. The model is however being utilised for licence applications having a lower potential impact due to the limited capacity available for implementing the Reserve in water use licences.
- The original outputs from the ResDSS showed a trend, i.e. a river in an unmodified river (A category) required approximately 40% to 50% of the natural mean annual runoff (MAR), a slightly modified river (B category) required 30% to 40% of the MAR, a moderately modified river (C category) required approximately 20% to 30% and a largely modified river (D category) required 10% to 20%. Increasing knowledge and assessments arising from doing more EWR studies have however shown that due to a high variability in the flows of our river systems this trend is not so clear cut (e.g. in Western Cape rivers, much higher flow requirements have been established due to the contribution required from the larger floods that occur during the wetter months for movement of large boulders and rocks in the river systems).

2. Reconciliation Strategies (King *et al* 2004, King and Pienaar, 2011)

- Water planning studies towards the development of reconciliation strategies (usually at a catchment area wide level) have primarily made use of Intermediate or Comprehensive Reserve determinations. Most Reserves determined before 2003 provided a single prescriptive Reserve recommendation, however those determined since 2003 produced multiple scenarios which allowed for better decision-making. These were usually the Present Ecological State (PES), the Recommended Ecological Category (REC) and at least one additional scenario.

- Most of the planning-level Reserve determinations were undertaken for water quantity in rivers but are increasingly including a water quality aspect as well as including the EWRs for estuaries, groundwater and to an as yet much lesser extent, wetlands.

2.1 Catchment system analysis and yield modelling requirements

- The yield of a proposed development is the overall available volume of water in the river system under study, and its assurance of supply. It represents the available water remaining after the Reserve has been allocated.

- The EWR output should be in the form of scenarios to allow for trade-offs in water allocation and planning.

- EWR assurance of supply: The percentages of time that maintenance and drought flows should occur differ from river to river, depending on the rivers' sensitivity to flow variation (Hughes 1999). These percentages can be estimated from the characteristics of the hydrological regime, based on flow variability, but are checked against the perceptions of the ecological specialists. The output is a description of the assurance relationships.
- In complex catchments the ecological Reserve requirements will be partly managed through the setting of reservoir operating rules. A systems model is then necessary. The Water Resources Yield Model (WRYM) is a complex system model that can account for natural flows in a system and a wide variety of water uses, all defined with different levels of assurance of supply and is used by DWA and water resource consulting engineers and hydrologists.
- These models operate on a monthly time step and comprise a complicated network of natural flow inputs, storages, losses and abstractions, return flows and transfers (internal and external). Most of the abstractions and transfers are defined through a set of supply assurance rules in a similar and compatible way that the Reserve scenarios are now defined.
- The most important consideration in the model is that the assurances of the flows required to satisfy the Reserve are linked to duration curve % points of the natural flows that occur in any one month during the model run.

2.2. Operational scenarios

- A catchment system analysis is used to identify the ecological consequences of different operational scenarios.
- One possible operational scenario may be to satisfy the low flow requirements of the Reserve through managed releases, but not to manage the high flows through releases (possibly because the existing dam infrastructure does not allow for the releases of high flows) and to assume that the high flows at the Reserve site will be provided by reservoir overflows and downstream tributary inflows.
- Often the main impacts on the yield are caused by the high assurance (i.e. lower flows) components of the Reserve. Alternative Reserve scenarios are then considered that will have a lower impact on the yield but still maintain the ecological functioning of the system in a certain ecological category.
- While the monthly time-step is appropriate for most scenario assessments, it is often necessary to consider the high flow Reserve requirements in more detail to determine whether the system operation has the capability to meet such flows. The most important factor to consider is the capacity of the dam outlet works to release flows to satisfy the flood requirements of the Reserve. The Reserve requirements may be specified for a point in the river downstream of the dam and the effects of attenuation and losses should be accounted for when quantifying the releases.
- The operational scenarios must be evaluated to supply the ecological consequences. Some scenarios may result in the same state / health (ecological reserve category). The ranking of scenarios must then take place with motivations and explanations. This is usually done using expert opinion. No recommendations are made on the acceptability of the scenarios. The specialist must provide as much information as possible to allow informed decision making.

3. Large Scale Systems – Dam Design and Operation (Hughes 2004 and Hughes *et al* 2008)

- Where large-scale storage systems are concerned there could be two groups of water users; those supplied directly from the reservoir (either through releases along the channel, or though pumping from the dam) and those who are run-of-river users between the dam site and the Reserve site. Users supplied from the reservoir will have license conditions that are controlled by the reservoir level. Downstream run-of-river users will be controlled in the same way as if there was no storage (i.e. through time series signals based on estimates of natural flow conditions). The extent to which high flow releases can be managed will largely depend upon the volume of storage (relative to typical natural flow volumes) as well as the capacity of the available release infrastructure (gates, valves, etc.).
- The EWR output is normally a table of flows for each month of the year for a set of assurance percentages, which are considered by the ecological specialists as being likely to achieve a defined environmental objective and a range of possibilities may be provided.
- A complication in operationalizing the EWRs is that it is also often not possible to achieve some of the components of the high flow part of the Reserve, in particular where there may be limited release capacity from the available storage reservoirs. While such constraints prevail within the catchment, the Reserve that will be managed should not include those high flows and the assumption is that they will either occur and the environmental objectives will be met, or they will not occur and it is possible that the river will degrade ecologically. The low flow requirements can usually be managed by placing different levels of restriction on abstractions at different storage levels in the dam.
- There are four main issues that need to be considered in the interpretation of the high flow results of a Reserve determination and in establishing the high flow operating rules:
  - **Attenuation and losses:** Water released from the dam will not be the same as the Reserve requirement downstream due to attenuation of the peak as well as losses to satisfy pool storage, bank storage and evaporation.
  - **Tributary inflows:** The volume of release water could be reduced if there are tributary inflows between the release site and the Reserve site and if the release can be timed to match those inflows.
  - **Release timing:** The real-time Reserve operation should achieve a modified flow regime that reflects natural flow conditions as closely as is possible. With respect to low flows, this means preserving seasonality and some degree of flow variability. High flows should occur at specific times in relation to the life-cycles of the biota. This is more difficult to achieve when the natural hydrological response time of the system is quite short (small and steep catchments). The key to this issue is therefore being able to identify real-time trigger information that is accessible to the water resource manager and can be used to reliably identify the appropriate time to make releases.
  - **Safety:** Of particular relevance to large releases, is the necessity to provide riparian river users with adequate warning of a high-flow release, to enable them to safeguard assets such as pumps.
- For the EWR to be included in dam designs, the main emphasis is usually on the size of outlets required to release large floods. There are various ways of providing these, for example by using a combination of multi-level outlets and bottom outlets. Each option has cost implications as well as positive and negative environmental effects.

The costs of dam construction (or alteration) to incorporate outlet works with the capacity to release high flows are very high, e.g. an additional R46 million or 9% of the total dam cost was required to extend the Berg River dam outlet works from 30 $m^3 s^{-1}$ to 160 $m^3 s^{-1}$.

- A software release tool has been developed to facilitate the implementation of the low and high flow releases. The purpose of the tool is to assist the dam operator to make the required high and low flow releases at the appropriate time, with the desired hydrograph shape, magnitude and water temperature. The tool is linked to a Supervisory Control and Data Acquisition (SCADA) system, which provides it with real-time information on river flows and temperatures and on temperature profiles in the reservoir. For high flows, the inflows to the dam are monitored continuously and the operator is advised when a release is required. The operator then uses the tool to determine the shape of the hydrograph to be released, which level to draw water from and what the radial gate openings should be. Similarly for the low flows, the operator can use the tool to determine the release required and the level from which the water must be drawn.
- Often the only solution to providing irrigation water and satisfying an environmental flow requirement is through engineering works (e.g. pipelines or canals) that allow the irrigation water to be distributed without using the natural channel. This is because irrigation water is frequently required during the dry season which can lead to a reversal of the seasonal distribution of low flows in the river reaches below the reservoir (in particular in winter rainfall areas). Artificial flows which are in excess of natural flows and which have very low variability (this can often occur as a result of treated wastewater discharges) are unlikely to satisfy the environmental flow requirement without substantial ecological consequences.
- A "Reference flow" site that can provide suitable, near real-time, trigger signals for the releases should be identified. Such a site should reflect relatively natural flow variations and could be based on a stream flow gauge, water balance calculations of reservoir inflow volumes or a near real-time simulation of catchment runoff.
- The high flow components are usually included to satisfy the geomorphological objectives of maintaining the channel form. However these relationships are often poorly understood.

4. Small-scale systems and water use licensing (Hughes 2004 and Hughes *et al* 2008)

- The NWA requires that the Reserve be determined prior to authorising any water use and is applicable for the authorisation of any of the eleven water uses listed in Section 21 of the NWA, as well as for the transfer of a water use entitlement between water users. The relevance of Reserve determinations for water uses relating to the alteration of the bed, banks or characteristics of a watercourse, the impedance or diversion of flow, or for recreational use, has often been questioned as the impact is more upon the habitat and biota than on the water quantity and quality.
- Implementation of the Reserve requirements where there is no release control would need to be met through allocation licensing and monitoring users to make sure that they comply with their license conditions. Water resource yield analyses, based on balancing the naturally available resource, the Reserve requirements and the licensed user requirements will be required to determine license conditions. The real-time implementation process is therefore confined to determining when certain license conditions (i.e. restrictions) will need to be applied to different water user sectors to

maintain flows in the river that will satisfy the Reserve requirements. In these situations only the low flows will be managed as no infrastructure is available to control high flows.

- The Institute for Water Research has developed a model that uses monthly time series data of natural flows and reserve assurance rules. It also requires information about existing and future licence applications. When there are no regulating mechanisms a simple water balance model can be used to estimate the present day effects of afforestation, small farm dams and run-of-river abstractions.
- The resolution and accuracy with which a Reserve is determined in small catchments will frequently be much lower than for major rivers therefore it is usually not cost effective to undertake detailed Reserve determinations on all small rivers and therefore more rapid approaches, based on regional extrapolation, are frequently used.
- From WSAM it also became apparent that for many catchments, particularly in the winter rainfall regions, the only available water for meeting future growth in requirements occur during the wet seasons. For this reason water resource managers have promoted the construction of off-channel dams to store winter water for use during summer in order to prevent the over abstraction of summer low flows through run-of-river abstractions. While the intent of this management action is good in trying to meet the Reserve requirements, it is also a rule that cannot unilaterally be applied. For many of the catchment, such as in the Klein Berg Catchment, the water resources are already very stressed and the reduction of runoff from the catchment into off-channel dams has drastically reduced the water available to existing downstream water users.

SELF-EVALUATION QUESTIONS

1. Discuss the various water resource planning levels and how EWR are taken into account in these assessments
2. Discuss the implementation of the high and low flow EWR and how these are best achieved within different systems and water user scenarios.

5 CASE STUDY OF INTEGRATED PLANNING AND RESOURCE PROTECTION

TIME

You will need approximately 30 hours to master this study unit.

REFERENCES

- DWA 2004. The National Water Resources Strategy First Edition (NWRS).
  - Chapter 2: SA water situation and strategies to balance supply and demand
  - Introduction pages D.1 and D.2 in Appendix D
  - Pages D19.2-D19.4 Berg River WMA
    - DWA 2007. Overview of Water Conservation and Demand Management in the City of Cape Town: Western Cape Water Supply System Reconciliation Strategy, June 2007. Report No. 4 of 7.
    - DWA 2007. Western Cape Water Supply System Reconciliation Strategy. Overview of the Water Conservation and Water Demand Management in the City of Cape Town, Department of Water Affairs, Directorate National Water Resource Planning.
- DWA 2012. The National Water Resources Strategy Second Edition (NWRS).
  Page 255-259 Berg River catchment
    - NWRS 2012 – Presentation Mr Seef Rademeyer.
    - CSIR 2008. Environmental management plan for the operational phase of the Berg River Dam project. November 2008. CSIR report No CSIR/CAS/EMS/2008/001-4/A.

Additional reading:

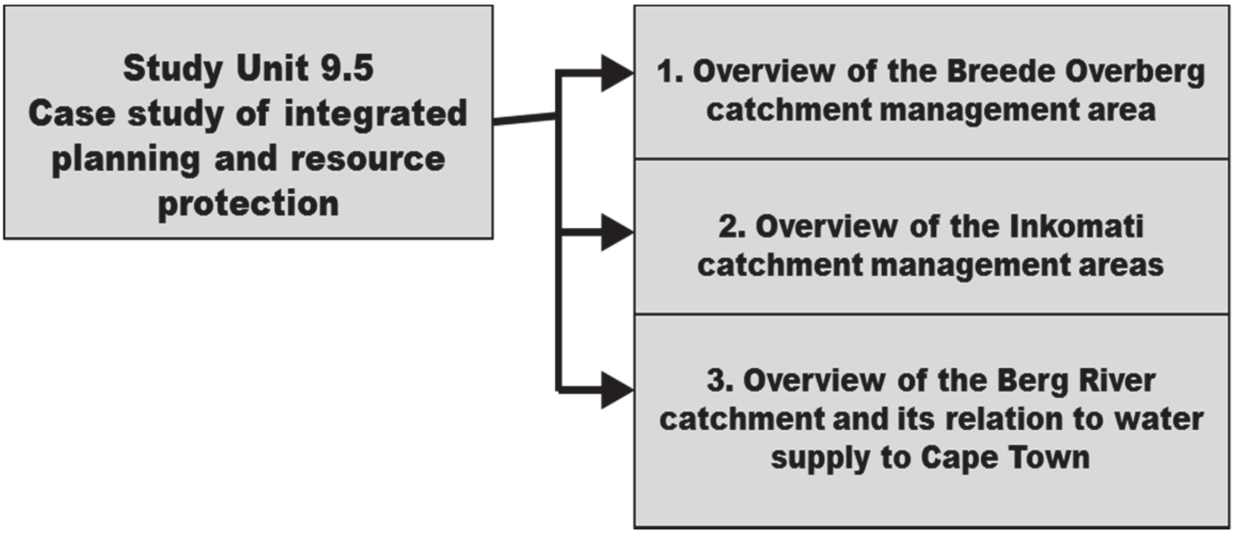
STUDY UNIT 9.5 OUTCOMES

NB Note: This study unit requires self-study with initial guidance from the lecturer. Two students are allowed to collaborate but each student must submit an **individually written** case study report.

At the end of this study unit, you should be able to demonstrate knowledge and insight about integrated water resource planning and implementation of planning recommendations by being able to:

- Compiling a case study report which will demonstrate your knowledge and insight of the following aspects:
- Water resource planning in the case study area and its relation to the need for the provision for environmental water requirements.
- The inter relationship between future water requirements and the need to implement demand management and water allocation strategies to ensure long-term sustainable use of the water resource.
- The constraints in the planning and execution of water resources planning and implementation of planning recommendations and the economic implication of these constraints.
- The regulatory framework in which the planning of water resources and implementation of recommendation and enforcement of water legislation should take place.

The study unit will be conducted as follows:



INTRODUCTION

The preceding five study units provided you with an overview and insight into the water resource planning process and the methods by which environmental water requirements should be considered and determined within this process.

South Africa provides various examples of the implementation of the regulatory mechanisms provided for by the NWA. The establishment of Catchment Management Agencies in the Breede and Inkomati catchment areas is spearheading the new water regulatory environment which was envisioned in 1996 when the water law principles were compiled. It provides decentralised management of water resources. In both the Breede and Inkomati catchments the Catchment Management Agencies have been established and have made progress with the compilation of catchment management strategies which follow from the earlier Internal Strategic Perspectives (ISP) which were compile by the Department of Water Affairs as a precursor to these strategies. Both these areas can be used as case studies of the progressive implementation of provisions of the National Water Act with specific reference to the implementation of environmental water requirements and reconciliation options for water supply.

It must be mentioned here that both these WMA now form part of larger WMAs, as the original 19 WMAs have been reduced to 9 WMAs. The Breede_Overberg and Gouritz WMAs have been combined to form the Breede-Gouritz WMA, while the Inkomati WMA and the Usuthu Catchment have been combined to form the Inkomati-Usuthu WMA.

The Berg River is part of the Cape Town Water Supply Systems and has almost been fully developed to supply water to the ever growing metropolitan area of Cape Town and surrounding towns, as well as to irrigation. The Berg and Breede River catchments are interlinked with water transfer schemes and cannot be managed as separate entities. The planning of the Berg River Dam, near Franschhoek, co-incided with the promulgation of the NWA in 1998 and the need for the implementation of water resource protection measures. The design and operation of the dam was therefore required to comply with requirements of the Ecological Reserve. Simultaneously the licensing conditions for the construction of the Berg River Dam were used to establish the pre-condition that the City of Cape Town should implement water demand management measures in order to delay the need for further resource development over the next 7 years. The City of Cape Town responded and implemented, with varying degrees of success, measures to reduce their water requirements. The details of the demand management and water conservation strategies adopted by the City of Cape are well documented.

The Berg River Dam development in conjunction with the Western Cape Water Supply System analysis process provided an ideal case study of the need for integrated planning in order to ensure economic and water resource sustainability.

1. Overview of the Breede-Overberg catchment management area

- Available potential water supply augmentation options, water allocation per water use sector, future water requirements of the Breede-Overberg catchment areas and reconciliation of the needs.
- Regulatory mechanisms used to plan and implement regulatory provisions and the implementation of environmental water requirements through these regulatory processes (NWRS, ISP, catchment management strategy, water use validation and verification, water conservation and water demand management, etc.).
- Inter basin transfer between catchment areas.

2. Overview of the Inkomati catchment management area

- Available potential water supply augmentation options, water allocation per water use sector, future water requirements of the Inkomati catchment areas and reconciliation of the needs.
- Regulatory mechanisms used to plan and implement regulatory provisions and the implementation of environmental water requirements through these regulatory processes (NWRS, ISP, catchment management strategy, water use validation and verification, water demand management, etc.).
- International obligations and environmental water requirements.

3. Overview of the Berg River catchment and its relation to water supply to Cape Town and the Western Cape Water Supply System analysis process

- Planning of the Western Cape Water Supply System water supply augmentation options and system analysis processes;
- Potential water reconciliation options and prediction of future water needs and supply options;
- Alternative supply options;
- Water conservation and water demand management in the Cape Town Metropolitan area;
- Construction of the Berg River Dam and the regulatory mechanisms to ensure improved water use efficiency and demand management in Cape Town; and
- Compliance with the Berg River environmental water requirements.

SELF-EVALUATION QUESTIONS

1. Describe the water resource planning cycle in perspective and specific to the case study area that you have selected;
2. Describe the alternative water supply augmentation options and considerations that can reduce the water requirements from the water resources in the case study area;
3. How did, and how should, environmental water requirements influence the planning process and system operations in the selected study area to achieve sustainable water resource utilisation.