PRELIMINARY GUIDELINE FOR THE DETERMINATION OF BUFFER ZONES FOR RIVERS, WETLANDS AND ESTUARIES

Consolidated Report

Report to the
WATER RESEARCH COMMISSION
by
INSTITUTE OF NATURAL RESOURCES

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EXECUTIVE SUMMARY

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

This report highlights the complete process that has been followed in the development of a preliminary guideline for the determination of buffer zones for rivers, wetlands and estuaries.

What are buffer zones?
Definitions of buffer zones are variable, depending on their purpose. Buffer zones have been used in land-use planning to protect natural resources and limit the impact of one land-use on another. This project specifically looks at aquatic buffer zones which are typically designed to act as a barrier between human activities and sensitive water resources thereby protecting them from adverse negative impacts.

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

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

What buffer zones do not do?
Despite the range of functions potentially provided by buffer zones, buffer zones are far from a 'silver bullet' that addresses all water resource related problems. Indeed, buffers can do little to address some impacts such as hydrological changes caused by stream flow reduction activities (i.e. changes in flow brought about by abstractions or upstream impoundments). Buffer zones are also not the appropriate tool for militating against point-source discharges (e.g. sewage outflows), which can be more effectively managed by targeting these areas through specific source-directed controls. Contamination or use of groundwater is also not well addressed by buffer zones and requires complementary approaches such as controlling activities in sensitive groundwater zones.

Conceptual framework – design criteria applied
In developing an approach for buffer zone determination, a number of key decisions were made that informed the development of the method, these include:

- Levels of user expertise;
- Precautionary principle;
- Predictability and administration;
- Data collection and assessment; and
- Buffer widths should be tailored according to risk.

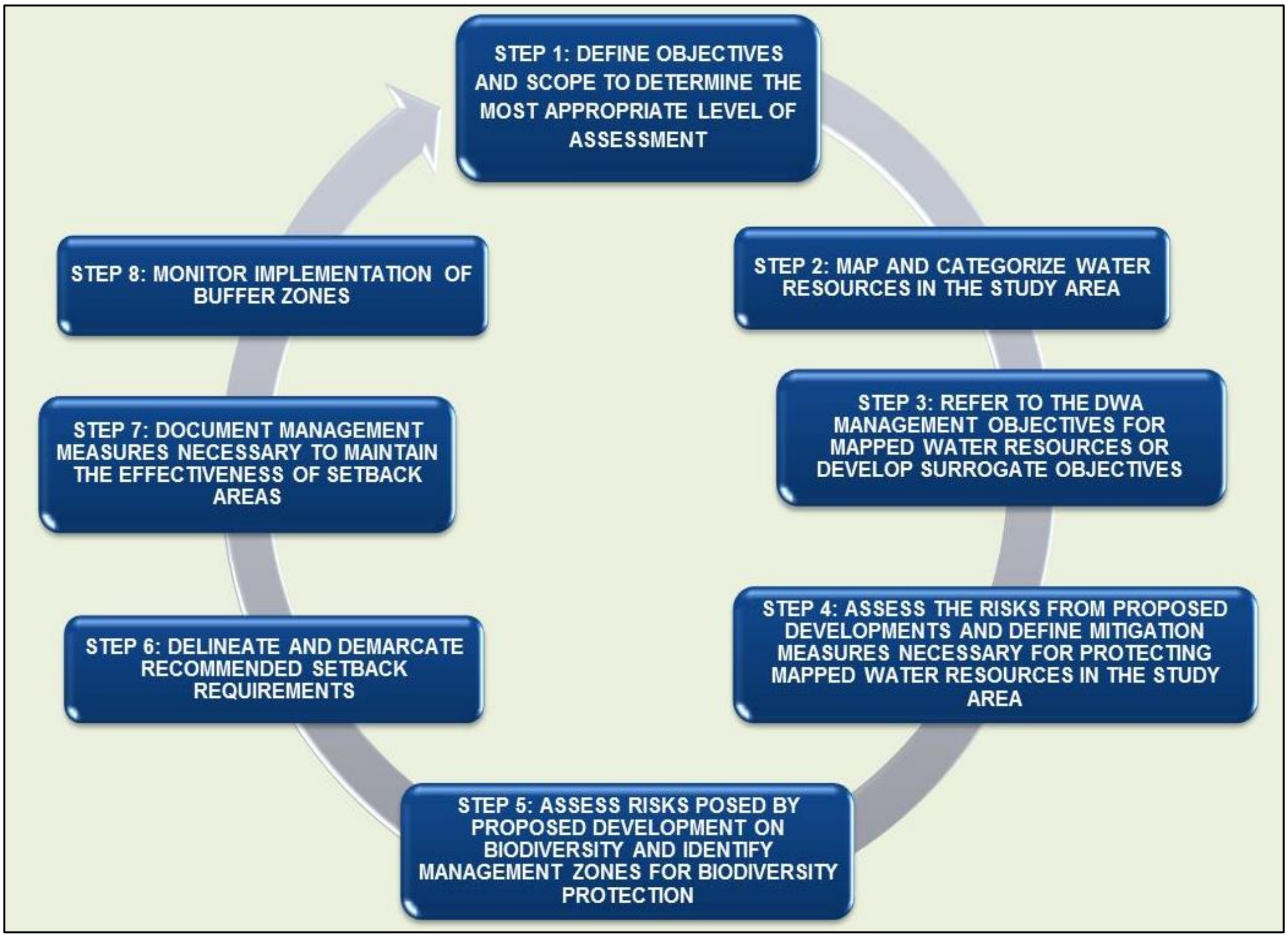
The selection of an appropriate approach to setting buffer zones
Three generic approaches were identified in the literature review, these included: the fixed-width, modified fixed-width, and variable-width approach. The modified fixed-width approach was regarded as most appropriate for the South African context. This was principally due to the need to develop a tool that could be

applied across different levels, while maintaining a level of predictability and consistency between approaches. The method outlined in this document therefore proposes highly conservative buffer widths based on generic relationships for broad-scale assessments but allows these to be modified based on more detailed site-level information. Resultant buffers therefore range from highly conservative, fixed-widths for different land uses at a desktop level to buffers that are modified based on a more thorough understanding of the water resource and specific site characteristics.

The assessment procedure

The assessment procedure is largely the core of the document. An eight step assessment procedure provides the user with a step-by-step approach for determining appropriate buffer zones, or rather setback areas that take into consideration the following:

- The aquatic impact buffer zone;
- Potential core habitats;
- Potential ecological corridors; and
- Relevant additional mitigating measures.



Determining appropriate management measures for aquatic impact buffer zones

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

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

Determining appropriate management measures for biodiversity conservation

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

Additional aspects requiring consideration to ensure effective management of setback areas

There are many aspects that need to be considered to ensure that, once established, setback areas continue to provide their required functions. Overlooking these aspects highlighted below may result in the degradation of setback areas over time:

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

Conclusions and recommendations

The assessment procedure detailed in this report, as well as the management practices that need to be taken into consideration, provide the guidelines for determining and managing appropriate buffer zones. The Buffer Zone Tools developed in conjunction with this report provide the user with the primary tool for determining appropriate buffer zones (included on the accompanying CD). In addition, the extensive supporting documents provided as annexures to the report, either in hardcopy or as electronic copies on the accompanying CD, provide extensive background information.

A second phase to the project is required. This will include providing practitioners with an opportunity to learn how to use the Buffer Zone Tools developed, which will in turn allow for the refinement of the preliminary guideline document and Buffer Zone Tools to produce a scientifically sound and well tested approach to determining buffer zones.

ACKNOWLEDGEMENTS

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- Dr Gordon O’Brien, for his contribution towards testing and developing the method for assessing the sensitivity of rivers and streams.
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ABBREVIATIONS USED IN THIS REPORT

ACRU	Agricultural Catchment Research Unit
AMD	Acid Mine Drainage
AMSL	Above Mean Sea Level
ARD	Acid Rock Drainage
BMP	Best Management Practice
CRS	Climate Risk Score
CSRI	Council for Scientific and Industrial Research
DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category
EI	Economic Importance
EIA	Environmental Impact Assessment
EIS	Ecological Importance and Sensitivity
EKZNW	Ezemvelo Kwa-Zulu-Natal Wildlife
EMC	Event Mean Concentration
EMF	Environmental Management Framework
EMP	Environmental Management Plan
EPA	Estuarine Protected Area
FBZ	Forest Buffer Zone
GBZ	Grassland Buffer Zone
GIS	Geographic Information System
GLV	General wastewater Limit Value
HGM	Hydro-geomorphic
ISO	International Organization for Standardization
KZN	KwaZulu-Natal
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
N	Nitrogen
NBA	National Biodiversity Assessment
NEC	Nested Ecological Categories
NEMA	National Environmental Management Act
NFEPA	National Freshwater Ecosystem Priority Area
NWA	National water Act
P	Phosphorus
PES	Present Ecological State
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RQO	Resource Quality Objective
SANBI	South African Biodiversity Institute
SCS-SA	Soil Conservation Services method for Southern Africa
SFR	Surface Flow Requirement
SI	Social Importance
SLV	Special wastewater Limit Value
TOPS	Threatened or Protected Species
UKZN	University of KwaZulu-Natal

WMA	Water Management Area
WRC	Water Research Commission
WRCS	Water Resource Classification System

1. INTRODUCTION

1.1. Purpose of this report

This report is the thirteenth and final deliverable in the Water Research Commission project K5/2200. It highlights the complete process that has been followed in the development of a preliminary guideline for the determination of buffer zones for rivers, wetlands and estuaries.

It is important to note that two deliverables, which may be of interest, have not been incorporated into this report. These include:

- Deliverable 1: Literature review (Annexure 1); and
- Deliverable 11: Practical testing / field testing report (Annexure 2).

In addition to this report, which provides the concepts, background and approach required for determining appropriate buffer zones, separate tools were developed for determining buffer zones for rivers, wetlands and estuaries. The report needs to be used in conjunction with the tools developed, namely:

- Buffer zone tool for the determination of aquatic impact buffers and additional setback requirements for wetland ecosystems (Macfarlane et al., 2014a);
- Buffer zone tool for the determination of aquatic impact buffers and additional setback requirements for river ecosystems (Macfarlane et al., 2014b); and
- Buffer zone tool for the determination of aquatic impact buffers and additional setback requirements for estuarine (Macfarlane et al., 2014c).

It is envisaged that the buffer tools developed will be the primary products from this project, and that users will use the final report as a guideline document to enhance the application of the tools developed. For this reason, a CD with the Buffer Zone Tools, additional deliverables of interest, the mitigation measures tool, and data that will be helpful for the buffer zone determining process, has been included as an attachment to this guideline document.

1.2. What are buffer zones?

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

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

1.3. Why are buffer zones regarded as important?

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

(i) Maintaining basic aquatic processes;
(ii) Reducing impacts on water resources from upstream activities and adjoining land uses;
(iii) Providing habitat for aquatic and semi-aquatic species;

(iv) Providing habitat for terrestrial species; and
(v) A range of ancillary societal benefits.

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

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

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

PRIMARY ROLE	BUFFER FUNCTIONS
	encourage deposition of pathogens, which soon die when exposed to the elements.
Meeting life-need requirements for aquatic and semi-aquatic species	• **Provision of habitat for aquatic species:** Riparian vegetation along stream lines provides food that supports in stream food chains while branches and trees that fall into the stream also provide vital habitat for certain species of aquatic fauna. • **Provision of habitat for semi-aquatic species:** Many semi-aquatic species rely on terrestrial habitats for the successful recruitment of juveniles and to maintain optimal adult survival rates. • **Screening of adjacent disturbances:** Anthropogenic disturbances to aquatic and semi-aquatic species may be direct, such as human presence and traffic, or indirect, such as through noise and light. These disrupt natural wildlife activities, such as feeding, breeding and sleeping, or may affect habitat quality, adversely affecting their survival. • **Habitat connectivity:** Buffers along water resources provide potentially useful corridors, allowing the connection of breeding, feeding and refuge sites crucial to maintain the viability of populations of semi-aquatic species.
Providing habitat for terrestrial species	• **Provision of habitat for terrestrial species:** In certain situations, buffers established alongside water resources may be critical for the persistence of terrestrial species. This is particularly likely in highly developed landscapes where undeveloped buffers may provide the only remaining terrestrial habitat. • **Habitat connectivity:** Buffers along water resources provide potentially useful corridors, allowing the connection of breeding, feeding and refuge sites crucial to maintain the viability of populations of terrestrial species.
Ancillary societal benefits	• **Reduces flood risk:** Through increased resistance to flow, riparian areas and buffer zones can increase residence time of floodwaters, reducing flow velocities and thereby reducing flood peaks. This can reduce safety risks to people and property in the downstream catchment. • **Enhances visual quality:** Buffer zones can enhance visual interest and screen undesirable views, thereby enhancing visual quality, particularly in urban areas. • **Control noise levels:** Wooded buffer zones can reduce noise from roads and other sources to levels that allow normal outdoor activities to occur. • **Improve air quality:** Vegetation in buffer zones can affect local and regional air quality by reducing temperature and removing air pollutants. • **Provides recreational opportunities:** The availability of open space associated with buffer zones provides opportunities for a range of recreational activities. This is particularly important in urban areas where availability of open space areas is often lacking. • **Economic benefits:** The proximity of residential areas to well-managed buffer zones can lead to increased property values due to perceived aesthetic, recreational and other benefits. Such areas may also provide opportunities for tourism activities and provide a sustainable supply of natural resources for local communities.

1.4. What buffers do not do

Despite the range of functions potentially provided by buffer zones, **buffer zones are far from a ‘silver bullet’ that addresses all water resource related problems**. Indeed, buffers can do little to address some impacts such as hydrological changes caused by stream flow reduction activities or changes in flow brought about by abstractions or upstream impoundments. Buffer zones are also not the appropriate tool for militating against point-source discharges (e.g. sewage outflows), which can be more effectively managed by targeting these areas through specific source-directed controls. Contamination or use of groundwater is also not well addressed by buffer zones and requires complementary approaches such as controlling activities in sensitive groundwater zones. The role that buffers can play must therefore be well understood when applying these guidelines. For an overview of typical threats posed to water resources and the role that buffers and other management measures can play in addressing these concerns, refer to Annexure 3.

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

2. CONCEPTUAL FRAMEWORK FOR DEVELOPING A BUFFER ZONE METHOD

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

2.1. Design criteria used to inform the development of a method and model for buffer determination

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

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

Precautionary principle: Where information is lacking or little information is available to inform the establishment of a buffer zone, a cautious approach is recommended, one that recognizes the potential shortfalls and inaccuracies of the assessment. In situations where adequate information is available however, and where buffer zone widths are informed by a sound understanding of requirements, a less conservative approach should be followed. This is consistent with the precautionary principle set out in the National Environmental Management Act (NEMA), which recommends following a risk-averse, cautious approach that takes into account the limits of current knowledge about the consequences of decisions and actions.

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

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

Buffer widths should be tailored according to risk: This criterion recognizes the importance of using risk as a basis for establishing an appropriate buffer width. Where risk or uncertainty is high, ecologically conservative buffers should be established whereas less conservative buffers are appropriate for low-risk situations. A number of key risk factors have been identified for possible inclusion in the approach. These include:

(i) Risks posed by adjacent land-uses or activities;
(ii) The importance and sensitivity of the water resource;
(iii) The conservation status (risk of extinction) of aquatic and semi-aquatic species;
(iv) Characteristics of the buffer that affects the functionality of the buffer; and
(v) Mitigation measures that may be applied to reduce risks.

2.2. Selection of an appropriate approach for setting buffers

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

- **Fixed-width:** The fixed width approach typically applies a standard buffer width to a particular water resource type. In some instances, a generic width is applied regardless of any characteristics of the water resource. However, this approach is more typically applied to a class of wetland or river type, or a specific land-use type / activity.

- **Modified fixed-width:** In this approach, a matrix of factors is typically used to categorize wetlands and / land-uses with category specific standard buffer widths being applied to the resource. These widths may however be modified based on relevant on-site factors where more detailed information is available.

- **Variable-width:** This approach usually requires the development of a detailed formula and methodology for considering site-specific factors such as wetland type, adjacent land-use, vegetation, soils, wildlife habitats, slope, desired function and other special site-specific characteristics to calculate buffer widths.

While each approach has a number of advantages and disadvantages, the modified fixed-width approach was regarded as most appropriate for the South African context. This was principally due to the need to develop a tool that could be applied across different levels (i.e. desktop and site-based), while maintaining a level of predictability and consistency between approaches. The method outlined in this document therefore proposes highly conservative buffer widths based on generic relationships for broad-scale assessments, but allows these to be modified based on more detailed site-level information. Resultant buffers therefore range from highly conservative, fixed-widths for different land-uses at a desktop level, to buffers that are modified based on a more thorough understanding of the water resource and specific site characteristics.

2.3. Designing an approach to cater for the full range of buffer functions

As previously discussed, buffer zones established around water resources perform a wide range of roles and functions. The importance of each of these roles is likely to be case-dependent, and as such, the approach needs to be flexible to allow buffers to be tailored according to site-specific requirements. It is important to note however that this guideline is not designed to address all these roles and functions, and is focused specifically on protecting water resources and associated biota. The approach adopted as part of this guideline has therefore been developed to ensure that relevant functions are adequately addressed. This includes:

- **Maintaining basic aquatic processes, services and values:** As a minimum, this requires the maintenance of the water resource, including any riparian habitat. Delineation and protection of water resources, as defined in South African legislation, including riparian habitat, is thus regarded as mandatory to ensure no direct impacts to these areas. The method developed is therefore designed to ensure that such areas are identified, mapped and included within any recommended setback area. The need for additional management measures, including potential additional management buffers to safeguard intact riparian habitat, is also addressed.

- **Reducing impacts from adjacent land use activities**: This requires an understanding of specific risks associated with planned land-uses / activities and the degree to which buffer zones can address these impacts. Aquatic impact buffers are therefore only proposed where appropriate, based on an understanding of specific risks and the ability of buffer zones to address potential impacts.

- **Meeting life-need requirements for aquatic and semi-aquatic species:** Although there is an apparent widespread application of buffers for biodiversity protection in the international literature, it is regarded as an overly simplistic approach for biodiversity protection. What is required, however, is an appropriate understanding of specific species habitat and protection requirements to safeguard important species present. This method has therefore been designed to guide the identification of important biodiversity elements and to help ensure that appropriate steps are taken to adequately cater for the protection of important species and habitats. This moves beyond the simple concept of buffer zones and considers aspects such as core area requirements, connectivity and management.

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

- **Reducing impacts from upstream activities**: Whilst buffer zones are not designed to specifically address impacts associated with upstream activities, the establishment of buffer zones (including riparian habitat) will help to ensure that these functions (e.g. stormwater attenuation and water quality enhancement) are retained. Managing catchment-level impacts should however be addressed through catchment management activities.

- **Providing habitat for terrestrial species:** Local protection requirements, including buffer zone establishment, may well be supported further by conservation objectives for terrestrial habitat and species which make use of habitat within delineated buffer zones. This requires an understanding of the conservation value of terrestrial ecosystems and the ecology of any terrestrial species of conservation concern.

- **Ancillary societal benefits:** In many instances, societal benefits can be addressed through design and management of buffer zones. This links to building an understanding of the importance of the resource in more than ecological terms and setting appropriate management objectives. Where societal benefits are particularly important, such as protecting people and property from flood risks, buffer zones may need to be enlarged to cater for these requirements (e.g. by limiting development within flood zones). In other situations, manipulation of species composition and structure may add significantly to societal benefits without compromising desired ecological outcomes.

2.4. Developing an approach in the absence of a formally structured assessment framework

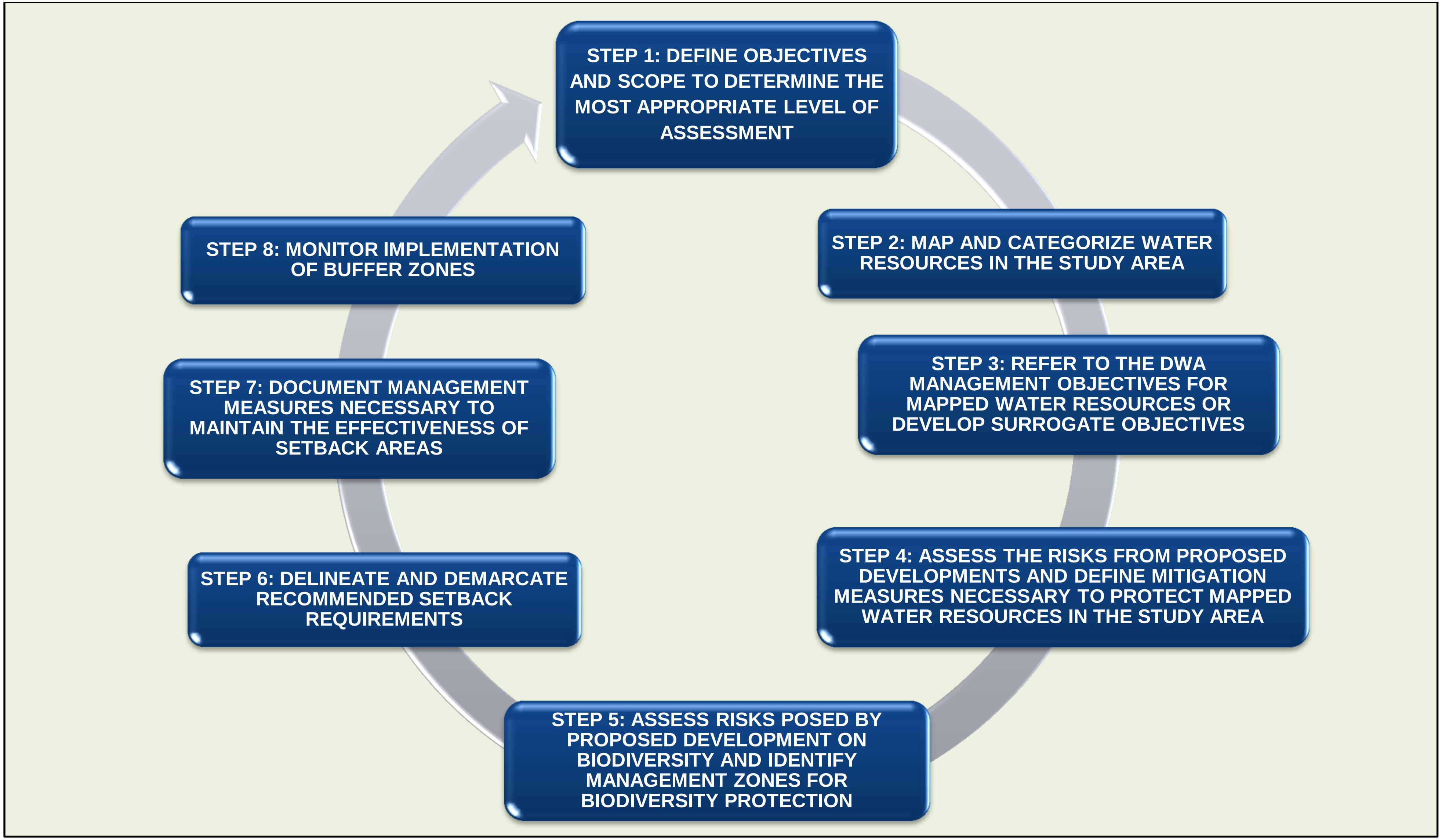
At the time of developing this guideline, there was no formal structured framework to guide water resource protection and assessment processes. The legislation supporting implementation of buffer zones, though present, is also fragmented and provides little guidance as to when and how this buffer zone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

In response to this concern, we have expanded the scope of this guideline in a number of ways. This includes:

- Contextualizing the use and applicability of buffer zones within a broader suite of management measures to protect water resources;
- Including objective setting as a separate step in the model to ensure that decision-making is informed by sound information, with specific outcomes in mind;
- Broadening the risk assessment framework to cater for a broad suite of potential diffuse source impacts, rather than simply focusing on those that buffer zones are known to help address;
- Identifying a suite of additional mitigation measures that can be used to address diffuse source impacts.

3. THE ASSESSMENT PROCEDURE

The assessment procedure has been structured in an 8 Step process as outlined in Figure 1 below. This provides a broad overview of the process, but is expanded with considerable detail in the chapters that follow Explicit instructions are also provided for populating the Excel model used to determine buffer zone requirements.



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

STEP 2: MAP AND CATEGORIZE WATER RESOURCES IN THE STUDY AREA

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

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

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

STEP 6: DELINEATE AND DEMARCATE RECOMMENDED SETBACK REQUIREMENTS

STEP 7: DOCUMENT MANAGEMENT MEASURES NECESSARY TO MAINTAIN THE EFFECTIVENESS OF SETBACK AREAS

STEP 8: MONITOR IMPLEMENTATION OF BUFFER ZONES

Figure 1. Overview of the step-wise assessment process

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

4.1. Define objectives and scope of the assessment

The requirements for assessing potential impacts and establishing buffer zone requirements may be very diverse. It is important therefore that before any assessment is undertaken, the specific objective for undertaking the assessment is clearly understood. Some instances in which the application of this procedure may be necessary and appropriate are outlined below:

- Flagging areas with potential constraints to development as part of an Environmental Management Framework (EMF) assessment;
- Re-zoning an area from residential to industrial land use and identifying property-specific limitations to developments within the rezoned areas;
- Assessing potential impacts and identifying appropriate mitigation measures as part of an Environmental Impact Assessment (EIA) application for a development proposed within 32 m of a wetland;
- Assessing impacts of section 21 (c) or (i) of the National Water Act (NWA Act No. 36 of 1998), i.e. assessing water use activities and identifying realistic and measurable mitigation measures for these impacts;
- Complying with Resource Quality Objectives (RQOs) where establishment of buffer zones have been recommended in line with management objectives for the water resource; and
- Applying best-practice guidelines as part of an environmental certification scheme aimed at minimizing or reducing potential environmental impacts (e.g. ISO 14001).

Although existing legislation makes provision for the application of these guidelines as shown above, no specific regulations have been developed to enforce the use of this tool. It is however envisaged that this guideline will be endorsed as a best-practice guideline by the Department of Water and Sanitation (DWS) and will therefore become entrenched in water resource assessments.

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

4.2. Determine the most appropriate level of assessment

Desktop	Site-based
✓	✓

Given the range of potential users and applications, a tiered approach for buffer zone determination has been developed, which incorporates two levels of assessment:

- **Desktop assessment**: This assessment is designed to characterize risks at a desktop level in order to red-flag land located adjacent to water resources that should potentially be set aside and managed to limit impacts on water resources. Whilst a precautionary approach is taken to calculating buffer requirements at this level, this assessment should not be used as a basis for authorizing development or activities with a potential impact on water resources as it does not cater for biodiversity considerations or other site factors.

- **Site-based assessment**: This assessment is designed for site-based assessments and includes a more detailed evaluation of risks and consideration of site-specific factors that can affect buffer requirements. Such an approach is designed to inform any detailed development planning and provide an appropriate level of information for authorization purposes.

Buffer zone determination may be undertaken at either of these levels and should be informed by (i) the intended purpose of buffer zone determination, (ii) the approach to be followed, (iii) the level of expertise available to undertake the assessment and (iv) the time and cost required to undertake the assessment. Table 2 provides a summary of the different levels of assessment that should be used to inform the selection of an appropriate approach based on the objectives of the assessment and resource constraints.

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

Level of assessment	**Desktop**	**Site-based**
Purpose	Identify areas of potential development constraints associated with water resources at a municipal or catchment scale to inform development planning. **Priority users**: National, Provincial, and Municipal planners, owners, developers	Establish buffer zone requirements to inform detailed development planning at a site level. **Priority users:** Developers, EIA consultants
Approach followed	Buffer zones are determined by accounting for generic risks associated with different land-use sectors. A precautionary approach is followed by calculating buffer requirements based on a ‘worst-case’ scenario. The model also takes basic climatic factors into account.	Buffer zone requirements are based on detailed site information. This includes local climatic conditions, risks associated with the specific land-use activity, the sensitivity of the receiving environment, and local buffer attributes. Specific consideration is also given to the maintenance of biodiversity attributes.
Level of expertise	Suitably qualified assessor.	Specialist aquatic ecologist. May need to supplement with further studies from a biodiversity specialist if important biota are present.
Time and cost	Rapid desktop assessment, with very low cost implications.	Comprehensive site assessment, with moderate cost implications. Costs will increase if a biodiversity assessment is required.

Depending on the particular requirements, the appropriate level of assessment should be chosen. This is then documented in the appropriate Buffer Zone Tool (separate tools have been created for wetlands, rivers and estuaries) which directs users to further data capture requirements. To help guide users through the document, a simple tab has also been included at the start of each step to indicate whether or not the step is relevant for the level of assessment being undertaken. Where not required, the assessor can simply move onto the next step. The same colour scheme is included in the model to help guide the assessor through the process.

Buffer zone tool:

- Select the appropriate Excel tool based on the type of water resource under investigation (wetland, river or estuary)
- Select the appropriate level of assessment from the drop-down list provided.

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

Desktop	Site-based
✓	✓

5.1. Map water resource boundaries

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

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

- **Estuary**: In line with the National Wetland Classification System (SANBI, 2009) and in terms of the recently enacted Integrated Coastal Management Act (Act No. 24 of 2008), an estuary is defined as "***a body of surface water – (a) that is part of a water course that is permanently or periodically open to the sea; (b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the water course is open to the sea; <u>or</u> (c) in respect of which the salinity is measurably higher as a result of the influence of the sea***"[3]. This is in line with the following definitions for the boundaries of an estuary contained in the Resource Directed Measures (RDM) Manual for Estuaries (DWAF, 2008):
  - **Downstream boundary:** The estuary mouth, or where the mouth is closed, the middle of the sand berm between the open water and the sea.
  - **Upstream boundary:** The extent of tidal influence (i.e. the point up to where tidal variation in water levels can still be detected), <u>or</u> the extent of saline intrusion, <u>or</u> the extent of back-flooding during the closed mouth state, whichever is furthest upstream.
  - **Lateral boundaries:** The 5 m Above Mean Sea Level (AMSL) contour along each bank.

  From consultations during the development of a National Wetland Classification System (SANBI, 2009), the above-mentioned definitions are regarded as more appropriate than that contained in the NWA (Act No. 36 of 1998), which is based on the more dated definition, whereby saline intrusion was the sole criterion for determining the upstream boundary of an estuary[4].

- **Rivers and streams**: This type of water resource is described as a channel (river, including the banks) in the National Wetland Classification System (SANBI, 2009). This is defined as ***"an open conduit with clearly defined margins that (i) continuously or periodically contains flowing water, or (ii) forms a connecting link between two water bodies. Dominant water sources include concentrated surface flow from upstream channels and tributaries, diffuse surface***

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

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

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

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

flow or interflow, and/or groundwater flow. Water moves through the system as concentrated flow and usually exits as such but can exit as diffuse surface flow because of a sudden change in gradient. Unidirectional channel-contained horizontal flow characterises the hydrodynamic nature of these units." According to the classification system, channels generally refer to rivers or streams (including those that have been canalised) that are subject to concentrated flow on a continuous basis or periodically during flooding. This definition is consistent with the NWA (Act No. 36 of 1998) which makes reference to (i) a river or spring and (ii) a natural channel in which water flows regularly or intermittently within the definition of a water resource. As a result of the erosive forces associated with concentrated flow, channels characteristically have relatively obvious active channel[5] banks which can be identified and delineated.

- **Wetland**: This means "land which is transitional between a terrestrial and aquatic system where the water table is usually at or near the surface or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil." (NWA (Act No. 36 of 1998)).

It is important to note that 'Riparian habitat' may be associated with either of these systems and is regarded by DWS as part of the water resource and 'regulated area'. **Riparian habitat** is defined in the NWA (Act No. 36 of 1998) as ***"the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas."*** Areas of riparian habitat which are saturated or flooded for prolonged periods would be considered 'wetlands' (in terms of the NWA) and should be mapped as such. Some riparian areas, however, are not 'wetlands' (e.g. where characteristic riparian trees have very deep roots drawing water from many metres below the surface). These areas do however provide a range of important services that maintain basic aquatic processes, services and values requiring protection in their own right. Where present, the boundary of the riparian habitat should therefore also be clearly delineated. Examples of riparian zone habitat associated with two different river systems are indicated in Photos 1 and 2 below.

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[5] According to the National Wetland Classification System (SANBI, 2009), *active channel* is defined as *"a channel that is inundated at sufficiently regular intervals to maintain channel form and keep the channel free of established terrestrial vegetation. These channels are typically filled to capacity during bank full discharge (i.e. during the annual flood, except for intermittent rivers that do not flood annually). [NOTE: Mid-channel bars (associated with braided river systems) and side bars (associated with meandering river systems) are unvegetated, transient features that are considered to be part of the active channel.]".* A useful description and illustration of the differences between the active channel and riparian zone of a river are included in Box 7 of the user manual for the classification system for wetlands and other aquatic ecosystems in South Africa (Ollis et al*.,* 2013).

Photo 1. Narrow riparian zone dominated by grasses and small shrubs along stream line in the KZN Midlands.

Photo 2. Large trees occupying a broader riparian zone along a river in the lowveld of Mpumalanga.

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

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

LEVEL OF ASSESSMENT	BOUNDARY LINE	MINIMUM MAPPING REQUIRED
Estuaries		
Desktop	5 m AMSL line	Use 5 m AMSL line available for 299 estuarine systems along the South African coastline (CSIR. National Estuaries GIS dataset [National estuaries_12_2012] 2012. Available from Biodiversity GIS website (http://bgis.sanbi.org).
Site-based		5 m AMSL line verified and refined based on more detailed topographical information if available.
Rivers		
Desktop	Edge of riparian habitat	Estimate of riparian zone width based on maximum of 1:100 flood line or relevant alluvial vegetation types included in the Vegetation map of South Africa (Mucina & Rutherford, 2006). Where available, aerial photography can be used to more accurately map riparian areas at a desktop level.
Site-based		Site-based delineation of riparian zone based on DWAF delineation manual (DWAF, 2008).
Wetlands		
Desktop	Edge of temporary zone	Wetlands included in the National Freshwater Ecosystems Priority Areas Map which includes the latest wetland classification layer – National Wetlands Map 4 (CSIR. NFEPA Wetlands / National Wetlands Map [NFEPA_wetlands]. Available from Biodiversity GIS website (http://bgis.sanbi.org). Where available, wetlands mapped at a finer catchment scale (c.a. 1:10 000) or at a desktop level from aerial photography should be used.
Site-based		Site-based delineation of wetland boundary based on DWAF delineation manual (DWAF, 2008)

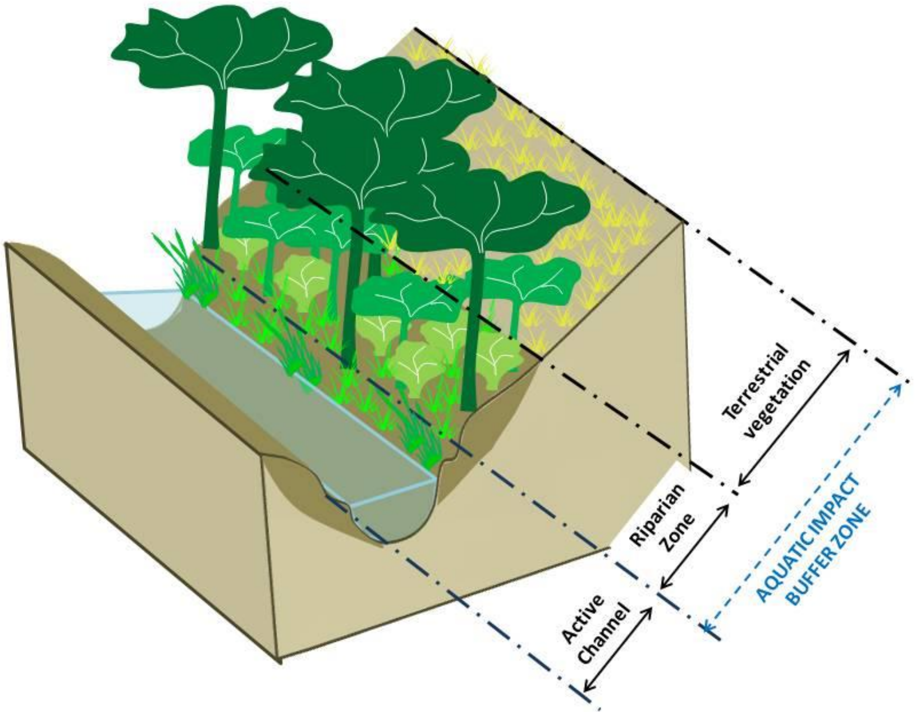
5.2. Map the line from which aquatic impact buffer zones will be delineated

Desktop	Site-based
✓	✓

Whilst the edge of the water resource (described above) must be accurately delineated, the starting point used for delineating aquatic impact buffer zones in this approach varies according to the water resource type under consideration:

- Rivers and streams – the outer edge of the active channel;
- Wetlands – the edge of the temporary zone (water resource boundary); and
- Estuaries – the upper edge of the supratidal zone.

Due to their positioning adjacent to water bodies, buffer zones associated with streams and rivers will typically incorporate riparian habitat. Riparian habitat, as defined by the NWA, includes the physical structure and associated vegetation of the areas associated with a watercourse. These areas are commonly characterised by alluvial soils (deposited by the current river system), and 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. However, the riparian zone is not the only vegetation type that lies in the buffer zone as the zone may also incorporate stream banks and terrestrial habitats depending on the width of the aquatic impact buffer zone applied. A diagram indicating how riparian habitat typically relates to aquatic buffer zones defined in this guideline is provided in Figure 2. There may however be instances in which the riparian zone extends beyond the aquatic impact buffer zone. In this instance, setback requirements include the full extent of the riparian zone and any additional requirements that may apply to managing this area.



Source: Doug Macfarlane

Figure 2. Schematic diagram indicating the boundary of active channel and riparian habitat, and the areas potentially included in an aquatic impact buffer zone.

In the case of estuaries, a zone of terrestrial habitat is typically included within the delineated water resource boundary. To be consistent with other water resource types, the aquatic impact buffer zone should therefore be measured from a comparative point. This is taken as the upper edge of the supratidal zone, defined as the area that is periodically inundated by tidal or flood waters and within which the sub-surface water is saline and is generally between 2.0 and 3.5 m AMSL (SANBI, 2009).

The starting line from which the aquatic impact buffer zone is determined must be delineated through an appropriate approach, depending on the level of assessment being undertaken (Table 4).

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

LEVEL OF ASSESSMENT	BOUNDARY LINE	MINIMUM MAPPING REQUIRED
Estuaries		
Desktop	Upper edge of the supratidal zone	Use the broader boundary of either (i) the open water boundary area available for 299 estuarine systems along the South African coastline (CSIR, 2012. National Estuaries GIS dataset. Available at: http://bgis.sanbi.org.) or (ii) SA Vegetation Map (water bodies and estuarine vegetation).
Site-based		Site-based delineation using GPS or delineation from 1:10 000 orthophotos or other available imagery.
Rivers		
Desktop	Edge of active channel	Use river lines and areas of open water areas obtained from 1:50 000 topo-cadastral maps.
Site-based		Site-based delineation of active channel banks.
Wetlands		
Desktop	Edge of temporary zone	Wetlands included in the National Freshwater Ecosystems Priority Areas Map which includes the latest wetland classification layer – National Wetlands Map 4 (CSIR.

LEVEL OF ASSESSMENT	BOUNDARY LINE	MINIMUM MAPPING REQUIRED
		NFEPA Wetlands / National Wetlands Map [NFEPA_wetlands]. Available from Biodiversity GIS website (http://bgis.sanbi.org). Where available, wetlands mapped at a finer catchment scale (c.a. 1:10 000) or at a desktop level from aerial photography should be used.
Site-based		Site-based delineation of wetland boundary based on DWAF delineation manual (DWAF, 2008)

Note: It is important that these buffer zone guidelines do not apply to ephemeral drainage features that lack active channel characteristics. As such, it is essential to differentiate between a stream (albeit ephemeral) with a clear 'active channel' and ephemeral drainage features that lack such characteristics.

This differentiation should be based on the classification of river channels outlined in the DWAF delineation guideline for wetlands and riparian areas (DWAF, 2005). The channel network is divided into three types of channels, which are referred to as A Section, B Section or C Section channels as shown in Figure 3. The essential difference between the A, B and C Sections is their position relative to the zone of saturation in the riparian area. Figure 3 shows two levels of the water table; the one marked "wet" depicts the highest level that the water table would reach in a wet period when recharge of the zone of saturation has taken place, while the one marked "dry" depicts the level of the water table at its lowest after a dry period. The zone of saturation must be in contact with the channel network for base flow to take place at any point in the channel and the classification separates the channel sections that do not have base flow (A Sections) from those that sometimes have base flow (B Sections) and those that always have base flow (C Sections).

A Sections are regarded as the least sensitive from a water yield and contaminant risk perspective as they typically only carry water after storm events. As such, these buffer zone guidelines do not apply to A Sections of rivers. It is nonetheless appropriate to take practical measures to limit the risk of diffuse source pollutants entering such sections. This could include the maintenance of a reduced vegetated buffer, based on expert opinion, around such features.

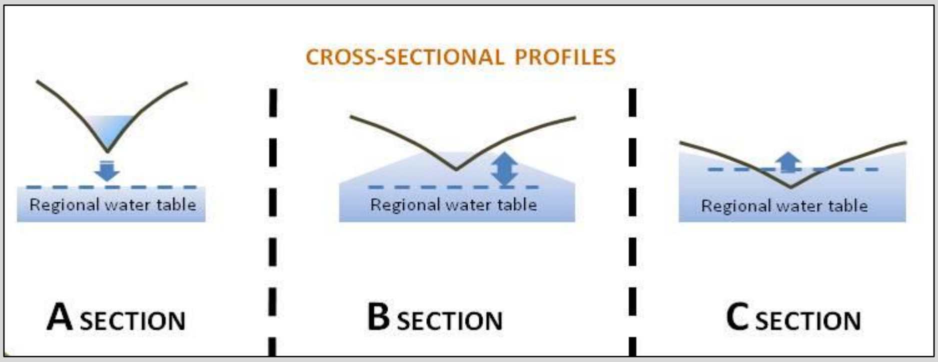


Figure 3. Classification of river channels (Adapted from DWAF, 2005)

5.3. Identify water resource type

Desktop	Site-based
✓	✓

Once water resources have been mapped, they should be fully identified in line with the level of assessment being undertaken. Hydro-geomorphological classification schemes exist to enable the full description and identification of wetlands, estuaries and river types.

For the purposes of this assessment, the refined National Wetland Classification System for South Africa is recommended (SANBI, 2009; Ollis et al*.*, 2013). Classification requirements for each level of assessment are as follows:

- **Desktop assessment:** Classification of each water resource to Level 3 (Sub-system / Landscape Unit).
- **Site-based assessment**: Classification of each water resource to Level 4 (Hydrogeomorphic unit).

A breakdown of the classification structure for each water resource type is provided in Tables 5 to 7 below. For further details on the definitions of water resource types and for guidance in applying the classification system, users are encouraged to obtain, from the South African National Biodiversity Institute (SANBI), a copy of the classification document and associated user manuals.

Table 5. Proposed classification system for estuaries (SANBI, 2009)

LEVEL 2: REGIONAL SETTING	**LEVEL 3: SUBSYSTEM**	**LEVEL 4: HYDROGEOMORPHIC UNIT**
BIOGEOGRAPHIC ZONES	***PERIODICITY OF CONNECTION***	***LANDFORM AND HYDRODYNAMICS***
Cool-temperate Zone **Warm-temperate Zone** **Subtropical Zone**	Permanently Open	Estuarine Bay
		Estuarine Lake
		Open Estuary
		River Mouth
	Temporarily Open/Closed	Estuarine Lake
		Closed Estuary
		River Mouth

Table 6. Proposed classification system for Rivers (adapted from SANBI, 2009 & Ollis et al., 2013)

LEVEL 3: HGM TYPE	**LEVEL 4: HYDROGEOMORPHIC (HGM) UNIT**
HGM TYPE	***LONGITUDINAL ZONATION / LANDFORM***
A	**B**
River	Mountain headwater stream
	Mountain stream
	Transitional
	Upper foothill
	Lower foothill
	Lowland river
	Rejuvenated bedrock fall
	Rejuvenated foothill
	Upland floodplain

Table 7. Proposed classification system for inland wetlands (adapted from SANBI, 2009 & Ollis et al., 2013)

LEVEL 3: LANDSCAPE UNIT	**LEVEL 4: HYDROGEOMORPHIC (HGM) UNIT**		
LANDSCAPE SETTING	***HGM TYPE***	***LONGITUDINAL ZONATION / LANDFORM***	***DRAINAGE – OUTFLOW***
	A	**B**	**C**
SLOPE	Seep	[not applicable]	With channelled outflow
			Without channelled outflow
	Depression	[not applicable]	Exorheic
			Endorheic
			Dammed

LEVEL 3: LANDSCAPE UNIT	**LEVEL 4: HYDROGEOMORPHIC (HGM) UNIT**		
LANDSCAPE SETTING	***HGM TYPE***	***LONGITUDINAL ZONATION / LANDFORM***	***DRAINAGE – OUTFLOW***
	A	**B**	**C**
VALLEY FLOOR	Channelled valley-bottom wetland	Valley-bottom depression	[not applicable]
		Valley-bottom flat	[not applicable]
	Unchannelled valley-bottom wetland	Valley-bottom depression	[not applicable]
		Valley-bottom flat	[not applicable]
	Floodplain	Floodplain depression	[not applicable]
		Floodplain flat	[not applicable]
	Depression	[not applicable]	Exorheic
			Endorheic
			Dammed
	Valley head seep	[not applicable]	[not applicable]
PLAIN	Floodplain wetland	Floodplain depression	[not applicable]
		Floodplain flat	[not applicable]
	Unchannelled valley-bottom wetland	Valley-bottom depression	[not applicable]
		Valley-bottom flat	[not applicable]
	Depression	[not applicable]	Exorheic
			Endorheic
	Wetland flat	[not applicable]	[not applicable]
BENCH (HILLTOP / SADDLE /	Depression	[not applicable]	
SHELF)			Exorheic
			Endorheic
	Wetland flat	[not applicable]	[not applicable]

Buffer zone tool:

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

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

Understanding the rationale and objective for resource protection is a key step in informing protection requirements. It effectively provides the vision for water resource protection and therefore sets the bar for water resource protection and rehabilitation This step is routinely carried out as part of the Resource Quality Objectives (RQO) approach aligned to the Water Resource Classification of the resource, which is the responsibility of DWS.

Where neither the RQOs nor the reserve have been undertaken, an investigation may be required by the assessor to help set management objectives for the water resources under consideration. These management objectives will not have the same validity as the DWS RQOs because the process in this determination is less inclusive of stakeholders.

Management objectives can also be informed by South Africa's National Biodiversity Assessment 2011 (Driver et al., 2011). The National Biodiversity Assessment (NBA) is central to fulfilling SANBI's mandate in terms of the National Environmental Management: Biodiversity Act (Act 10 of 2004) to monitor and report regularly on the state of biodiversity in South Africa. The NBA provides an assessment of the current state of health and protection for all types of ecosystems in South Africa.

The national-level biodiversity plan for South Africa's estuaries can be used to set management objectives. This plan prioritises estuaries and establishes which should be assigned Estuarine Protected Area (EPA) status (Turpie et al., 2012). Annexure 4 lists the national and regional priority estuaries, provides recommendations regarding the extent of protection required for each, the recommended extent of the estuary perimeter that should be free from development to an appropriate setback line of at least 500 m, and a provisional estimate of the Recommended Ecological Category (REC), or recommended future health class determining the limitations of future water use, as required under the NWA.

The level of reserve determination or classification required for a particular site is determined by DWS based on a number of criteria, including:

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

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

Once the appropriate level of assessment has been defined, it will guide the level of data collection required in order to set the management objective for the water resource under consideration. In the absence of classification, this requires an assessment of Present Ecological State (PES), Ecological Importance and Sensitivity (EIS) and Social Importance (SI). To do this, the recommendation is to follow a process similar to the current accepted Reserve process to define surrogate management objectives to inform the need for mitigation measures, including aquatic buffer zones.

It is worth noting, however, that where impacts are likely to be low, it may be appropriate to simply set a management objective to "Maintain" the status quo. This would ensure that existing impacts are managed to a certain level without forcing applicants to undertake extensive surveys to establish whether or not improvement in water resource quality is required. This would also move away from an approach in which the environment may be given precedence – by setting a management objective to "Improve" without giving any consideration to the impacts that such a decision would have on current users of the water resource.

6.1. Determine the Present Ecological State (PES) and anticipated trajectory of water resource change

Desktop	Site-based
	✓

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

- Drivers (physico-chemical, geomorphology, hydrology) which provide a particular habitat template; and
- Biological responses (e.g. fish, riparian vegetation, aquatic invertebrates, and diatoms).

Ecological categories that can be defined for each of these components range from A to F – A being the unmodified state and F being critically modified (Table 8). The scale represents a continuum as illustrated below – the boundaries are notional (Figure 4).

Table 8. Generic ecological categories for Ecostatus components (modified from Kleynhans, 1996; Kleynhans, 1999)

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

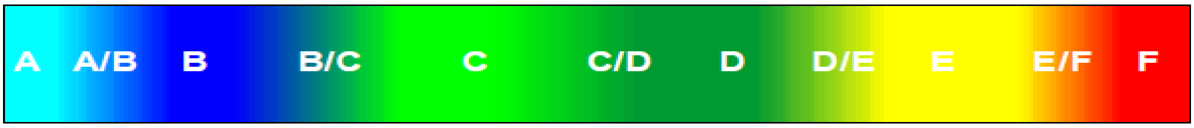


Figure 4. Illustration of the distribution of Ecological Categories (EC) on a continuum

The so-called Ecostatus (integrated state) is regarded as the totality of the features and characteristics of a water resource that affect its ability to support natural fauna and flora (Table 9). The ability relates to the capacity of the system to provide a variety of goods and services. The components selected to determine the Ecostatus are dependent on the water resource type and the level of reserve required.

Table 9. Illustration of the summary of an EcoStatus assessment for a river system.

DRIVER COMPONENT	COMPONENT EC
Hydrology	E
Geomorphology	E
Water Quality	B/C
RESPONSE COMPONENTS	**COMPONENT EC**
Fish	C
Aquatic Invertebrates	D
Instream	C/D
Riparian Vegetation	D
ECOSTATUS	D

Desktop information of PES is available at various scales for different water resources across the country and may be used to inform a desktop assessment. A range of tools have been developed to determine the present state of different water resources and associated components at a site or reach level and should be applied as directed for the rapid or detailed approach. Where a PES determination is required, guidance from DWS should be obtained regarding the level of detail required to assess the PES. Relevant tools must then be applied to assess PES and the associated EcoStatus.

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

A desktop assessment of PES is available for all estuaries from the NBA (van Niekerk and Turpie, 2011). This status may need to be checked for site-based buffer assessment studies. If more recent ecological reserve studies than that of van Niekerk and Turpie (2011) exist, it should be examined to provide a higher confidence of the PES. There are a number of ongoing Water Management Area (WMA) classification studies which will also provide updates on PES for estuaries.

6.2. Determine the importance and sensitivity of the water resources

Desktop	Site-based
	✓

Obtaining an understanding of the importance and sensitivity of the water resource, in ecological, social and economic terms, helps to highlight functions that need to be maintained or enhanced. Such information should be used to guide or influence the decision on the level of protection required, which in turn determines the appropriate management objective. Where importance is regarded as high, this may provide an appropriate motivation to improve management of the water resource, while simply maintaining the status quo may be acceptable where importance is moderate to low. In order to determine the overall importance and sensitivity of a water resource, the ecological, social and economic importance should be considered. Guidance as to how this assessment should be undertaken is provided below.

6.2.1. Assessing ecological importance and sensitivity

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

In the determination of EIS, the following ecological aspects are typically considered by an ecological specialist as the basis for the estimation of ecological importance and sensitivity:

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

As with PES, desktop EIS scores are available for some resources and may be used to obtain an indication of ecological importance in some instances (e.g. desktop assessments). In most cases however, it is anticipated that site-specific information will need to be collected to inform an assessment of the importance of the particular water resource under consideration. DWS have developed a number of tools to assist in this process and should be selected according to the level of assessment required and the type of water resource being assessed. Table 10 provides a breakdown of the EIS categories typically applied.

Table 10. Generic EIS categories

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

An importance rating / index for all of South Africa's estuaries is available from Turpie and Clark (2007). This represents the importance of an estuary for the maintenance of biological and ecological diversity and functioning on a national scale. Importance of the estuary together with the PES is used to set the REC. The Estuary Importance Score takes size, the rarity of the estuary type within its biographical zone, habitat and biodiversity of the estuary into account. Biodiversity importance is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds. All scores are presented on a scale of 0 (totally unimportant) to 100 (critically important) (Annexure 5).

6.2.2. Assessing social importance

Social importance can be assessed, by a social specialist, within a similar framework as ecological importance. Social Importance reflects the dependency of people on a healthy functional water resource and how people value the resource. It considers the cultural and tourism potential of the water resource.

Aspects included in the assessment of economic and social / cultural importance of the water resource are typically:

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

Guidance for undertaking this assessment can be obtained from DWS, who are responsible for developing appropriate tools for different water resources. Although some element of subjectivity is inevitable in assessments such as these, the results are intended to be as objective as possible and a reflection of the relative importance. They are not intended to be subject to complex statistical analysis, nor to measure social values with precision, but to capture a general feeling of the importance of different aspects of a water resource.

6.2.3. Assessing economic importance

In some circumstances, it may be appropriate to assess the economic importance of the water resource. The economic value of a water resource is typically assessed in terms of the net value generated by consumptive and non-consumptive use of the resource. Typical indicators include the number and value of jobs generated by the use of the water, or the amount of revenue generated.

Water resources also provide other services which should be included in an economic resource valuation where possible. These include the services and benefits provided by aquatic ecosystems such as:

- Transport and / or purification of biodegradable wastes;
- Recreation and aesthetic opportunities;
- Food production;
- Flood attenuation and regulation; and
- Water-based transport.

Several tools to quantify the value of ecosystem services and benefits have been developed and these should be used when assessing economic importance. Guidance for undertaking this assessment should also be obtained from DWS, based on the level of detail required to inform the assessment.

6.3. Determine the management objectives for water resources

Desktop	Site-based
	✓

The process required for determining appropriate management objectives is dependent on whether or not the Water Resource Classification System (WRCS) has been applied and consequently if RQOs have been determined. Guidance for setting appropriate management objectives with and without classification is described below.

6.3.1. With classification

Where the WRCS has been undertaken, and especially where RQOs have been set, then both ecological and user requirements have been considered and a management class and associated Nested Ecological Categories (NECs) have been agreed based on due consideration of relevant management implications. In this case, the management objective is determined simply by comparing the PES with the gazetted NEC for the water resource being assessed using Table 11 below.

Table 11. Determining the management objective where the WRCS has been applied

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

A description of possible management objectives is briefly described:

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

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

6.3.2. Without classification

In the case of a desktop assessment, where information is not available and has not been collected, the default objective should be set to "Maintain" the water resource in its present state.

For site-based assessments, a REC and associated management objective for the water resource is informed by an understanding of PES, EIS, SI and Economic Importance (EI) where available. Trajectory of change should be considered here in selecting a PES that is attainable rather than necessarily using the current PES, which may be subject to rapid change in a high threat environment or to improvement through planned rehabilitation interventions. The default table used to inform this process is detailed in Table 12 below but may be further informed through a process of formal consultation and participation where a comprehensive determination is required.

Table 12. Determining the management objective based on PES and importance of the water resource.

		IMPORTANCE			
		Very high	**High**	**Moderate**	**Low**
ATTAINABLE PES	**A**	A Maintain	A Maintain	A Maintain	A Maintain
	B	A Improve	A/B Improve	B Maintain	B Maintain
	C	B Improve	B/C Improve	C Maintain	C Maintain
	D	C Improve	C/D Improve	D Maintain	D Maintain
	<D	D Improve	D Improve	D Improve	D Improve

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

While this framework is useful in deciding on broad management objectives, it is very simplistic and should ideally be adjusted based on an understanding of the rationale for water resource protection. This encourages a move away from decision making dictated purely by reference conditions and opens the door for creative thinking and objective-driven decision making. This thinking is in line with recent ideas of Dufour and Piegay (2009), described in the text box below. The stated objective should therefore be appropriately justified and used to inform how management and mitigation measures are selected and described. In some cases, this may develop objectives that result in controlled degradation but help to secure key values and services.

Rethinking restoration objectives (Dufour and Piegay, 2009)

A review of river restoration strategies argues that the **aim of returning streams to a reference state should be replaced by an objective-based approach** where river **repair or improvement is valued in terms of the provision of ecosystem goods and services, and where objectives are defined by reference to a broad array of factors, including conservation, aesthetics, resource extraction, water quality, heritage protection and flood management.** The authors suggest that a major challenge for future river restoration will be evaluating 'naturalness' and showing how it is profitable to human society.

Buffer zone tool:

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

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

As previously mentioned, it is important to note that this step has been expanded to include a wide spectrum of risks posed by diffuse lateral surface inputs, in attempt to ensure that a wide range of risks are evaluated and appropriately considered as part of a development application. A range of potential impacts not well addressed by the establishment of buffer zones, but with potentially significant impacts on water resources, have therefore been included in this assessment.

It is important to note, however, that this assessment has been developed as a flagging tool and has not been developed to replace comprehensive risk assessments or to assess the significance of potential impacts to water resources. This is specifically relevant to mining operations where risks are often substantial and are frequently linked with groundwater impacts not addressed in this guideline. Therefore the risk assessment included in the buffer zone model specifically excludes risks associated with point-source discharges and groundwater use and contamination.

7.1. Undertake a risk assessment to assess the potential impacts of planned activities on water resources

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

Where risk is high, a more conservative approach (e.g. larger buffer zone) is recommended, whereas a less conservative approach (e.g. narrower buffer zone) is regarded as appropriate where risks are low. In this assessment, risk is based on two criteria, namely (i) the threat or potential impact of the activity on the resource, and (ii) the sensitivity of the water resource that would be affected by the proposed development / activity. These are integrated into a risk score which is used to inform the level of mitigation required.

It is also worth noting that the risk assessment considers both construction and operational phases. This is important in that some risks (e.g. sedimentation) may be very high during the construction phase but decline considerably in the operational phase, while other risks (e.g. toxic contamination) may be much higher during the operational phase. Some mitigation measures may therefore only be necessary for a specific phase of the project and can be removed once risk levels decline.

7.2. Evaluate the threats posed by land use / activities on water resources

Desktop	Site-based
✓	✓

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

Generic threat tables have been developed for this assessment for both construction and operational phases across a wide range of sectors and subsectors ranging from agriculture to industry and mining activities (Table 12). Wherever possible, activities have been grouped into uniform classes based on the primary threat type identified (e.g. mining activities have been grouped according to the risk of toxic contaminants (Mining Hazard Classes – DWAF (2007)). For a full description of sub-sectors, please see Annexure 6.

Table 13. List of sectors and sub-sector land-use classes / activities

	SECTOR								
	Agriculture	**Industry**	**Mixed-use/ Commercial / Retail / Business**	**Civic and Social**	**Residential**	**Open space**	**Transportation**	**Service infrastructure**	**Mining**
SUB-SECTOR LAND USE CLASSES / ACTIVITIES	Forestry/timber	High-risk Chemical industries	Core Mixed-use	Government and municipal	Residential Low impact / Residential only	Parks and gardens	Paved roads	Above-ground communication/power (electricity) infrastructure	Prospecting (all materials)
	Nurseries and tunnel farming operations	Chemical storage facilities	Medium Impact Mixed-use	Place of worship	Residential Medium Impact	Sports fields	Unpaved roads	Below-ground communication/power (electricity) infrastructure	High-risk mining operations
	Dryland commercial cropland (Annual)	Drum/container reconditioning	Low Impact Mixed-use	Education	High density urban	Golf courses – fairways	Paved trails	Hazardous waste disposal facility	Moderate-risk mining operations
	Dryland commercial cropland (Longer rotation)	Paper, pulp or pulp products industries	Multi-Purpose Retail and Office	Cemetery	Resort	Golf courses – tee boxes and putting greens	Unpaved tracks and trails	General solid waste disposal facility	Low-risk mining operations
	Irrigated commercial cropland	Petroleum works	Petrol station / Fuel depot	Health and Welfare	Hotel	Maintained lawns and gardens	Parking lots	Sewage treatment works	Plant and plant waste from mining operations – high risk activities
	Subsistence cultivation	Livestock processing operations	Maintenance and repair facilities		Informal settlements		Airport – runways and taxiways	Sludge dams associated with concentrated livestock operations	Plant and plant waste from mining operations – moderate risk activities
	Extensive livestock grazing operations	Medium-risk Chemical industries	Offices		Residential High Impact		Railway	Pipelines for transportation of hazardous substances	Plant and plant waste from mining operations – low risk activities
	Intensive livestock grazing operations	Ceramic works						Pipelines for the transportation of waste water	Moderate-risk quarrying operations
	Concentrated livestock operations	Electricity generation works							Low-risk quarrying operations
	Aquaculture or marine culture	Timber milling or processing works							Exploratory drilling
		Dredging works							
		Cement / concrete works							
		Breweries/distilleries							
		Industries processing livestock derived products							
		Composting facilities							

Threats posed by lateral (diffuse) surface inputs were qualitatively assessed on the level of threat posed by land-use activities associated with each sub-sector on the following aspects:

- Water Quantity – volumes of flow
- Water Quantity – patterns of flow
- Sedimentation and turbidity
- Water Quality – increased inputs of nutrients
- Water Quality – increased toxic contaminants
- Water Quality – changes in pH
- Water Quality – concentration of salts (salinization)
- Water Quality – temperature
- Water Quality – pathogens (i.e. disease-causing organisms)

This threat assessment was informed as far as possible by an understanding of current legal obligations for managing impacts to water resources. Although diffuse source impacts are not specifically regulated at present, wastewater discharges are currently regulated through a licensing process. A General Authorization[6] has been issued for activities disposing <2000 ℓ/day provided it complies with the wastewater limit values[7] defined in the General Authorization. The authorization defines both general wastewater limit values (GLVs), set for non-listed water resources, and stricter special wastewater limit values (SLVs) set for listed water resources requiring more careful management. Given that diffuse-source impacts can have a similar effect to wastewater; these limits were used to inform the threat ratings applied in the threat assessment.

This concept is further illustrated in Figure 5 below. The diagram shows a container filled with diffuse source discharges of varying pollutant loadings which reflects the level of threat posed by a development. Where discharge concentrations are likely to be below SLV levels, threat is regarded as very low (as represented by a small volume in the cup), while a discharge up to the GLV limit is considered low, in line with current general authorizations. Additional threat classes are defined based on the anticipated exceedance of GLV standards in diffuse runoff from a development in the absence of mitigation as reflected by increasing volumes of water in the container.

The threat rating applicable is provided in Table 14 below, and includes reference to GLVs and SLVs. For more details of the specific limits set for evaluating different threat types, see Annexure 7.

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

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

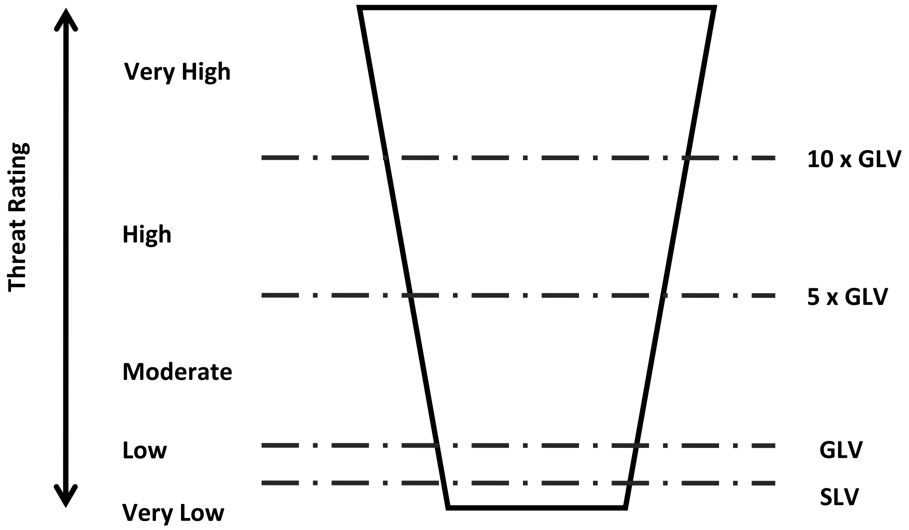

Figure 5. Diagram illustrating how threat classes have been related to SLV and GLV limits.

Table 14. Ratings used to evaluate the level of threat posed by diffuse surface runoff from various land-uses / activities located adjacent to water resources.

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

The threat assessment was initially carried out through an expert-workshop, mostly comprising of DWS personnel. In the case of potential water-quality impacts, land-use threats were evaluated based primarily on the anticipated pollutant loading from surface runoff although the effects of land-uses on runoff characteristics (e.g. increased surface runoff in land-uses characterised by hardened surfaces or bare ground) was also considered. This process was also informed by quantitative information pertaining to the Event Mean Concentration (EMC)[8] values obtained from research undertaken in the United States (EPA, 2001; and Lin,

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[8] “Event Mean Concentration “is defined as the mean concentration of pollutants in the runoff from a storm event. EMCs are typically used for calculating runoff pollutant loads for watersheds based on the occurrence of landuse types present.

2004). EMCs are reported as a mass of pollutant per unit volume of water (usually mg/ℓ), which allowed these values to be compared against wastewater limit values. A summary of the average EMC values from a range of studies is provided in Annexure 8, with further details from specific studies included in Annexure 9. It is important to note that a conservative approach was taken when undertaking this assessment by considering the realistic 'worst-case' scenario but given standard accepted management measures where appropriate[9]. For example, for extensive livestock grazing the ratings applied were by considering potential risks associated with an extensive grazed system having stocking rates up to (but not exceeding) maximum carrying capacity.

Preliminary threat ratings were then reviewed and refined by the specialist team during the development and further refinement of the buffer zone model. The outcome is a rating of threats of each sector and sub-sector for the range of potential threats identified (Annexure 10). These ratings form a key driver for establishing the risk posed by land-uses / activities on water resources as part of this assessment[10]. When using the Buffer Zone Tools, the assessor simply selects the sector and appropriate sub-sector relevant to the assessment, and desktop threat ratings are auto-populated for each threat type. The threat assessment is used in different ways, depending on the level of assessment being undertaken:

- **Desktop assessment:** Where the specific sub-sector is unknown, threat ratings are based on the worst-case threat ratings for all sub-sector activities. If the sub-sector is known, sub-sector threat ratings are used to provide a preliminary indication of the level of threat posed by land-uses / activities on water resources.
- **Site-based assessment**: Desktop sub-sector-specific threat ratings are used to guide the selection of a specialist threat rating based on available knowledge of the nature of the planned development. While desktop threat ratings provide an indication of the level of threat posed by different land-uses / activities, there is likely to be some level of variability between activities occurring within a sub-sector. **It is therefore important that these threat ratings be reviewed based on specialist input for the site-based assessment and that a justification for any changes is also documented.** When reviewing the threat ratings, the following aspects should be considered:
  - **Development-specific information:** Specific knowledge about the planned development may provide a strong basis for refining desktop threat ratings.
  - **Intensity of development:** While desktop scores have been rated based on a realistic worst-case scenario, there may be justification to reduce threat scores in instances where development density / intensity is considerably lower than that typical for the sub-sector.
  - **Site attributes:** There may be situations where site attributes such as slope steepness, slope length, soil depth and soil erodibility exacerbate potential impacts at a site level.

It is important to emphasize that aquatic impact buffer zones are designed to ensure that threats are internalized and appropriately mitigated by each and every development, irrespective of scale. It is only by adopting this precautionary approach, that cumulative impacts can be managed over the long-term. The threat of a small industrial site or residential development being planned adjacent to a water resource is therefore treated the same as if this land-use was planned along the entire perimeter of the water resource. As such, threat ratings should not be reduced simply on the basis of the scale of the planned development relative to

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[9] When assessing threat at a desktop level, the following assumptions should be made:

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

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

the water resource under investigation. This would however have an impact on the significance ratings calculated as part of any impact assessment process.

Refined threat ratings should be based on standard accepted management and operational practices. A range of additional management and mitigation measures can also be used to motivate for a reduction in the levels of threat posed by different land-uses. These are catered for later in the assessment through the identification and implementation of additional site-specific mitigation measures (See Section 7.10).

As previously indicated, it is also important to note that this threat assessment is restricted to an assessment of threats posed by pollutants in diffuse surface runoff. An assessment of other key threats, including (i) threats to groundwater and (ii) threats from point-source discharges, was not considered. These aspects also need to be considered by the aquatic specialist when defining mitigation measures to reduce potential impacts to water resources.

Buffer zone tool:

- Depending on the level of assessment, select the “Sector” and/or “Sub-sector” for the activity being investigated.
- For the site-based assessment, review desktop threat ratings and capture specialist threat ratings based on best-available information.
- Provide a justification for any deviations to desktop threat ratings.

7.3. Integrate climatic factors into the threat assessment

Desktop	Site-based
✓	✓

While potential impacts to water resources are driven primarily by the threats associated with different land-uses / activities, surface runoff and associated contamination risk is also influenced by climatic factors. Indeed, in areas of higher mean annual precipitation (MAP) (Figure 6) and characterized by more intense rainfall events (Figure 7), the frequency and intensity of surface overland flow will be higher than in climates characterized by low rainfall and less intensive rainfall events. This was clearly demonstrated in a hydrological simulation study undertaken for this project (Annexure 11).

In order to account for this variability, the threat score used to inform buffer zone determination is adjusted to account for these basic climatic factors. This is accounted for in the buffer zone model which calculates a ‘Climate Risk Score’ (CRS)[11] that reflects the variability in peak discharges anticipated as a result of changes in the climatic criteria relative to “Reference” conditions which were taken as a MAP range of 1000-2000 mm and a moderately high rainfall intensity zone (Zone 3). The CRS is calculated based on the modifiers for MAP and the rainfall intensity zone in which the land-use / activity is proposed (Table 15).

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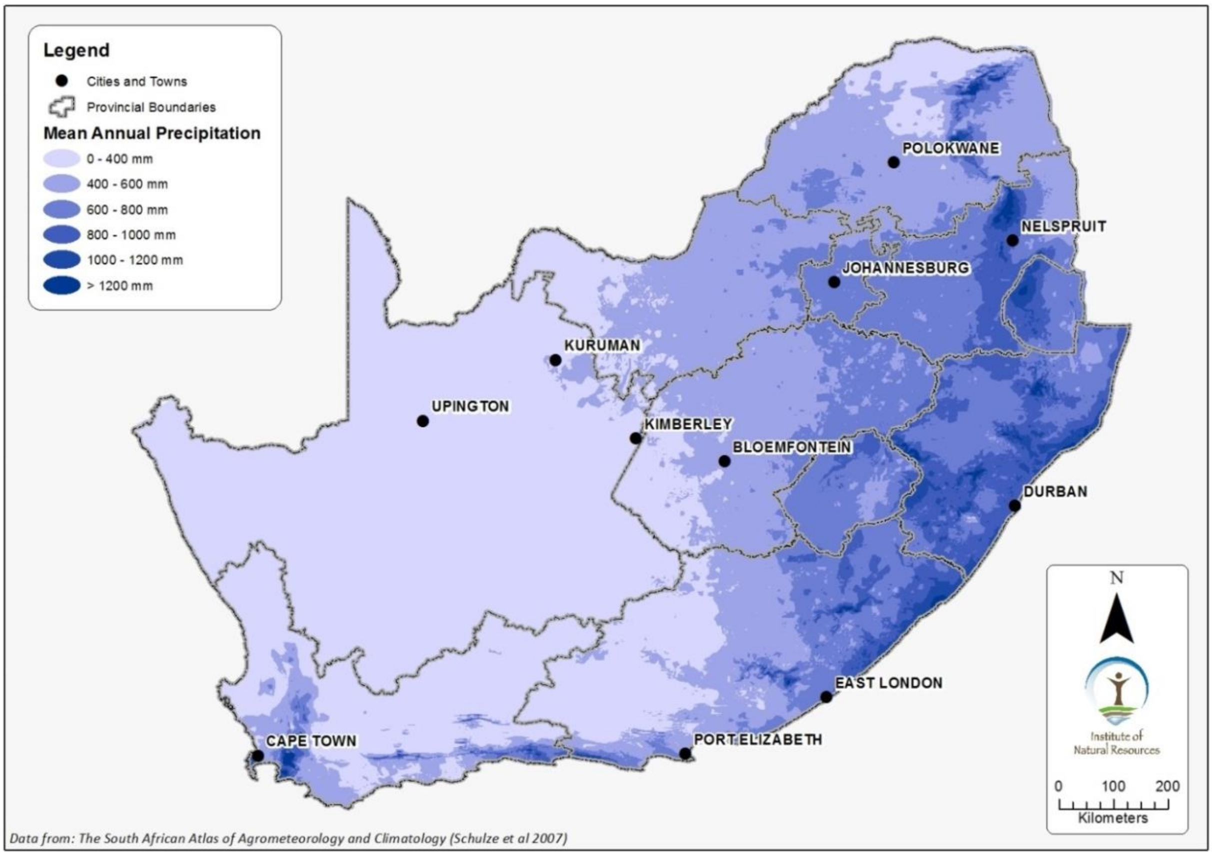
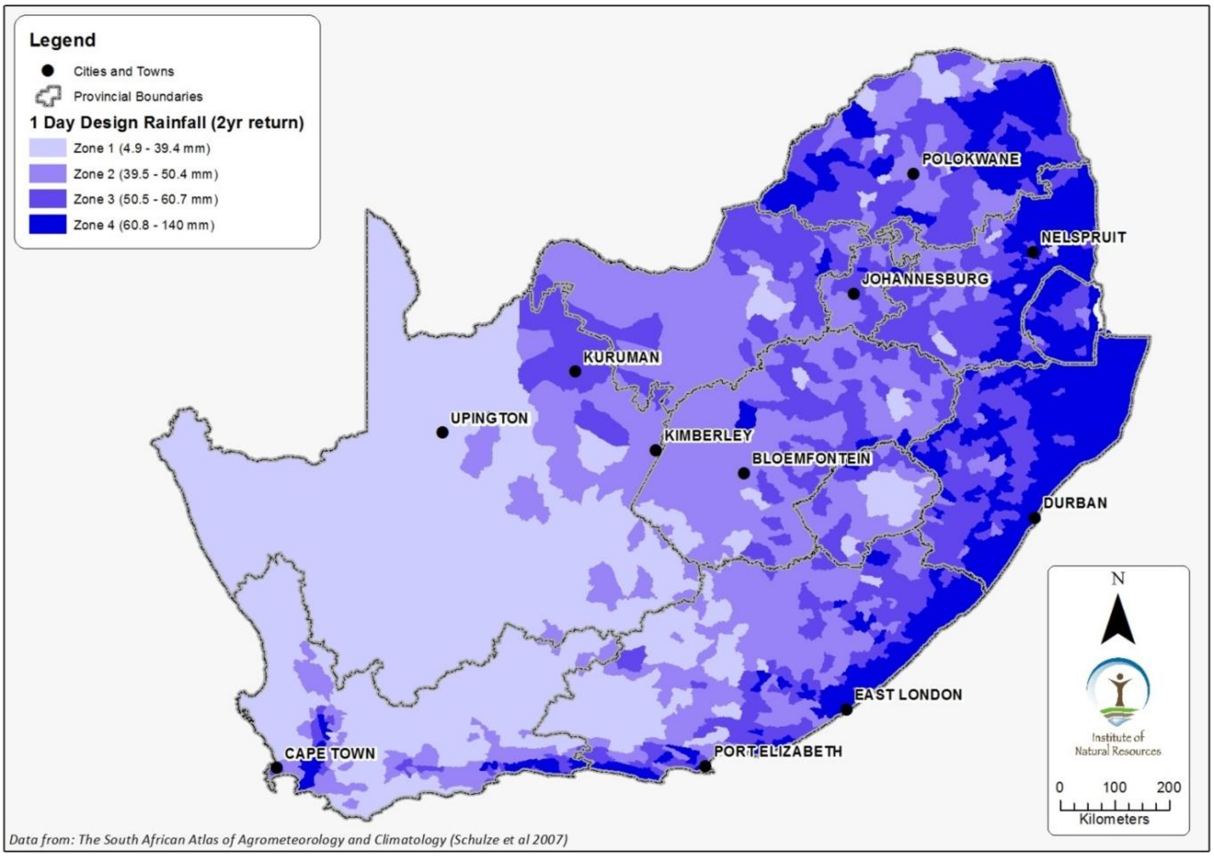
[11] Climatic risk score is calculated by multiplying the modifiers for MAP and rainfall intensity and normalizing these values to a range from 0-1.



Data from: The South African Atlas of Agrometeorology and Climatology (Schulze et al 2007)

Figure 6. Mean annual precipitation (Adapted from Schulze et al., 2007)



Data from: The South African Atlas of Agrometeorology and Climatology (Schulze et al 2007)

Figure 7. Rainfall intensity zones based on one day design rainfall over a two year return (Adapted from Schulze et al., 2007)

Table 15. Modifiers used to calculate a Climate Risk Score.

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

The threat score is then adjusted automatically in the buffer zone model by applying an adjustment factor based on the CRS[12]. This effectively increases the threat ratings in high rainfall environments or areas located within intense rainfall intensity zones[13].

Buffer zone tool:

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

7.4. Assess the sensitivity of water resources to threats posed by lateral land-use impacts

Desktop	Site-based
	✓

The sensitivity of water resources to lateral impacts is another factor that affects the level of risk posed by a development. A more conservative approach is therefore required when proposed developments take place adjacent to water resources which are sensitive to lateral impacts, as opposed to the same development taking place adjacent to a water resource which is inherently less sensitive to the impacts under consideration. For example: Agriculture, posing a high siltation threat may be planned alongside a small and isolated depression wetland (pan) that is highly sensitive to lateral sediment inputs. The risk posed by agricultural activities in this instance is far higher than for agricultural activities adjacent to a large floodplain wetland, characterized by inherently high natural sediment inputs.

The assessment of sensitivity is based on key attributes of different water resources that act as easily measurable indicators[14]. The sensitivity assessment has therefore been tailored for wetlands, rivers and estuaries. Sensitivity scores and classes used in the assessment are described in Table 16.

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

[13] Typical pollutant loading of different land-uses (as expressed by the desktop threat score) is regarded as being of overriding importance when assessing buffer zone requirements. However, given that storm flow is the primary mechanism for diffuse pollutant inputs, climatic factors have also been integrated into the model. The influence of climatic factors on buffer requirements has been moderated by restricting the change in threat score to a maximum of one threat class. By following this approach, buffer zone requirements for land-uses in arid climates with low rainfall intensities therefore score one threat class less than when the same land-use is located in moist climates characterized by intense rainfall events.

[14] It is important to point out that this assessment is different to that used to define EIS, as the focus is specifically on the sensitivity of water resources to lateral impacts rather than broader catchment impacts.

Table 16. Sensitivity classes used to guide the assessment of sensitivity of water resources to lateral impacts.

SENSITIVITY CLASS	SYMBOL	SENSITIVITY SCORE	DESCRIPTION
Very Low	VL	0.85	Water resource is likely to have a very low susceptibility to the specific impact type.
Low	L	0.93	Water resource is likely to have a low susceptibility to the specific impact type.
Moderate	M	1.00	Water resource is likely to be moderately susceptible to the specific impact type.
High	H	1.08	Water resource is likely to have a high susceptibility to the specific impact type.
Very High	VH	1.15	Water resource is likely to have a very high susceptibility to the specific impact type.

It is important to point out that this assessment is designed to assess the inherent sensitivity of the water resource, rather than the sensitivity of important biota that may be reliant on the water resource. Where important biodiversity elements are present, buffer requirements are adjusted to account for these features (See Section 8.1).

7.4.1. Assessing the sensitivity of wetlands to lateral land-use inputs

The sensitivity of wetlands to lateral impacts is assessed using a range of indicators outlined in Table 17 below. For details on the rationale for indicator selection, scoring criteria and method of assessment, refer to the guidelines included in Annexure 12. The rationale and method of assessment is also captured as comments in the buffer zone models.

Table 17. Indicators used to assess the sensitivity of wetlands to lateral land-use impacts

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

7.4.2. Assessing the sensitivity of estuaries to lateral inputs

The sensitivity of estuaries to lateral impacts is assessed using a range of indicators, depending on the threat under consideration and the level of assessment being undertaken. Indicators used to inform this assessment are briefly outlined in Table 18 below. For details on the rationale for indicator selection, scoring criteria and method of assessment, refer to the guidelines included in Annexure 13. The rationale and method of assessment is also captured as comments in the buffer zone models.

Table 18. Indicators used to assess the sensitivity of estuaries to lateral land-use impacts

INDICATOR
Estuary size
Estuary length
Perenniality of river inflow
The inherent runoff potential of the soil in the estuary's catchment
Mouth closure
Water clarity
Presence of submerged macrophytes
Level of domestic use
Average temperature

7.4.3. Assessing the sensitivity of rivers and streams to lateral inputs

The sensitivity of rivers and streams to lateral impacts is assessed using a range of indicators, depending on the threat under consideration and the level of assessment being undertaken. Indicators used to inform this assessment are briefly outlined in Table 19 below. For details on the rationale for indicator selection, scoring criteria and method of assessment, refer to the guidelines included in Annexure 14. The rationale and method of assessment are also captured as comments in the buffer zone models.

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

INDICATOR
Stream order
Channel width
Perenniality
Average catchment slope
Inherent runoff potential of catchment soils
Longitudinal river zonation
Inherent erosion potential (K factor) of catchment soils
Retention time
Inherent level of nutrients in the landscape (e.g. is the river / stream and its catchment underlain by sandstone?)
Inherent buffering capacity
Underlying geographical formations
River depth to width ratio
Mean annual temperature
Level of domestic use

7.5. Assess the sensitivity of important biodiversity elements to threats posed by lateral land-use impacts

Desktop	Site-based
	✓

While the sensitivity of the water resource to threats posed by lateral inputs may be low, specific important biota or habitats may be sensitive to such impacts. Where relevant, it is therefore important to consider the sensitivity of any important biodiversity elements identified in Step 5, and to adjust the sensitivity scores accordingly. See Section 8.4 for further guidance on how biodiversity considerations should be incorporated into an assessment of aquatic impact buffer requirements.

7.6. Determine the risk posed by proposed activities on water resources

Desktop	Site-based
✓	✓

Once both threats posed by potential land-uses / activities, and the inherent sensitivity of receiving water resources have been assessed, this information is used to evaluate the risks posed by such activities on the water resource under consideration. Note that in the case of a desktop assessment, water resources are assumed to have a very high sensitivity to the full suite of potential impacts evaluated. Risk scores are calculated by multiplying threat and sensitivity scores to obtain a risk score for each impact type evaluated, as illustrated in Table 20 below[15].

Table 20. Table used to integrate threat and sensitivity scores into a composite risk score as part of the buffer zone model.

		INHERENT SENSITIVITY				
POTENTIAL THREAT OF LAND-USE / ACTIVITY		VH	H	M	L	VL
		1.15	1.08	1.00	0.93	0.85
VH	1	1.15	1.075	1.0	0.925	0.85
H	0.8	0.92	0.86	0.8	0.74	0.68
M	0.6	0.69	0.645	0.6	0.555	0.51
L	0.4	0.46	0.43	0.4	0.37	0.34
VL	0.2	0.23	0.215	0.2	0.185	0.17

From a technical perspective, it is important to note that sensitivity scores for moderately sensitive water resources have been set at 1. This is consistent with the approach used to link risk classes with buffer zone widths in Step 3.4.2, which links required buffer zone efficiency to compliance with GLV standards – appropriate for moderately sensitive systems. Where water resources are more sensitive, the risk class and associated requirement for mitigation typically increases, highlighting the need for more stringent controls (more effective buffer zones). Where sensitivity is regarded as low however, mitigation requirements are relaxed accordingly, as indicated by lower risk scores for water resources with a low or very low sensitivity. Risk scores calculated are then grouped into one of 5 Risk Classes for reporting purposes as described in Table 21 below.

Table 21. Risk classes used in this assessment.

RISK CLASS	RISK SCORE	DESCRIPTION
Very Low	<0.3	The proposed development / activity pose a very low risk to the water resource under investigation for the threat type assessed.

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[15] Note that the range of sensitivity scores was refined through a sensitivity analysis of the model under a range of scenarios (Bredin et al., 2014). This suggested that a narrow score range selected was most appropriate to cater for variability in water resource sensitivity.

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

Buffer zone tool:

- For site-based assessments, collect the information necessary to assess the sensitivity of the water resource using acceptable methods (See Annexures 12-14).
- Review sensitivity scores and select a sensitivity class for biodiversity where this is likely to be higher than that for the water resource.
- Risk scores are automatically calculated by the Buffer Zone Tool based on threat and maximum sensitivity score.

7.7. For selected impacts, determine desktop aquatic impact buffer requirements

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

It is important to note, however, that buffer zones can only assist in mitigating some of the risks identified and that other mitigation measures may be necessary. For example, while buffers can help to reduce the impact of afforestation on stream flow, the area of the catchment planted to commercial species is the primary determinant of hydrological impacts. Buffers are most effective in reducing pollutants in diffuse surface runoff while their ability to remove pollutants from sub-surface flows is less well documented. Buffers also do little to address pollutants discharged at point-sources or in concentrated flows. Therefore, buffers should be seen as only one of a suite of possible mitigation measures to reduce potential impacts of land-uses / activities on water resources. Table 22 below serves to highlight situations in which the establishment of buffer zones can have a potentially positive impact and should be considered.

Table 22. Summary of common threats posed by adjoining land-uses / activities on water resources and typical approaches to addressing them. Instances where buffer zones can play a particularly important role are highlighted in blue.

THREAT	SOURCE OF IMPACT	APPROACH FOR ADDRESSING THREATS
Water Quantity – volumes of flow	Reduction in water inputs	Source directed controls Restricting surface flow requirement (SFR) activities *(including application of buffer zones)*
	Increase in water inputs	Control of water inputs (e.g. piped water) and other mitigation measures
Water Quantity – patterns of flow	Concentrated flows	Address through on-site Best Management Practices (BMPs) and mitigation measures
	Diffuse runoff	BMPs to control runoff and mitigation measures (*including buffer zones*) to address increased storm flows

THREAT	SOURCE OF IMPACT	APPROACH FOR ADDRESSING THREATS
Sedimentation and turbidity	Concentrated flows	Address through on-site BMPs and mitigation measures
	Diffuse runoff	Buffer zone together with other mitigation measures and BMPs
Water Quality – Increased inputs of nutrients	Concentrated flows	Address through on-site BMPs and mitigation measures
	Diffuse runoff	Buffer zone together with other mitigation measures and BMPs
Water quality – Increased organic contaminants	Concentrated flows	Address through on-site BMPs and mitigation measures
	Diffuse runoff	Buffer zone together with other mitigation measures and BMPs
Water quality – Increased toxic contaminants (heavy metals)	Concentrated flows	Address through on-site BMPs and mitigation measures
	Diffuse runoff	Buffer zone together with other mitigation measures and BMPs
Water quality – changes in acidity (pH)	Concentrated flows	Address through on-site BMPs and mitigation measures
	Diffuse runoff	
Water quality – concentration of salts (salinization)	Concentrated flows	Address through on-site BMPs and mitigation measures
	Diffuse runoff	
Water quality – temperature	Concentrated flows	Address through on-site BMPs and mitigation measures (*including maintenance of riparian zones*).
	Diffuse runoff	
Water quality – pathogens (i.e. disease-causing organisms)	Concentrated flows	Address through on-site BMPs and mitigation measures
	Diffuse runoff	Buffer zone together with other mitigation measures and BMPs

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

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

A buffer zone identified to perform these functions is referred to as an Aquatic Impact Buffer Zone as defined below:

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

7.8. Determine preliminary aquatic impact buffer zone widths required to mitigate risks identified

Desktop	Site-based
✓	✓

Determining the required buffer width is largely an exercise of assessing the situation and linking it to an acceptable level of risk. In this approach, threats have already been defined for each of the required buffer functions with reference to existing standards (Table 14). The determination of buffer zone widths is therefore guided by the level of effectiveness required to mitigate risks to acceptable limits. The relationship between risk classes and buffer zone effectiveness is illustrated in Table 23 below.

Table 23. Guideline for linking buffer width with buffer zone effectiveness

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

Rule-curves have been developed based on the best available science to link buffer width and buffer effectiveness. These relationships are summarized below, while further information, including reference to relevant studies that support these relationships, are included in Annexure 15 of this report[16].

These relationships assume that buffer width is the most important factor for effective mitigation, which is consistent with findings in the international literature (e.g. Phillips, 1989). Other factors that affect buffer zone efficiency, such as slope and vegetation cover, are not explicitly considered at this stage but are dealt with later at a site level (See Section 7.9). Details of each of the relationships used to establish preliminary buffer requirements are presented here.

Desktop aquatic impact buffer zone requirements are automatically calculated in the buffer zone model based on the level of risk defined for each of the four potential impacts considered[17]. The aquatic impact buffer zone

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[16] It is important to note that these rule curves have been developed based on a suite of default or "reference" buffer zone attributes (See Section 7.10). Site specific buffer requirements may therefore vary considerably in response to local buffer zone attributes that affect the effectiveness of buffers to trap pollutants.

[17] Given the importance of following a precautionary approach when calculating desktop buffer requirements, buffers have been determined based on a worst-case scenario. This assumes that the receiving water resource is very sensitive

width required is then taken as the maximum of the buffer zone widths proposed for each of the potential impacts evaluated.

7.8.1. Increased sedimentation and turbidity

Numerous studies have been undertaken to assess the effectiveness of buffer zones in retaining sediments washed off in surface runoff. These suggest that the relationship between the length covered by the runoff (buffer width) and sediment removal is not linear, with most sediment being deposited in outer portions of the buffer. Although there is considerable variation in reported efficiencies, it is clear that high efficiencies can be obtained from small (<10 m) buffer zones, but that wider buffer zones are required to effectively remove greater amounts of suspended sediment. Based on a review of available literature, standard buffer widths of between 2 m and 50 m have been proposed for sediment removal, depending on the effectiveness of the buffer zone required (Figure 8).

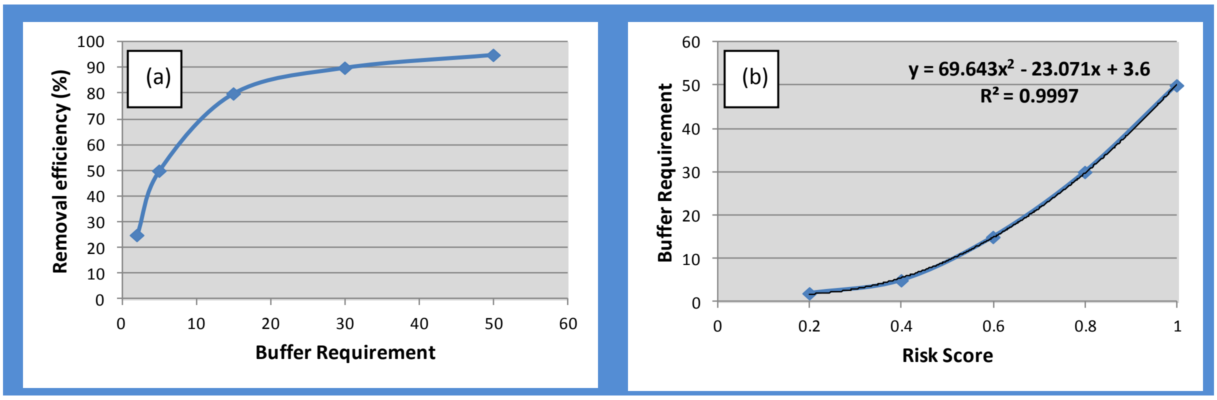

Figure 8. Relationship between (a) sediment removal efficiency and buffer width, and (b) risk of sediment inputs and buffer requirements used to calculate aquatic impact buffer requirements (m)

7.8.2. Increased nutrient inputs from lateral inputs

Many studies have shown that buffer zones can be very effective at removing nitrogen and phosphorous from lateral water inputs. Although removal effectiveness varied widely among studies, there is a clear relationship between buffer width and buffer effectiveness. As with sediment removal, a curvilinear relationship is typically used to describe the relationship between buffer width and nutrient removal efficiency. This relationship is presented in Figure 9 below, and suggests that high levels of buffer efficiency can be achieved with small buffers of < 20 m in width. Very wide buffers may however be necessary to effectively remove nutrients in high risk situations.

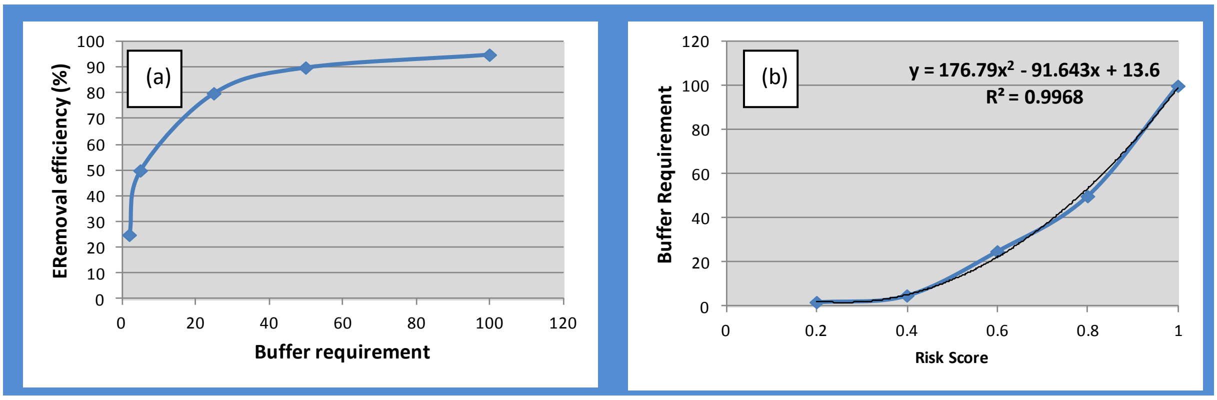

Figure 9. Relationship between (a) nutrient removal efficiency and buffer width, and (b) risk of nutrient inputs and buffer requirements used to calculate aquatic impact buffer requirements

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(maximum sensitivity score) and that the characteristics of the buffer zone are poorly suited to address diffuse source pollutants (worst case site-based attributes).

7.8.3. Increased toxic contaminants from lateral inputs

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

As an initial approach to determining the effectiveness of a buffer zone at trapping toxic substances, toxic contaminants have been considered as two broad categories, namely organic contaminants (which include pesticides) and toxic heavy metals. Buffer widths proposed for these groups have been based on available information. In addition, the precautionary principle was applied.

These relationships are presented in Figures 10 and 11 respectively and suggest that for toxic metals, high levels of buffer efficiency can be achieved with small buffers (i.e. approximately 20 m in width). However, wider buffers (i.e. up to 80 m) may be necessary to effectively remove toxic metals in high risk situations. For organic pollutants, including pesticides, a buffer of 20 m would also be effective. However, for high risk situations a larger buffer would be required (i.e. a buffer of approximately 40 m).

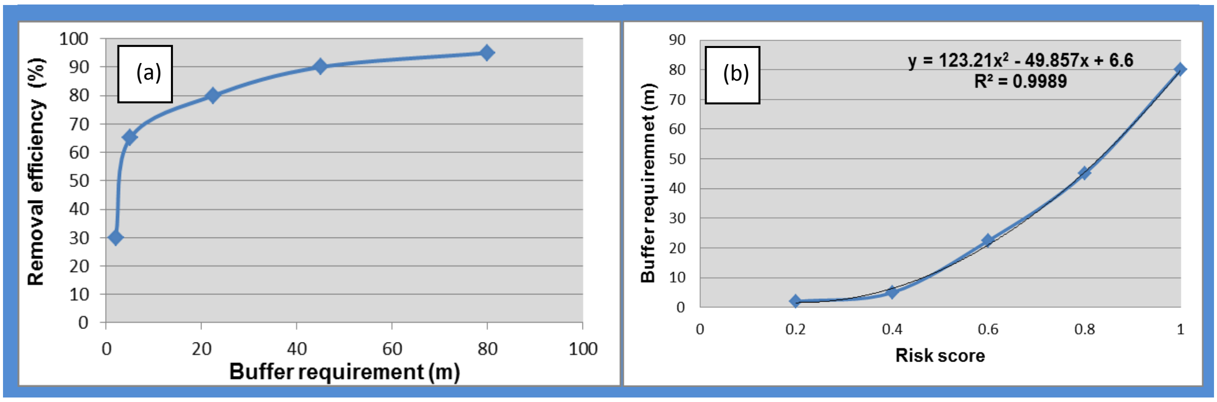

Figure 10. Relationship between (a) toxic metal removal efficiency and buffer width, and (b) risk of toxic metal inputs and buffer requirements used to calculate aquatic impact buffer requirements

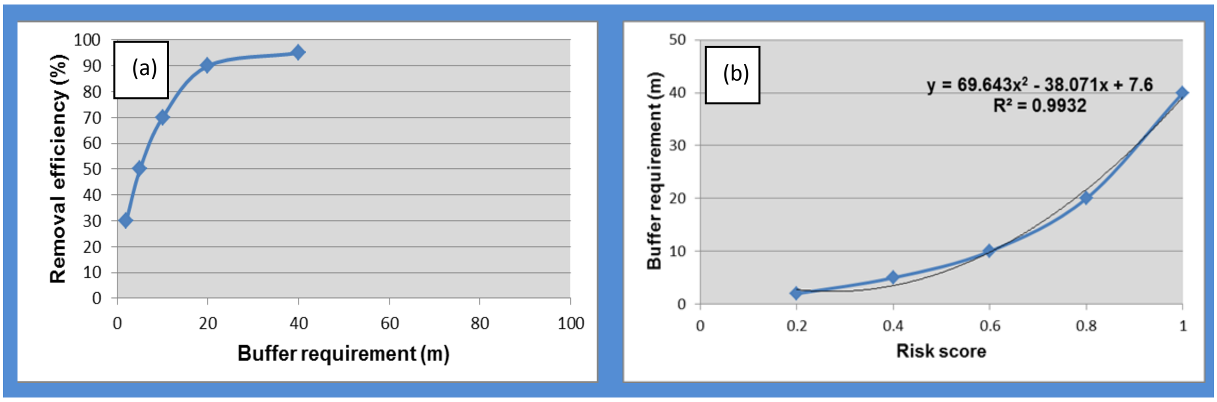

Figure 11. Relationship between (a) organic pollutants and pesticide removal efficiency and buffer width, and (b) risk of organic pollutants and pesticide inputs and buffer requirements used to calculate aquatic impact buffer requirements

7.8.4. Increased pathogen inputs from lateral sources

Studies undertaken on the effectiveness of buffers at removing pathogens suggest that small buffers may be effective in performing this function. Based on the information available, maximum recommended buffers for pathogen removal were set at 30 m, reduced to 2 m in the case of low-risk activities. Given that research suggests that very small buffers are effective at removing pathogens, a curvilinear relationship was again assumed as illustrated in Figure 12 below.

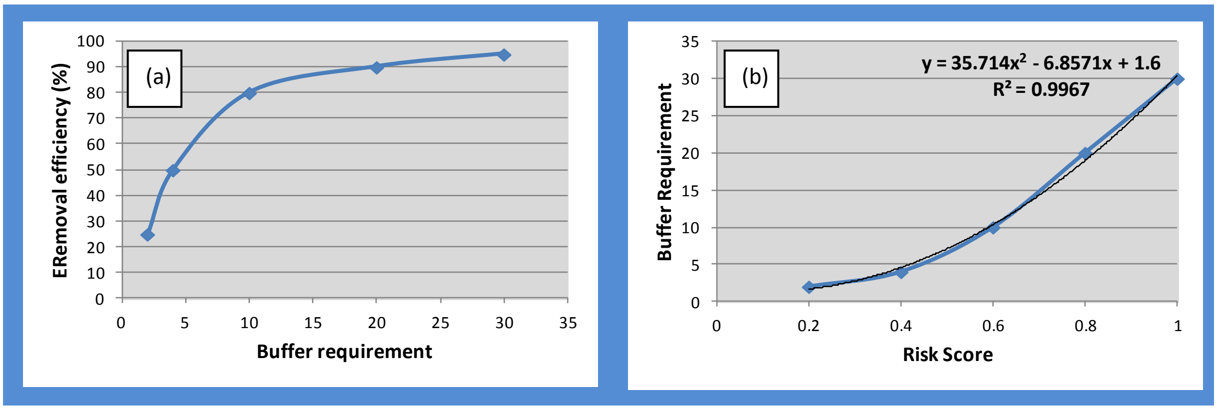

Figure 12. Relationship between (a) pathogen removal efficiency and buffer width, and (b) risk of pathogen inputs and buffer requirements used to calculate aquatic impact buffer requirements

Buffer zone tool:

- Preliminary buffer zone requirements for construction and operational phases are automatically calculated for each threat type based on risk ratings already calculated.
- The maximum of the buffer widths for construction and operational phase can be used to define desktop buffer requirements.

7.9. Refine preliminary buffer requirements based on site-based investigations

Desktop	Site-based
	✓

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

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

- Vegetation characteristics;
- Slope;
- Soil permeability; and
- Topography.

Details of why these criteria were selected together with further guidance on undertaking the assessment are detailed for each buffer zone function in Annexure 16. Buffer width “Modifiers” are defined for each buffer characteristic based on the anticipated effect of possible attributes on buffer zone effectiveness across different buffer functions. These characteristics are rated relative to default or “Reference” buffer characteristics[18].

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[18] “Reference” buffer zone attributes were defined as follows:

- **Slope of buffer**: Moderate (10.1-20%);
- **Vegetation characteristics (basal cover)**: High (Dense vegetation, with good basal cover (e.g. natural grass stands));
- **Soil permeability**: Moderate. Moderately textured soils (e.g. sandy loam);

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

The buffer zone model then calculates a modifier rating for each buffer zone function[19] which is used to adjust the preliminary buffer zone recommendation for each of the buffer segments identified[20].

Buffer zone tool:

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

7.10. Where appropriate, identify additional mitigation measures and refine aquatic impact buffer width accordingly

Desktop	Site-based
	✓

While buffer zones are advocated as standard mitigation measures to address a range of threats, they are only one of a suite of mitigation measures that can be used to reduce potential impacts. Indeed, pollution prevention and on-site mitigation (e.g. water treatment / water reuse and reclamation) are regarded as preferable rather than simply relying on buffer zones as a last form of defence to address these impacts. It may also be desirable to reduce the buffer zone requirement by implementing additional complementary mitigation measures that reduce threats and associated buffer zone requirements.

To help practitioners identify suitable additional complimentary mitigation measures, a range of potential mitigation options have been identified from existing literature. These have been consolidated into a user-

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- **Topography of the buffer zone**: Dominantly smooth topography with few/minor concentrated flow paths to reduce interception.

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

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

[20] It is important to note that maximum buffer zone widths were integrated into the model to limit the possible upper range of buffer recommendations in line with those cited in the literature report (Annexure 1). In the case of sediment retention, a maximum buffer of 125 m is applied whilst values of 260 m and 90 m were applied for nutrient and pathogen removal respectively. In the case of toxics contaminants, a maximum of 200 m was applied.

friendly Excel-based “**Mitigation Measures Tool**”[21]. An overview of the mitigation measures tool is provided in Annexure 17. The look-up lists provided in this tool can be used to identify a suite of additional potential mitigation measures for different impact types that are relevant to the sector of interest.

Based on an understanding of the effectiveness of proposed mitigation measures, refined threat ratings are selected for the affected risks, together with appropriate justifications. For risks that have a bearing on buffer zone width, buffer zones are adjusted accordingly to obtain a revised aquatic impact buffer zone requirement.

Buffer zone tool:

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

7.10.1. Review and refine aquatic impact buffer requirements to cater for practical management considerations

While the Buffer Zone Tool provides a recommended buffer width to address potential risks from adjacent land-use activities, it is essential that buffer zones cater for risks of buffer zone failure and are sufficiently wide to allow the buffer and any important attributes to be managed and maintained.

In a study on the use and effectiveness of buffer zones, Castelle et al*.* (1992) found that nearly all of the buffers assessed that were less than 15 m in width were significantly reduced within a few years, and some were found to have been eliminated through complete clearing of indigenous vegetation. Of the buffers assessed that were wider than 15 m, most still had some portion intact and generally exhibited fewer signs of human disturbance. The risk of poor management is likely to be particularly high in contexts characterized by low management capacity (e.g. low-cost housing developments) or in areas subject to high levels of use (e.g. in peri-urban areas where vacant land is often used for subsistence cultivation).

In addition, a review of recommended minimum buffer zones (i.e. different types of buffer zones) revealed that the most frequently recommended minimum buffer zones width is 15 m (Table 24).

Table 24. Review of different buffer types and the recommended minimum buffer zone widths

BUFFER TYPE	MINIMUM BUFFER ZONE WIDTH (M)	REFERENCE
Vegetated filter strip	30	Barling and Moore 1994
Vegetated filter strip	11	Corbert et al., 1978
Vegetated filter strip	20	Department of Conservation and Environment, 1990
Forested riparian buffer	15	Blinn and Kilgore 2001
Forested riparian buffer	15	Bray, 2010
Grass filter strip and vegetated buffer	35	Hansen et al., 2010
Vegetated filter strip	5	Hawes and Smith, 2005
Vegetated filter strip	20	Ives et al., 2005
Vegetated filter strip	15	Lee et al., 2004
Vegetated filter strip	10.7	Lowrance et al., 2001
Vegetated filter strip	50	Mayer et al., 2007
Forested buffer strip	15	Palone and Todd, 1997

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[21] The “**Mitigation Measures Tool”** is included in the attached CD.

BUFFER TYPE	MINIMUM BUFFER ZONE WIDTH (M)	REFERENCE
Vegetated filter strip	27	Parkyn, 2004
Vegetated filter strip	10	Parkyn et al., 2000
Vegetated filter strip	30	Castelle et al., 1994
Vegetated filter strip	45	Brosofske et al., 1997
Forested buffer strip	9	Schultz et al., 2004
Grass filter strip and vegetated buffer	15	Semlitsch and Bodie, 2003
Vegetated filter strip	15	Technology Associates, 2010
Forested buffer strip	11	Tjaden and Weber, 1998
Riparian buffer strip	15	Wegner, 1999
Hardwood buffer	15	Woodard and Rock, 1995
Vegetated filter strip	25	Young et al., 1980
Grass filter strip and vegetated buffer strip	61	Horner and Mar, 1982
Grass filter strip	9	Ghaffarzader et al., 1992
Grass filter strip	5	Madison et al., 1992
Vegetated filter strip	9	Dillaha et al., 1989
Grass filter strip	18	Nichols et al., 1998
Grass filter strip and forested buffer	4	Doyle et al., 1977
Forested riparian buffer	19	Shisler et al., 1987
Most frequently recommended minimum buffer zone (m)	**15**	

A minimum aquatic impact buffer zone of 15 m has therefore been integrated into the buffer zone models to help cater for this concern. There may however be instances where a more risk adverse approach is required to cater for potential deterioration in buffer conditions (particularly vegetation cover) over time[22]. In this instance, the motivation for adjusting the buffer zone upwards should be clearly documented.

7.11. Evaluate aquatic impact buffer zone requirements in light of management objectives

Desktop	Site-based
	✓

For the purposes of this guideline, mitigation guidelines have been developed in order to reduce potential risks to a desirable level such that water resource quality should not be compromised. There may however be an argument to increase or reduce mitigation requirements in line with management objectives or special local circumstances for the water resources defined in Step 3.3.3. Guidelines for interpreting these requirements are provided in Table 25 below.

Table 25. Guideline for identifying appropriate management and mitigation measures.

MANAGEMENT OBJECTIVE	GUIDELINES FOR IDENTIFYING MITIGATION AND MANAGEMENT MEASURES
Improve	Any potential risks must be managed and mitigated to ensure that no deterioration to the water resource takes place. In addition, relevant on-site management measures should be identified to help improve the present state of the water resource (e.g. through rehabilitation interventions).

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[22] Determination of more appropriate setback requirements can be informed by tweaking the buffer zone models to account for potential changes in vegetation cover during the operational phase. This is simply done by adjusting the vegetation attributes in the site-based attributes.

MANAGEMENT OBJECTIVE	GUIDELINES FOR IDENTIFYING MITIGATION AND MANAGEMENT MEASURES
Maintain	Any potential risks must be managed and mitigated to ensure that no deterioration to the water resource takes place. Standard management measures should be implemented to ensure that any on-going activities do not result in a decline in water resource quality.
Controlled degradation	It may be permissible to impact the water resource through the implementation of less stringent management or mitigation measures. Where relaxation of requirements is proposed, these would first need to be authorized by the relevant implementing authority to prevent undue deterioration of the water resource.

While not advocated, where relaxation of buffer widths is proposed, the potential reduction in buffer zone effectiveness can be estimated based on an understanding of the relationship between buffer width and buffer zone effectiveness as described in this document[23]. This could be used by DWS to assess to what degree relaxation of buffer zones may be acceptable.

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

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

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

While the protection of riparian areas and aquatic impact buffer zones may be adequate to protect many aquatic species, such buffers may be insufficient to protect a range of aquatic and semi-aquatic species that rely on terrestrial habitat for their survival. While this may be acceptable for species that are not at risk, further interventions are required to ensure that important biodiversity elements are not adversely impacted by planned land-uses or activities.

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

- **The location of critical habitat for the species within the aquatic resource**: For some species, this may be a small reed bed, an area of permanent wetland or open water. Under such a scenario, simply buffering the entire water resource would over-estimate conservation requirements for the species.
- **Specific terrestrial habitat requirements of semi-aquatic species**: Species are likely to have specific habitat requirements that may not be adequately protected through the application of a fixed-width buffer area around the resource. For example, Crowned Cranes specifically forage in grassland areas around

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

nest sites, avoiding wooded or transformed habitats. Identification and protection of suitable grassland habitats within a reasonable distance from the nest site would therefore be critical for the survival of this species.

- **The condition of adjoining habitat**: In some circumstances, very little natural habitat may remain and, despite these areas being located a little distance from the aquatic resource, remaining fragments of natural habitat may be critical for the survival of the species. Inclusion of degraded areas in a buffer zone that is developed without taking this into account may therefore provide little benefit for a species.

Rather than simply allocating 'arbitrary' buffers around water resources, a more scientifically correct approach is presented here. This includes the identification of core habitat, together with the consideration of a range of other protection measures to limit impacts from adjoining land-uses / activities on these core habitats.

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

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

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

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

Desktop	Site-based
	✓

8.1. Undertake a desktop assessment to determine whether important biodiversity elements are likely to be present

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

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

If no biodiversity elements have been flagged through this investigation, no further assessment may be required unless specifically requested by a key stakeholder (i.e. provincial conservation body or interested and affected parties). Where important elements have been flagged, further effort is required to determine whether or not they occur at the site and if so, what mitigation measures are necessary to protect them.

For biodiversity elements that have been flagged, information sheets, where available, should be obtained from provincial conservation bodies. Examples of draft information sheets for a range of biodiversity features have been included in Annexure 18 of this report. These information sheets have been designed to facilitate the assessment process, and include the following information:

- **Scientific and common names**
- **Description**: A description of the species to facilitate identification, including key features that enable the species to be distinguished from similar species. Where appropriate, reference is provided to other documents with more detailed descriptive information.
- **Conservation status**: This section documents the conservation status (both nationally and internationally) together with a description of relevant criteria that informed the threat status at a national level. Any information on legislation governing protection of the species, including National (Threatened or Protected Species (TOPS) listing) or Provincial legislation, together with any permit requirements, are also included.
- **Distribution**: A description of the species distribution range is provided. Where possible, this should include a map of known and potential occurrence within South Africa. For migratory species, appropriate descriptive information and a link to a broader distribution map must be provided where appropriate.
- **Current level of protection within protected areas**: This section provides an indication as to the degree to which conservation requirements (targets) for the biodiversity element are already accounted for through an existing protected area network. This should inform the need for additional protection of remaining sub-populations.
- **Key threats to the species:** Key threats to the species identified at a national / provincial level are included to flag issues of potential concern.
- **Priority actions required to protect the species:** Key actions / management priorities required to protect the species at a provincial / national level are documented. This includes a consideration of the need / importance of protecting sub-populations outside of protected areas.
- **Guidelines for species surveys**: Relevant guidelines to inform survey requirements linked to the ecology of the species are provided in this section. This may include appropriate seasons for sampling, reference to appropriate survey techniques and the level of expertise required to undertake the survey. Additional information such as bird or frog calls, track and scat descriptions are also included where possible.
- **Description of core habitat characteristics:** This includes areas where the species occurs and associated areas required for the species to persist. Key habitat characteristics are therefore identified which are required for the species to live, breed and persist. These requirements differ for different groups of species and are therefore tailored accordingly. This information is provided to (i) help direct survey efforts, and (ii) to identify key areas of habitat requiring protection to ensure the persistence of the species.
- **Guidelines for identifying and mapping core areas:** Guidelines are provided to guide decision making for the protection of sub-populations of the species encountered. This may include, for example, information on recommended minimum patch size or the need to limit development within a distance from breeding areas to facilitate other life history activities (e.g. foraging / hibernation).
- **Sensitivity to potential site-based impacts:** Sensitivity of the species to potential site based impacts is provided here to inform development planning and associated activities. This may include:
  - Sensitivity to direct disturbance (e.g. human presence, noise, dust, light, physical disturbance) from peripheral development or associated activities (e.g. tourism activities) that need to be considered to ensure the species is not unduly disturbed.
  - Sensitivity to pollutants that could have a direct effect on the species (e.g. pesticides, nutrients, salts, etc.). These may be higher than the sensitivity of the water resource per-se, potentially requiring the implementation of more stringent mitigation measures than required to protect the water resource.
  - Sensitivity to factors that may affect species habitat (e.g. alteration of hydrological regimes, burning practices, etc.).

- **Key management considerations**: Management measures necessary to maintain the functionality of core habitats that need to be considered are highlighted in this section. This includes aspects such as fire management, livestock management, management of tourism or recreational activities, etc.
- **Relevance of corridors for species persistence**: An indication of the likely importance of establishing corridors between sub-populations for the persistence of the species is provided.
- **Corridor design requirements**: Where corridors are regarded as important, guidance to inform corridor design is provided.
- **References**: A list of key references used to develop the information sheet is provided.

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

8.2. If important biodiversity elements are likely to be present, undertake a survey to verify them and establish the need for site-based conservation efforts

Desktop	Site-based
	✓

Where the desktop assessment has flagged the potential occurrence of important biodiversity features, a survey must be undertaken to assess whether or not the species occurs at or near the proposed development site. The scope, timing and survey methods should be guided by an understanding of the ecology of the species being investigated. Where possible, such information should be included in species information sheets. Depending on the potential importance of connectivity, consideration should also be given to extending surveys beyond the immediate site location to assess whether corridor design is likely to be necessary.

8.3. Identify core areas required to protect any important biodiversity features

Desktop	Site-based
	✓

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

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

Table 26. Key buffer functions provided by a core habitat

BUFFER FUNCTION	DESCRIPTION
Maintenance of habitat for aquatic species	Vegetation along stream lines provides food that supports in-stream food chains. These areas are therefore vital for a range of aquatic species which are dependent on these resources for their survival.

Provision of habitat for semi-aquatic species	Many semi-aquatic species rely on both aquatic habitats and terrestrial areas for the successful recruitment of juveniles and to maintain optimal adult survival rates. Such areas are therefore necessary to meet the living requirements of these species and thus enable such species to persist in the area.

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

8.4. Adjust aquatic impact buffer requirements based on sensitivities of any important biota identified

Desktop	Site-based
	✓

Once core areas have been established, it is important to assess threats posed by planned land-uses / activities on the species and associated core areas. The first step is to re-assess the sensitivity scores used to define aquatic impact buffer requirements for the water resource. While aquatic impact buffers may be appropriate to reduce impacts to the functioning of the water resource, more stringent mitigation measures may be necessary based on the susceptibility (sensitivity) of biodiversity elements to lateral impacts. For example, the sensitivity of a floodplain system to sediment inputs may be low but an important population of endangered plant species may occur down-slope of the proposed development, which could potentially be significantly impacted if stringent sediment control measures are not in put in place. In this case, the buffer zone should be adjusted outwards to ensure appropriate protection of this plant community. This is accounted for in the Buffer Zone Tool by selecting a sensitivity class for biodiversity where this is likely to be higher than that for the water resource (See Section 8.1). This refined sensitivity score is then used to refine aquatic impact buffer requirements.

8.5. Identify any additional biodiversity buffer requirements

Desktop	Site-based
	✓

While identification of areas of core habitat is necessary to ensure the persistence of important biodiversity elements, these areas may be prone to disturbance and degradation from adjacent land-use / activities. Adjacent land-use / activities could disrupt natural wildlife activities, such as feeding, breeding and sleeping, or may affect habitat quality, adversely affecting their survival. However, the degree to which wildlife are affected by disturbance is dependent upon many factors, including intensity of the disturbance, duration, species, and the life-cycle stage of the species.

The ‘flushing’ of birds due to human presence is one example of the impact of disturbance on biota. Such disturbance may cause birds to leave their nests, which can cause clutch failure or the abandonment of the nest altogether, thereby reducing breeding success of the species. Much research has been done on this aspect (Annexure 1) and this information should be consulted when determining biodiversity buffers for species prone to noise and direct human disturbance.

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

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

Table 27. Description of key biodiversity buffer function

BUFFER FUNCTION	DESCRIPTION
Screening of adjacent disturbances	Anthropogenic disturbances to aquatic and semi-aquatic species may be direct, such as human presence and traffic, or indirect, such as through noise and light. These disrupt natural wildlife activities, such as feeding, breeding and sleeping, or may affect habitat quality, adversely affecting their survival. Biodiversity buffers can mitigate these impacts, thereby maintaining values of important biodiversity features.

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

8.6. Assess the need for connectivity and identify suitable fine-scale corridors where appropriate

Desktop	Site-based
	✓

In some instances, persistence of a species may be significantly improved by increasing the level of connectivity between available patches of suitable habitat. Biodiversity corridors should therefore be introduced, where possible, to increase the viability of species populations which are dependent on dispersal between sub-population nodes for long-term persistence. A definition for biodiversity corridors is included below, together with a description of key functions that would be provided by such areas (Table 28).

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

Table 28. Description of key biodiversity corridor function

BUFFER FUNCTION	DESCRIPTION
Habitat connectivity	Buffers along water resources provide potentially useful corridors, allowing the connection of breeding, feeding and refuge sites crucial to maintaining the viability of populations of semi-aquatic species.

The need for establishing biodiversity corridors will depend on characteristics of the species concerned. As a result, the need for establishing such areas is included in the species information sheets, together with guidelines regarding the nature of such a corridor required to meet the needs of the particular species concerned. A basic guideline document outlining guiding principles for corridor design has also been developed to help guide assessors (Annexure 19).

Note: Provincial conservation bodies should be consulted regarding local and landscape-level corridors identified to maintain biological processes.

9. STEP 6: DELINEATE AND DEMARCATE RECOMMENDED SETBACK REQUIREMENTS

Desktop	Site-based
✓	✓

Now that protection requirements for water resources and associated biodiversity have been established, the next step is to finalize and delineate setback requirements on a layout plan and in the field. In doing so, it is also important to ensure that setback requirements also cater for a range of other potentially important management, functional and legal requirements.

9.1. Delineate the boundary of water resources

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

9.2. Map required for aquatic impact buffer zones

Once the starting point for mapping aquatic impact buffers has been delineated (Section 5.3), aquatic impact buffer requirements must be mapped to indicate the implications of buffer requirements for development planning. In most cases, this will simply entail mapping the maximum of buffers recommended for construction and operational phases. There may be instances, however, where a narrower buffer is permissible during the construction phase (e.g. to account for sediment risk associated with site clearing) and should be mapped separately from a larger operational buffer (defining setback requirements for actual infrastructure).

In cases where the initial site-based buffer requirement has been refined through the identification of additional mitigation measures, it is recommended that both the initial buffer and refined buffer recommendations (with mitigation) are mapped.

The process of mapping is aided considerably through the use of GIS, which has tools to buffer mapped features based on a specified width. Where this is not available, the desktop buffer zone line may be simply drawn on a 1:10 000 topographic map sheet or layout plan. It is important to note that the calculated buffer widths are based on horizontal rather than a diagonal distance as illustrated in Figure 13.

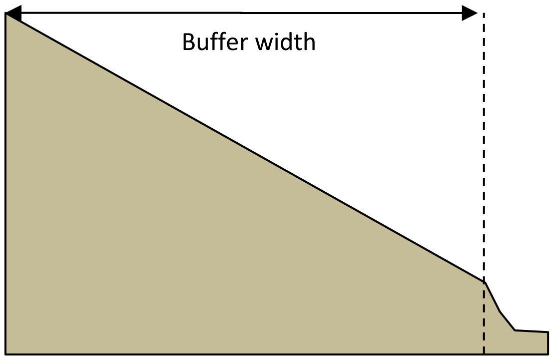

Figure 13. Cross-section through a slope adjacent a water resource indicating how buffer zone widths should be measured

9.3. Map setback requirements for water resource protection

It is important to note that setback requirements are not only dictated by requirements for minimizing impacts of pollutants on the water resource. No development is typically permitted within the water resource boundary. As a consequence, setback requirements are effectively determined by the maximum distance of (i) the water resource boundary (including riparian habitat), or (ii) the aquatic impact buffer zone required to protect the water resource. This is illustrated for a river and estuarine system in Figures 14 and 15 below.

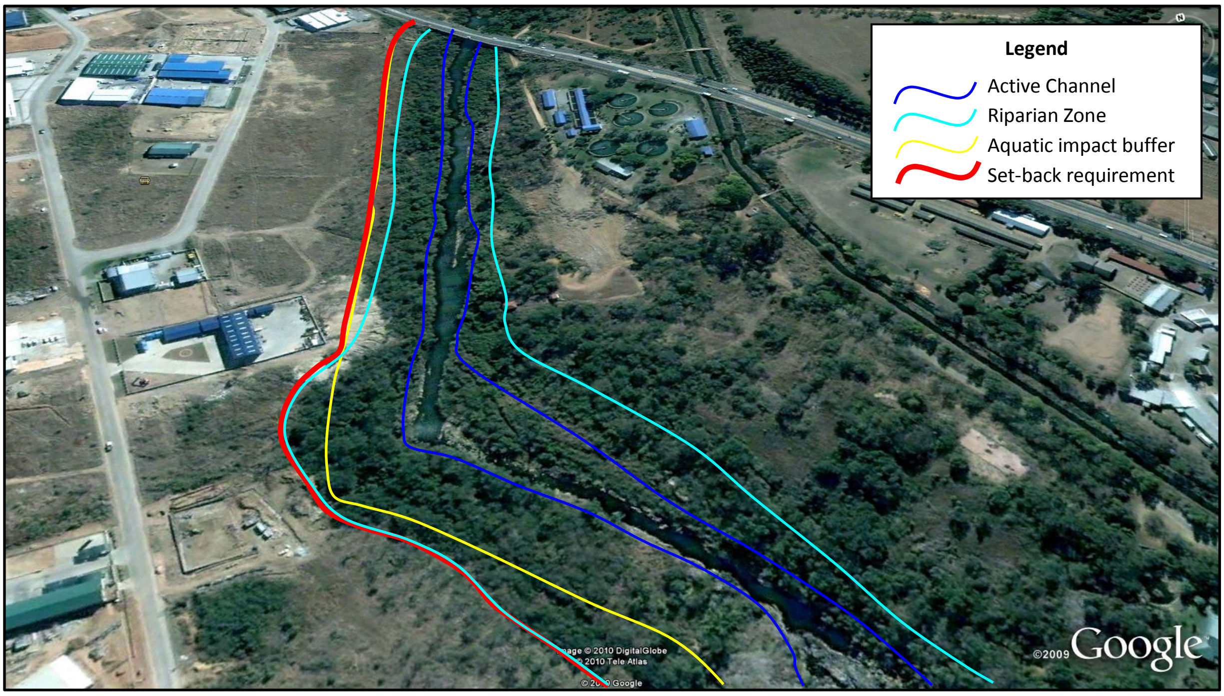

Figure 14. Example 1: Map indicating the active channel, riparian zone, recommended aquatic impact buffer zone and final recommended setback requirement for a proposed residential development planned alongside a river system

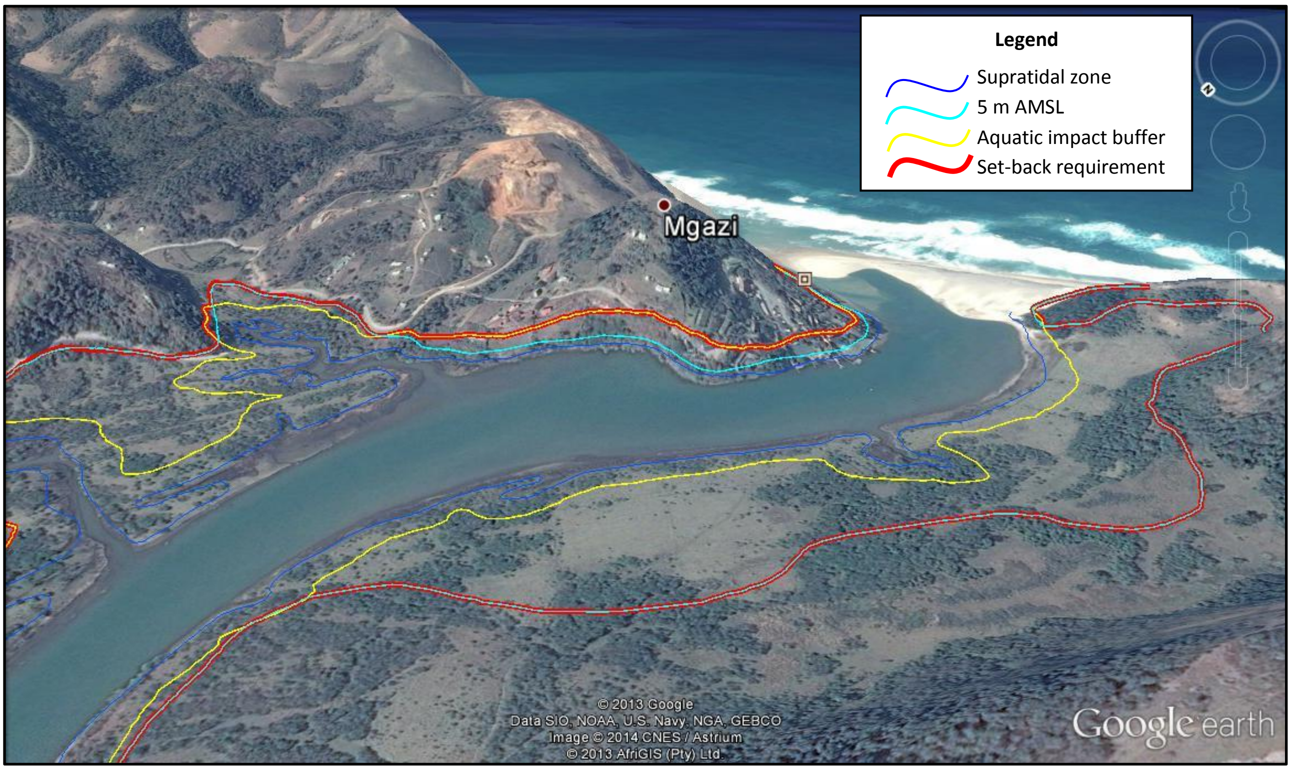

Figure 15. Example 2: Map indicating the edge of the supratidal zone, estuary boundary (5 m AMSL), recommended aquatic impact buffer zone and final recommended setback requirement for a proposed residential development planned alongside an estuarine system

9.4. Map zones for biodiversity protection

Desktop	Site-based
	✓

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

9.5. Ensure that any additional factors have been considered before finalizing setback requirements

Desktop	Site-based
	✓

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

- **Hydrological buffers**: Where there is a risk of planned developments having a negative impact on groundwater, it may be necessary to establish hydrological buffers to reduce the risk of drawdown or pollution of groundwater resources[24]. This is typically an important consideration where mining operations pose a significant risk to groundwater resources.

  Guidelines for determining this 'hydrological buffer' or protection zone are included in the Groundwater Resource Directed Measures (Parsons and Wentzel, 2007). Provision is also made for determining protection zones to cater for anticipated impacts from on-site sanitation that can affect

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

water resource quality and cause health impacts to communities (Parsons and Wentzel, 2007; Denise et al*.*, 2013).

- **Flood risk**: Local policies may require flood lines to be determined which may impose additional restrictions (other than those required to maintain water resource quality) to minimize potential impacts associated with risks to water quality during flood events or potential impacts on the welfare, health or safety of human beings or to property in the downstream area. In other instances, local authorities may impose wider setback requirements to provide ‘adjustment space’ to cater for anticipated future flood risks.
- **Aesthetic considerations**: Buffer zones can screen undesirable views and so enhance visual quality, appreciation and increase property values particularly in urban areas. There may therefore be occasions where setback requirements are adjusted for aesthetic purposes.
- **Recreational use**: The availability of open space associated with buffer zones provides opportunities for a range of recreational activities. This is particularly important in urban areas where availability of open space is often lacking.

Additional buffer zone guidelines may also be applicable for particular habitats. For example, guidelines for forest buffers are contained within the draft Guidelines for Biodiversity Impact Assessment in KwaZulu-Natal (KZN) (EKZNW, 2011). These guidelines recommend that buffer widths ranging from 20 m up to 200 m are established for different forest types (measured from the forest edge). In such instances, setback requirements may need to be adjusted considerably from those initially identified.

9.6. Map recommended setback requirement based on the maximum width for water resource, biodiversity protection and additional considerations

Desktop	Site-based
	✓

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

9.7. Finalize proposed setback requirements with motivations for any deviations from recommended requirements

Desktop	Site-based
	✓

There may be instances where strong motivations can be made for encroaching on recommended setback areas. These may be linked to the management objectives of the water resource (Section 7.10) or directly to aspirations of a development proposal. Any plans of such a nature should be appropriately assessed, motivated and indicated on a revised layout plan.

10. STEP 7: DOCUMENT MANAGEMENT MEASURES NECESSARY TO MAINTAIN THE EFFECTIVENESS OF SETBACK AREAS

Once a setback area has been determined, appropriate management measures need to be determined and documented accordingly. Key aspects of the setback requirements will include:

- An aquatic impact buffer zone;
- Possible core habitat requirements;
- Possible corridor requirements; and
- Any additional aspects requiring consideration to ensure effective management of setback areas.

All of these aspects need to be taken into consideration when determining and documenting management measures necessary to maintain or enhance the effectiveness of the setback area. To do this, a buffer zone management plan is required. Management measures for each of the sections of the buffer zone management plan are discussed in the sections below.

Buffer Zone Management: The principle of buffer zone management is to ensure that measures are tailored to address the relevant potential threats from the proposed land-use / adjacent activity, while taking into consideration the site characteristics.

In addition to the key aspects that require management measures, there are also a number of additional aspects that may require consideration. For example, management measures for potential additional mitigating measures may require consideration before finalizing the setback requirements (i.e. hydrological buffers, aesthetic considerations, recreational use, etc.). Likewise, a range of other aspects associated with the effective management of setback areas may also need to be considered (e.g. regulation requirements, demarcation, rehabilitation or enhancement, etc.). A range of these aspects are discussed in Section 10.3.

10.1. Document management measures to maintain or improve the functionality of aquatic impact buffers

Desktop	Site-based
	✓

Once an aquatic impact buffer zone has been determined, management measures need to be tailored to ensure buffer zone functions are maintained for effective mitigation of relevant threat/s. Management measures must therefore be tailored to ensure that buffer zone functions are not undermined. Aspects to consider include:

- Aquatic impact buffer zone management requirements;
- Management objectives for the aquatic impact buffer zone; and
- Management actions required to maintain or enhance the aquatic impact buffer zone in line with the management objectives. Activities that should not be permitted in the aquatic impact buffer zone should also be stipulated.

Based on a review of buffer attributes (Annexure 16), it is clear that the following characteristics are particularly important in ensuring that aquatic impact buffer zones function effectively:

- The slope of the buffer;
- Vegetation characteristics (basal cover);
- Soil permeability; and
- The topography of the buffer zone.

Practically, this means that risks affecting vegetation, soil permeability (and infiltration) and buffer topography (including erosion) must be managed to ensure that aquatic impact buffer functions are retained or enhanced.

10.1.1. Buffer zone vegetation

Vegetation mechanically filters runoff, causing sediment to be deposited in the buffer zone. The more suitable the vegetation is at slowing flows and encouraging infiltration, the more effective the buffer zone is likely to be. Once infiltration has occurred, other plant characteristics affect the amount of uptake of pollutants that can occur from the subsurface flow. Whilst simply maintaining vegetation cover in the buffer zone should be a key management focus, some vegetation attributes are particularly relevant in trapping or assimilating different pollutants:

- **Sediment**: Whilst the type of vegetation (grass verse forest) appears to have little bearing on buffer zone effectiveness, the robustness and density of vegetation is important since this has a direct impact on flow rate, encouraging deposition of sediment. For this reason, buffer zone effectiveness for sediment retention can be maximized by promoting good basal cover and vegetation that is able to intercept water flow. The latter is particularly important in situations where high runoff volumes are anticipated (e.g. in climates characterized by large, intense rainfall events and sites with characteristically steep slopes and shallow or poorly drained soils).
- **Nutrients**: Information in the literature suggests that species composition can affect the ability of buffer zones to assimilate nitrate as can the productivity of buffer zone vegetation. Since phosphate is typically bound to sediment, vegetation attributes that promote sediment retention are regarded as important in assimilating both these nutrients. Due to the different modes of particulate and dissolved contaminant transport, multi-tier or combination buffers may be most effective in assimilating nutrients in surface runoff.
- **Toxins**: Removal of organic pollutants and pesticides typically requires similar buffer attributes as that for sediment retention. Likewise, removal of toxic metal contaminants typically requires similar buffer attributes for assimilating nutrients in surface runoff.
- **Pathogens**: Removal of pathogenic micro-organisms typically requires similar buffer attributes as that for sediment retention.

While there is some variability in the importance of different vegetation attributes in performing different functions, it is clear that this has a critical role to play in ensuring that buffer functions are maintained or enhanced. The key point to emphasize is that buffer zone vegetation must be managed in a reasonable state to maintain effectiveness. For this reason, management measures should be carefully documented to ensure that the site is not undermined by poor management or undesirable activities within the buffer zone.

From a management perspective, there are a range of activities which need to be considered that can negatively affect buffer zone vegetation. Typical threats to buffer zone vegetation that need to be prevented by good management include:

- Overgrazing;
- Trampling by livestock;
- Transformation (e.g. new infrastructure);
- Alien plant encroachment; and
- Undesirable burning regimes.

While a range of site-specific mitigation measures may be relevant, the following generic management measures are recommended to ensure that aquatic impact buffer zones continue to function in a suitable manner:

- Demarcation in high risk areas (refer to Section 10.3.2);
- Suitable management of livestock and pedestrian traffic. For example:
    - Grazing in riparian habitats should be avoided. Livestock generally cause damage to the banks of rivers (from trampling) and the resulting erosion can be very difficult to repair. If there are indications that an erosion problem is developing, an alternative may be to pipe water to a point away from the stream / river (SANBI, 2013).
- To not allow infrastructure that permanently destroys buffer vegetation;
- Maintenance of natural fire regimes, where appropriate, to maintain indigenous vegetation cover; and
- The application of appropriate alien plant control operations.

10.1.2. Soil characteristics

Whilst soil characteristics are determined by local geology, it is useful to understand what factors affect the ability of the buffer zone to perform various functions:

- **Sediment:** Soil characteristics affect soil drainage which has a direct bearing on time taken for soil saturation to occur and therefore surface runoff that carries soil particles. Soil texture in particular, affects infiltration and therefore the likelihood of water flow velocity being reduced as it moves through the buffer zone. This is particularly true for finer clay particles, as the more the water infiltrates the more fine sediment is trapped in the soil profile.
- **Nutrients**: The primary mechanism of phosphorous removal is co-deposition with sediments. As such, buffer zone attributes that promote sediment retention are best suited for phosphorous removal. The relationship between soil properties and nitrogen removal is more complicated with coarse soils, which are well suited for removal of sediments attached nutrients, while poorly drained soils, on the other hand, create favourable conditions for de-nitrification, by promoting the formation of anaerobic conditions.
- **Toxins**: Refer to Section 10.1.1.
- **Pathogens**: The primary mechanism for the removal of micro-organisms in runoff is infiltration (Tate et al., 2004). This is usually coupled with their adsorption to soil particles, hindering their passage to the water body, resulting in their eventual death.

From a management perspective, there are a range of activities that can negatively affect buffer zone soil characteristics which need to be considered. Typical threats to buffer zone soil characteristics include:

- Soil compaction;
- Surface-water flows that create channels, which could lead to erosion[25]; and
- General physical disturbance to the soil profile.

10.1.3. Topography of the buffer zone

Topography has an influence on the rate at which runoff flows over the landscape. Uniform topography with few areas where runoff can concentrate to form erosion gullies will lead to uniform movement across the buffer zone. Where local topography concentrates flows and increases runoff velocity, buffer zones are likely to be less effective. However, it is useful to understand what factors affect the ability of the buffer zone to perform various functions:

- **Sediment and nutrients:** The effectiveness of a buffer at reducing sediment and nutrients when flows become concentrated is reduced significantly. This suggests that buffer widths need to be increased significantly where local topography encourages concentrated flows.
- **Toxics**: Refer to Section 10.1.1.
- **Pathogens**: Refer to Section 10.1.1.

10.2. Document management measures to safeguard species and habitat over the long-term

Desktop	Site-based
	✓

A review of international literature found that, in general, significantly larger buffers are required for the protection of biodiversity that is dependent on water resources, in comparison to those adequate for providing water quality protection (as illustrated in Figure 16). Many aquatic and semi-aquatic faunal species depend upon water resources for only portions of their life cycles and they require terrestrial habitats adjacent to the water resources to meet all their life needs. Without access to appropriate terrestrial habitat and the opportunity to move safely between habitats across a landscape, it will not be possible to maintain viable populations of many species. Therefore, core habitats and corridors need to be developed for the protection of species or habitats of conservation concern.

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[25] Concentrated flow can undermine the effectiveness of buffer zones, leading to contamination of water resources from adjacent land uses. As such, it is important that concentrated flows are minimised through appropriate on-site management measures and that any erosion is quickly identified and addressed.

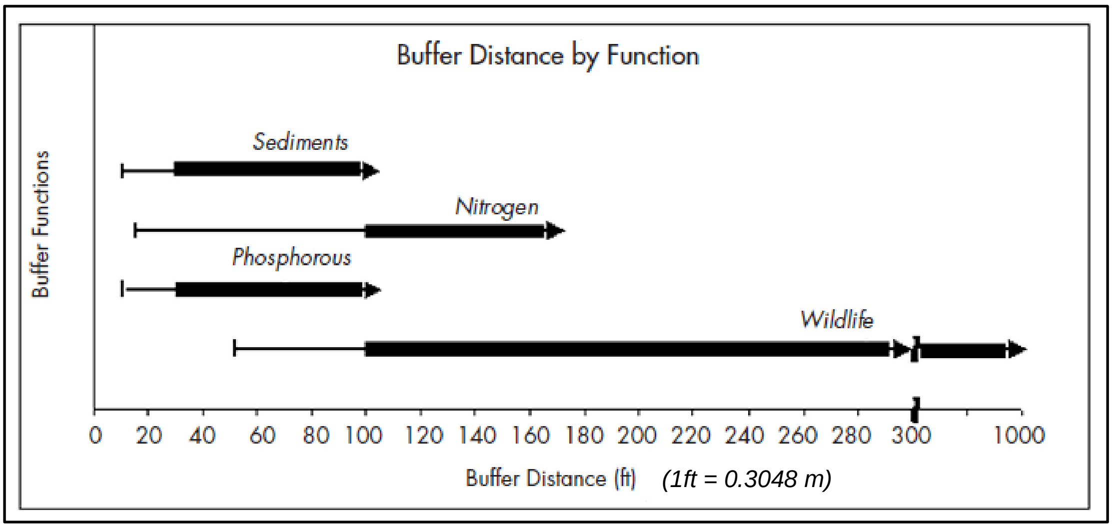

Figure 16. An illustration of the significant difference between biodiversity buffer requirements and water quality protection requirements (Nichols et al., 2008).

Once protection zones for important biodiversity elements have been identified, the next step is to define specific management measures to ensure that these features persist over the long term. Here, assessors are referred to information sheets for specific biodiversity features in which key management considerations are identified (examples are included in Annexure 18). These should be used to help develop appropriate management plans for the areas identified. Core habitat and ecological corridor management plans should include:

- Establishing the management requirements for the core habitats and / or corridors;
- Determining management objectives; and
- Determining and documenting management actions required to maintain or enhance the core habitats and corridors in line with the management objectives. In addition, activities that should not be permitted in the core habitats and corridors should be noted.

10.2.1. Core habitat management

While determining the area and distribution of a core habitat is important, it is equally important that appropriate management measures be determined to ensure the core habitat continues to function effectively. Biodiversity conservation management measures that need to be taken into consideration when determining management measures for core habitats and corridors include (adapted from SANBI, 2013):

- Habitat and species management;
- Alien and invasive species management;
- Fire management;
- Grazing management; and
- The management of soil erosion and physical disturbances.

In general, management measures aimed at maintaining natural disturbance regimes (e.g. grazing and fire) and reducing impacts from disturbance (e.g. alien vegetation) are likely to contribute meaningfully towards maintenance of habitat quality of a buffer zone. For example, the maintenance of natural vegetation structure and composition would largely cater effectively for the needs of the target species, for which the core habitat and corridor is required.

Note: Buffer averaging[26] may also be a useful tool to ensure that important habitat attributes are retained without unduly constraining development opportunities.

Management measures for biodiversity conservation will be dependent on the relevant species or habitat requirements and therefore management measures will need to be determined on a site-by-site basis. Guidelines on biodiversity conservation management are readily available in South Africa and should be used to inform biodiversity conservation management within buffer areas. In addition, it is important that the relevant conservation authorities be consulted with regards to the required specific management measures for the species or habitat of concern (which is where the recommended biodiversity information sheets in Annexure 18 would be particularly useful).

10.2.2. Ecological corridor design and management

Maintaining connectivity is another key consideration that can largely only be achieved through broader landscape scale planning initiatives. While scientific literature indicates that corridors should be hundreds of meters wide to provide functions over an extended period (Bennett, 2003), it may still be beneficial to provide narrower corridors (Granger et al., 2005). Indeed, corridors as narrow as 30 m may have some wildlife and habitat value (Desbonnet and Pogue, 1994). Design of such corridors should, however, be undertaken with due consideration of particular species, particularly where rare, threatened or endangered species are known to utilize the area. The seven step approach, as described in Annexure 19, should be used as a guideline for ecological corridor design:

Step 1
- **Identify priority species requiring protection**

Step 2
- **Understand the biology of the priority species identified**

Step 3
- **Assess whether there are other viable patches in the surrounding landscape that support priority species**

Step 4
- **Identify focal species for further consideration**

Step 5
- **Evaluate feasibility for implementing corridors**

Step 6
- **Refine the list of focal species based on the availability of suitable corridor options**

Step 7
- **Design the ecological corridor**

In addition, the following general recommendations for corridor management should be taken into consideration (Fischer and Fischenich, 2000):

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[26] An example of buffer averaging (adapted from Nichols et al., 2008): A wetland requires a 30 m minimum buffer, however, a 20 m buffer over part of its margin may be tolerated if a wider buffer is provided along another part. This may depend upon such issues as water flow, topography, habitat and species needs, and other factors that can best be assessed on a case-by-case basis.

- Many semi-aquatic and aquatic species may at some stage of their life cycle need to use corridors for habitat, movements, or dispersal.Therefore management of corridors should be considered at a landscape level;
- Corridors that maintain or restore natural connectivity are better than those that link areas historically unconnected;
- Continuous corridors are better than fragmented corridors;
- Wider corridors are better than narrow corridors;
- Riparian corridors are more valuable than other types of corridors because of habitat heterogeneity, and the general availability of food and water;
- Several corridor connections are better than a single connection;
- Structurally diverse corridors are better than structurally simple corridors;
- Indigenous vegetation in corridors are better than non-indigenous vegetation; and
- Practical ecological management of corridors should mimic naturally occurring processes.

10.3. Additional aspects requiring consideration to ensure effective management of setback areas

Desktop	Site-based
	✓

There are many aspects that need to be considered to ensure that, once established, setback areas continue to provide their required functions. Overlooking these aspects, discussed below, may result in the degradation of setback areas over time.

10.3.1. Regulating aquatic impact buffer zones

The responsibility for managing or maintaining a buffer required to mitigate the impacts of an adjacent land-use / activity is suggested to be either the developers or the landowners. They will need to be responsible for ensuring that management measures required, both during the construction and operation phases (and if necessary the decommissioning / closure phase) of the development, are implemented. To achieve this, buffer management measures should be included in the Environmental Management Plan[27] (EMP) for the proposed development.

10.3.2. Aquatic impact buffer zone demarcation

Clearly delineating and marking a buffer zone will help to ensure that it is not degraded over time (Granger et al., 2005). Once a project has been approved, and prior to construction, the buffer should be measured and clearly marked on the ground.

Granger et al. (2005) suggests that during the construction phase, erecting a temporary sediment fence will help to ensure that the boundary is clearly demarcated. Likewise during the operational phase, erection of a permanent fence may be desirable, particularly in an urban environment where uncontrolled human access could result in trampling of vegetation and subsequent erosion. Active exclusion may also be appropriate in intensive livestock operations where over-use could lead to a reduction in vegetation condition and stream bank collapse. Where buffer zones are established with a clear emphasis on biodiversity protection, fencing off the boundary may also be important to reduce noise and light intrusion and to limit direct disturbance to wildlife.

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

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

10.3.3. Aspects that may require the expansion of the aquatic impact buffer zone

In documenting the management measures, it is important to consider additional aspects that may require the buffer zone to be expanded further. For example:

- Fire breaks: These are particularly relevant in circumstances where buffer zone habitat is prone to outside disturbance or requires regular fire management to maintain the vigour of indigenous vegetation[28].
- There may also be a strong motivation to establish a management buffer to prevent damage to important intact areas such as indigenous riparian areas. Examples of where this should be considered include:
  - Forestry activities where felling of trees and other operational activities could damage adjacent habitat[29]; and
  - Industrial or similar activities where a physical barrier is required to limit the risk of machinery impacting important conservation areas.

Note: In the case of intact indigenous riparian areas, where the setback requirement is determined to be the edge of the riparian area, consideration of a ‘riparian edge management buffer’ to protect the edge of the riparian area is advised (i.e. this would be in addition to the aquatic impact buffer zone).

10.3.4. Maintenance of supporting mitigation measures

In many instances, aquatic impact buffer zones may be reduced based on a commitment to implement effective alternative mitigation measures. It is therefore essential that these additional mitigation measures are managed effectively to ensure that contaminant risk is minimized and that erosion or smothering of buffer zone habitat does not take place. Specific requirements necessary to ensure the ongoing functioning of these measures must therefore also be clearly documented in environmental management plans / programmes and be enforced through regular monitoring.

10.3.5. Buffer zones in urban areas

According to Granger et al. (2005), a frequent concern about buffers is their relevance to urban areas. The concerns generally fall into two categories:

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[28] This is typically the case in forestry areas where buffers need to be wide enough to facilitate burning without such activities placing an unacceptable risk on plantation areas.

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

- The science on buffers comes largely from sectors such as the agricultural and forestry sector, and are therefore perceived to be irrelevant to urban areas; and
- The need to maximize density of development in urban areas is in direct conflict with the protection of riparian and terrestrial habitat adjacent to water resources.

Granger et al. (2005) suggests that the concern over the relevancy of the literature on buffers to urban areas is largely unfounded. Buffers do not function any differently in urban settings. The same processes of sediment, nutrient, toxins and pathogen removal operates similarly in urban areas as they do in non-urban areas. In an urban setting it could be argued, for example, that a good storm water management program could reduce the need for buffers to perform filtration functions to the same level as those in non-urban areas. The role of buffers in providing needed habitat for aquatic, semi-aquatic and terrestrial species, and in screening adjacent noise and light is also performed similarly. In fact, a case can be made that buffers in urban areas are even more important from a habitat perspective because there is little other habitat available. Factors that may differ in urban areas are that urban water resources may perform some functions at a lower level because of degradation, and that species diversity may be lower. However, remaining water resources in urban areas may, in fact, function as habitat islands and be critical to many species (Granger et al., 2005). Generally, the protection of habitat functions of water resources requires larger buffers than those used to protect water quality functions. However, the best way to address the issue of buffers in urban areas is to conduct an assessment of water resources at a landscape level, and develop a plan that identifies, prioritizes and protects the most important water resources. In addition, the use of relevant alternative mitigating measures might help to find a balance between development and protection of water resources.

10.3.6. Rehabilitation or enhancement of buffer zones

Existing or previous land-use practices often impact / alter the terrestrial habitat adjacent to water resources. These impacts generally include the clearing of vegetation, significant degradation of the vegetation and soil, and / or the presence of alien invasive vegetation. In these situations, simply providing a buffer with a set width is likely to fail to provide the necessary characteristics to protect a water resource’s functions (Sheldon et al., 2005). Rehabilitation will therefore be required to restore buffer functionality.

In other cases, a buffer zone may be in relatively good condition but still be sparsely vegetated with trees and shrubs. In such cases, to ensure the relevant functions are provided, it may be desirable to improve the screening and habitat value of the buffer by planting additional trees and shrubs or other vegetation appropriate to the vegetation type for the ecoregion. Generally, for buffer zones to function effectively they need to be well vegetated, and largely with indigenous vegetation (Sheldon et al., 2005). This assumption should guide rehabilitation or enhancement of buffer zones.

In cases where the area available for a buffer may not be well vegetated, it may be necessary to either increase the buffer width or require that the recommended buffer zone be rehabilitated. When buffer rehabilitation is required, indigenous vegetation for the ecoregion of concern should be used for re-vegetation purposes. Buffer rehabilitation will also require the same diligence as is prescribed in wetland rehabilitation, and should therefore require monitoring to ensure success.

Note: The relevant authorities should be consulted as to whether or not a developer / landowner will be given the option of rehabilitating the recommended buffer or forego rehabilitation / enhancement and allow a wider but poorly vegetated buffer (this allowance would not apply to category 1 and 2 alien invasive plant species).

10.3.7. Buffer zones and climate change

The effects of climate change are likely to add to the challenges of managing aquatic resources. Therefore the development of setback areas should ideally cater for the potential impacts of climate change. At best, a precautionary approach should be taken when determining setback requirements, thus ensuring adequate measures are taken to address potential impacts resulting from the effects of climate change.

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

11. STEP 8: MONITOR IMPLEMENTATION OF BUFFER ZONES

Monitoring the effectiveness of determined setback areas and the recommended management measures for the relevant aspects of the setback area is vital for ensuring its effectiveness. In keeping with the approach for determining and documenting management measures, monitoring implementation should include:

- Determining monitoring objectives and indicators of buffer zone effectiveness; and
- Designing a monitoring program (e.g. timing, methods, etc.) for achieve the monitoring objectives.

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

In compliance with the requirements of an Environmental Management Plan (EMP), the Environmental Officer and / or the Environmental Control Officer should be checking that the following aspects are being effectively implemented:

- The setback area has been demarcated clearly;
- Disturbances are being managed effectively;
- Possible rehabilitation is being successfully implemented; and
- Required management measures are being effectively implemented.

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

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

In addition, where rehabilitation or some form of enhancement of a buffer is required, it is essential that the maintenance of the buffer zone be monitored. A monitoring / maintenance program should include evaluation of the rehabilitation measures and provide for alternative mitigation measures to aid the buffer in achieving its required function. The developer or landowner should be responsible for any maintenance or monitoring.

Likewise, it is also important to monitor buffer zones when human use is allowed or anticipated (Granger et al., 2005). If monitored, adverse effects of human access, such as vegetation trampling, littering and soil compaction or erosion, could be addressed before there is a negative impact on the water resource. In some scenarios, it may also be appropriate to implement an ecological monitoring programme to ensure that mitigation measures are effective at addressing potential impacts to water resources. This is likely to be particularly important in high risk situations and should be based on specialist input and input from regulating authorities.

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

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

12. CONCLUSIONS AND RECOMMENDATIONS

The development of the preliminary guideline for determining buffer zones for rivers, wetlands and estuaries required a comprehensive literature review to be undertaken at the onset of the project. This provided the platform for the development of a conceptual framework to work within. Once the framework was conceived, the step-wise approach to determining buffer zones was developed. The eight-step assessment procedure provides the user with a step-by-step approach to determining appropriate buffer zones, or rather setback areas, which take into consideration the following:

- The aquatic impact buffer zone;
- Potential core habitats;
- Potential ecological corridors; and
- Possible additional aspects that will influence the final setback area or the management of the setback area.

The assessment procedure detailed in this report, as well as the management practices that need to be taken into consideration, provide the guidelines for determining and managing appropriate buffer zones. The Buffer Zone Tools developed in conjunction with this report provide the user with the primary tool for determining appropriate buffer zones (included on the accompanying CD). In addition, the supporting documents provided as annexures to the report, either in hardcopy or as electronic copies on the accompanying CD, provide extensive background information.

While a sound scientific approach was adopted for the development of the preliminary guideline for determining buffer zones, a number of assumptions and limitations were identified, these included:

- Whilst the threat assessment was informed by readily available scientific literature, there was limited information available for some sub-sectors. As such, threat ratings should be seen as preliminary and subject to further verification. This has been catered for in the Buffer Zone Tools by making provision for specialists to review the preliminary threat ratings.
- Rule curves to inform buffer requirements were developed based on an interpretation of best available science at the time of the assessment. It is, however, important to note that there was high

variability in reported buffer efficiencies for different contaminants and therefore these rule curves should be seen as an initial approximation. These should be reviewed and refined in time to cater for more up-to-date information.
- Whilst minimum buffer requirements have been recommended to address some risks associated with modelled outcomes and management risks, it is essential that such buffer zones be appropriately managed to maintain their effectiveness. If this is not done, there is a real risk that buffer zones will not perform functions in line with expectations.
- Whilst testing of the Buffer Zone Tools was undertaken as part of this project, the tools have subsequently been updated following feedback from the project team and steering committee members. There is therefore a risk that some errors may be present in the Buffer Zone Tools. It is hoped that any teething problems will be addressed during further testing of the preliminary versions.
- It is recognize that biodiversity considerations are largely dependent on species information sheets being developed. While some examples have been compiled as part of this project, these should be viewed as preliminary and subject to further specialist input. It is hoped that conservation agencies will take-up the challenge to develop information sheets for priority species to better inform protection requirements.

The decision to only release a preliminary guideline for buffer zone determination was because the project team and the WRC steering committee agreed that a second phase to the project will be required. The primary objective for a second phase would be to provide practitioners (i.e. specialists, authorities and key stakeholders) with an opportunity to learn how to use the Buffer Zone Tools developed. It is envisaged that a series of national training and development workshops will be held to firstly train participants, and secondly obtain feedback from users to further refine the guideline document and Buffer Zone Tools. In following this approach there may also be an opportunity in the future to incorporate additional aspects, for example the inclusion of possible buffer requirements to mitigate issues such as groundwater and / or airborne contaminants.

It is hoped that this preliminary guideline for the determination of buffers for rivers, wetlands and estuaries provides the initial tools to meet the demand for a scientifically defensible approach to determining buffer zones. Furthermore it is hoped that over time (i.e. a second phase to the project) there will an opportunity to refine the preliminary guideline document and Buffer Zone Tools.

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14. ANNEXURES

Annexure 1 – Deliverable 1: Literature review *(electronic copy only – refer to the CD provided)*

Annexure 2 – Deliverable 11: Practical testing *(electronic copy only – refer to the CD provided)*

Annexure 3 – Range of management measures available to address threats posed to water resources

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

THREAT	LOCATION OF THREAT	SOURCE OF THREAT	PRIMARY MANAGEMENT MEASURES
Changing the amount of water (increasing or decreasing the amount)	Upstream catchment	• Direct abstraction • Abstraction from groundwater • Impoundments and associated increased evaporation losses • Stream flow reduction activities • Invasion by woody alien invasive plants • Inter-basin transfers	• Licensing of water use (including groundwater abstraction) • Protection of groundwater reserves • Reserve determination • Water resource classification • Setting and monitoring of Resource Quality Objectives • Alien plant control activities
	Adjacent land use	• Abstraction from groundwater lowering water levels • Stream flow reduction activities • Invasion by woody alien invasive plants • Discharge of water from outside catchment (e.g. grey water from municipal supply) • Diversion of water away from water resource (e.g. irrigation)	• Limiting impacts to preferential recharge areas • Restriction of SFR activities (***including maintenance of buffer zones***) • Alien plant control activities • Preventing diversion of water
	Within water resource	• Direct abstraction from water resource • SFR activities in the water resource • Invasion by woody alien invasive plants • Extra water into the water resource	• Management of abstraction • Restriction / removal of SFR activities • Alien plant control activities • Management of point discharges
Changing the fluctuation of water levels (frequency, amplitude, direction of flow)	Upstream catchment	• Impoundments upstream of water resource • Inter-basin transfers • Development leading to hardened surfaces in catchment • Poor land management leading to reduced basal	• Management of releases from impoundments (allowance for natural floods) • Stormwater detention and treatment • Sound land management practices

THREAT	LOCATION OF THREAT	SOURCE OF THREAT	PRIMARY MANAGEMENT MEASURES
		cover	
	Adjacent land use	• Hardened surfaces leading to increased runoff intensity • Storm water drains and associated discharge	• Storm water detention and treatment • Prevention of canalized flows • **Buffer zones to mitigate diffuse flows**
	Within water resource	• Development within water resources • Drainage to minimize flooding • Impeding features redirecting flows • Alteration of surface characteristics (roughness) • Direct water losses • Impoundments causing flooding	• Control of activities directly impacting on water resources • Blockage of drainage channels • Demolition of impeding features • Rehabilitation / restoration of vegetative cover • Management of on-site water use • Decommissioning of impoundments
Changing the amount of sediment entering water resource and associated change in turbidity (increasing or decreasing the amount)	Upstream catchment	• Impoundments upstream of water resource (sediment trapping) • Breaching of dams (scouring) • Poor land use management (increased sediment supply) • Changes in water inputs resulting in elevated flows and associated erosion • Road infrastructure (density and management) • Mining operations (e.g. coal and gold mines)	• Sound land management practices • Management of road infrastructure • Dam construction techniques (dam safety) • **Implementation of buffers at a catchment-scale to reduce sediment inputs**
	Adjacent land use	• Bulk earthwork activities • Disturbance of soil surface • Disturbance of slopes through creation of roads and tracks • Poor land management • Inappropriate burning • Changes in runoff characteristics	• Implementation of best-management practices ○ Roads and associated drainage ○ Earthwork activities ○ Fire and livestock management ○ Agricultural activities • Source-directed controls • **Buffer zones to trap sediments**
	Within water resource (geomorphology)	• Channel straightening (reducing flooding) • Artificial infilling (affecting water distribution) • Erosion (e.g. gully formation, bank collapse) • Peat extraction • Sand winning • Dredging • Clearing of natural vegetation up to stream banks	• Active rehabilitation • Management of sediment removal activities (permits)

THREAT	LOCATION OF THREAT	SOURCE OF THREAT	PRIMARY MANAGEMENT MEASURES
		- Stock-trampling and overgrazing	
Alteration of water quality – increasing the amounts of nutrients (phosphate, nitrite, nitrate)	Upstream catchment	- Disposal or discharge of human (including partially treated and untreated sewage) and animal debris and excrement into water resources - Runoff from agricultural activities such as the large-scale concentration of livestock (feedlots) - Over-use of nitrate-based fertiliser, for example limestone ammonium nitrate, etc. - Orthophosphates applied to agricultural or residential lands as fertilizers and carried into the surface water during storm events - Activities that influence the oxidising or reducing circumstances in the Nitrogen-cycle, such as aeration or acidification - Activities that disturbs bedrock which is high in elemental nitrogen (N) such as excavation, ploughing, building, and mining (Bossman et al., 2009[30]) - Runoff from land areas being mined for phosphate deposits - Industrial discharges (e.g. sugar and dairy industries) - Elevated phosphorous levels in urban sewage from use of household products, such as toothpaste, detergents, pharmaceuticals, and food-treating compounds - Runoff / leachate from solid waste disposal sites	- Licensing of water use (including point-source discharges) - Provision of sanitation facilities - Management of waste-water facilities - Source-directed controls for agricultural activities - Management of mining activities - **Implementation of buffers at a catchment-scale to reduce water quality impacts**
	Adjacent land use	- As above	- **Rehabilitation / maintenance of riparian zone** - **Establishment of buffer zones to reduce nutrient inputs in diffuse flow** - Implementation of appropriate stormwater management around the excavation to

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

THREAT	LOCATION OF THREAT	SOURCE OF THREAT	PRIMARY MANAGEMENT MEASURES
			prevent the ingress of run-off into the excavation. This will reduce the volume of pit water that is contaminated with **nitrate**, which would reduce the costs associated with the management of this water. • Implementation of appropriate stormwater management around rock dumps through the establishment of a clean and dirty water system, which would reduce the volume of run-off contaminated with **nitrate** from the rock dumps. • Implementation of appropriate containment measures for all impoundments used to store contaminated water, such as pollution control dams, return water dams and tailings dams, such as clay and plastic linings
	Within water resource	• Defecation by livestock • Point-source discharges of waste water	• Management of livestock • Source directed controls
Alteration of water quality – **toxic contaminants (including toxic metal ions (e.g. copper, lead, zinc), toxic organic substances (reduces oxygen), hydrocarbons and pesticides)**	Upstream catchment	Toxic metal ions • Mining operations, leading to the release of toxic metal ions • Purification of metals, e.g., the smelting of copper and the preparation of nuclear fuels • Industrial discharge (e.g. electro-plating, tanning, smelting activities) • Urban runoff containing lead from road surfaces Toxic organic substances • Spray drift from pesticides • Runoff of pesticides from agricultural lands • Careless disposal of pesticide containers • Release of household pesticides. • Discharge of solvents, and other industrial	Toxic metal ions • Mining: Implementation of appropriate containment measures for all impoundments used to store contaminated water, such as pollution control dams, return water dams and tailings dams, such as clay and plastic linings • Control of waste discharges • Guidelines for implementing Clean Technologies • Environmental management systems (such as ISO14001), which seek continuous improvement in environmental management.

THREAT	LOCATION OF THREAT	SOURCE OF THREAT	PRIMARY MANAGEMENT MEASURES
		chemicals • Discharge of pharmaceuticals and personal care products through excretion or disposal by flushing.	Toxic organic substances • Control of pesticide application, particularly in proximity to water resources
	Adjacent land use	As above	• As above • **Maintenance of riparian zones** • **Establishment of buffer zones (especially wooded areas) to catch spray drift and trap sediments with associated toxics**
Alteration of water quality – acidity (pH)	Upstream catchment	• Acid mine drainage (AMD), or acid rock drainage (ARD), from abandoned and active **metal** mines or coal mines • Runoff from coal stocks, coal handling facilities, coal washers, and coal waste tips	• Controlled placement of overburden or management of water to prevent AMD (involves methods to minimize or neutralize the formation of AMD. According to the generally accepted chemical equations for pyrite oxidation, oxygen and water are necessary to initiate acid formation. Exclusion of either reactant should preclude or inhibit acid production) • Limestone chips may be introduced into sites to have a neutralizing effect. • Constructed wetlands to filter out heavy metals and raise pH
	Adjacent land use	• As Above	• AS above
Alteration of water quality – concentration of salts (salinization)	Upstream catchment	• Return flows from irrigated croplands • Fertilizers and biocides applied to agricultural croplands • Mine drainage (e.g. coal and gold mines) • Point-source releases of salts from industrial plants (e.g. Tanneries)	• Control of water use and point source discharges
Alteration of water quality – **temperature**	Upstream catchment	• Overflow or release from impoundments • Release / discharge from industries	• Design of overflow structures • Control of point-source discharges
	Adjacent land use	• Removal / damage to riparian zone, important for	• **Protection / re-establishment of**

THREAT	LOCATION OF THREAT	SOURCE OF THREAT	PRIMARY MANAGEMENT MEASURES
		shading • Release / discharge from industries • Runoff from hardened surfaces	**riparian zone to shade water resource** • Establishment of buffer zones to allow cooling of water before entering water resources
Alteration of water quality – pathogens (.e. disease-causing organisms)	Upstream catchment	• Wash from animal feeding operations • Release from municipal wastewater treatment plant effluents • Discharge of partially treated sewage from malfunctioning on-site systems (e.g. septic tanks), • Treated sewage sludge (bio-solids) for crop and landscape irrigation. • Application of untreated manure as fertilizer on agricultural lands	• Placement and management of animal feeding areas • Implementation of microbial standards for reclaimed wastewater • Implementation of best-practice guidelines for construction of waste water systems • Composting of manure to effectively eliminate pathogens
	Adjacent land use	• Wash from animal feeding operations • Discharge of partially treated sewage from malfunctioning on-site systems (e.g. septic tanks), • Treated sewage sludge (bio-solids) for crop and landscape irrigation. • Application of untreated manure as fertilizer on agricultural lands	• **Placement and management of animal feeding areas** • Implementation of microbial standards for reclaimed wastewater • Implementation of best-practice guidelines for construction of waste water systems • Composting of manure to effectively eliminate pathogens • **Establishment of buffer zones to help trap pathogens before reaching water resource**
	Within water resource		• Drainage inflows eliminated or managed
Changing the physical structure within a water resource (habitat)	Upstream catchment	• Alteration of hydrological regime • Alteration in sediment regime • Alteration of water quality	• See relevant sections
	Adjacent land use	• Encroachment to achieve maximum commercial returns • Loss of fringing vegetation and erosion from stock trampling • Loss of fringing vegetation to provide aesthetic views • Alteration in natural fire regimes	• Delineation and protection of water resource • **Establishment of buffer zones to limit disturbance** • Weed control in buffer zone • Barriers to prevent trampling / damage to buffer zone

THREAT	LOCATION OF THREAT	SOURCE OF THREAT	PRIMARY MANAGEMENT MEASURES
		• Shading of natural vegetation	• Introduction of fire break and appropriate burning regime
	Within water resource	• Infrastructure development (e.g. housing, bridges, etc.) • Canalization or diversion of watercourses • Mining within water resources • Inundation by impoundments • Cropping and pastures • Encroachment by alien invasive plants • Overgrazing and trampling by livestock • Sports fields & gardens • Seepage below dams • Alteration in natural fire regimes	• Restricting developments with direct impact on water resources • Removing of crops and pastures and associate re-vegetation • Alien invasive plant control within water resource • Control of livestock numbers • Introduction of fire break and appropriate burning regime
Other disturbances	Adjacent land use	• Noise from urban areas and transportation networks • Light pollution from residential / industrial developments • Physical disturbance through hunting or recreational activities • Dust pollution from exposed areas, active earthworks and dirt roads	• Restrict development away from water resources with threatened species sensitive to disturbance • **Construction of barriers (including buffers) to reduce disturbance** • Use fencing or other means to control access • Use best management practices to control dust
	Within water resource	• Physical disturbance through direct human presence	• Restrict access, particularly where sensitive species occur

Annexure 4 – National and/or sub-national (CAPE) priority estuaries *(electronic copy only – refer to the CD provided)*

Annexure 5 – Estuary importance scores for all South African estuaries *(electronic copy only – refer to the CD provided)*

Annexure 6 – Description of sectors and sub-sectors included in the threat assessment

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
Agriculture	Agricultural-based land-use activities that range from the large-scale commercial production of crops and timber to small-scale subsistence crop farming and livestock rearing. May be associated with rural and / or urban contexts.	**Forestry / timber**	Includes the planting and harvesting of various species of non-indigenous trees (pine, wattle, gum) but also includes intensive planting and harvesting of indigenous species.
		Nurseries and tunnel farming operations	Intensive agricultural activities, associated with the production of flowers, vegetables or other plant materials (e.g. flower farms and crops in tunnels).
		Dryland commercial cropland – Annual rotation	The agricultural production of produce including crops, vegetables or other plant material using conventional tillage cultivation with no irrigation and requiring annual re-establishment.
		Dryland commercial cropland – infrequent rotation	The agricultural production of produce including crops, trees, seeds, fruit, or other plant material using conventional tillage cultivation with no irrigation. Re-establishment takes place on a bi-annual or more infrequent basis.
		Irrigated commercial cropland	The agricultural production of produce including crops, trees, seeds, fruit, vegetables or other plant material using conventional means of irrigation.
		Subsistence cultivation	Communal land used for the cultivation of crops and for livestock grazing activities. Typically involves less intensive use of machinery, with lower nutrient and fertilizer inputs than commercial operations.
		Extensive livestock grazing operations	Includes the rearing and husbandry of a range of domestic livestock (e.g. cattle, sheep, horses, goats) on areas of natural or largely natural pastures without irrigation.
		Intensive livestock grazing operations	Includes the rearing and husbandry of a range of domesticated livestock (e.g. cattle, sheep, horses, goats) on

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
			enhanced pastures, typically supplemented with irrigation.
		Concentrated livestock operations	Livestock intensive operations associated with areas of concentrated animal activities including (1) Dairies; (2) Piggeries; (3) Poultry Facilities; (4) Stables, (5) Sale yards (6) Feedlots and (7) Zoos.
		Sludge dams associated with concentrated livestock operations	Sludge dams containing waste water from intensive livestock operations.
		Aquaculture or marine culture	Commercial production including the breeding, hatching, rearing or cultivation of marine, estuarine or freshwater organisms, including aquatic plants or animals (such as fin fish, crustaceans, molluscs or other aquatic invertebrates but not including oysters).
Industry	Includes a range of industrial activities from light industrial with limited impacts on surrounding land use, to hazardous or noxious industry with high impact on surrounding land use. Includes activities such as the processing of resources and storage of manufactured materials and products.	**High-risk Chemical industries**	Industries that produce/manufacture batteries (acid and alkaline), paint solvents, petrochemicals, explosives, radioactive materials, pharmaceuticals, pesticides, herbicides, fungicides, rodenticides, nematocides, miticides, fumigants and related products.
		Chemical storage facilities	Includes facilities to store or package chemical substances in containers, bulk storage facilities, stockpiles or dumps.
		Drum / container reconditioning	Industries that recondition and package containers (including metal, plastic or glass drums, bottles or cylinders) previously used for the transport of storage or substances classified as poisonous or radioactive.
		Paper, pulp or pulp products industries	Industries that manufacture paper, pulp or pulp-related products.
		Petroleum works	Industries that: (1) refine crude petroleum, shale oil or natural gas; (2) Manufacture petroleum products (including aviation fuel, petrol, kerosene, mineral turpentine, fuel oils, lubricants, wax, bitumen, liquefied gas and the precursors to petrochemicals, such as acetylene, ethylene, toluene and xylene); or (3) Dispose of oil waste or petroleum waste or process or recover oil waste or petroleum.
		Breweries/distilleries	Industries responsible for the production of alcohol-based products such as ethanol and beer.
		Cement/concrete works	Industries involved in the production of quicklime including the use of argillaceous and calcareous materials in the production

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

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
		Medium Impact Mixed-use	A mixed-use area where the full range of residential, businesses, offices, service and light industries, civic and social, educational and environmental uses are freely permitted but excludes other forms of industry.
		Low Impact Mixed-use	Includes areas where a full range of residential, businesses, offices, civic and social, educational and environmental uses are freely permitted, and under certain conditions light industry might be permitted but excludes other industrial uses, and which can act as an interface between residential and higher impact non-residential uses or major traffic routes. The general level of amenity is intended to be good.
		Multi-Purpose Retail and Office	Land use that provides for the development of a full range of shopping centre types and can comprise a mix of retail, office, residential and entertainment uses. Examples include: Commercial / Business; Hawking / Informal Trading; Laundrette; Parking Garage; Restaurant ; Shop; Spaza; Take Away / Fast Food; Tavern / Bar.
		Petrol station / Fuel depot	Land designated for buildings used for the sale of motor fuels, lubricants, motor spares and motor accessories.
		Maintenance and repair facilities	Facilities for the repair and maintenance of vessels, vehicles or other machinery. Includes workshops, service yards, etc.
		Offices	This includes all office development as the primary developmental focus in suburban and peripheral locations, adjacent to shopping centres or a mixed-use core, or as independent zones. Forms of office development may include: Doctor's Consulting Rooms; Home Business; Office Building; Private Clinic; Professional Office.
Civic and Social	This category includes buildings and land associated with public and private service providers and administrative or government functions including education, health, pension offices, museums, libraries, correctional facilities and community	**Government and municipal**	Buildings to be used for National, Provincial and Municipal administration and services.
		Place of worship	Buildings or portion of a building to be used as a church, chapel, oratory, synagogue, mosque, and temple.
		Education	Educational facilities, including infants, pre-primary, primary, secondary, tertiary and adult education and training with associated buildings.
		Cemetery	Land used for public and private cemeteries, memorial parks, funeral chapel and crematoria.
		Health and Welfare	Buildings for public and private hospital, medical centres,

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
	halls.		clinics, sanatoria, community care, welfare and social requirements.
Residential	Provides for land and buildings for a variety of housing types, ranging from areas that are almost entirely residential to those areas having a mix of other compatible land uses, where the predominant land use is residential.	**Residential Low impact / Residential only**	Includes buildings for a variety of housing types with a limited number of compatible ancillary land uses permissible so as to cater for every day needs of the residents. The building density is likely to be low (<1unit/acre) and the amenity high, and generally in harmony with the natural environment.
		Residential Medium Impact	Buildings for primary residential land uses with an increasing number of appropriate ancillary land uses to satisfy local demands and convenience. The residential density may also increase which will increase the impact of the residential land use on the area. Housing density of <1unit/acre: Includes tourism cottage settlements, smaller cluster complexes, family hotels, B&B Lodges.
		High density urban – Residential High Impact	Comprises the full range of residential accommodation and a wide variety of services and activity mix to cater for broader community needs. The residential density is likely to be higher (>1unit/acre) thus increasing the impact of the residential use on the area and requiring additional retail, civic and social and service activity to serve the needs of the community.
		Resort	Accommodation in the form of lodges, bush camps, cultural villages and bed and breakfast establishments within a rural setting.
		Hotel	The development of a licensed hotel. Accommodation and public lounge and bar areas may be provided as well as other recreational facilities and parking.
		Informal settlements	Housing density of >1unit/acre: intensive rural housing development such as formal/informal settlements.
Open space	Areas defined as open space include a range of land-uses with minimal infrastructural development, such as parks, gardens and off-road trails. Includes areas set aside for preservation and conservation because	**Parks and gardens**	Land which is either publicly or privately owned/managed as part of the sustainable open space system and the local authority's environmental services. It includes independent or linked open space areas and green lung areas such as parks, lawns and gardens for sporting and recreational activities.
		Sports fields	Land which is typically grassed and regularly maintained for sporting activities.
		Golf courses – fairways	The part of a golf course covered with short grass and extending from the tee to the putting green and maintained

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
	they provide ecosystem services, are unique natural landscapes, viewpoints, areas of ecological, historical and/or cultural importance, bio-diversity, and/or have unique, rare or endangered habitats or species.		through regular mowing.
		Golf courses – tee boxes and putting greens	Small areas of a golf course with very short grass that are heavily manicured to maintain the condition of the grass surface.
		Maintained lawns and gardens	Areas of lawn and gardens of introduced species, typically requiring maintenance (fertilization, and / or irrigation).
Transportation infrastructure	Land used to provide for developments and buildings associated with public and private transportation in all its forms.	**Paved roads**	Land that has been provided for the full range of road infrastructures within rural and urban areas. Roads that have been paved/asphalted (includes major roads and freeways, as well as bridges over waterways).
		Unpaved roads	Land that has been provided for the full range of road infrastructures mainly within rural areas. Including dirt tracks and gravel roads that have not been formerly paved / asphalted.
		Paved trails	Small trails that have been constructed by paving/asphalting.
		Unpaved tracks and trails	Unpaved tracks and trails used for recreational purposes (e.g. biking/jogging)
		Parking lots	Extensively asphalted/paved areas used for the parking of vehicles.
		Airport – runways and taxiways	Tarred runways and taxiways associated with private and commercial airports used by various forms of commercial and private aircraft.
		Railway	Commuter, passenger and goods railway infrastructure within the rural and urban context. Activities include one or more of the following: installation of track; on-site repair of track; onsite maintenance of track; on-site upgrading of track; construction or significant alterations; operation of rolling stock on track.
Service infrastructure	Land use relating to the provision of all necessary utility services such as communication, municipal waste handling facilities and associated transfer	**Above-ground communication/power (electricity) infrastructure**	Above-ground infrastructure designed for the transfer of power (electricity cables) or data (telephone lines).
		Below-ground communication/power (electricity) infrastructure	Below-ground infrastructure designed for the transfer of power (electricity cables) or data (underground data cables).

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
	pipeline infrastructure for fuels and water.	**Hazardous waste disposal facility**	Facilities for the disposal of Hazardous Waste, as analysed and characterised according to SABS Code 0228, the Basel Convention and Appendix 9.2 "Hazardous Waste Classification Tables", of the Department of Water Affairs and Forestry's Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste. Material with a Hazard Rating 1 (extreme risk) or Hazard Rating 2 (high risk) can only be disposed of at a permitted landfill with an H:H classification.
		General solid waste disposal facility	Facilities such as landfills for the disposal of household waste, builder's rubble and industrial waste that is not classified as hazardous.
		Sewage treatment works	Treatment works and associated infrastructure including pumping stations, sewage overflow structures and the reticulation system.
		Septic tanks and french drains	Septic tank and french drains used in residential areas for the bacterial treatment and distribution of waste water.
		Sludge dams associated with concentrated livestock operations	Sludge dams containing waste water from intensive livestock operations.
		Pipelines for transportation of hazardous substances	Pipelines (above or underground) for the transportation of fuels and related chemicals.
		Pipelines for the transportation of waste water	Pipelines for the transportation of waste water (e.g. sewage) to treatment facilities.
Mining	This class comprises all mining-related activities including surface and sub-surface mining, quarrying and dredging for the extraction of minerals or materials, including sand and stone.	**Prospecting (all materials)**	Prospecting activities including excavation of test-pits
		High-risk mining operations	Mining operations (including mine and mine waste) posing a high water quality risk to water resources including mining of the following substances: Antimony (Large mines), Asbestos, Base metals (Copper Cadmium, Cobalt, Iron ore, Molybdenum, Nickel, Tin, Vanadium) – sulphide ore, Coal, Gold, silver, uranium.
		Moderate-risk mining operations	Mining operations (including mine and mine waste) posing a high moderate risk to water resources. Includes underground mining of the following substances: Antimony (Small mines), Base metals (Copper Cadmium, Cobalt, Iron ore, Molybdenum, Nickel, Tin, Vanadium) – oxide ore, Chrome, Diamonds and precious stones, Phosphate, Platinum,

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
			Magnesium, Manganese, Mineral sands (Ilmenite, Titanium, Rutile, Zircon), Zinc and Lead, Industrial Minerals (Andalusite, Barite, Bauxite, Cryolite, Fluorspar)
		Low-risk mining operations	Mining operations (including mine and mine waste but excluding underground mining operations) posing a low water quality risk to water resources including mining of the following substances: Antimony (Small mines), Base metals (Copper Cadmium, Cobalt, Iron ore, Molybdenum, Nickel, Tin, Vanadium) – oxide ore, Chrome, Diamonds and precious stones, Phosphate, Platinum, Magnesium, Manganese, Mineral sands (Ilmenite, Titanium, Rutile, Zircon), Zinc and Lead, Industrial Minerals (Andalusite, Barite, Bauxite, Cryolite, Fluorspar)
		Plant and plant waste from mining operations – high risk activities	Waste generated from plant and plant waste from processing of minerals and metals extracted from the ground, which pose a high water quality risk to water resources. These include: Antimony (Large mines), Asbestos, base metals (Copper Cadmium, Cobalt, Iron ore, Molybdenum, Nickel, Tin, Vanadium), Chrome (Large mines), Coal, Gold, silver, uranium, Zinc & Lead
		Plant and plant waste from mining operations – moderate risk activities	Waste generated from plant and plant waste from processing of minerals and metals extracted from the ground, which pose a moderate water quality risk to water resources. These include: Diamonds and precious stones (Large mines), Phosphate (Large mines), Platinum, Magnesium (Large mines), Manganese (Large mines), Mineral sands (Ilmenite, Titanium, Rutile, Zircon) – (Large mines).
		Plant and plant waste from mining operations – low risk activities	Waste generated from plant and plant waste from processing of minerals and metals extracted from the ground, which pose a low water quality risk to water resources. These include: Diamonds and precious stones(small mines), Phosphate (Small mines), Magnesium (Small mines), Manganese (Small mines), Mineral sands (Ilmenite, Titanium, Rutile, Zircon) – (Small mines), Industrial Minerals (Andalusite, Barite, Bauxite, Cryolite, Fluorspar)
		Moderate-risk quarrying operations	Quarrying operations of minerals with a moderate water quality risk to water resources. These include: Granite,

SECTOR	SECTOR DESCRIPTION	LAND USE / ACTIVITY	DESCRIPTION OF LAND USE / ACTIVITY
			Cement limestone, Limestone, Slate
		Low-risk quarrying operations	Quarrying operations of minerals with a low water quality risk to water resources. These include: Attapulgite (Special clays), Calcrete, Clays, Dolerite, Kyanite, Mica, Norite (Dimension stone), Pyrophyllite, Quartzite (Dimension Stone and abrasive), Sand and Gravel, Siltstone Fines, Soil, Bentonite (Special clays), CaC03, Diatomaceous Earth, Feldspar, Graphite, Lime (Produced from limestone), Mineral Aggregates, Phosphate Rock, Quartz, Rare earths, Shale, Silica, Talc, Calcite, Dolomite, Fullers Earth, Kaolin, Montmorillonite, Pumice, Quartzite, Salt, Siltstone (Dimension Stone), Vermiculite
		Exploratory drilling	Drilling for mineral/fuel exploration.

Annexure 7 – Specific limits set for evaluating different threat types assessed *(electronic copy only – refer to the CD provided)*

Annexure 8 – Summary of Average Event Mean Concentrations (EMCs) for sectors & sub-sectors (*electronic copy only – refer to the CD provided)*

Annexure 9 – Event Mean Concentrations (EMCs) for sectors & sub-sectors obtained from international literature *(electronic copy only – refer to the CD provided)*

Annexure 10 – Initial desktop threat ratings based on expert workshops *(electronic copy only – refer to the CD provided)*

Annexure 11 – Hydrological sensitivity analysis

A hydrological sensitivity analysis was undertaken by Hydro-Geomorphic Systems, based at the University of KwaZulu-Natal (UKZN)[31] in order to better understand how a suite of climatic and site-based attributes affect peak discharge (when surface flows are most likely to take place).

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

1. Methodology applied

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

Various simulations represented changes in slope, soil textures, land cover, mean annual precipitation (MAP[32]) and rainfall intensity. The input climate data was from the quinary catchment database and for the 50 year period 1950 to 1999. Five scenarios were simulated to establish the sensitivity of changing the catchment land-use, rainfall intensity, slope, change in the buffer zone vegetation, and change in the soil texture. For the rainfall intensity simulations, the Schmidt-Schulze equation (Schmidt and Schulze, 1984) was used for peak discharge, as it considers the 30-minute rainfall intensity (mm.h^{-1}) for the 2-year return period. The other peak discharge simulations used the Soil Conservation Service (SCS-SA) equation as it considers the impact of land-use and soil on peak discharge. The land-uses considered included grassland, maize cultivation, commercial forestry, urban residential and industrial. In the buffer zone, the vegetation cover included grassland in good condition, degraded grassland and bare soil. Four rainfall intensity scenarios of 90

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[31] Authors included: Mr Nicholas Davis (MSc Hydrology); Dr Hartley Bulcock (PhD hydrology); and Mrs Lauren Bulcock (MSc Bioresource Systems).

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

mm.h^{-1}, 70 mm.h^{-1}, 50 mm.h^{-1} and 30 mm.h^{-1} were considered in the simulation of peak discharge. Slope was varied from a 0-45^{o}. Eight soil textural classes were also considered.

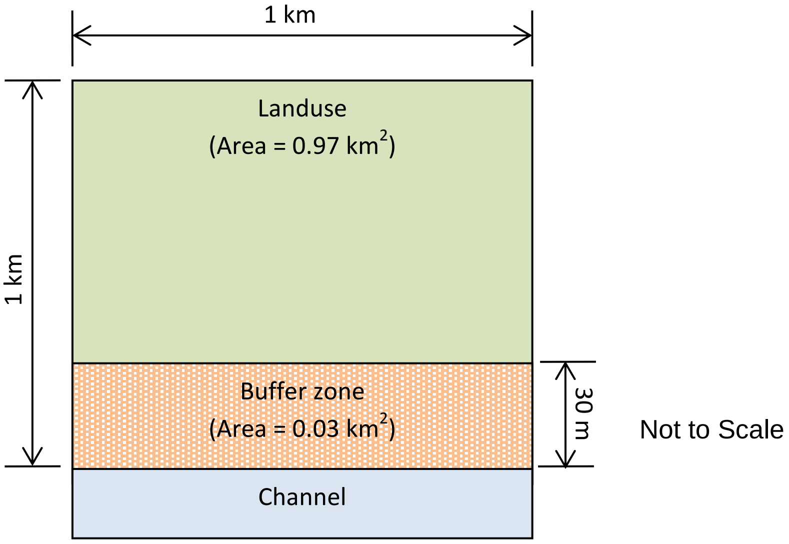


Figure 1. Schematic of the hypothetical 1 km^2 catchment used for hydrological simulations.

Given that the buffer zone model has been developed by applying a series of modifiers to a given ‘reference’ scenario, it was important to set reference parameters against which changes in site-characteristics could be evaluated. For this exercise, the baseline simulation considered the land-use to be grassland, slope to be between 5-10 degrees, the buffer zone vegetation to be grass in good condition, and the soil texture to be clay-loam. These variables were kept constant for all simulation unless the scenarios required them to be changed (for example, the land-use was grassland for all scenarios unless the scenario was specifically considering a change of land-use, etc.). The parameters that were kept constant are highlighted in grey in the results tables. The rainfall intensity zones were not kept constant for all simulations because they were only required in the calculation of peak discharge using the Schmidt-Schulze equation. Thereafter, the model did not require rainfall intensity for the other simulations. Table 1 below details the input parameters used for to each simulation.

Table 1. Input variables used

SIMULATION	***VARIABLE CHANGED***	***FULL VARIABLE NAME***	***VALUE***
XI30_Z1	MAP\XI30	Mean Annual Precipitation (mm) \ 30min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [90 mm.h^{-1}]
XI30_Z2	MAP\XI30	Mean Annual Precipitation (mm) \ 30min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [70 mm.h^{-1}]
XI30_Z3	MAP\XI30	Mean Annual Precipitation (mm) \ 30min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [50 mm.h^{-1}]
XI30_Z4	MAP\XI30	Mean Annual Precipitation (mm) \ 30min 2yr return period rainfall intensity (mm\h)	666; 192; 1117; 1281 [30 mm.h^{-1}]
LU_GRASS	CROPNO	Land cover type	Southern tall grassveld
LU_FORESTRY	CROPNO	Land cover type	Eucalyptus general
LU_INDUSTRIAL	CROPNO	Land cover type	Industrial
LU_MAIZE	CROPNO	Land cover type	Maize October planting date
LU_RESIDENTIAL	CROPNO	Land cover type	Residential (formal, medium density)
LUS_GRASS (1)	SLOPE	Slope (%)	2.2
LUS_GRASS (5)	SLOPE	Slope (%)	5
LUS_GRASS(10)	SLOPE	Slope (%)	16.5
LUS_GRASS(15)	SLOPE	Slope (%)	27.5
LUS_GRASS(30)	SLOPE	Slope (%)	49.5
LUS_GRASS(45)	SLOPE	Slope (%)	82.5
BZ_GRASS_GOOD	CROPNO	Buffer zone land cover type	Veld in good condition – general
BZ_GRASS_DEG	CROPNO	Buffer zone land cover type	Veld in poor condition – general
BZ_GRASS_BARE_SOIL	CROPNO	Buffer zone land cover type	Bare Rock\soil
BZ_GRASS_SLOPE(1)	SLOPE	Slope of only buffer zone (%)	2.2
BZ_GRASS_SLOPE(5)	SLOPE	Slope of only buffer zone (%)	5
BZ_GRASS_SLOPE(10)	SLOPE	Slope of only buffer zone (%)	16.5
BZ_GRASS_SLOPE(15)	SLOPE	Slope of only buffer zone (%)	27.5
BZ_GRASS_SLOPE(30)	SLOPE	Slope of only buffer zone (%)	49.5
BZ_GRASS_SLOPE(45)	SLOPE	Slope of only buffer zone (%)	82.5
BZ_SOIL_TEXT1	ITEXT	Soil texture	1 (Clay)
BZ_SOIL_TEXT2	ITEXT	Soil texture	2 (Loam)
BZ_SOIL_TEXT3	ITEXT	Soil texture	3 (Sand)
BZ_SOIL_TEXT4	ITEXT	Soil texture	4 (Loamy sand)
BZ_SOIL_TEXT5	ITEXT	Soil texture	5 (Sandy loam)
BZ_SOIL_TEXT7	ITEXT	Soil texture	7 (Sandy Clay loam)
BZ_SOIL_TEXT8	ITEXT	Soil texture	8 (Clay loam)
BZ_SOIL_TEXT10	ITEXT	Soil texture	10 (Sandy clay)

2. Results of the hydrological sensitivity assessment

The results presented in the tables below are for the outputs of total streamflow from the subcatchment and includes the upstream contributions (CELRUN) and peak discharge (QPEAK) although peak discharge is the variable of interest to this study. The simulations were for four climatic zones with different MAP ranging from 0-400 mm to >1200 mm. The QPEAK values were summed for the 50 year period in order to be able to make a relative comparison of the impact of each scenario. It was decided for this study that the QPEAK value would be used as this accounts for rainfall intensity, which was a required outcome y and provides a useful surrogate measure for surface overland flow (flows carrying diffuse pollutants through the buffer zone).

2.1. Land-use impacts

The comparison shows that land-use has a clear impact on runoff characteristics (Table 2.1), with land-uses dominated by high levels of hardened surfaces / bare ground leading to increased peak discharge (Table 2.2). When compared to reference conditions, this shows that maize lands and industrial land uses in particular can result in peak discharges that are more than double that simulated under natural (grassland) conditions (Table 2.3). The importance of climate is also clearly demonstrated here, with a dramatic reduction in simulated peak discharge occurring in drier climatic conditions and is discussed further in Section 3.6. Table 2.4 shows that peak discharge responds consistently to land use changes across all climatic ranges.

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

Table 2.1. Impacts of changes in land use on runoff from the test catchment

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

Table 2.2. Impacts of changes in land use on peak quick flows from the test catchment

	land use	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Grassland	5.93	388.77	1694.20	2187.84
	Maize	15.01	831.47	3633.90	4670.81
	Forestry	3.94	383.83	1693.58	2124.39
	Residential	7.34	625.95	2614.43	3337.37
	Industrial	13.41	1003.01	4254.32	5468.79

Table 2.3. Variation in peak discharge relation to ‘Reference’ conditions

	land use	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Grassland	0.00	0.23	1.00	1.29
	Maize	0.01	0.49	2.14	2.76
	Forestry	0.00	0.23	1.00	1.25
	Residential	0.00	0.37	1.54	1.97
	Industrial	0.01	0.59	2.51	3.23

Table 2.4 Consistency of peak discharge responses to rainfall intensity zones across different MAP zones

	land use	MAP (mm)				
		0-400	401-800	801-1200	>1200	Average
Qpeak (m3.s-1)	Grassland	1.00	1.00	1.00	1.00	1.00
	Maize	2.53	2.14	2.14	2.13	2.24
	Forestry	0.66	0.99	1.00	0.97	0.91
	Residential	1.24	1.61	1.54	1.53	1.48
	Industrial	2.26	2.58	2.51	2.50	2.46

2.2. Rainfall intensity

The simulation outcomes show that the rainfall intensity zone has a moderate effect on peak discharge across all ranges of MAP considered (Table 3.1). In high rainfall intensity zones, a 24% increase in peak discharge can be expected over ‘Reference’ whereas a reduction of 25% and 51% can be expected in rainfall zones 3 and 4, respectively (Table 3. 3). This relationship is consistent across different MAP zones (Table 3. 4) and a suite of adjustment factors have therefore been included relative to the "Reference" to account for variations in Rainfall intensity zone in the buffer zone model (Table 3. 5).

Table 3.1 Impacts of changes in rainfall intensity on runoff from the test catchment

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

Table 3.2 Effect of rainfall intensity on peak discharge from the test catchment

	Rainfall zone	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Zone 4	5.00	84.00	204.00	225.00
	Zone 3	4.00	67.00	164.00	182.00
	Zone 2	3.00	50.00	123.00	137.00
	Zone 1	2.00	32.00	80.00	89.00

Table 3. 3 Variation in peak discharge relation to ‘Reference’ conditions

	Rainfall zone	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Zone 4	0.03	0.51	1.24	1.37
	Zone 3	0.02	0.41	1.00	1.11
	Zone 2	0.02	0.30	0.75	0.84
	Zone 1	0.01	0.20	0.49	0.54

Table 3. 4. Consistency of peak discharge responses to rainfall intensity zones across different MAP zones

	Rainfall zone	MAP (mm)				
		0-400	401-800	801-1200	>1200	Average
Qpeak (m3.s-1)	Zone 4	1.25	1.25	1.24	1.24	1.25
	Zone 3	1.00	1.00	1.00	1.00	1.00
	Zone 2	0.75	0.75	0.75	0.75	0.75
	Zone 1	0.50	0.48	0.49	0.49	0.49

Table 3. 5. Simulated adjustment factors for buffer zones to account for Rainfall intensity

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

2.3. Slope of the buffer zone

As expected, simulation outcomes show that the slope angle across the buffer zone has a clear impact on peak discharges across all ranges of MAP considered (Table 4.2). In situations where slopes are steep, an increase of 66% above reference was simulated while this declined to only 56% of reference where buffer zones were very gently sloping (Table 4.3). This relationship is consistent across different MAP zones (Table 4.4) and a suite of adjustment factors have therefore been included relative to the ‘Reference’ to account for variations in Rainfall intensity zone in the buffer zone model (Table 4.5).

Table 4.1. Impacts of changes in the slope of the buffer zone on runoff from the test catchment

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

Table 4.2. Effect of slope (degrees) on peak discharge from the test catchment

	degrees	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	0-1	3	51	125	139
	0-5	4	65	160	177
	5-10	5	93	227	251
	10-15	7	109	265	292
	15-30	8	130	315	348
	30-45	9	151	367	405

Table 4.3. Variation in peak discharge relation to "Reference" conditions

	degrees	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	0-1	0.01	0.22	0.55	0.61
	0-5	0.02	0.29	0.70	0.78
	5-10	0.02	0.41	1.00	1.11
	10-15	0.03	0.48	1.17	1.29
	15-30	0.04	0.57	1.39	1.53
	30-45	0.04	0.67	1.62	1.78

Table 4.4. Consistency of peak discharge responses to slope variation across different MAP zones

	degrees	MAP (mm)				
		0-400	401-800	801-1200	>1200	Average
Qpeak (m3.s-1)	0-1	0.60	0.55	0.55	0.55	0.56
	0-5	0.80	0.70	0.70	0.71	0.73
	5-10	1.00	1.00	1.00	1.00	1.00
	10-15	1.40	1.17	1.17	1.16	1.23
	15-30	1.60	1.40	1.39	1.39	1.44
	30-45	1.80	1.62	1.62	1.61	1.66

Table 4.5. Simulated adjustment factors for buffer zones to account for variations in buffer zone slope.

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

2.4. Vegetation characteristics of the buffer zone

As expected, simulated results show that buffer zone vegetation has a clear impact on peak discharge with higher simulated peak discharge volumes occurring in situations where the buffer zone is degraded (lower basal cover) that natural grassland reference conditions (Table 5.2). Indeed, where vegetation is lacking (bare soil), peak discharge is likely to be more than double that observed under reference conditions (good condition grassland) (Table 5.3). This emphasizes the importance of buffer zone management in slowing surface overland flow, promoting infiltration and allowing pollutants to be deposited in the buffer zone. A range of preliminary adjustment factors have therefore been calculated relative to the 'Reference' to account for variations in buffer zone vegetation characteristics in the buffer zone model.

Table 5.1 Impacts of changes in the buffer zone vegetation characteristics on runoff from the test catchment

	Buffer vegetation	MAP (mm)			
		0-400	401-800	801-1200	>1200
celrun	good grass	0.86	69.26	355.7	489.34
	degraded grass	0.92	69.76	358.08	492.84
	bare soil	0.9	70.32	359.62	494.54

Table 5.2 Effect of changes in buffer zone vegetation characteristics on peak discharge from the test catchment

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

Table 5.3 Variation in peak discharge relation to 'Reference' conditions

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

Table 5.4 Consistency of peak discharge responses to variation in buffer vegetation characteristics across different MAP zones

	Buffer vegetation	MAP (mm)				
		0-400	401-800	801-1200	>1200	Average*
Qpeak	good grass	1.00	1.00	1.00	1.00	1.00
	degraded grass	6.50	2.30	2.15	2.16	2.20
	bare soil	7.00	2.66	2.43	2.43	2.51

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

Table 5.5. Simulated adjustment factors for buffer zones to account for variations in buffer vegetation characteristics.

Condition of buffer zone vegetation	Category	good grass	degraded grass	bare soil
	Modifier	1.00	2.20	2.51

2.5. Soil texture in the buffer zone

This simulation shows a reduction in peak discharge where soil characteristics of the buffer zone are more coarsely textured (Table 6.2). When compared with reference (clay-loam soils), there is approximately a 25% reduction in peak discharge for sandy soils while clay soils result in a considerable increase in discharge (Table 6.3). This is in line with expectations as such soils have a higher infiltration capacity than fine textured soils. A range of preliminary adjustment factors have therefore been calculated relative to the 'Reference' to account for variations in variations in soil texture in the buffer zone.

Table 6.1. Impacts of changes in the soil textural characteristics in the buffer zone on runoff from the test catchment

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

Table 6.2 Effect of changes in soil texture in the buffer zone on peak discharge from the test catchment

	Soil texture	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Sand	0.13	8.9	39	51
	Loamy sand	0.13	9	39	50
	Clay loam	0.19	12.1	53	68
	Sandy loam	0.23	15.5	67	86
	Sandy loam	0.23	15.5	67	86
	Loam	0.24	15.5	67	86
	Sandy clay loam	0.28	18.5	80	102
	Clay	0.83	24.7	85	112

Table 6.3 Variation in peak discharge relation to 'Reference' conditions

	Soil texture	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Sand	0.00	0.17	0.74	0.96
	Loamy sand	0.00	0.17	0.74	0.94
	Clay loam	0.00	0.23	1.00	1.28
	Sandy loam	0.00	0.29	1.26	1.62
	Sandy loam	0.00	0.29	1.26	1.62
	Loam	0.00	0.29	1.26	1.62
	Sandy clay loam	0.01	0.35	1.51	1.92
	Clay	0.02	0.47	1.60	2.11

Table 6.4 Consistency of peak discharge responses to variation in soil textural characteristics of the buffer zone across different MAP zones

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

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

Table 6.5. Simulated adjustment factors for buffer zones to account for variations in buffer zone soil characteristics.

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

2.6. Mean Annual Precipitation (MAP)

This simulation shows that MAP has a significant and consistent effect on peak discharge with dramatic reductions in discharge expected in drier parts of the country (Tables 7.1 to 7.6). Indeed, in very low rainfall areas, even peak discharge is likely to be very low due to typically small rainfall events. This suggests that the risk of contaminated surface flows emanating from land use activities adjacent water resources is likely to be negligible in very dry areas and significantly lower in moderate rainfall areas (MAP = 401-800 mm) than in high rainfall areas (MAP = 801-1200 mm). A range of preliminary adjustment factors have therefore been calculated relative to the 'Reference' to account for variations in MAP in the buffer zone model.

Table 7.1 Consistency of the effect of MAP on peak discharge across changes in land use types

	Land use	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Grassland	0.00	0.23	1.00	1.29
	Maize	0.00	0.23	1.00	1.29
	Forestry	0.00	0.23	1.00	1.25
	Residential	0.00	0.24	1.00	1.28
	Industrial	0.00	0.24	1.00	1.29
	Average	0.00	0.23	1.00	1.28

Table 7.2 Consistency of the effect of MAP on peak discharge across different rainfall intensity zones

	Rainfall zone	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Zone 4	0.02	0.41	1.00	1.10
	Zone 3	0.02	0.41	1.00	1.11
	Zone 2	0.02	0.41	1.00	1.11
	Zone 1	0.03	0.40	1.00	1.11
	Average	0.02	0.41	1.00	1.11

Table 7.3 Consistency of the effect of MAP on peak discharge in relation to changes in buffer zone slope classes

	degrees	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	0-1	0.02	0.41	1.00	1.11
	0-5	0.03	0.41	1.00	1.11
	5-10	0.02	0.41	1.00	1.11
	10-15	0.03	0.41	1.00	1.10
	15-30	0.03	0.41	1.00	1.10
	30-45	0.02	0.41	1.00	1.10
	Average	0.02	0.41	1.00	1.11

Table 7.4 Consistency of the effect of MAP on peak discharge in relation to changes in buffer zone vegetation characteristics

	Buffer vegetation	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	good grass	0.00	0.23	1.00	1.30
	degraded grass	0.01	0.25	1.00	1.31
	bare soil	0.01	0.26	1.00	1.30
	Average	0.01	0.25	1.00	1.30

Table 7.5 Consistency of the effect of MAP on peak discharge in relation to changes in buffer zone textural characteristics

	Soil texture	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Sand	0.00	0.23	1.00	1.31
	Loamy sand	0.00	0.23	1.00	1.28
	Clay loam	0.00	0.23	1.00	1.28
	Sandy loam	0.00	0.23	1.00	1.28
	Loam	0.00	0.23	1.00	1.28
	Sandy clay loam	0.00	0.23	1.00	1.28
	Sandy clay	0.00	0.23	1.00	1.28
	Clay	0.01	0.29	1.00	1.32
	Average	0.00	0.24	1.00	1.29

Table 7.6 Consistency of the effect of MAP on peak discharge across different criteria considered during the simulation

	Criteria	MAP (mm)			
		0-400	401-800	801-1200	>1200
Qpeak (m3.s-1)	Land use	0.00	0.23	1.00	1.28
	Rainfall Zone	0.02	0.41	1.00	1.11
	Slope	0.02	0.41	1.00	1.11
	Buffer vegetation	0.01	0.25	1.00	1.30
	Soil texture	0.00	0.24	1.00	1.29
	Overall Average	0.01	0.31	1.00	1.22

Table 7.7. Simulated adjustment factors for buffer zones to account for variations in MAP.

Mean Annual Precipitation	Category	0-400	401-800	801-1200	>1200
	Modifier	0.01	0.31	1.00	1.22

3. References

Schmidt, E.T., and Schulze, R.E. (1984). Improved estimation of peak flow rates using modified SCS lag equations. Water Research Commission, Pretoria, RSA.

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

Annexure 12 – Guidelines for assessing the sensitivity of wetlands to lateral land-use inputs

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

Indicators have been defined in order to assess the sensitivity of wetlands to common threats posed by lateral land-use impacts. The indicators were scored relative to a typical 'Reference' wetland of intermediate sensitivity and are used to calculate a sensitivity score and associated class for each threat type under consideration.

1. Sensitivity to changes in water quantity (volumes of flow) from lateral inputs

Table 1. Wetland characteristics affecting the sensitivity of the water resource to changes in the volumes of inputs from lateral inputs

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

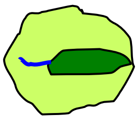
1.1 Overall size

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

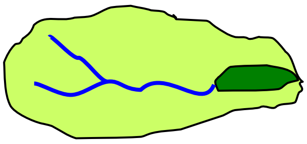
Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

1.2 Size of the wetland relative to its catchment

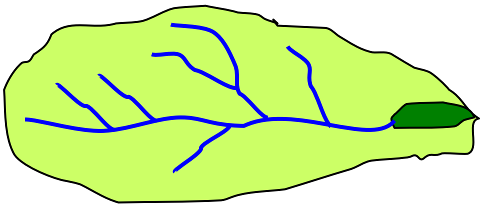
Rationale: Reinlet and Taylor (2001) observed that wetlands that were small in relation to their contributing watersheds had greater water level fluctuations and were dominated by surface inflow. Wetlands that were larger in comparison to their contributing watersheds had smaller water level fluctuations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



Very high sensitivity
(Score = 1.5)



Intermediate sensitivity
(Score=1.0)



Very low sensitivity
(Score=0.5)

Method: This assessment requires that the catchment of the HGM unit adjacent to the proposed development be roughly estimated. Once estimated, the relative extent of the wetland is compared to that of catchment. Here, it is important to note that although the wetland itself may be large, the HGM unit potentially impacted may be small, and largely reliant on lateral inputs. A sensitivity score is then assigned with reference to the diagram above and wetland: area ratios indicated in Table 1. Note: In the case of groundwater-fed systems, sensitivity should be based on the anticipated importance of lateral flows to the groundwater system relative to the broader recharge area.

1.3 The extent to which the HGM setting is characterized by sub-surface water input

Rationale: Generally, hillslope seepages are fed primarily from lateral inputs from their immediate catchment, whilst floodplains are fed primarily from an upstream area (although some floodplains, particularly those in higher rainfall areas, may be fed by extensive lateral inputs). Other HGM types tend to be intermediate.

Method: Assign a sensitivity score based on the grouping of different HGM types in Table 1. At a rapid level it is assumed that hillslope seepages are characterized by high levels of lateral input and floodplains by low levels, and further that the other HGM types are characterized by intermediate levels. Where site assessments are undertaken, this assumption should be verified and sensitivity scores adjusted where required based on field observations.

2. Sensitivity to changes in patterns of flow (frequency, amplitude, direction of flow) from lateral inputs.

Table 2. Wetland characteristics affecting the sensitivity of the water resource to changes in the patterns of flow from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Size of the wetland relative to (as a percentage of) its catchment	Large (>20%)	10-20%	*Intermediate (6-10%)*	2-5%	Small (<2%)
Average slope of the wetland's catchment	<3%	3-5%	*6-8%*	9-11%	>11%
Inherent runoff potential of catchment soils	Low	Moderately low	*Moderate*	Moderately high	High
The extent to which the wetland (HGM) setting is generally characterized by sub-surface water input	High (Hillslope seepage)	Moderately high	*Intermediate (The remaining HGM types)*	Moderately low	Low (Floodplain)

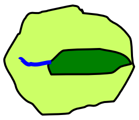
2.1 Overall size

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

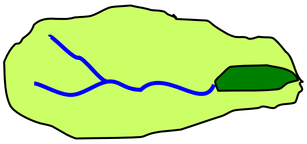
Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

2.2 Size of the wetland relative to its catchment

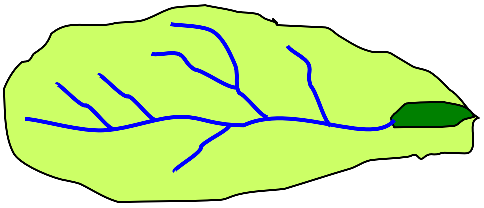
Rationale: The larger the wetland relative to its catchment, the greater the extent to which a wetland is fed hydrologically by lateral inputs from its immediate catchment as opposed to from an upstream area, and the more sensitive it will be to changes in changes in timing from lateral inputs. At the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



Very high sensitivity
(Score = 1.5)



Intermediate sensitivity
(Score=1.0)



Very low sensitivity
(Score=0.5)

Method: Use method 1.2 to determine the size of the wetland relative to the catchment. A sensitivity score is then assigned with reference to the diagram above and wetland: area ratios indicated in Table 2. Note: In the case of groundwater-fed systems, sensitivity should be based on the anticipated importance of lateral flows to the groundwater system relative to the broader recharge area.

2.3 Average slope of the wetland’s catchment

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

Method: Average slope can be roughly calculated simply from available topographic maps or from GIS datasets or Google Earth information. This is done by first taking elevation readings from (i) the upper-most point of the catchment and (ii) the site being assessed and calculating the altitudinal change. The distance between these points is then measured and average slope estimated by dividing the altitudinal change by the distance from the upper reaches of the catchment.

2.4 The inherent runoff potential of catchment soils

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

Method: The Soil Conservation Services method for Southern Africa (SCS-SA) uses information of hydrologic soil properties to estimate surface runoff from a catchment (Schulze et al., 1992). With reference to the SCS-SA (Figure 1 and Table 3), the appropriate hydrological soil group that defines the entire catchment based on available soils information can be determined.

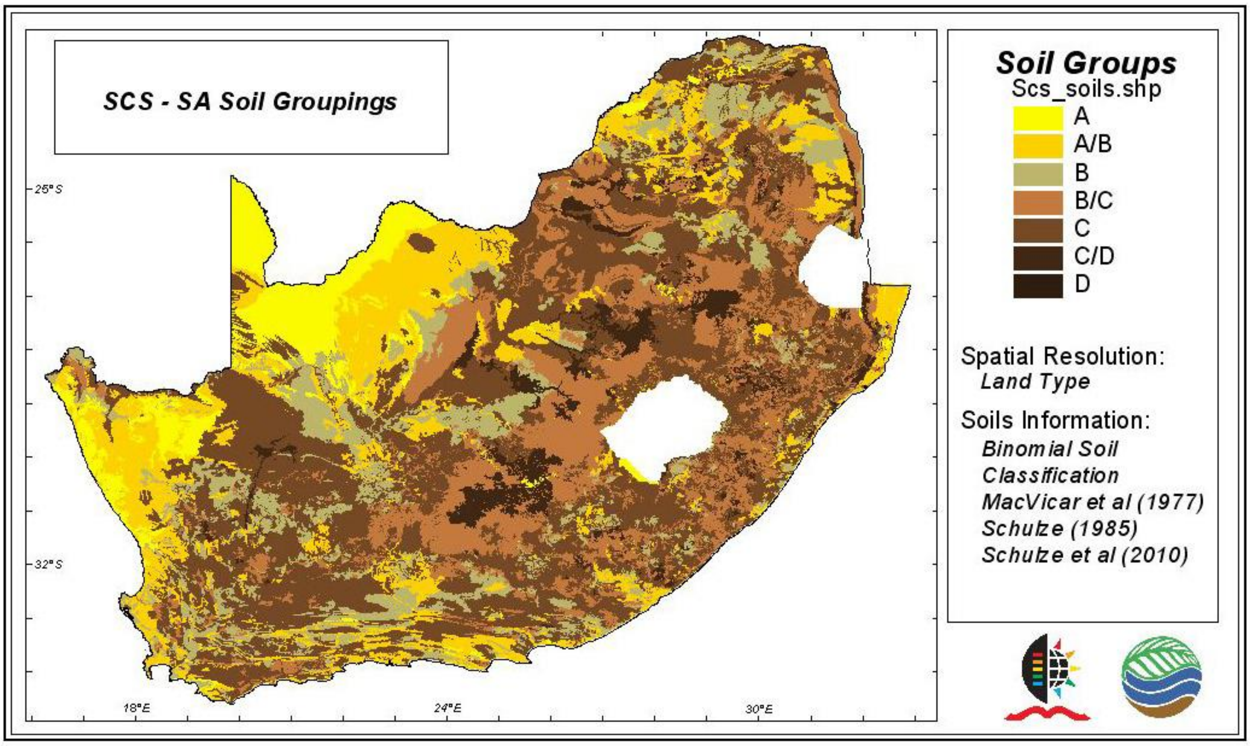


Figure 1. Distribution of SCS soil groups A to D over South Africa at a spatial resolution of Land Type polygons (Schulze, 2010)

Table 3. Runoff potential classes (after Schulze et al*.,* 1992)

LOW RUNOFF POTENTIAL	MODERATELY LOW RUNOFF POTENTIAL	MODERATELY HIGH RUNOFF POTENTIAL	HIGH RUNOFF POTENTIAL
Soil Group A: Infiltration is high and permeability is rapid. Overall drainage is excessive to well-drained.	**Soil Group B:** Moderate infiltration rates, effective depth and drainage. Permeability slightly restricted.	**Soil Group C:** Infiltration rate is slow or deteriorates rapidly. Permeability is restricted.	**Soil Group D:** Very slow infiltration and severely restricted permeability. Includes soils with high shrink-swell potential.

2.5 The extent to which the HGM setting is characterized by sub-surface water input

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

Method: Assign a sensitivity score based on the grouping of different HGM types in Table 2. At a rapid level it is assumed that hillslope seepages are characterized by high levels of lateral input and floodplains by low levels, and further that the other HGM types are characterized by intermediate levels. Where site assessments are undertaken, this assumption should be verified and sensitivity scores adjusted where required based on field observations.

3. Sensitivity to changes in sediment inputs and turbidity from lateral inputs

Table 4. Wetland characteristics affecting the sensitivity of the water resource to changes in sediment inputs and turbidity from lateral inputs

CRITERION	SENSITIVITY SCORES				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Perimeter to area ratio	High (>1500 m per ha)	Moderately high	*Moderate (e.g. 1000 m per ha)*	Moderately low	Low (<500 m per ha)
Vulnerability of the HGM type to sediment accumulation	Depression – endorheic, Flat	Depression – exhoreic	*Hillslope seep, Valley head seep, Unchannelled valley bottom*	Channelled valley-bottom	Floodplain wetland
Vulnerability of the site to erosion given the site's slope and size	High (Vulnerability score>8)	Moderately High (Vulnerability score: 6-7)	*Moderate (Vulnerability score :4-5)*	Moderately Low (Vulnerability score: 2-3)	Low (Vulnerability score <2)
Extent of open water, particularly water that is naturally clear	High (>9% of the area)	Moderately High (7-9%)	*Moderate (4-6%)*	Low (0.5-3%)	Very low (<0.5%)
Peat versus mineral soils	Peat	-	Mixed	-	Mineral
Sensitivity of the vegetation to burial under sediment (adjacent planned development)	High (e.g. short growing & slow colonizing)	Moderately high	*Intermediate*	Moderately low	Low (e.g. tall growing & fast colonizing)

3.1 Overall size

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

Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

3.2 Perimeter to area ratio

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

Method: Determine the approximate perimeter of the wetland being assessed and divide this by the area to obtain a perimeter: area ratio. Use this to place the wetland into one of three classes indicated.

3.3 Vulnerability of the HGM type to sediment accumulation

Rationale: Wetland systems that are well connected to the drainage network, characterized to naturally high sediment inputs and subject to regular flushing, are likely to be significantly less susceptible to long-term impacts of sedimentation than wetlands that have not formed under these processes. Floodplains are therefore likely to be least sensitive to increased sediment inputs, with sediment deposition characteristic of these systems, together with high flows that may cause considerable scouring of sediments. Pans, particularly those with a closed drainage system however, are likely to be highly susceptible to increases in sediment inputs, as are flats, where any accumulation of sediment is likely to remain. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 4.

Method: Assign a sensitivity score based on the grouping of different HGM types in Table 4.

3.4 Vulnerability of the site to erosion given the site's slope and size

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

Method: Measurement of the approximate longitudinal slope can be carried out using a topographical map or available contour data. To calculate longitudinal slope, simply estimate the change in elevation from the top to the bottom of the wetland and divide this value by the length of the wetland and covert into a percentage. Measurement of the approximate area of the wetland is based upon a map of the wetland (see 3.1). The vulnerability score is then derived with reference to Figure 2 below, which assumes that wetland area is a proxy for discharge.

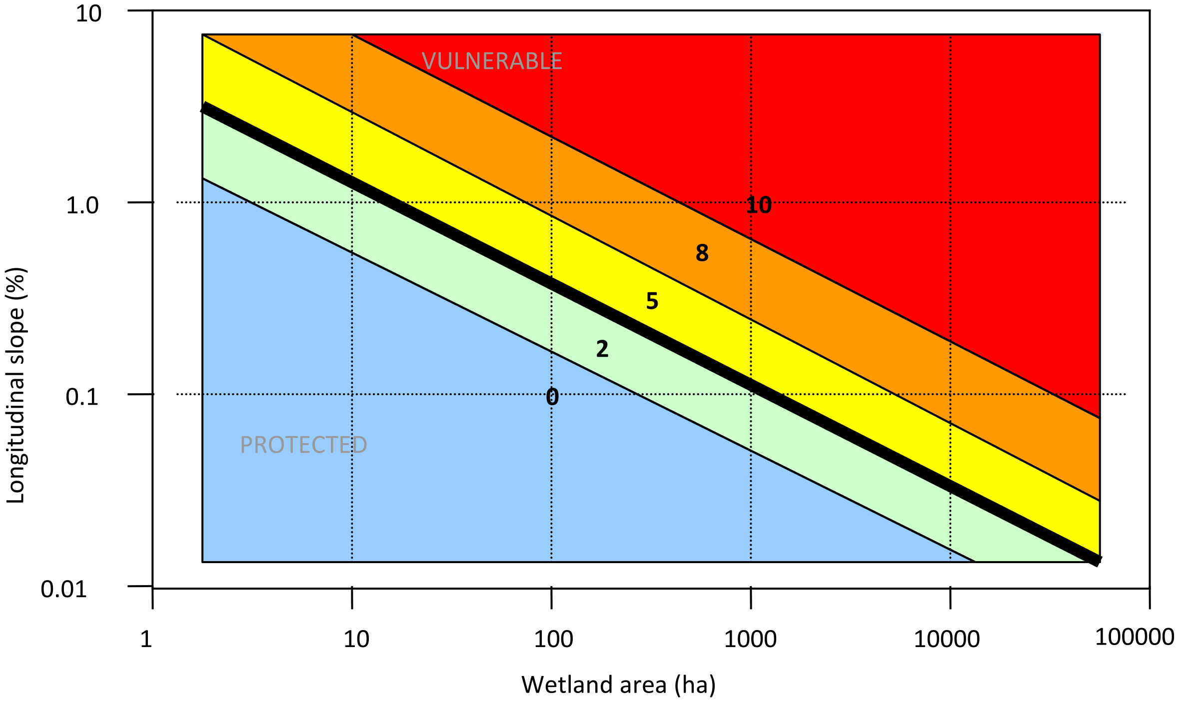


Figure 2. Vulnerability of HGM units to geomorphological impacts based on wetland size (a simple surrogate for mean annual runoff) and wetland longitudinal slope (Macfarlane et al., 2007).

3.5 Extent of open water, particularly where water is naturally clear

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

Method: This assessment is informed by a rapid site assessment to estimate the average extent of open water. Where possible, this assessment should be supplemented with orthophoto maps or aerial photographs that can be used to better understand the relative extent of open water habitat.

3.6 Peat versus mineral soils

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

Method: Peat is defined as organic soil material with a particularly high organic matter content which, depending on the definition of peat, usually has at least 20% organic carbon by weight. The presence of peat can be determined in the field based on observation of soil morphology and the 'feel' of the peat in the hand.

3.7 Sensitivity of the vegetation to burial under sediment

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

Method: This assessment is based on observation, during a rapid field visit, of the growth form of the dominant plant species present in the HGM unit adjacent to planned developments.

4. Sensitivity to increased inputs of nutrients (phosphates, nitrite, nitrate) from lateral inputs

Table 5. Wetland characteristics affecting the sensitivity of the water resource to increase nutrient inputs from lateral sources

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	1	0.925	0.85
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Perimeter to area ratio	High (>1500 m per ha)	Moderately high	*Intermediate (e.g. 1000 m per ha)*	Moderately low	Low (<500 m per ha)
Inherent level of nutrients in the landscape: Is the wetland and its	-	Yes	*Partially*	No	-

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	1	0.925	0.85
catchment underlain by sandstone?					
Vulnerability of the HGM type to nutrient enrichment	Depression – endorheic, Flat	Depression – exhoreic	*Hillslope seep, Valley head seep, Unchannelled valley bottom*	Channelled valley-bottom	Floodplain wetland
Extent of open water, particularly water that is naturally clear	High (>9% of the area)	Moderately High (7-9%)	*Moderate (4-6%)*	Low (0.5-3%)	Very low (<0.5%)
Sensitivity of the vegetation to increased availability of nutrients	High (e.g. short and/or sparse vegetation cover with high natural diversity)	Moderately high	*Intermediate (e.g. short vegetation with moderate natural plant diversity)*	Moderately low	Low (e.g. tall and dense vegetation with low natural diversity)

4.1 Overall size

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

Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

4.2 Perimeter to area ratio

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

Method: Determine the approximate perimeter of the wetland being assessed and divide this by the area to obtain a perimeter: area ratio. Use this to place the wetland into one of three classes indicated.

4.3 Inherent level of nutrients in the landscape

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

Method: This assessment is based on existing geological maps for the area. Where the threat of nutrients is high or very high, it may be beneficial to assess current nutrient levels through nutrient sampling.

4.4 Vulnerability of the HGM type to nutrient enrichment

Rationale: The less open (i.e. the more closed) the drainage system of a wetland (e.g. in the case of an endorheic pan) and the less common natural flushing events, the more readily nutrients will be able to accumulate within the system. Wetland systems with open drainage systems that are characterized by regular flushing are therefore likely to be significantly less susceptible to nutrient inputs. Floodplains are therefore likely to be least sensitive while pans, particularly those with a closed drainage system, are likely to be most susceptible. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 5.

Method: Assign a sensitivity score based on the grouping of different HGM types in Table 5.

4.5 Extent of open water, particularly where the substrate is non-muddy

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

Method: This assessment is informed by a rapid site assessment to estimate the average extent of open water. Where possible, this assessment should be supplemented with orthophoto maps or aerial photographs that can be used to better understand the relative extent of open water habitat.

4.6 Sensitivity of the vegetation to increased availability of nutrients

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

Method: This assessment is based on a rapid observation of the vegetation characteristics in the HGM unit below the area of planned development. Note must be made of the height of natural vegetation and diversity of indigenous vegetation. Occurrence of alien invasive species should not be considered.

Note: Although little work has been done on the growth response of individual species to nutrients in South Africa, numerous studies have been undertaken in North America. Information on the response of many individual species to nutrients can be obtained for the National Database of Wetland Plant Tolerances[33].

5. Sensitivity to increases in toxic contaminants (including toxic metal ions (e.g. copper, lead, zinc), toxic organic substances (reduces oxygen), hydrocarbons and pesticides) from lateral inputs

Table 6. Wetland characteristics affecting the sensitivity of the water resource to increase inputs of toxic substances from lateral sources

CRITERION	**SENSITIVITY SCORES**				
	1.15	**1.075**	**1**	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Perimeter to area ratio	High (>1500 m per ha)	Moderately high	*Intermediate (e.g. 1000 m per ha)*	Moderately low	Low (<500 m per ha)
Vulnerability of the HGM type to toxic inputs	Depression – endorheic, Flat	Depression – exhoreic	*Hillslope seep, Valley head seep, Unchannelled valley bottom*	Channelled valley-bottom	Floodplain wetland
Sensitivity of the vegetation to increased toxic inputs	High (high natural diversity)	Moderately high	*Intermediate (e.g. moderate natural plant diversity)*	Moderately low	Low (e.g. low natural diversity)

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[33] http://www.epa.gov/owow/wetlands/bawwg/publicat.html#database1

5.1 Overall size

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

Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

5.2 Perimeter to area ratio

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

Method: Determine the approximate perimeter of the wetland being assessed and divide this by the area to obtain a perimeter: area ratio. Use this to place the wetland into one of three classes indicated.

5.3 Vulnerability of the HGM type to toxic inputs

Rationale: The less open (i.e. the more closed) the drainage system of a wetland (e.g. in the case of an endorheic pan), and the less common natural flushing events, the more readily toxics will be able to accumulate within the system. Wetland systems with open drainage systems that are characterized by regular flushing are therefore likely to be significantly less susceptible to toxic inputs. Floodplains are therefore likely to be least sensitive while pans, particularly those with a closed drainage system, are likely to be most susceptible. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 6.

Method: Assign a sensitivity score based on the grouping of different HGM types in Table 6.

5.4 Sensitivity of the vegetation to toxic inputs

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

Method: This assessment is based on a rapid observation of the vegetation characteristics in the HGM unit below the area of planned development. Note must be made of the diversity of indigenous vegetation. Occurrence of alien invasive species should not be considered.

6. Sensitivity to changes in acidity (pH) from lateral inputs

Table 7. Wetland characteristics affecting the sensitivity of the water resource to changes in acidity from lateral sources

CRITERION	**SENSITIVITY SCORES**				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Perimeter to area ratio	High (>1500 m per ha)	Moderately high	*Intermediate (e.g. 1000 m per ha)*	Moderately low	Low (<500 m per ha)
Vulnerability of the HGM type to changes in pH	Depression – endorheic, Flat	Depression – exhoreic	*Hillslope seep, Valley head seep,*	Channelled valley-bottom	Floodplain wetland

CRITERION	SENSITIVITY SCORES				
	1.15	**1.075**	***1***	**0.925**	**0.85**
			Unchannelled valley bottom		
Sensitivity of the vegetation to changes in acidity	High (high natural diversity)	Moderately high	*Intermediate (e.g. moderate natural plant diversity)*	Moderately low	Low (e.g. low natural diversity)
Natural wetness regimes	Dominated by temporarily saturated soils	Mix of seasonal and temporarily saturated soils	*Dominated by seasonally saturated soils*	Mix of permanently and seasonally saturated soils	Dominated by permanently saturated soils

6.1 Overall size

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

Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

6.2 Perimeter to area ratio

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

Method: Determine the approximate perimeter of the wetland being assessed and divide this by the area to obtain a perimeter: area ratio. Use this to place the wetland into one of three classes indicated.

6.3 Vulnerability of the HGM type to changes in pH

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

Method: Assign a sensitivity score based on the grouping of different HGM types in Table 7.

6.4 Sensitivity of the vegetation to changes in acidity

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

Method: This assessment is based on a rapid observation of the vegetation characteristics in the HGM unit below the area of planned development. Note must be made of the diversity of indigenous vegetation. Occurrence of alien invasive species should not be considered.

6.5 Natural wetness regimes

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

Method: The level of wetness can be determined by inferring level of wetness from soil morphology (described based on visual observations of soil samples extracted with a Dutch screw auger to a depth of 0.5 m) using the guidelines given in DWAF (2005). Knowledge of the hydric status of wetland plants can also provide a useful indication of wetness regimes in untransformed wetland areas.

7. Sensitivity to changes in concentration of salts (salinization) from lateral inputs.

Table 8. Wetland characteristics affecting the sensitivity of the water resource to changes in acidity from lateral sources

CRITERION	**SENSITIVITY SCORES**				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Perimeter to area ratio	High (>1500 m per ha)	Moderately high	*Intermediate (e.g. 1000 m per ha)*	Moderately low	Low (<500 m per ha)
Vulnerability of the HGM type to changes in salinity	Depression – endorheic, Flat	Depression – exhoreic	*Hillslope seep, Valley head seep, Unchannelled valley bottom*	Channelled valley-bottom	Floodplain wetland
Natural salinity levels	-	-	*Naturally low saline levels*	Intermediate salinity levels	Naturally saline systems
Sensitivity of the vegetation to changes in salinity	High (high natural diversity)	Moderately high	*Intermediate (e.g. moderate natural plant diversity)*	Moderately low	Low (e.g. low natural diversity)

7.1 Overall size

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

Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

7.2 Perimeter to area ratio

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

Method: Determine the approximate perimeter of the wetland being assessed and divide this by the area to obtain a perimeter: area ratio. Use this to place the wetland into one of three classes indicated.

7.3 Vulnerability of the HGM type to changes in pH

Rationale: The less open (i.e. the more closed) the drainage system of a wetland (e.g. in the case of an endorheic pan) and the less common natural flushing events, the more likely that salinity levels will change in response to lateral impacts. Wetland systems with open drainage systems that are characterized by regular flushing are therefore likely to be significantly less susceptible. Floodplains are therefore likely to be least sensitive while pans, particularly those with a closed drainage system, are likely to be most susceptible. Other HGM types are likely to be of intermediate sensitivity as detailed in Table 8.

Method: Assign a sensitivity score based on the grouping of different HGM types in Table 8.

7.4 Natural salinity levels

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

Method: For wetlands with naturally high salt levels, the sensitivity score is refined downwards.

7.5 Sensitivity of the vegetation to changes in acidity

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

Method: This assessment is based on a rapid observation of the vegetation characteristics in the HGM unit below the area of planned development. Note must be made of the diversity of indigenous vegetation. Occurrence of alien invasive species should not be considered.

8. Sensitivity to changes in water temperature from lateral inputs

Table 9. Wetland characteristics affecting the sensitivity of the water resource to changes water temperature from lateral sources

CRITERION	**SENSITIVITY SCORES**				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Perimeter to area ratio	High (>1500 m per ha)	Moderately high	*Intermediate (e.g. 1000 m per ha)*	Moderately low	Low (<500 m per ha)
Extent of open water	High (>9% of the area)	Moderately High (7-9%)	*Moderate (4-6%)*	Low (0.5-3%)	Very low (<0.5%)
Mean Annual Temperature	MAT Zone 1 (Coolest)	MAT Zone 2	*MAT Zone 3*	MAT Zone 4	MAT Zone 5 (Warmest)

8.1 Overall size

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

Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

8.2 Perimeter to area ratio

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

Method: Determine the approximate perimeter of the wetland being assessed and divide this by the area to obtain a perimeter: area ratio. Use this to place the wetland into one of three classes indicated.

8.3 Extent of open water

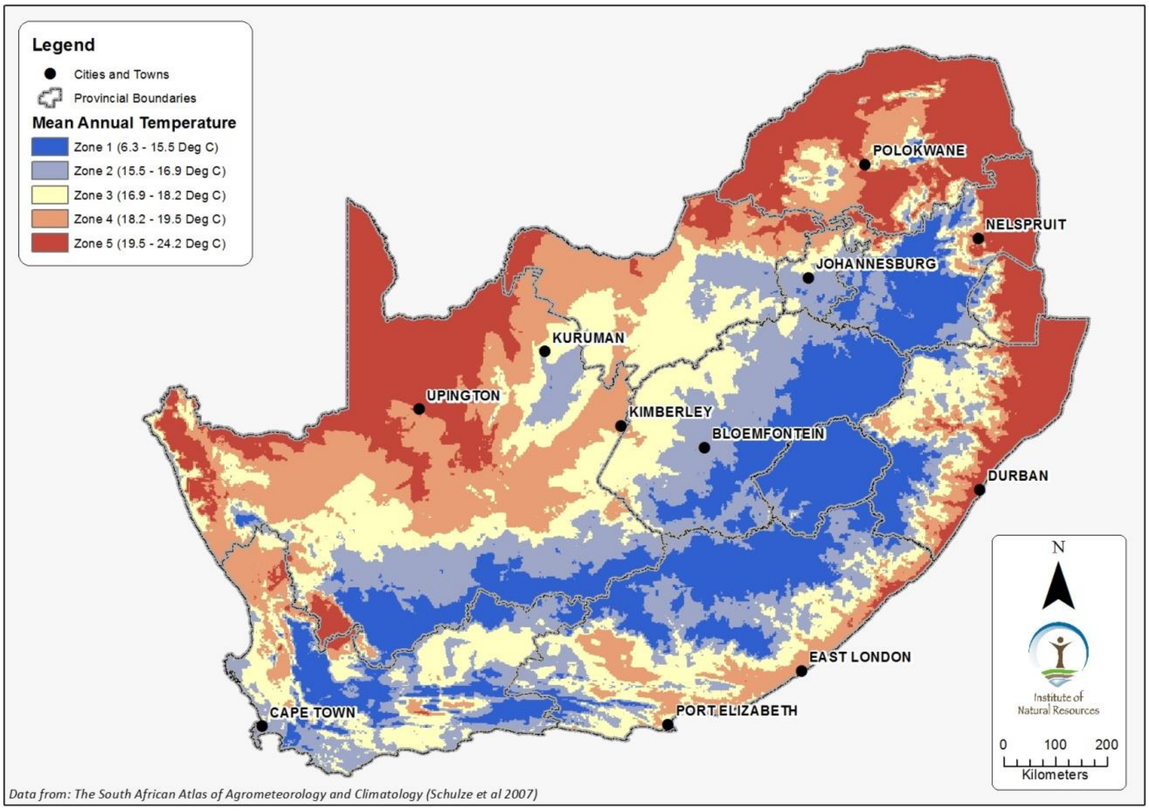
Rationale: Submerged aquatic plants and aquatic fauna are generally more severely affected by changes in water temperature, given the fact that they are contained entirely within the water column. Therefore, open water areas are considered more sensitive to changes in water temperature from lateral inputs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

Method: This assessment is informed by a rapid site assessment to estimate the average extent of open water. Where possible, this assessment should be supplemented with orthophoto maps or aerial photographs that can be used to better understand the relative extent of open water habitat.

8.5 Mean Annual Temperature

Rationale: Rivers characterised by cooler water are more sensitive to thermal pollution than rivers with higher temperatures. Rivers situated in cooler regions are likely to be more sensitive to changes in water temperature (Figure 3).

Method: At a desktop level of assessment, determine the mean annual temperature zone that characterises the catchment.



Data from: The South African Atlas of Agrometeorology and Climatology (Schulze et al 2007)

Figure 3. Mean annual temperature separated into five temperature zones, based on five equal quantiles) (Data from Schulze et al*.,* 2007)

9. Sensitivity to changes in pathogens from lateral inputs

Table 10. Wetland characteristics affecting the sensitivity of the water resource to increased pathogen inputs from lateral sources

CRITERION	**SENSITIVITY SCORES**				
	1.15	**1.075**	***1***	**0.925**	**0.85**
Overall size	Small (<0.5 ha)	0.5-5 ha	*(6-50) Intermediate*	(51-300 ha)	Large (>300 ha)
Perimeter to area ratio	High (>1500 m per ha)	Moderately high	*Intermediate (e.g.1000 m per ha)*	Moderately low	Low (<500 m per ha)
Level of domestic use	High	Moderately high	*Moderate*	Moderately low	Low

9.1 Overall size

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

Method: Determine the approximate area of the wetland (HGM unit) being assessed using available tools (e.g. GIS).

9.2 Perimeter to area ratio

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

Method: Determine the approximate perimeter of the wetland being assessed and divide this by the area to obtain a perimeter: area ratio. Use this to place the wetland into one of three classes indicated.

9.3 Level of domestic use

Rationale: The higher the level of domestic water use, the higher the threat of increasing pathogen levels to water users.

Method: Based on an evaluation of land-use around the wetland and discussions with local stakeholders, establish the level of domestic water use (including recreational use).

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Annexure 13 – Guideline for assessing the sensitivity of rivers and streams to impacts from lateral land use inputs

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

Indicators have been defined in order to assess the sensitivity of rivers to common threats posed by lateral land-use impacts. The indicators were scored relative to a typical Reference' river of intermediate sensitivity and are used to calculate a sensitivity score and associated class for each threat type under consideration.

1. Sensitivity to changes in water quantity (volumes of flow) from lateral inputs

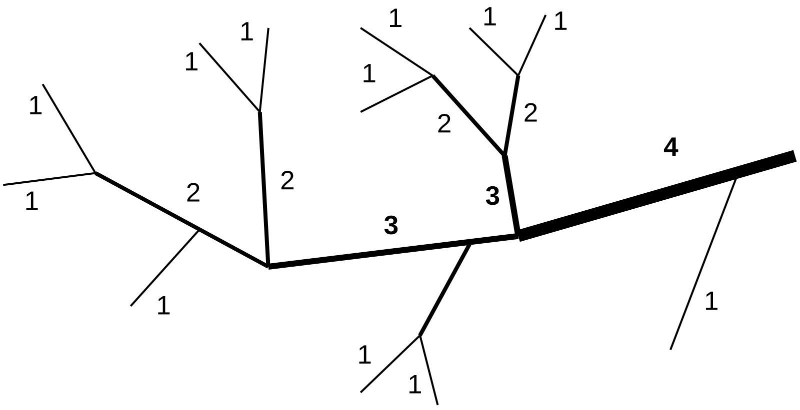
Table 1. Stream / river characteristics affecting the sensitivity of the water resource to changes in the volumes of inputs from lateral inputs

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Stream order	1st order	2nd order	*3rd order*	4th order	> 5th order
Channel width	< 1 m	1-5 m	*5-10 m*	10-20 m	> 20 m
Perenniality		Perennial systems	*Ephemeral systems*	Episodic systems	

1.1. Stream order

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

Method: Using the Horton-Strahler stream ordering method, determine the stream order using 1:50 000 rivers coverage or 1:50 000 topographical maps to ascertain the stream order for the reach of river. The diagram (right) illustrates how stream orders are incrementally determined relative to catchment position. This is a desktop procedure where stream order is manually determined using 1:50 000 topographical maps or rivers coverage in GIS. Alternatively, numbering may be derived using a GIS algorithm.



1.2. Channel width

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

Method: Widths of streams are grouped into broad categories, obviating the need for detailed site-based measurements. Width is taken as the distance between active channel banks which can be established during site visits or estimated based on measurements made from appropriate remote imagery such as that available on Google Earth.

1.3. Perenniality

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

Method: At a desktop level, perenniality may be interpreted from 1:50 000 topographical sheets, where rivers indicated with a solid line are considered to be perennial systems, and dotted lines represent non-perennial rivers (i.e. seasonal and intermittent). Distinction between seasonal and intermittent rivers is made where the former consists of river systems that flow for extended periods during the wet seasons/s (generally between 3 and 9 months), at intervals varying from less than a year to several years (Ollis et al., 2013). Intermittent rivers flow for a relatively short time of less than one season's duration (i.e. less than approximately 3 months) at intervals varying from less than a year to several years (Ollis et al., 2013). The perenniality of the watercourse can typically be identified by checking the stream bed for signs of wetness (linked to groundwater interaction) and the presence of hydric plant species in the active channel. In the case of episodic streams, signs of wetness and hydric plant species are typically absent.

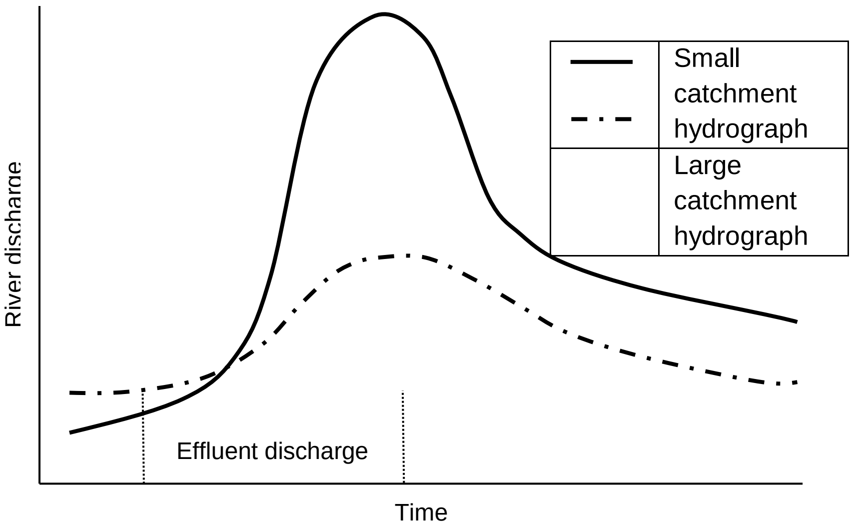
2. Sensitivity to changes in patterns of flow (frequency, amplitude, direction of flow) from lateral inputs

Table 2. Stream / river characteristics affecting the sensitivity of the water resource to changes in the patterns of flow from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Stream order	1st order	2nd order	*3rd order*	4th order	> 5th order
Average catchment slope	<3%	3-5%	*6-8%*	9-11%	>11%
Inherent runoff potential of catchment soils	Low (A & A/B)	Mod. Low (B)	*Moderate (B/C)*	Mod. High (C)	High (C/D & D)

2.1. Stream order

Rationale: Similar to Section 1.1, streams with small catchments are generally more sensitive to changes in patterns of flow as they are to changes in quantity of water generated within the catchment. As a result small contributions of water from lateral inputs will have a much greater effect on a small streams as opposed to those associated with larger catchments. For example, a volume of stormflow generated from an impervious area (e.g. parking areas and roofs) adjacent to a river of a small catchment will have a more dramatic effect on the natural hydrograph than a river draining a large catchment. The diagram below illustrates this example of the relative sensitivity of small and large catchments to a similar volume of effluent water (note the scale of river discharge is not in proportion).



Method: Refer to Method 1.1 to determine the stream order using the Horton-Strahler stream ordering method.

2.2. Average catchment slope

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

Method: Average slope can be roughly calculated simply from available topographic maps, GIS datasets or Google Earth information. This is done by first taking elevation readings from (i) the upper-most point of the catchment and (ii) the site being assessed and calculating the altitudinal change. The distance between these points is then measured and average slope estimated by dividing the altitudinal change by the distance from the upper reaches of the catchment.

2.3. Inherent runoff potential of catchment soils

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

Method: The Soil Conservation Services method for Southern Africa (SCS-SA) uses information of hydrologic soil properties to estimate surface runoff from a catchment (Schulze et al., 1992). With reference to the SCS-SA (Table 3), determine the appropriate hydrological soil group that defines the entire catchment based on available soils information. Such information is obtainable from the Land Type maps of South Africa, which includes information on soil texture.

Table 3. Runoff potential classes (after Schulze et al., 1992)

LOW RUNOFF POTENTIAL	MODERATELY LOW RUNOFF POTENTIAL	MODERATELY HIGH RUNOFF POTENTIAL	HIGH RUNOFF POTENTIAL
Soil Group A: Infiltration is high and permeability is rapid. Overall drainage is excessive to well-drained.	**Soil Group B:** Moderate infiltration rates, effective depth and drainage. Permeability slightly restricted.	**Soil Group C:** Infiltration rate is slow or deteriorates rapidly. Permeability is restricted.	**Soil Group D:** Very slow infiltration and severely restricted permeability. Includes soils with high shrink-swell potential.

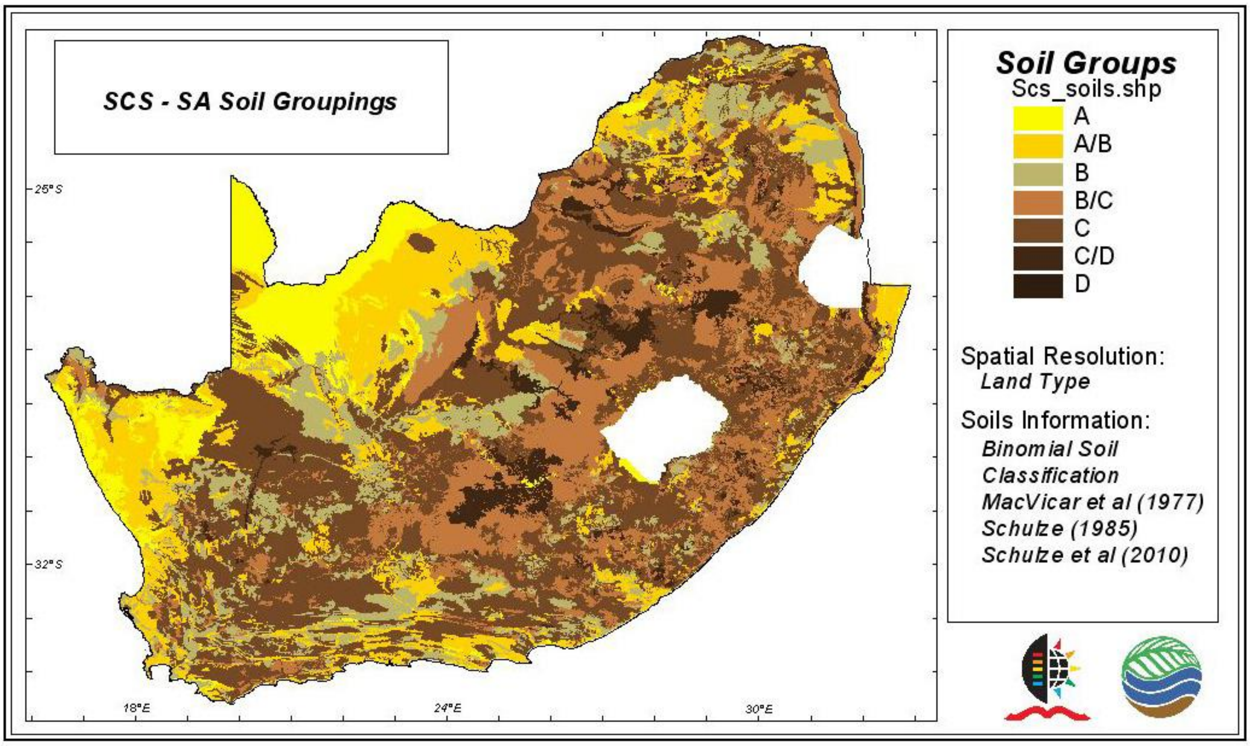


Figure 1. Distribution of SCS soil groups A to D over South Africa at a spatial resolution of Land Type polygons (Schulze, 2010)

3. Sensitivity to changes in sediment inputs and turbidity from lateral inputs

Table 4. Stream / river characteristics affecting the sensitivity of the water resource to changes in sediment inputs and turbidity from lateral inputs

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Channel width	< 1 m	1-5 m	*510 m*	10-20 m	> 20 m
Longitudinal river zonation	Upper foothill river	Transitional river	*Mountain stream*	Lower foothill river	Lowland river
Inherent erosion potential (K factor) of catchment soils	< 0.13	0.13-0.25	*0.25-0.50*	0.50-0.70	> 0.70
Average catchment slope	<3%	3-5%	*6-8%*	9-11%	>11%
Inherent runoff potential of	Low (A & A/B)	Mod. Low (B)	*Moderate (B/C)*	Mod. High (C)	High (C/D & D)

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
catchment soils					

3.1. Channel width

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

Method: See method in 1.2 for estimating channel width

3.2. Longitudinal river zonation

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

Method: At a desktop level[34], determine the suitable geomorphological classification of the river based on the classification system of Rowntree and Wadeson (2000) and establish which of the following categories the river would be classed as:

- **Mountain stream** – steep to very steep-gradients where gradients exceed 0.04 (Includes Mountain headwater streams). Substrates are generally dominated by bedrock and boulders, with cobbles or coarse gravels in pools.
- **Transitional River** – moderately steep stream dominated by bedrock and boulders; reach types include plain-bed, pool-riffle or pool-rapid; usually in confined or semi-confined valley. Characteristic gradient is 0.02-0.039.
- **Upper Foothill River** – moderately steep, cobble-bed or mixed bedrock-cobble bed channels, with plain-bed, pool-riffle or pool-rapid reach types; length of pools and riffles/rapids is similar. Characteristic gradient is 0.005-0.019.
- **Lower Foothill River** – lower-gradient, mixed-bed alluvial channel with sand and gravel dominating the bed and may be locally bedrock controlled; reach types typically include pool-riffle or pool-rapid, with sand bars common in pools; pools are of significantly greater extent than rapids or riffles. Characteristic gradient is 0.001-0.005.
- **Lowland River** – low-gradient, alluvial fine-bed channels, which may be confined, but fully developed meandering pattern within a distinct floodplain develops in unconfined reaches where there is increased silt content in bed or banks. Characteristic gradient is 0.0001-0.001.

Rapid site assessments are recommended in addition to desktop determination procedures in order to verify site specific river characteristics. The aforementioned features should be considered when conducting site assessments, i.e. typically channel substrates, deposition features, etc.

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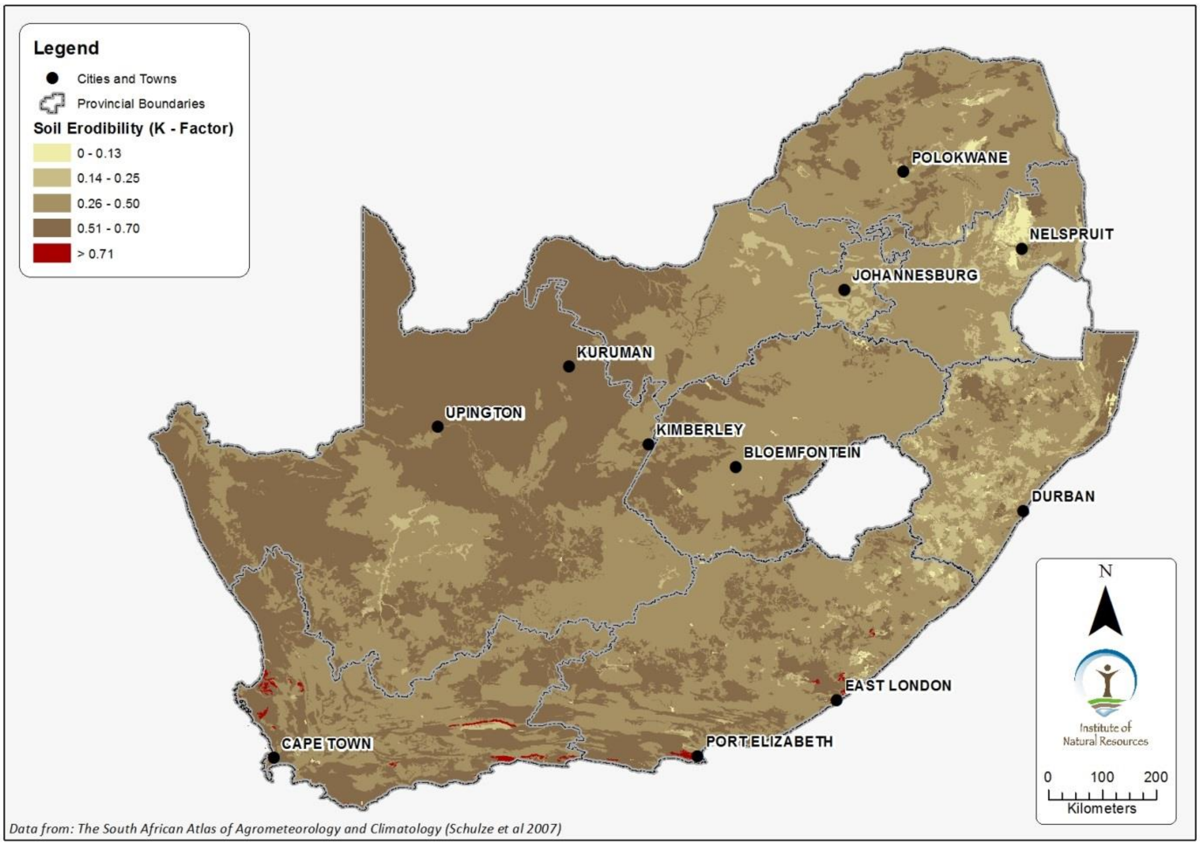
[34] Geomorphological categories have been mapped at a national scale using the 1:500 000 rivers of South Africa. These maps may be obtained from the Department of Water Affairs' Water Quality Services (http"//www.dwa.gov.za/iwqs/gis_data/rivslopes/rivprofil.asp) . The NFEPA rivers map (available via a link from http://bgis.sanbi.org/nfepa/NFEPAmap.asp) also provides longitudinal river zonation information for mainstem rivers and larger tributaries.

3.3. Inherent erosion potential of catchment soils

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

Method: Using the South African Atlas of Climatology and Agrohyrology (Schulze, 2007), determine the soil erodibility factor for the general catchment area within which the river reach occurs according to the corresponding soil erodibility classes and K-factors (Figure 2).



Data from: The South African Atlas of Agrometeorology and Climatology (Schulze et al 2007)

Figure 2. Soil erodibility (K-Factor) (Schulze et al., 2007)

The following are used to define soil erodibility according to the prevailing soil K-factor.

SOIL ERODIBILITY CLASS	SOIL K-FACTOR
Very high	> 0.70
High	0.50-0.70
Moderate	0.25-0.50
Low	0.13-0.25
Very low	< 0.13

Note: *For catchments characterised by more than one area of differing K-factors, an average area-weighted K-factor for the catchment needs to be determined.*

3.4. Average catchment slope

Rationale: Given that slope is a key driver of catchment hydrological response (c.f. Section 2.2), it is also has a significant influence on secondary factors such as soil erosion. Catchments that are affected by heavy soil erosion are expected to have high rates of sedimentation within the rivers. As a consequence, rivers draining catchments characterised by steep topography are likely to experience higher levels of sedimentation due to higher erosion.

Method: Refer to Method 2.2 when calculating average catchment slope.

3.5. Inherent runoff potential of catchment soils

Rationale: Refer to Rationale 2.3.

Method: Using the method from 2.3, determine the appropriate hydrological soil group that defines the entire catchment based on available soils information.

4. Sensitivity to increased inputs of nutrients (phosphate, nitrite, nitrate) from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Channel width	< 1 m	1-5 m	*510 m*	10-20 m	> 20 m
Stream order	1st order	2nd order	*3rd order*	4th order	> 5th order
Retention time		Generally free-flowing (lotic)		Generally slow moving (lentic)	
Inherent level of nutrients in the landscape: Is the river/stream and its catchment underlain by sandstone?		Yes	*Partially*	No	
Inherent erosion potential (K factor) of catchment soils	< 0.13	0.13-0.25	*0.25-0.50*	0.50-0.70	> 0.70

4.1. Channel width

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

Method: See method in 1.2 for estimating channel width.

4.2. Stream order

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

Method: Refer to Method 1.1 to determine the stream order using the Horton-Strahler stream ordering method.

4.3. Retention time

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

Method: Assess whether the section of river is generally free-flowing (lotic) or slow moving (lentic).

4.4. Inherent level of nutrients in the landscape

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

Method: This assessment is based on existing geological maps for the area. Where the threat of nutrients is high or very high, it may be beneficial to assess current nutrient levels through nutrient sampling.

4.5. Inherent erosion potential of catchment soils

Rationale: Soil erosion is regarded as a major contributor to Phosphorous levels in streams. As such, streams fed by catchments with high erodibility are likely to have higher inherent Phosphate loadings that where catchments are characterized by low soil erodibility.

Method: Using the method from 3.3.

5. Sensitivity to increases in toxic contaminants (including toxic metal ions (e.g. copper, lead, zinc), toxic organic substances (reduces oxygen), hydrocarbons and pesticides) from lateral inputs

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Channel width	< 1 m	1-5 m	*5-10 m*	10-20 m	> 20 m
Stream order	1st order	2nd order 1-5 m	*3rd order*	4th order	> 5th order
Inherent erosion potential (K factor) of catchment soils	< 0.13	0.13-0.25	*0.25-0.50*	0.50-0.70	> 0.70
Inherent runoff potential of catchment soils	Low (A & A/B)	Mod. Low (B)	*Moderate (B/C)*	Mod. High (C)	High (C/D & D)

5.1. Channel width

Rationale: See Rationale 4.1

Method: See method in 1.2 for estimating channel width.

5.2. Stream order

Rationale: See Rationale 4.2.

Method: Refer to Method 1.1 to determine the stream order using the Horton-Strahler stream ordering method.

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

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

Method: Refer to Method 3.3 to determine the appropriate soil erodibility classes and K-factors.

5.4. Inherent runoff potential of catchment soils

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

Method: Using the method from 2.3, determine the appropriate hydrological soil group that defines the runoff potential for the entire catchment based on available soils information.

6. Sensitivity to changes in acidity (pH) from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Channel width	< 1 m	1-5 m	*510 m*	10-20 m	> 20 m
Stream order	1st order	2nd order	*3rd order*	4th order	> 5th order
Inherent buffering capacity	Pure waters with poor pH buffering		*Neutral pH*		'Hard' water rich in bicarbonate and carbonate ions or naturally acid waters high in organic acids[35]

6.1. Channel width

Rationale: See Rationale 4.1

Method: See method in 1.2 for estimating channel width

6.2. Stream order

Rationale: See Rationale 4.2.

Method: Refer to Method 1.1 to determine the stream order using the Horton-Strahler stream ordering method.

6.3. Inherent buffering capacity

Rationale: pH is determined by the concentration of hydrogen ions (H^+). In very pure waters (i.e. water containing no solutes) pH can change rapidly because the rate of change is determined by the buffering capacity, which in turn is usually determined by the concentration of carbonate and bicarbonate ions in the water. Consequently, pH in river water to some degree is driven naturally by geological formations due to the dominance of bicarbonate and carbonate ions present in the mineral composition of geological formations. At the opposite end of this scale, acid rivers dominated by organic acids have an entirely different buffering system based on the presence of those organic acids. This system is not well understood.

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

Method: At a desktop level, determine whether the river system has a low buffering capacity and thus sensitive to changes in pH according to the four broad geographical patterns as defined by Day and King (1995).

7. Sensitivity to changes in concentration of salts (salinization) from lateral inputs

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Channel width	< 1 m	1-5 m	*510 m*	10-20 m	> 20 m
Stream order	1st order	2nd order	*3rd order*	4th order	> 5th order
Underlying geographical formations	Rock formations characterised with granite, siliceous sand and well-leached soils		*Primarily Precambrian formations*		Primarily Palaeozoic and Mesozoic sedimentary rock formations

7.1. Channel width

Rationale: See Rationale 4.1

Method: See method in 1.2 for estimating channel width

7.2. Stream order

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

Method: Refer to Method 1.1 to determine the stream order using the Horton-Strahler stream ordering method.

7.3. Underlying geographical formations

Rationale: River water has natural salt concentrations that are a result of the dissolution of minerals in rocks and soils; hence the natural contributions of the minerals vary according to geological formations. As a result the concentrations of salts in river water are low where granite, siliceous sand and well-leached soils prevail. Salt concentrations are higher where Precambrian formations are present, and highest for Palaeozoic and Mesozoic sedimentary rock formations.

Method: At a desktop level of assessment, determine the dominant geological formations that characterise the catchment.

8. Sensitivity to changes in water temperature from lateral inputs

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Stream order	1st order	2nd order	*3rd order*	4th order	> 5th order
River depth to width ratio	> 0.25		0.25-0.75		< 0.75
Mean Annual Temperature	MAT Zone 1 (Coolest)	MAT Zone 2	*MAT Zone 3*	MAT Zone 4	MAT Zone 5 (Warmest)
Longitudinal river zonation	Mountain stream and headwaters		*Transitional and upper foothill rivers*		Lower foothill and lowland rivers

8.1. Stream order

Rationale: See Rationale 4.1.

Method: Refer to Method 1.1 to determine the stream order using the Horton-Strahler stream ordering method.

8.2. River depth to width ratio

Rationale: Rivers that have a large depth to width ratio have a low thermal inertia and thus a low capacity to absorb solar radiation compared to shallow systems. Systems with a low thermal inertia are therefore more sensitive to changes in water temperature from lateral inputs, e.g. heated industrial effluents.

Method: Determine the approximate depth and width of the river channel for the site and then calculate the depth to width ratio (i.e. depth divided by width).

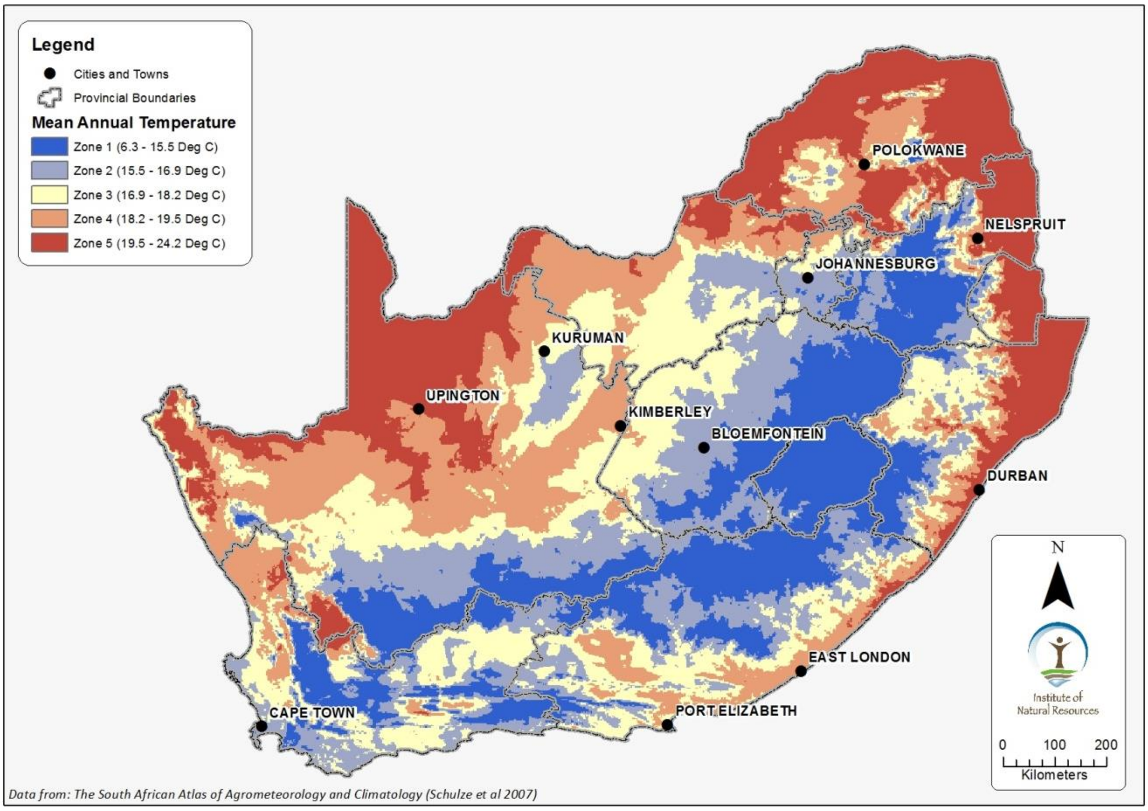
The following categories are used to represent the sensitivity of a river to changes in water temperature based on the river's thermal capacity:

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

8.3. Mean Annual Temperature

Rationale: Rivers characterised by cooler water are more sensitive to thermal pollution than rivers with higher temperatures. Rivers situated in cooler regions are likely to be more sensitive to changes in water temperature (Figure 3).

Method: At a desktop level of assessment, determine the mean annual temperature zone that characterises the catchment.



Data from: The South African Atlas of Agrometeorology and Climatology (Schulze et al 2007)

Figure 3. Mean annual temperature separated into five temperature zones, based on five equal quantiles) (Data from Schulze et al., 2007)

8.4. Longitudinal river zonation

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

Geomorphological status also defines to some extent the concentration of suspended sediments contained within the river which further influences river water temperature. Lowland rivers, because of the accumulation of sediments and fines with downstream distance, tend to be more turbid than rivers situated in the upper catchment reaches. Rivers with a high turbidity have a low albedo[36] and thus have a greater ability to absorb solar radiation rather than reflecting incoming solar rays. Thus rivers that are naturally turbid are generally warmer and thus less sensitive to changes in river water temperature caused by thermal pollution from lateral inputs.

Method: At a desktop level, determine the geomorphological position of the river according to the geomorphological classification system of Rowntree and Wadeson (2000) as outlined in Section 3.2. These are grouped broadly into three classes, namely:

- **Mountain Headwater Streams and Mountain Streams** – steep to very steep-gradients where gradients exceed 0.04. Substrates are generally dominated by bedrock and boulders, with cobbles or coarse gravels in pools.
- **Transitional and Upper Foothill Rivers** – moderately steep stream (characteristic gradient is 0.005-0.04) dominated by bedrock, boulders and cobbles; reach types include plain-bed, pool-riffle or pool-rapid.
- **Lower Foothill and Lowland Rivers** – lower-gradient (characteristic gradient is 0.0001-0.005). Substrates range from mixed-bed alluvial channel with sand and gravel dominating the bed to alluvial fine-bed channels. Reach types range from pool-riffle or pool-rapid, with sand bars common in pools to fully developed meandering pattern within a distinct floodplain and unconfined reaches where there is increased silt content in bed or banks.

9. Sensitivity to changes in pathogens from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Channel width	< 1 m	1-5 m	*510 m*	10-20 m	> 20 m
River depth to width ratio	> 0.25		0.25-0.75		< 0.75
Level of domestic use	High	Moderately high	*Moderate*	Moderately low	Low

9.1. Channel width

Rationale: See Rationale 4.1

Method: See method in 1.2 for estimating channel width

9.2. River depth to width ratio

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

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[36] Is a measure of how strongly an object reflects light from light sources such as the sun.

Method: Similar to Section 8.3, conduct a rapid site assessment to determine the approximate depth and width of the river channel for the site and then calculate the depth to width ratio (i.e. depth divided by width). For detailed assessments, refer to Method 8.3.

9.3. Level of domestic use

Rationale: The higher the level of domestic water use, the higher the threat of increasing pathogen levels to water users.
Method: Based on an evaluation of landiuse around the river and discussions with local stakeholders, establish the level of domestic water use (including recreational use).

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Annexure 14 – Guidelines for assessing the sensitivity of estuaries to lateral land-use inputs

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

Indicators have been defined in order to assess the sensitivity of estuaries to common threats posed by lateral land-use impacts. These impacts include volume and timing of lateral water inputs, sediment, nutrients and toxins, and pathogen inputs from lateral inputs as well as changes in salt input and temperature. The indicators were scored relative to a typical 'Reference' estuary of intermediate sensitivity and are used to calculate a sensitivity score and associated class for each threat type under consideration.

1. Sensitivity to changes in water quantity (volumes of flow) from lateral inputs

Table 1. Estuary characteristics affecting the sensitivity of the water resource to changes in the volumes of inputs from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Perenniality of river inflows		Intermittent	*Seasonal*	Perennial	

1.1 Estuary size

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

Method: NBA dataset available for estuary size. If necessary check the approximate area of the estuary being assessed using available tools (e.g. GIS).

1.2 Estuary length

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

Method: NBA dataset available for estuary length. If necessary check the approximate length of the estuary being assessed using available tools (e.g. GIS).

1.3 Perenniality of river inflows

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

Method: At a desktop level, perenniality may be interpreted from 1:50 000 topographical sheets where rivers indicated with a solid line are considered to be perennial systems and dotted lines represent non-perennial rivers (i.e. seasonal and intermittent). Distinction between seasonal and intermittent rivers is made where the former consists of river systems that flow for extended periods during the wet seasons/s (generally between 3 and 9 months), at intervals varying from less than a year to several years (Ollis et al*.,* 2013). Intermittent rivers flow for a relatively short time of less than one season's duration (i.e. less than approximately 3 months) at intervals varying from less than a year to several years (Ollis et al., 2013).

2. Sensitivity to changes in patterns of flow (frequency, amplitude, direction of flow) from lateral inputs?

Table 2. Estuary characteristics affecting the sensitivity of the water resource to changes in the patterns of flow from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Estuary length		<5 km	*5-10 km*	*10-20* km	>20 km
Inherent runoff potential of catchment soils	Low	Mod. Low	*Moderate*	Mod. high	High
Mouth closure	>80%	50-80%	*50%*	20-50%	20%

2.1 Estuary size

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

Method: See method in 1.1 for assessing estuary size.

2.2 Estuary length

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

Method: See method in 1.2 for assessing estuary length.

2.3 Inherent runoff potential of catchment soils

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

Method: The Soil Conservation Services method for Southern Africa (SCS-SA) uses information of hydrologic soil properties to estimate surface runoff from a catchment (Schulze et al., 1992). With reference to the SCS-SA (Table 2), determine the appropriate hydrological soil group that defines the entire catchment based on available soils information. Such information is obtainable from the Land Type maps of South Africa, which includes information on soil texture.

2.4 Mouth closure as a measure of water exchange

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

Method: With the use of available data estimate the duration of mouth closure for a year.

Sensitivity to changes in sediment inputs and turbidity from lateral inputs

Table 3: Estuary characteristics affecting the sensitivity of the water resource to increased sediment inputs from lateral sources

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Water clarity		Clear	*blackwater*	turbid	-
Submerged macrophytes present (adjacent planned development)		Yes		No	

3.1 Estuary size

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

Method: See method in 1.1 for assessing estuary size.

3.2 Estuary length

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

Method: See method in 1.2 for assessing estuary length.

3.3 Water clarity

Rationale: Clear estuaries will be more sensitive to lateral inputs than naturally turbid systems. Blackwater systems are those which are rich in tannins. The NBA has classified all estuaries as “clear, blackwater or turbid” based on the quality of the freshwater inflow to the system.

Method: NBA dataset available for river water inflow types as an indication of estuary water clarity.

3.4 Presence of submerged macrophytes

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

Method: The NBA database indicates those estuaries where submerged macrophtyes are present. The estuary habitat adjacent to the planned development should be checked in the field for the presence of submerged macrophytes. Reports and aerial photographs should also be used to assess whether submerged macrophytes have occurred in the area. This is necessary as these plants are dynamic and rapidly change their habitat distribution in response to droughts and floods.

Sensitivity to increased inputs of nutrients (phosphates, nitrite, nitrate) from lateral inputs

Table 4: Estuary characteristics affecting the sensitivity of the water resource to increase nutrient inputs from lateral sources

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Water clarity		Clear	*blackwater*	turbid	-
Mouth closure	>80%	50-80%	*50%*	20-50%	<20%
Submerged macrophytes present (adjacent planned development)		Yes		No	

4.1 Estuary size

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

Method: See method in 1.1 for assessing estuary size.

4.2 Estuary length

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

Method: See method in 1.2 for assessing estuary length.

4.3 Water clarity

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

Method: NBA dataset available for river water inflow types as an indication of estuary water clarity.

4.4 Mouth closure as a measure of flushing / residence time

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

Method: With the use of available data estimate the duration of mouth closure for a year.

4.5 Presence of submerged macrophytes

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

Method: The NBA database indicates those estuaries where submerged macrophtyes are present. Where feasible, this should be checked in the field as this is a dynamic habitat changing in response to droughts and floods.

Sensitivity to increases in toxic contaminants (including toxic metal ions (e.g. copper, lead, zinc), toxic organic substances (reduces oxygen), hydrocarbons and pesticides) from lateral inputs

Table 5. Estuary characteristics affecting the sensitivity of the water resource to changes in contaminants from lateral inputs

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Mouth closure	>80%	50-80%	*50%*	20-50%	<20%

5.1 Estuary size

Rationale: See Rationale 4.1 *Method:* See method in 1.1 for assessing estuary size.

5.2 Estuary length

Rationale: See Rationale 4.2.

Method: See method in 1.2 for assessing estuary length.

5.3 Mouth closure

Rationale: See Rationale 4.4.

Method: See method in 4.4 for assessing frequency of mouth closure.

6. Sensitivity to changes in acidity (pH) from lateral inputs.

Table 6 Estuary characteristics affecting the sensitivity of the water resource to changes in acidity (pH) from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Mouth closure	>80%	50-80%	*50%*	20-50%	<20%

6.1 Estuary size

Rationale: See Rationale 4.1

Method: See method in 1.1 for assessing estuary size.

6.2 Estuary length

Rationale: See Rationale 4.2.

Method: See method in 1.2 for assessing estuary length.

6.3 Mouth closure

Rationale: See Rationale 4.4.

Method: See method in 4.4 for assessing frequency of mouth closure.

7. Sensitivity to changes in salinity from lateral inputs

Table 7. Estuary characteristics affecting the sensitivity of the water resource to changes in salinity from lateral inputs

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Estuary length		<5 km	*5-10 km*	10-20 km	>20 km
Mouth closure	>80%	50-80%	*50%*	20-50%	<20%

Inputs from lateral flow can have a localized effect in estuaries. For example development and run-off often freshens the system leading to a loss of salt marsh and expansion of reeds at the estuary boundary. Similarly, run-off from some sources such as salt works / salt pans can increase salinity causing die-back of estuarine vegetation such as reeds, sedges and salt marsh. All natural plant communities in estuaries would have a high sensitivity to salinity changes caused by lateral flow inputs.

Naturally saline estuaries (which are more open to sea), are characterized by highly variable salinity and likely to be less sensitive than estuaries that are naturally characterized by lower and less variable salinity levels. Estuaries in the warm-temperate zone are characterized by low rainfall and runoff which results in elevated salinity (Harrison, 2004) and sensitivity to lateral inflows.

7.1 Estuary size

Rationale: See Rationale 4.1

Method: See method in 1.1 for assessing estuary size.

7.2 Estuary length

Rationale: See Rationale 4.2.

Method: See method in 1.2 for assessing estuary length.

7.3 Mouth closure

Rationale: See Rationale 4.4.

Method: See method in 4.4 for assessing frequency of mouth closure.

8. Sensitivity to changes in water temperature from lateral inputs

Table 8. Estuary characteristics affecting the sensitivity of the water resource to changes water temperature from lateral sources

CRITERION	SENSITIVITY SCORES				
	1.15	1.075	*1*	0.925	0.85
Estuary size		<10 ha	10-50 ha	50-100 ha	>100 ha
Estuary length		<5 km	5-10 km	*10-20 km*	>20 km
Biogeographic zone	Low latitude Subtropical		*Moderate latitude Warm temperate*		High latitude Cool temperate

Inputs from lateral flow could have a localized temperature effect in estuaries. Industries can discharge warm or cool waters. Temperature in estuaries follow the trend for marine coastal waters, decreasing from the subtropical east coast, along the warm-temperate south coast and up the cool-temperate west coast. Naturally cooler systems are likely to be more susceptible to increased water temperatures from lateral inputs than are warmer estuaries.

8.1 Estuary size

Rationale: See Rationale 4.1

Method: See method in 1.1 for assessing estuary size.

8.2 Estuary length

Rationale: See Rationale 4.2.

Method: See method in 1.2 for assessing estuary length.

8.3 Biogeographic zone

Rationale: Estuaries characterized by cooler water are more sensitive to thermal pollution than those with higher temperatures. Estuaries situated on the west coast are generally cooler and thus more sensitive to increases in water temperature.

Method: Determine the biogeographic zone in-which the estuary is located using the map provided in Figure 1, below. This shows that all estuaries north of the Mbashe Estuary are subtropical, while those west of Heuningnes Estuary are cool temperate. Estuaries located in between are classified as warm temperate estuaries.

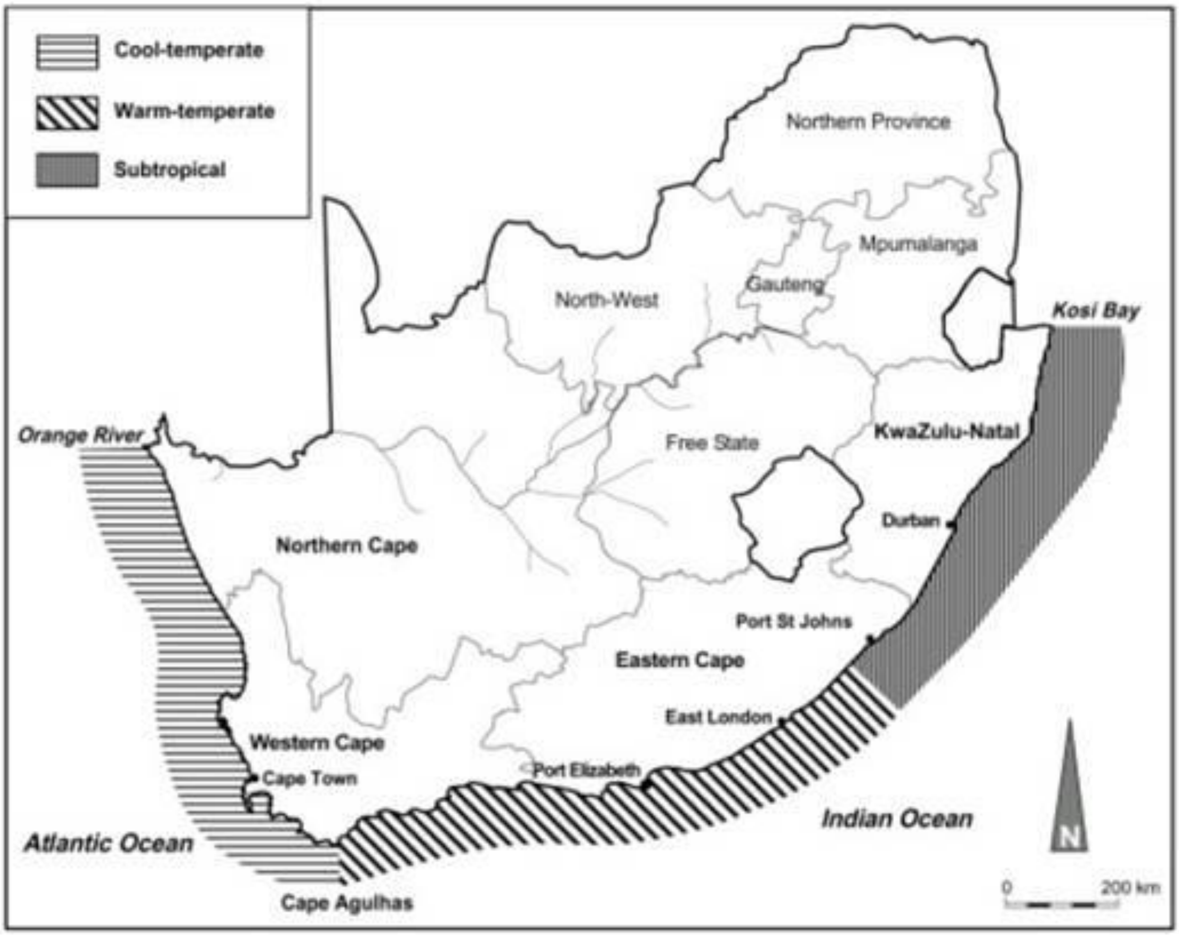

Figure 1. Map of Biogeographic Zones as used in National Spatial Biodiversity Assessment (NSBA, 2004) for Estuarine Ecosystems (from Harrison, 2003)

9. Sensitivity to changes in pathogens from lateral inputs

Table 10: Estuary characteristics affecting the sensitivity of the estuary to increased pathogen inputs from lateral sources

CRITERION	**SENSITIVITY SCORES**				
	1.15	1.075	*1*	0.925	0.85
Overall size		<10 ha	*10-50 ha*	50-100 ha	>100 ha
Length		<5 km	*5-10 km*	10-20 km	>20 km
Level of domestic use	High		*Moderate*		Low

9.1 Estuary size

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

Method: See method in 1.1 for assessing estuary size.

9.2 Estuary length

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

Method: See method in 1.2 for assessing estuary length.

9.3 Level of domestic use

Rationale: The higher the level of domestic water use, the higher the threat of increasing pathogen levels to water users.

Method: Based on an evaluation of land use around the estuary and discussions with local stakeholders, establish the level of domestic water use (including recreational use).

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Annexure 15 – Development of rule-curves to link buffer efficiency to buffer width

This annexure includes a summary of the available scientific literature used to inform the development of rule-curves that link buffer efficiency to buffer width for selected buffer functions. These rule curves form the basis for buffer zone determination in the buffer zone models but are refined to cater for climatic variability, the sensitivity of the receiving environment and buffer zone attributes for the site-based assessment.

1. Increased sedimentation and turbidity

Yuan et al.(2009) recently undertook a thorough review of the effectiveness of vegetative buffers on sediment trapping in agricultural areas. In this review of a large number of quantitative studies, there was clear evidence that although sediment trapping capacities are site- and vegetation-specific, and many factors influence the sediment trapping efficiency, the width of a buffer is important in filtering agricultural runoff and wider buffers tended to trap more sediment. Despite some variability between studies, results indicated that first 3-6 m of a buffer plays a dominant role in sediment removal. This finding is backed up by Sheldon et al. (2003) who showed that the relationship between the length covered by the runoff (buffer width) and sediment removal is not linear, with most sediment being deposited in outer portions of the buffer. In a study undertaken by Barling and Moore (1994), for example, on forested buffers, the majority (91%) of sediment deposition took place within the first 0.25 to 0.6 m of the outer edge of the buffer. Robinson et al. (1996) also found that sediment was reduced by 70% and 80% from the 7% and 12% slope plots, respectively, within the first 3 m of the buffer. Dillaha et al. (1989) and Magette et al. (1989) reported sediment trapping efficiencies of 70-80% for 4.6 m and 84-91% for 9.1 m wide grass filter strips. Yuan et al. (2009) conclude that generally, buffers 4-6 m can reduce sediment loading by more than 50%.

Yuan et al. (2009) further report that buffers greater than 6 m are effective and reliable in removing sediment from any situation. They refer, for example, to Hook et al. (2003), who reported that more than 97% of sediment was trapped in the rangeland riparian buffer area with a 6 m buffer in any of the experimental conditions they studied. Sheridan et al. (1999) reported sediment trapping efficiencies of 77-90% across three different management schemes (clear cut, thinned, and untouched) when studying the impact of forest management practices within the riparian zone. Cooper et al. (1992) estimated that 90% of the sediment leaving fields was retained in the wooded riparian zone.

Yuan et al. (2009) indicated that the overall, the sediment trapping efficiency to buffer width relationship can be best fitted with logarithm models (Figure 1). This is similar to the relationship previously developed by Gilliam (1994) and to that recently modelled by Zhang et al. (2009).

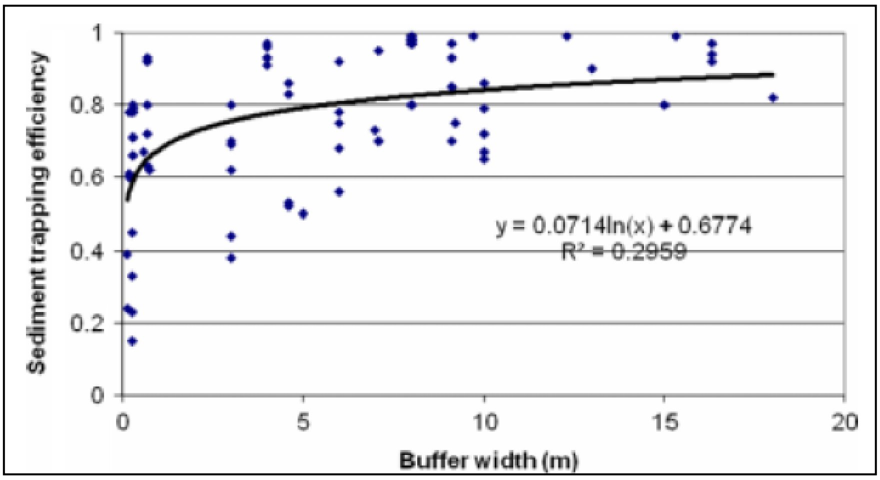


Figure 1. Buffer width and sediment trapping efficiency (Yuan et al., 2009).

According to this relationship, a 5 m buffer can trap about 80% of incoming sediment. Yuan et al. (2009) further observed that effectiveness differed among buffer width categories (Figure 2). Buffers of 3-6 m wide have greater sediment trapping efficiency than buffers of 0-3 m wide, and buffers of greater than 6 m wide have greater sediment trapping efficiency than buffers of 3-6 m wide. Thus, wider buffers are likely to be more efficient in trapping sediment than narrower buffers.

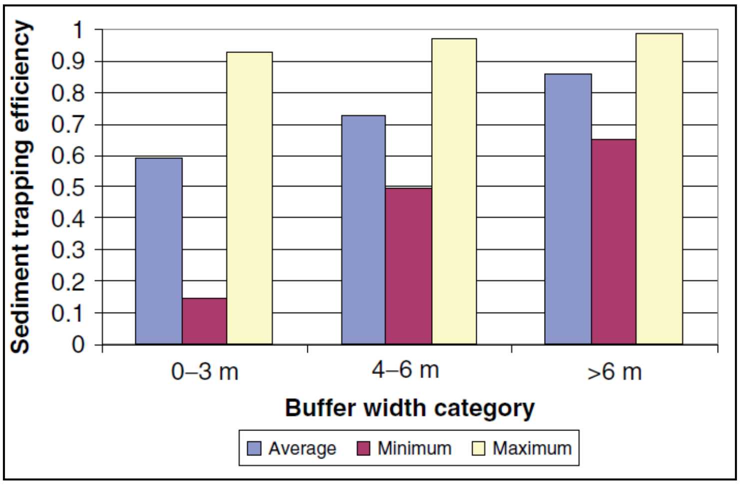
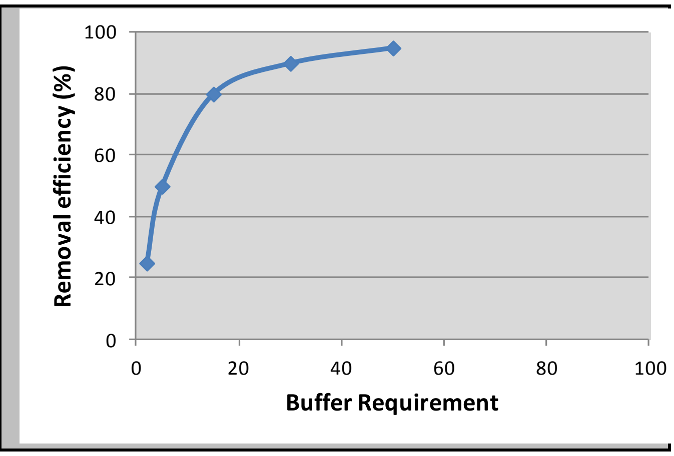


Figure 2. Average, minimum, and maximum sediment trapping efficiency for different buffer width category. (Yuan et al.,2009).

Based on this information, a curvilinear relationship between sediment removal efficiency and buffer width is assumed. Details of starting buffer widths proposed on the basis of risk and associated buffer effectiveness scores are provided below.

RISK CLASS	EFFECTIVENESS (%)	BUFFER WIDTH
Very Low	25	2
Low	50	5
Moderate	80	15
High	90	30
Very High	95	50



It is important to note however that these results reflect buffer effectiveness in situations where the buffer is designed to trap sediment (good vegetative cover) and concentrated flows are avoided. High levels of variability are also known to be reported for different size particles, with fine particles requiring a far larger buffer width.

2. Increased nutrient inputs from lateral inputs

Many studies have shown >90% reductions in nitrate concentrations in subsurface flows as water passes through riparian areas or wetlands (e.g. Gilliam, 1994; Fennesey and Cronk, 1997). Buffers are consistently reported to reduce nitrate to below 2 mg/L (in line with SLV limits), often throughout the year and even when nitrate inputs are extremely high (Muscutt et al. 1993). As such, the establishment of buffer zones is regarded as an effective and appropriate mitigation measure to remove nitrogen from diffuse lateral inputs.

In a recent meta-analysis of 73 studies undertaken by Zhang et al. (2009), theoretical models were developed to quantify the relationship between pollutant removal efficiency and buffer width. Models developed, suggested that buffer width was a primary factor affecting nutrient removal efficiency, with about 50% of the variation in N removal efficiency and 48% of the variation in P removal efficiency explained by buffer width and vegetation. This highlights the usefulness of buffer width as a primary discriminator for assessing nutrient removal efficiency.

Another recent meta-analysis of Nitrogen Removal in Riparian Buffers was undertaken by Mayer et al. (2007). This included analysis of data from 89 individual riparian buffers from 45 published studies. Although nitrogen removal effectiveness varied widely among studies, there was a clear relationship between buffer width and buffer effectiveness. In particular, this review showed that Nitrogen removal effectiveness of buffers 50 m wide was greater than that of buffers 0 to 25 m, whereas effectiveness of buffers 26 to 50 m did not differ from the other categories (Figure 3). Thus, wider buffers are likely to be more efficient zones of nitrogen removal than narrower buffers.

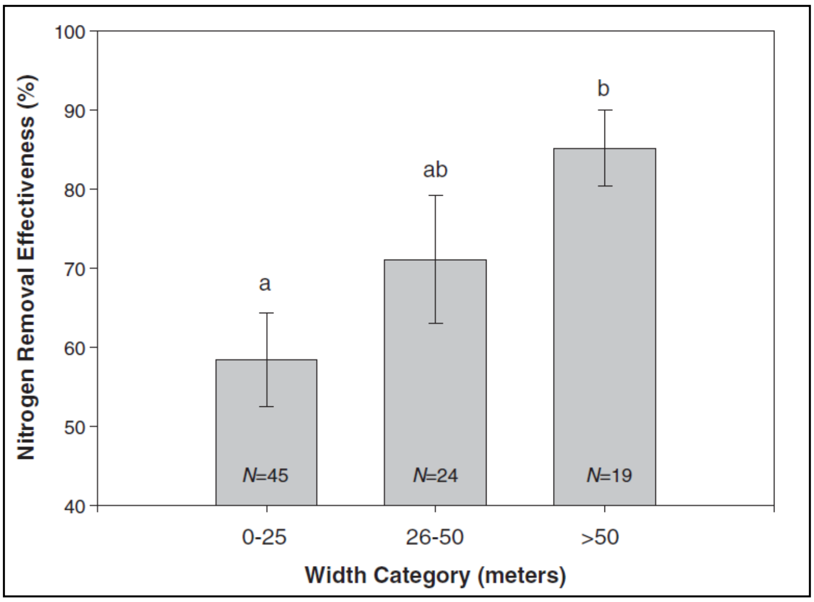


Figure 3. Nitrogen removal effectiveness in riparian buffers by buffer width category. Bars represent means ±standard error. Mean ranks of width categories differ if denoted by different letters (Kruskal-Wallis one-way analysis of variance on ranks with Dunn's method of multiple comparisons, P, 0.05).

Based on a limited data set fitted to a log-linear model, Oberts and Plevan (2001) found that NO_3^- retention in wetland buffers was positively related to buffer width (R^2 values ranged from 0.35-0.45). Nitrogen removal efficiencies of 65 to 75% and 80 to 90% were predicted for wetland buffers 15 and 30 m wide, respectively, depending on whether NO_3^- was measured in surface or subsurface flow (Oberts and Plevan, 2001). A similar relationship was demonstrated by Mayer et al. (2007) but with their model suggesting that removal efficiencies of 50, 75, and 90% occurred at buffer widths of 4, 49, and 149 m respectively as illustrated in Figure 4, below.

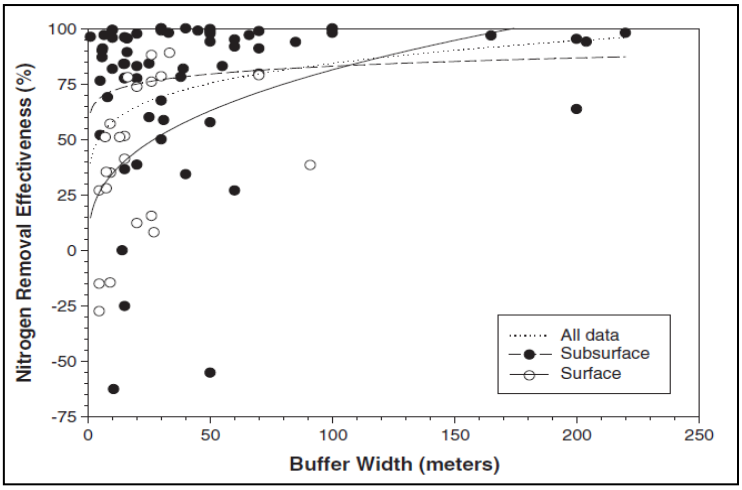


Figure 4. Relationships of nitrogen removal effectiveness to riparian buffer width over all studies and analysed by water flowpath (Mayer et al., 2007).

Zhang et al. (2009) also developed a curvilinear relationship for illustrating the relationship between buffer efficiency and nutrient removal efficiency. These relationships are presented in Figure 5, below and suggest that higher levels of buffer efficiency can be achieved with small buffers less than 25 m in width.

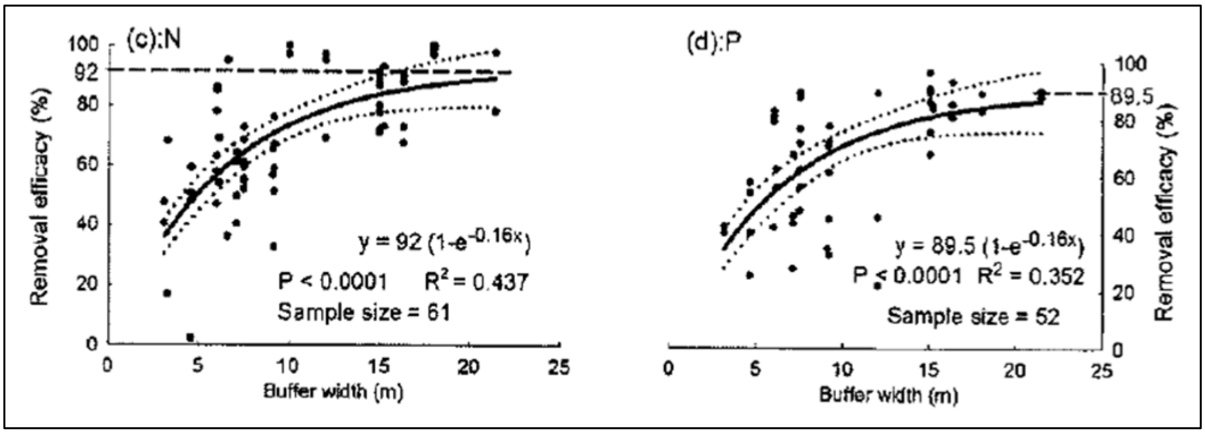
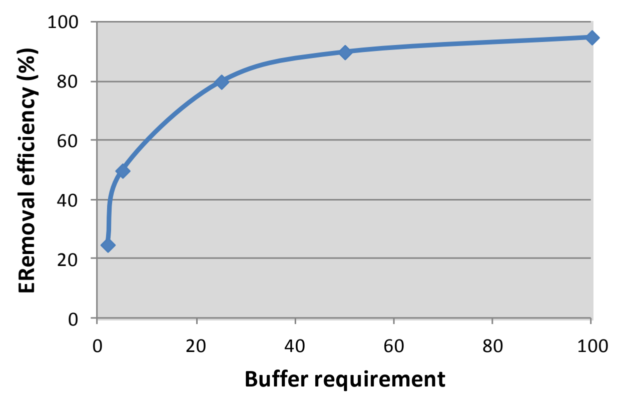


Figure 5. Pollution removal efficiency vs. buffer width for nitrogen and phosphorous. Dotted lines indicate 95% confidence band (Zhang et al., 2009).

Based on this information, a curvi-linear relationship between nutrient removal efficiency and buffer width is assumed, with the following conservative starting buffer widths proposed on the basis of risk and associated buffer effectiveness scores.

RISK CLASS	EFFECTIVENESS (%)	BUFFER WIDTH
Very Low	25	2
Low	50	5
Moderate	80	25
High	90	50
Very High	95	100



3. Increased toxic contaminants from lateral inputs

When developing guidelines for the width of buffer zones to address threats posed by toxic contaminants, it is first important to note that the term “toxic contaminants” covers a broad suite of potentially toxic substances. These include toxicants (including toxic metal ions (e.g. copper, lead, zinc, etc.), toxic organic substances (which reduce oxygen availability), hydrocarbons, and pesticides. In addition, the efficiency of a buffer at trapping toxic substances is dependent on a wide range of factors, such as residence times, flushing rates, and dilution and re-suspension rates of the toxic substances.

Buffer guidelines could potentially be tailored according to specific toxic substances. However, this is unrealistic for this project and little information is available on buffer zone efficiencies for all toxic substances. As an initial approach to determining the effectiveness of a buffer zone at trapping toxic substances, toxic contaminants have been considered as two broad categories, namely organic contaminants (which include pesticides) and toxic heavy metals. Buffer widths proposed for these groups have been based on available information. In addition, the precautionary principle was also applied.

A review of international literature does provide some useful indicators of the efficiencies of buffers of particular widths for removing certain toxic contaminants. According to Blanche (2002) removal efficiencies for sediment-attached and dissolved toxics are likely to be similar to those determined for sediments and dissolved nutrients. However, literature also highlights the differences with respect to organic pollutants and pesticides, and metals. These broad categories are discussed in the following subsections.

3.1 Organic pollutants and pesticides

Organic pollutants include substances such as persistent organic pollutants (POPs, e.g. DDT and its metabolites), various organochlorine pesticides (OCPs), polycyclic aromatic hydrocarbons (PAHs), dioxin-like compounds (DLCs), and non-dioxin-like polychlorinated biphenyls (PCBs). Most organic toxicants are hydrophobic and do not dissolve readily in water and general bind to organic matter in sediments. Some can stay in the sediment for long periods of time with minimal breakdown and natural decomposition while others break down relatively quickly under anaerobic conditions. Substance breakdown is dependent on environmental factors, which need to be considered when interpreting decomposition data for the different organic toxicants (Gevao et al., 2010). Bioaugmentation of the sediment and sorption by plants and organic matter is of particular importance in the removal of some organic pollutants from the environment. There is a general lack of knowledge on the detailed removal pathways for organic compounds (Haberl et al., 2003), which renders determining the effectiveness of buffers a challenge. Given the vast range of organic toxic substances and the limited literature concerning buffer removal efficiencies, pesticides have been selected as a sub-group representative of organic toxic substances.

Individual pesticide characteristics have a significant bearing on removal efficiency as this affects the mechanism of removal, which can be either by co-deposition with sediment or by immobilization from solution. This is determined primarily by the adsorbing properties of the pesticide, which determines its ability to adsorb to organic carbon in sediment. Where pesticides have a strong adsorption capacity most of the pesticide is lost as co-deposition with sediment (Reichenberger et al., 2007). Removal efficiencies for these pesticides are therefore likely to be similar to those for sediment retention (Zhang et al., 2009). Zhang et al. (2009) developed a model for pesticide removal efficiency based on a review of 49 studies. Buffer width alone accounted for over half the variation in pesticide removal efficiency in these studies, supporting the notion that buffer width is a primary driver of pesticide removal. This model suggested that a 30 m buffer could remove 93% of pesticides in runoff. This relationship is illustrated in Figure 6, below. These results are comparable to the results presented Reichenberger et al. (2007), in a review of 14 studies who indicated that on average, pesticide load reduction efficiencies were 50% reduction for 5 m buffers strips, 90% for 10 m buffer width and 97.5% for 20 m widths. Variability in efficiencies were however very high, particularly for pesticides predominantly transported in the water phase (low adsorption capacity). This resulted in more conservative assumptions being applied to the full spectrum of pesticides and organic pollutants.

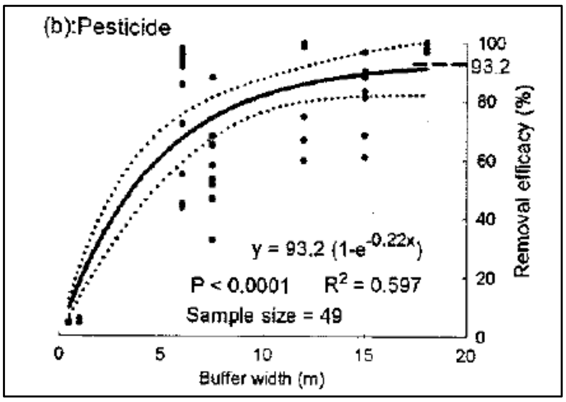
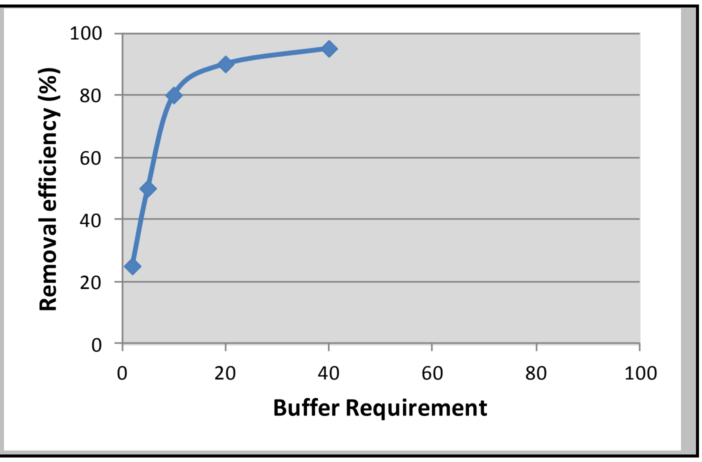


Figure 6. Removal efficiency vs. buffer width for pesticides. Dotted lines indicate 95% confidence band (Zhang et al., 2009).

Based on this information, a curvilinear relationship between organic pollutant / pesticide removal efficiency and buffer width is assumed, with the following starting buffer widths proposed on the basis of risk and associated buffer effectiveness scores.

RISK CLASS	**EFFECTIVENESS (%)**	**BUFFER WIDTH**
Very Low	25	2
Low	50	5
Moderate	80	10
High	90	20
Very High	95	40



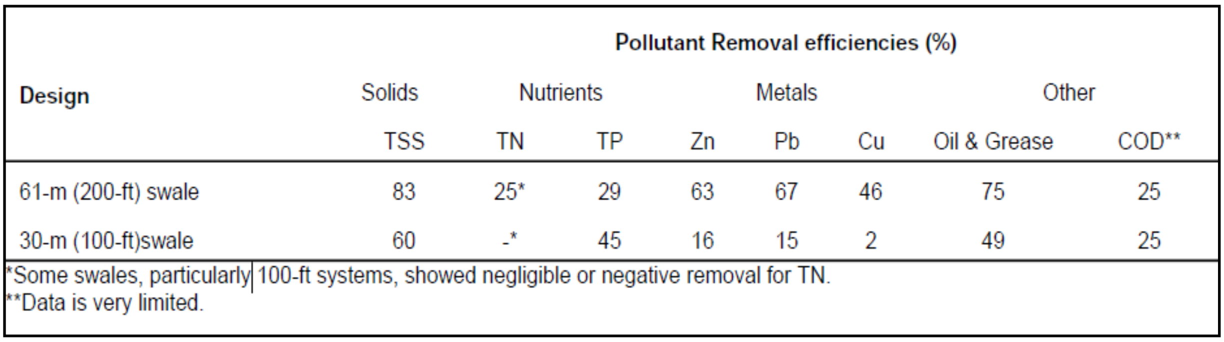
3.2 Heavy / Toxic metals

Limited information is available on the mobilisation of toxic metals by overland flow through buffers. Generally, metals are transported through the landscape attached to particles in sediments or dissolved in storm water. The concentration of the metal will depend mainly on the concentration of the metal at the source and the source substance's solubility.

In a dissolved state, the biological availability and chemical reactivity (sorption or desorption, precipitation or dissolution) towards other components is determined by the chemical form of the metal (Pintilie et al. 2003). Charged species are retained by sorption processes and the removal efficiencies are governed by the predominant ionic species and complexes (Hamilton and Harrison, 1991). Preliminary findings do, however, suggest that this varies considerably for the different heavy metals considered. Dissolved species of Zn, Cd, Pb, and Cr are more effectively removed than Cu and Fe (Yousef et al., 1987).

Yousef et al. (1987) also found swales[37] to filter out heavy metals through adsorption, precipitation and / or biological uptake. Average mass removal rates were however highly site and condition specific and influenced by the total mass input (concentrations), velocity of flow and percentage of infiltration. Table 1, below, presents the pollutant removal efficiencies for swale lengths of 61 meters and 30 meters reported in a report prepared for the U.S. Environmental Protection Agency. Although research results varied between studies, the data clearly indicate greater pollutant removal for wider swales. Indeed, this data suggest that removal efficiencies of 30 m wide swales are limited but increase to 50-70% at widths close to 60 m.

Table 1. Swale Pollutant Removal Efficiencies (Barret et al., 1993; Schueler, et al., 1991; Yu, 1993; Yousef et al., 1985) as reported in Clar et al. (2004).



Design	Pollutant Removal efficiencies (%)							
	Solids	Nutrients		Metals			Other	
	TSS	TN	TP	Zn	Pb	Cu	Oil & Grease	COD**
61-m (200-ft) swale	83	25*	29	63	67	46	75	25
30-m (100-ft)swale	60	-*	45	16	15	2	49	25

*Some swales, particularly 100-ft systems, showed negligible or negative removal for TN.
**Data is very limited.

Given the lack of available data for various heavy metals, comparative studies are also useful when comparing buffer zone effectiveness relationships with that of other pollutants. In this regard, the study alluded to above suggests that sediment removal efficiency of buffer zones is likely to be higher than for metals but that nutrient removal effectiveness is lower (Table 1). Hamilton and Harrison (1991) also noted that metals are more effectively removed than Nitrogen and Phosphorus. This finding is also supported through a reported study by the U.S. Department of Transportation who conducted a field study to determine the pollutant removal efficiencies of grassed channels and swales along highways in the U.S.A. (U.S. Environmental Protection Agency, 2000). This research showed that removal of metals was found to be directly related to the removal rate of total suspended solids, and the removal rate of metals was greater than removal of nutrients.

A range of other studies have also suggested strong linkages between removal of metal and sediment removal (e.g. Yousef et al., 1985; U.S. Environmental Protection Agency, 2000; Caltrans, 2003; Barrett et al., 2004). These findings therefore suggest that buffer requirements for metal removal should be strongly linked to that of sediment removal but that wider buffers should be advocated for nutrient removal.

Various authors do, however, emphasize that chemical removal ability is finite: once metals are adsorbed to soils, they can be freed for transport by further chemical or physical disturbance of the soil layer (e.g. Kearfott et al., 2005). The capacity of soils to retain heavy metals over the long-term is another important consideration, and would probably require regular monitoring to ensure that assimilative capacities of the soils were not exceeded. As such, the application of somewhat conservative buffer widths is recommended in high risk scenarios where heavy contaminant loads could reduce buffer zone efficiencies over time.

Based on this information, a curvilinear relationship between metal removal efficiency and buffer width is assumed. Following a precautionary approach the following starting buffer widths have been proposed for different risk classes.

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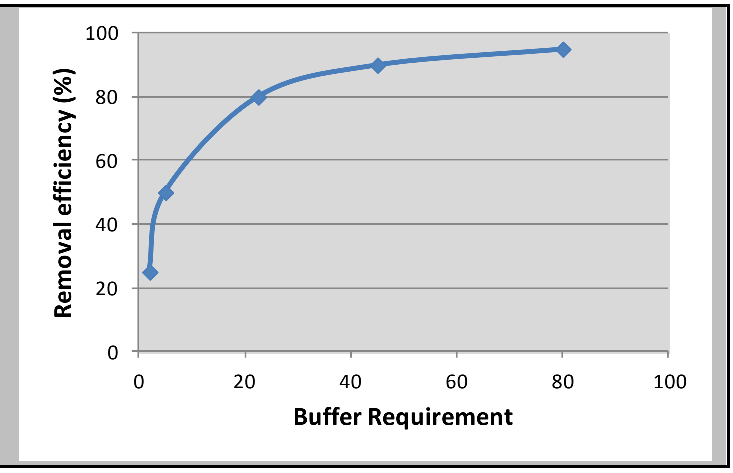
[37] According to Deeks and Milne (2005), vegetated swales and buffers perform both a stormwater treatment and stormwater conveyance function. Both systems treat stormwater via filtration through the vegetation. Additional pollutant removal is achieved through stormwater infiltration to groundwater and vegetative uptake.

RISK CLASS	EFFECTIVENESS (%)	BUFFER WIDTH
Very Low	25	2
Low	50	5
Moderate	80	22.5
High	90	45
Very High	95	80



It is important to note that chemical removal ability is finite. Once metals are adsorbed to soils, they can be freed for transport by further chemical or physical disturbance of the soil layer. The capacity of soils to retain heavy metals over the long-term is another important consideration, and would probably require regular monitoring to ensure that assimilative capacities of the soils were not exceeded. The effectiveness of the buffer zone will also depend on the metal in question.

4. Increased pathogen inputs from lateral sources

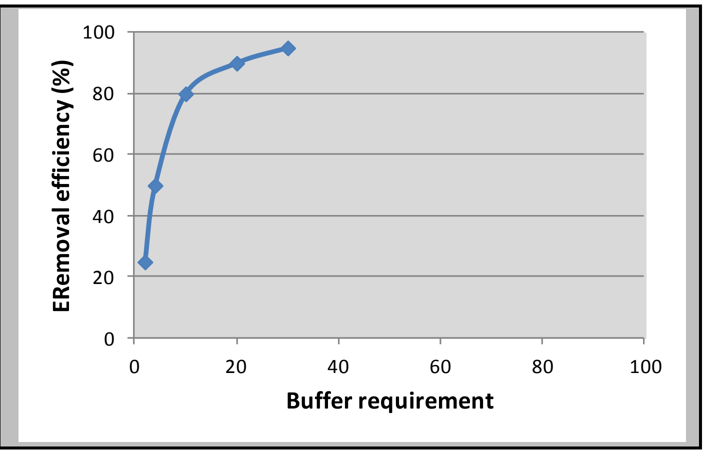
Most pathogenic bacteria are removed by physical and chemical adsorption within the soil profile (Gerba et al., 1975), and faecal coliform bacteria (FCB) concentrations therefore typically decline substantially when transported through soil, suggesting that transport to surface water occurs mainly by surface flow (Abu-Ashour et al., 1994; Howell et al., 1996; Huysman and Verstraete, 1993; Kunkle, 1970). Buffer zones that are able to intercept surface flow, promote leaching and prevent or retard overland transport may therefore be effective in reducing pathogen loads entering water resources (Sullivan et al., 2007).

Studies undertaken on the effectiveness of buffers in removing FCB suggest that small buffers may be effective in performing this function. Indeed, in a study by Sullivan et al. (2007), showed that the presence of a vegetated buffer of any size, from 1 to 25 m, generally reduced the median FCB concentration of runoff water after heavy storms from agricultural land amended with dairy cow manure by more than 99%. Only 10% of the runoff samples collected from treatment cells having vegetated buffers exhibited FCB concentrations >200 faecal coliforms / 100 ml, and the median concentration for all cells containing vegetated buffers was only 6 faecal coliforms / 100 ml. This suggests that very narrow vegetated buffer strips can effectively reduce FCB levels to within GLV limits of 1000 faecal coliforms / 100 ml.

Results obtained by Roodsari et al. (2005) provide additional evidence that small buffers can be very effective at absorbing FCBs. This showed that FCB released from surface-applied bovine manure through a 6 m buffer strip with a 20% slope was reduced to 1% of the applied bacteria amount on the vegetated clay loam soil and nondetectable on the vegetated sandy loam soil. These findings do however conflict with findings from earlier studies which suggested that wider buffer zones were required to effectively reduce FCB levels. For example, a faecal reduction model developed by Grismer (1981), suggested that 30 m buffers would only reduce FCB levels by 60%. Young et al, (1980), similarly concluded that 35 m vegetated buffers were required to reduce FCB levels from feedlot runoff during summer storms. Sullivan et al. (2007) do point out however that these earlier studies employed experimental designs based on high rates of artificial irrigation to force soil saturation and overland flow. They therefore conclude that new regulations that specify uniform minimum buffer sizes of 10.8 m (cf. US EPA, 2003) may be unnecessary for water quality protection under some soil and slope conditions.

Based on the information available, maximum starting buffers for FCB removal were set at 30 m, reduced to 2 m in the case of low-risk activities. Given that research suggests that very small buffers are effective at removing pathogens, a curvi-linear relationship was again assumed as illustrated below.

RISK CLASS	EFFECTIVENESS (%)	BUFFER WIDTH
Very Low	25	2
Low	50	4
Moderate	80	10
High	90	20
Very High	95	30



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Annexure 16 – Guidelines for refining buffer requirements based on site characteristics

This Annexure provides guidelines for refining buffer requirements based on site-specific buffer zone attributes. This has been informed by a review of available literature and on the outcomes of the hydrological sensitivity assessment undertaken for this study which specifically simulated the effect of a suite of buffer characteristics on peak discharge (See Annexure 9).

The guideline has been developed to cater for buffer zone efficiencies associated with each of the following threats:

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

In each case, a brief introduction is provided that outlines the key buffer zone attributes that are known to effect buffer zone efficiencies. A table is then provided that summarizes the buffer zone attributes used to modify buffer zone requirements which have been included in the buffer zone model. These tables also highlight default buffer characteristics that have been assumed in the desktop model. A rationale for selecting each criterion, together with a rationale and table for modifiers used in the buffer zone model is then provided. Finally, a brief methodology describing how each buffer characteristic should be assessed in the field is outlined.

1. Increases in sedimentation and turbidity

Sediment removal begins with the a reduction in the flow rate, which decreases the sediment carrying capacity of the water causing the excess sediment to drop out of suspension (Sheldon et al., 2003). This reduction in flow rate is caused mainly through the presence of vegetation, which increases surface roughness, increasing the resistance to flow (Blanché, 2002). Hydrological simulations have also clearly demonstrated that buffer zone slope and soil texture have a direct impact on the ability of buffer zones to attenuate flows (Annexure 9). Topographic characteristics also affect the ability of the buffer zone to effectively intercept influent water and promote deposition. A summary of the buffer zone attributes and modifiers used to adjust buffer zone width to cater for variability in the sediment retention capacity of buffer zones is presented in Table 1.1 below. Further details including the rationale for considering each criteria, together with modifier ratings and the method to be followed in collecting appropriate site-based information is detailed in the text that follows.

Table 1.1. Buffer zone characteristics used to refine buffer zone requirements to cater for the variability in sediment retention efficiency. Default values are highlighted in green.

Slope of the buffer	Category	Very Gentle	Gentle	Moderate	Moderately steep	Steep	Very steep
	Score	0.6	0.75	1	1.25	1.5	1.75
Vegetation characteristics (basal cover)	Category	Very high	High	Moderately low	Low		
	Score	0.75	1	1.5	2		
Soil permeability	Category	Low	Moderately low	Moderate	High		
	Score	1.75	1.25	1	0.75		

Topography of the buffer zone	Category	Uniform topography	*Dominantly uniform topography*	Dominantly Non-uniform topography	Concentrated flow paths dominate.	
	Score	0.75	*1*	1.5	2	

1.1 Slope of the buffer

***Rationale*:** A large number of authors have indicated that slope angle is a key factor in determining sediment trapping within the buffer zone (Young et al. 1980; Peterjohn and Correll 1984; Dillaha et al.,1989; Magette et al. 1989; Phillips, 1989; Hussein et al., 2007). In a recent review of a large number of studies, Yuan et al.(2009) however, concluded that slope does affect sediment trapping efficiency although the relationship was weak. This weak linear relationship is explained to some degree by a recent meta-analysis of the effectiveness of vegetated buffers (Zhang et al., 2009) which suggests that buffer efficiency increases up to a slope of round 10%, and then begins to decline with increasing slope angles. This finding is consistent with a review by Yuan et al. (2009) which highlighted that slope becomes more important as a modifier when slopes are greater than 5%. Indeed Sheldon et al. (2003), reported that the maximum slope should be between 5-10 degrees to prevent concentrated flows, while Blanché (2002) suggested it should be no greater than 15 degrees. This deterioration in buffer zone effectiveness suggests that larger buffers are required for steep slopes which is consistent with a number of review articles that concluded that buffers need to be wider when the slope is steep, generally to give more time for the velocity of surface runoff to decrease (Barling and Moore, 1994; Collier et al., 1995; Parkyn, 2004).

***Modifier ratings*:** From the literature, it is clear that there is negative relationship between slope and buffer effectiveness at slopes greater than c.a. 10%. Other research does however indicate that buffer zones remain highly effective with slopes up to 20% (Hook, 2003). Based on available literature and results of the hydrological sensitivity analysis, buffer modifiers ranging from 0.6 to 1.75 have been proposed for different slope classes (Table 1.2).

Table 1.2. Buffer zone modifier based on slope steepness

BUFFER CHARACTERISTIC	SLOPE CLASS	DESCRIPTION	MODIFIER RATING
Slope of the buffer zone	Very Gentle	0-2%	0.6
	Gentle	2.1-10%	0.75
	Moderate	10.1-20%	1
	Moderately steep	20.1-40%	1.25
	Steep	40.1-75%	1.5
	Very steep	>75%	1.75

Method: Use a 1:10 00 topographic map or GIS with contour data of the study area to measure the steepest slope of the potential buffer associated with the proposed development (apply to area within c.a.50vm of the edge of the water resource). Slope is calculated by measuring the ratio of the horizontal distance between the lowest and highest contour on each slope and the vertical distance (difference between contour elevations). Slope is expressed as a percentage (for example, if the horizontal distance is 50 m and the vertical distance is 0.5 m then the slope = 0.5 ÷ 50 x 100% = 1%). If the steepest slope is less than 2%, all other slopes will be less than this, so no further calculations are required. If the slope is >2%, break the boundary of the water resource into units of variable slope classes as reflected in Table 1.2.

1.2 Vegetation characteristics

Rationale: Vegetation mechanically filters runoff, causing sediment to be deposited in the buffer zone. The more suitable the vegetation is at slowing flows and mechanically intercepting sediment, the more effective the buffer zone is therefore likely to be.

A range of different vegetation characteristics were considered to inform buffer zone effectiveness by reviewing a number of studies that considered the effect of vegetation variables on buffer function. Although vegetation type may be considered a useful surrogate, Yuan et al. (2009) found that overall, sediment trapping efficiency did not vary by vegetation type with both grass buffers and forest buffers having similar sediment trapping efficiencies. This is supported by Lowrance et al. (1998) who reported that forested buffers are good at removing sediments (>90% effective) from upstream flooding whilst grass is just as effective but may provide a more useful cover in areas of concentrated flow (Barling and Moore, 1994). Hook (2003) provides some alternatives, suggesting that vegetation characteristics such as biomass, cover, or density are more appropriate than stubble height for judging capacity to remove sediment from overland runoff (Hook, 2003). The most useful suggestion is perhaps made in a report by Biohabitats Inc. (2007) which suggests that robustness and density of vegetation, is an appropriate indicator since this has a direct impact on flow rate, encouraging deposition of sediment as well as minimising streambank erosion. This is certainly supported by a study by Van Dijk et al. (1998), where differences between retention by grass strips was attributed mainly to differences in grass density. This is consistent with results obtained by Hook (2003) who noted that dense vegetation of moist and wet riparian sites generally retained sediment effectively, whereas lower sediment retention was associated with sparse vegetation. The number of tillers or shoots was also identified as an important factor in trapping sediment in a recent study of sediment trapping and transport on steep slopes in the French Alps (Isselin-Nondedeu and Bédécarrats, 2007)

Modifier ratings: Although few studies have specifically related vegetation density to sediment trapping efficiency, an experimental study of filter strip efficiency by Jin and Romkens (2001) does provide some insights. Their findings showed that trapping efficiency increased with vegetation density. More specifically, they found that when the density of filter strips increased from 2,500 to 10,000 bunches/m^2, the trapping efficiency increased by about 45%. Other studies do, however, suggest that the importance of vegetation density declines with increasing buffer width (e.g. Hook, 2003). The hydrological sensitivity analysis also provides some useful insights suggesting that a well vegetated buffer zone of 30 m can reduce quickflows by two and a half times relative to bare soil (See Annexure 9). Based on the information at hand, buffer modifiers ranging from 0.75 to 2.0 have been proposed for different vegetation characteristics (Table 1.3)

Table 1.3. Buffer zone modifier based on vegetation characteristics

BUFFER CHARACTERISTIC	CLASS	DESCRIPTION	MODIFIER RATING
Vegetation characteristics	Very high	Very dense vegetation, with very high basal cover (e.g. vetiver grass filter strips).	0.75
	High	Dense vegetation, with good basal cover (e.g. natural grass stands)	1
	Moderately low	Moderately low density with moderate basal cover (e.g. Forests, shrub dominated vegetation / heavily grazed grassland)	1.5
	Low	Sparse vegetation cover with large areas of bare soil	2.0

Method: Assess current vegetation characteristics including basal cover of vegetation within the proposed buffer zone and rate accordingly.

Note: For the **construction phase**, the assessment should be based on current vegetation attributes. In situations where the buffer is degraded, simply 'protecting' a buffer with a set width may fail to provide the necessary characteristics to protect adjacent water resources. As such, management should aim to restore the buffer to a more naturally vegetated condition through the operational phase. The applicant does however have the option of improving the existing buffer in order to minimize buffer requirements or foregoing buffer restoration and providing a wider but poorly vegetated buffer. If buffer restoration is adopted, the buffer should ideally be vegetated with native plant communities that are appropriate for the ecoregion or with a plant community that provides similar functions. Depending on the agreed approach, the appropriate class should be selected to calculate **operational phase** buffer zone requirements.

1.3 Soil properties

Rationale: There is good scientific evidence to suggest that soil properties of areas adjacent water resources can have a significant bearing on the level of sediment entering such systems. Soil characteristics affect soil drainage which has a direct bearing on time taken for soil saturation to occur and therefore surface runoff that carries soil particles.

Soil texture also determines the size of soil particles washed off exposed areas. This may have a major bearing on buffer zone effectiveness, with fine particles being held in suspension far more easily than course sediment, and therefore being washed more easily through a buffer zone. Indeed, Pearce et al. (1998) found that sediment yields from a riparian zone were greater when finer silica sediments were introduced to overland flow than when coarser sandy loam sediment was introduced. This is consistent with Syversen (2005), who found that the trapping efficiency of buffer zones was higher for coarse particles than for fine ones with coarse clay trapped in the buffer zone independent of its width, while the silt and sand fractions were mostly trapped in the upper part of the buffer zone. They also found an increasing content of clay particles in runoff from the soil to runoff throughout the buffer zone. In a simulation study on vegetated filter strips by Abu-Zreig (2001), results also showed that inflow sediment class had a major influence on sediment trapping effectiveness. The trapping efficiency of clay sediments in a 15 m length filter strip was 47% compared with 92% for silt from incoming sediment.

Soil texture within the buffer zone also affects infiltration and therefore the likelihood of water flow velocity being reduced as it moves through the buffer zone. This is particularly true for finer clay particles, as the more the water infiltrates the more fine sediment is trapped in the soil profile (Blanché, 2002). Buffers with coarse-grained, well drained and organic rich soils are thus more effective at removing sediment by infiltration than those in areas with fine grained, poorly drained and organic poor soils (Kent, 1994). This is because the hydraulic conductivity of coarse grained soil is high (Reichenberger et al., 2007), allowing large volumes of runoff to infiltrate. It should be noted, however, that although the infiltration capacity of the soil is determined mainly by its texture and associated conductivity, it also increases with increasing soil structure and the presence of macro pores at the surface. Thus, clay soils with abundant macro pores, such as shrinking cracks and earthworm channels, can exhibit high infiltration capacities (Reichenberger et al., 2007).

Although a range of soil characteristics could be used as an indicator of the risks associated with sediment entering into a buffer and being removed, soil permeability is perhaps the most appropriate measure. Soils with a high permeability (typically coarse-grained) and good infiltration capacity will generally trap and remove sediments more effectively. Soils with low permeability (typically fine grained) give rise to finer sediments and have lower infiltration capacities, reducing buffer zone effectiveness.

Modifier ratings: The hydrological sensitivity assessment showed that soil texture has a moderate impact on quick flows, with reductions of close to 25% anticipated for sandy soils relative to clay-loam soils. Flows can increase by as much as 75% in fine-textured clay soils (See Annexure 9). When considered together with the findings of the literature review outlined above, buffer modifiers ranging from 0.5 to 2 have been proposed for soils with different permeability (Table 1.4).

Table 1.4. Buffer zone modifier based on soil properties/characteristics

BUFFER CHARACTERISTIC	CLASS	DESCRIPTION	MODIFIER RATING
Soil permeability	Low	Fine textured sols with low permeability (e.g. clay loam and clay).	1.75
	Moderately low	Moderately fine textured soils (e.g. loam)	1.25
	Moderate	*Moderately textured soils (e.g. sandy loam).*	*1*
	High	Deep well-drained soils (e.g. sand and loamy sand).	0.75

Method: Take a sample of the soil in the buffer zone or up-slope area and use the following technique to assess soil texture. Take a teaspoon-size piece of soil and add sufficient water to work it in your hand to a state of maximum stickiness, breaking up any lumps that may be present. Now try to form the soil into a coherent ball. If this is impossible or very difficult (i.e. the ball collapses easily), then soil is sand or loamy sand. If the balls forms easily but collapses when pressed between the thumb and the fore-finger then soil is sandy loam. If the soil can be rolled into a thread but cracks when bent then soil is loam. If the thread can be bent without cracking and it feels slightly gritty then soil is clay loam, but if it feels very smooth then soil is clay. Once soil texture has been established, use this information, together with observations of soil surface conditions (e.g. shrinking cracks, earthworm channels) to place the soils into one of three classes.

Note: A more comprehensive guide for assessing soil texture is included in Ollis et al. (2013): Refer to Section 7.4.2 and particularly "Box 24: How to determine soil texture in the field" P55 of OLLIS, D.J., SNADDON, C.D., JOB, N.M. & MBONA, N. 2012. Classification System for wetlands and other aquatic ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria.

1.4 Topography of the buffer

Rationale: Topography has an influence on the rate at which runoff flows over the landscape. Uniform topography with few areas where runoff can concentrate to form erosion gullies will lead to uniform movement across the buffer zone. Where local topography concentrates flows and increases runoff velocity, buffer zones are likely to be less effective. This is supported by Helmers et al. (2005) who found through modelling that as the convergence of overland flow increases, sediment trapping is reduced. Buffers should therefore be widened in areas where concentrated flows are anticipated, resulting in a non-uniform buffer width along the length of the water resource.

Modifier ratings: Dosskey et al. (2002) studied four farms in Nebraska, USA, to develop a method for assessing the extent of concentrated flow in riparian buffers and for evaluating the impact that this has on sediment trapping efficiency. Riparian buffers averaged 9-35 m wide and 1.5-7.2 ha in area, but the effective buffer area that actually contacted runoff water was only 0.2-1.3 ha due to the patterns of topography preventing uniform distribution of runoff. Using mathematical relationships, it was estimated that between the four farms, buffers could theoretically remove 41-99% of sediment, but because of non-uniform distribution it was estimated that only 15-43% would actually be removed. These results reflect the extent of concentrated flows and its subsequent impact on sediment-trapping efficiency. In another study by Blanco-Canqui et al. (2006), they showed that the effectiveness of 0.7 m grass filter strips was reduced from 25% to 10% for reducing sediment when diffuse flow became concentrated flow. This suggests that buffer widths may need to be increased significantly where local topography encourages concentrated flows (Table 1.5).

Table 1.5. Buffer zone modifier based on topography of the landscape

BUFFER CHARACTERISTIC	CLASS	DESCRIPTION	MODIFIER RATING
Topography of the buffer zone	Uniform topography	Smooth topography with no concentrated flow paths anticipated.	0.75
	Dominantly uniform topography	*Dominantly smooth topography with few/minor concentrated flow paths to reduce interception.*	*1*
	Dominantly Non-uniform topography	Dominantly irregular topography with some major concentrated flow paths (i.e. erosion gullies, drains) that will substantially reduce interception.	1.5
	Concentrated flow paths dominate.	Area of topography dominated by concentrated flow paths (i.e. depression, erosion gullies, drains)	2.0

***Method*:** Use a 1:10 00 topographic map or GIS with contour data of the study area to assess the general topography of landscape and identify potential concentrated flow paths. Use this, together with on-site observations, to rate the potential impact of topography on buffer effectiveness. This may require areas with different topographic characteristics to be mapped and assessed separately.

2. Increased nutrient inputs

Barling and Moore (1994) maintain that up to 97% of Nitrates and 78% of Phosphates in runoff is sediment bound. Blanché (2002) also notes that one of the common factors affecting uptake of N and P is the time they spend in the buffer zone. This is mainly linked to infiltration since the infiltration rate of the soil must be such that it enables water to be stored in the soil for a long enough period for effective plant uptake and chemical immobilisation processes to occur (Blanché, 2002). Effective infiltration is achieved by buffer characteristics that cause a reduction in the flow rate, similar to those needed for sediment removal; this includes slope, type and amount of flow, infiltration rate, buffer width, soil characteristics and the type and condition of the vegetation (Kent, 1994). Slow shallow lateral subsurface and uniform surface flow were found by Blanché (2002) to be the most effective as they increase the time spent by the runoff in the buffer zone, allowing more effective infiltration. Barling and Moore (1994) found that uniform flows were 61-71 and 70-95% more effective at removing N and P, respectively, than concentrated flows, which allowed only a small percentage of the fast flowing water to percolate into the root zone and be taken up by the plants (Kent,1994). This means buffer zones and the upland areas above them with lower slopes (Blanché, 2002) and smoother topography (Kent, 1994), which are less likely to cause concentrated flows, will have better nutrient attenuation abilities (Barling and Moore, 1994).

Given that the most important mode of nutrient removal is via the co-deposition of nutrients with sediments buffer zone criteria used for sediment trapping are also included in this assessment (Table 2.1). Details of these criteria with further details of the relationships of these attributes with nutrient absorption are detailed in the text that follows.

Table 2.1. Buffer zone characteristics used to refine buffer zone requirements to cater for the variability in nutrient removal efficiencies. Default values are highlighted in green.

Slope of the buffer	Category	Very Gentle	Gentle	Moderate	Moderately steep	Steep	Very steep
	Score	0.6	0.75	1	1.25	1.5	1.75
Vegetation characteristics (basal cover)	Category	Very high	High	Moderately low	Low		
	Score	0.75	1	1.5	2		
Soil permeability	Category	Low	Moderately low	Moderate	High		
	Score	1.5	1	1	1		
Topography of the buffer zone	Category	Uniform topography	*Dominantly uniform topography*	Dominantly Non-uniform topography	Concentrated flow paths dominate.		
	Score	0.75	*1*	1.5	2		

2.1 Slope of the buffer

Rationale: The importance of buffer slope in affecting flow rate and sediment retention has been described in section 1.1. Given the close relationship between sediment and nutrient retention, buffer slope is regarded as equally important for nutrient uptake.

Modifier ratings: The same modifiers are applied as used for sediment retention (Table 2.2).

Table 2.2. Buffer zone modifier based on slope steepness

BUFFER CHARACTERISTIC	SLOPE CLASS	DESCRIPTION	MODIFIER RATING
Slope of the buffer zone	Very Gentle	0-2%	0.6
	Gentle	2.1-10%	0.75
	Moderate	***10.1-20%***	***1***
	Moderately steep	20.1-40%	1.25
	Steep	40.1-75%	1.5
	Very steep	>75%	1.75

Method: As described in section 1.1

2.2 Vegetation characteristics

Rationale: The importance of buffer slope in affecting flow rate, promoting infiltration and sediment retention has been described in section 1.1. Once infiltration has occurred, other plant characteristics affect the amount of uptake that can occur from the subsurface flows. These include the density, structure and condition of the vegetation. Interestingly, vegetation type was shown to not be a significant factor in a recent meta-analysis of Nitrogen Removal efficiencies in riparian buffers (Mayer et al., 2007). This is supported by a recent study by Syverson (2005) whose results showed no significant differences between forest buffer zones (FBZ) and grass buffer zones (GBZ) regarding their retention efficiency for nitrogen and phosphorus.

Between buffers with similar vegetation types, though, species composition may also play an important role, with Basnyat et al. (1999) reporting that native and non-native vegetation with similar structure and density had vastly different nutrient uptake levels species. This is supported by Richardson and Van Wilgen (2004), who showed that in the Western Cape Port Jackson willows (*Acacia saligna*) changed the nutrient dynamics and cycling of the soil relative to the natural fynbos vegetation. The productivity of different species or vegetation types is also a major factor in determining nutrient uptake and plants with high productivity, especially annuals, are regarded as most efficient at removing nutrients, by uptake. Thus the more annuals there are in the vegetation the better its nutrient removal ability will be (Chapman and Kreutzwiser, 1999). However, as these plants are annual, they will release these nutrients as they decompose, but because they take up nutrients mostly in spring and summer, when downstream ecological systems are most biologically active, they do help retain nutrients when the river is most active (Chapman and Kreutzwiser, 1999). Therefore the plant uptake ability is affected by season, with less nutrients being taken up during the winter, when plants are dormant, allowing more nitrates to escape into the water body (Gilliam, 1994). In many such cases trees would therefore be more effective as they remain active deep underground during winter, taking up nutrients. This was supported by Haycock and Pinay (1993), who showed that poplars were more effective than grasses at removing nutrients during the winter (summer rates were almost equal) in England, as they remain more active and intercept more runoff due to their roots penetrating deep into the soil.

It is also worth noting that vegetation biomass has an impact on nutrient uptake efficiency. Indeed, the greater the biomass, the greater the provision of microhabitat and organic matter critical for soil microbes involved in the assimilation of nutrients from influent water. In addition, the greater the vegetation biomass, the greater will be the potential for direct assimilation of nutrients by plants. It is recognized, however, that at the end of the growing season significant amounts of nutrients taken up by the plants may be lost through litter fall and subsequent leaching, although this is limited by the translocation of nutrients to the belowground storage portions of the plant (Hemond and Benoit, 1988).

Note: Because of the different modes of particulate and dissolved contaminant transport, multi-tier or combination buffers are often advocated. A narrow combination buffer consisting of 5 m of grass filter strip and a 1 m wide row of deciduous trees significantly reduced nitrate in subsurface flows beneath cropland in Italy (Borin and Bigon, 2002). A substantial reduction in nitrate (average 81%) was observed at the field / grass buffer boundary and the authors concluded that the roots of the trees were extending beyond the combined 6 m buffer so that the zone of influence was larger than the land that was retired from use. Further reductions in nitrate were measured through the buffer and discharge to the stream had concentrations that were less than 2 ppm.

Despite these complexities, it is clear that vegetation plays an important role in nutrient removal. To prevent complicating the assessment, the vegetation characteristics used for sediment trapping are regarded as relevant and have been included for nutrient retention effectiveness.

Modifier ratings**:** The same modifiers are applied as used for sediment retention (Table 2.3).

Table 2.3. Buffer zone modifier based on vegetation characteristics

BUFFER CHARACTERISTIC	CLASS	DESCRIPTION	MODIFIER RATING
Vegetation characteristics (basal cover)	Very high	Very dense vegetation, with very high basal cover (e.g. vetiver grass filter strips).	0.75
	High	***Dense vegetation, with good basal cover (e.g. natural grass stands)***	***1***
	Moderately low	Moderately low density with moderate basal cover (e.g. forests, shrub dominated vegetation / heavily	*1.5*

BUFFER CHARACTERISTIC	CLASS	DESCRIPTION	MODIFIER RATING
		grazed grassland)	
	Low	Sparse vegetation cover with large areas of bare soil	2.0

Method: As described in section 1.2

2.3 Soil properties

***Rationale*:** The importance of buffer slope in affecting flow rate and sediment retention has been described in section 1.1. Given the close relationship between sediment and nutrient retention, soil properties have also been included as a modifier for nutrient uptake efficiency.

It is worth noting though that although soils with high permeability generally provide greater filtration of sediment and attached pollutants, highly permeable soils such as sandy soils, may allow for the rapid movement of water into the groundwater. The movement may be so rapid that no removal of pollutants is allowed by plants, and only minimal removal by physical and chemical adsorption. The better aeration of these sandy soils is also unfavourable to denitrification as it increases the oxidation/reduction potential. This was well illustrated by Groffman and Tiedje (1989) who found that well-drained soils were only half as effective at removing nitrogen as poorly drained soils. Sandy soils provided the least nitrogen removal, regardless of drainage capacity (Groffman and Tiedje, 1989). This was further supported by a study by Ehrenfeld (1987) who found that nitrogen from septic system leachate moved greater distances vertically than horizontally through permeable sandy soils, percolating quickly below the root zone of buffer vegetation. Poorly drained soils on the other hand, generally retain water long enough, and often under conditions favourable enough that pollution removal is accomplished (Desbonnet et al., 1994)

Clay soils are also unfavourable for nutrient attenuation, due to their low permeability, reducing the amount of infiltration that occurs. Apart from the effect on infiltration, the size of sediment particles in the buffer zone also influences its nutrient removal ability, as the greater surface area created by smaller particles retains far more nutrients than coarser grained sediment. Soils with high clay content, but not high enough to prevent infiltration, are therefore much better at filtering nutrients, which can then be removed by plant uptake or denitrification. Indeed, when mixed clay soils are present, water is retained for longer and organic content is high, resulting in optimum levels of denitrification (Blanché, 2002). Of further benefit is the increased denitrification during drier times, caused by the good water retention properties of these soils that maintain anaerobic conditions for longer periods (Blanché, 2002). Mixed-clay soils are therefore regarded as most effective in pollutant removal (Desbonnet et al., 1994).

***Modifier ratings*:** Based on the literature review, it is clear that the primary mechanism of phosphorous removal is co-deposition with sediments. As such, buffer zone attributes that promote sediment attenuation are best suited for phosphorous removal. The relationship between soil properties and nitrogen removal is more complicated with course soils being well suited for the nutrient removal of sediments attached nutrients while poorly drained soils, on the other hand, create favourable conditions for denitrification, by promoting the formation of anaerobic conditions. Thus soils with moderate drainage would enable co-deposition of nutrients and denitrification (Blanché, 2002). Taking these factors into account, together with the reported dominance of sediment-bound pollutants, modifiers have been adjusted slightly for nutrient removal (Table 2.4).

Table 2.4. Buffer zone modifier based on soil properties/characteristics

BUFFER CHARACTERISTIC	CLASS	DESCRIPTION	MODIFIER RATING
Soil permeability	Low	Fine textured sols with low permeability (e.g. clay loam and clay).	1.5
	Moderately low	Moderately fine textured soils (e.g. loam)	1
	Moderate	***Moderately textured soils (e.g. sandy loam).***	***1***
	High	Deep well-drained soils (e.g. sand and loamy sand).	1

Method: As described in section 1.3

2.4 Topography of the buffer

Rationale: The importance of topography in affecting flow rate and sediment retention has been described in section 1.1. Given the close relationship between sediment and nutrient retention, topography has also been included as a criterion for nutrient assimilation.

Modifier ratings: The same modifiers are applied as used for sediment retention (Table 2.5).

Table 2.5. Buffer zone modifier based on topography of the landscape

BUFFER CHARACTERISTIC	CLASS	DESCRIPTION	MODIFIER RATING
Topography of the buffer zone	Uniform topography	Smooth topography with no concentrated flow paths anticipated.	0.75
	Dominantly uniform topography	***Dominantly smooth topography with few/minor concentrated flow paths to reduce interception.***	***1***
	Dominantly Non-uniform topography	Dominantly irregular topography with some major concentrated flow paths (i.e. erosion gullies, drains) that will substantially reduce interception.	1.5
	Concentrated flow paths dominate.	Area of topography dominated by concentrated flow paths (i.e. depression, erosion gullies, drains)	2.0

Method: As described in section 1.4

3. Water quality – Increased toxic contaminants

Removal efficiencies for sediment-attached and dissolved toxics are likely to be similar to those determined for sediments and dissolved nutrients (Blanche, 2002). Literature also highlights the differences with respect to organic pollutants and pesticides, and metals. These two broad categories have been considered for refining buffer requirements at a site-based level. Site-based characteristics applicable for the removal of sediments and nutrients were considered appropriate for refining buffer zone requirements to cater for the variability in toxic organic and metal contaminant retention efficiency.

A summary of the buffer zone attributes and modifiers used to adjust buffer zone width to cater for variability in toxic organic and metal contaminant retention efficiency of buffer zones is presented in Table 3.1, below. For further details including the rationale for considering each criteria, together with modifier ratings and the method to be followed in collecting appropriate site-based information, please see Section 1.

Table 3.1. Buffer zone characteristics used to refine buffer zone requirements to cater for the variability in toxic organic and metal contaminant retention efficiency. Default values are highlighted in green.

Slope of the buffer	Category	Very Gentle	Gentle	*Moderate*	Moderately steep	Steep	Very steep
	Score	0.6	0.75	*1*	1.25	1.5	1.75
Vegetation characteristics (basal cover)	Category	Very high	*High*	Moderately low	Low		
	Score	0.75	*1*	1.5	2		
Soil permeability	Category	High	*Moderate*	Moderately low	Low		
	Score	0.75	*1*	1.25	1.75		
Topography of the buffer zone	Category	Uniform topography	*Dominantly uniform topography*	Dominantly Non-uniform topography	Concentrated flow paths dominate		
	Score	0.75	*1*	1.5	2		

4. Water quality – pathogens (i.e. disease-causing organisms)

The primary mechanism for the removal of micro-organisms in runoff, though, is infiltration (Tate et al., 2004). This is usually coupled with their adsorption to soil particles, hindering their passage to the water body, resulting in their eventual death. As with sediment retention functions, the velocity of the contaminated water entering and flowing through the buffer is therefore regarded as a particularly important attribute in affecting the ability of buffers to remove pathogens. Some micro-organisms are in fact attached to the sediment and deposited with sediment, just as with sediment attached nutrients and other toxics (Kent, 1994). Many, however, are suspended freely in the runoff and to be removed they must settle out from the solution, through a reduction in flow rate, just as with sediments (Kent, 1994). They may then infiltrate into the soil and / or adsorb to soil or organic material (Tate et al*.,* 2004).

Increased velocity increases the detachment and flushing transport or micro-organisms from substrates in the upland and buffer areas, increasing the amount delivered to the water body (Tate et al., 2004). This is illustrated in an investigation on the rate of *Cryptosporidium parvum* oocyst delivery to a water body, across a buffer by Tate et al*.* (2004) who demonstrated that the rate of delivery was related to the velocity of the surface runoff. With increasing velocity, the micro-organisms became dislodged more easily from the substrate, resulting in greater concentrations entering the water body.

Besides influencing their transport, runoff also influences micro-organism mortality, which is largely due to desiccation (Biohabitats Inc., 2007) and therefore the link between runoff velocity and residence time is also important in determining micro-organism removal (Kent, 1994). In this regard, Kent (1994) found that even a short residence time can vastly reduce the number of pathogens. He showed that even though domestic sewage in a particular study originally contained more pathogens than stormwater runoff, the stormwater contributed more pathogens to the water body. This is because it delivered water at a higher velocity, giving little time for the desiccation or death of the pathogens to occur, whilst the sewage was delivered at a far slower velocity, resulting in the desiccation and death of a larger portion of the pathogens. He then demonstrated that just 7 m of buffer was needed to reduce both these amounts to an acceptable level.

Removal of pathogenic micro-organisms therefore typically requires similar buffer attributes as that for sediment retention including gentle slope, slow uniform flow, dense vegetation and good soil permeability. **As such, the criteria and associated attributes used to assess sediment retention efficiency have been used to inform buffer requirements for pathogen removal.**

A summary of the buffer zone attributes and modifiers used to adjust buffer zone width to cater for variability in the pathogen retention efficiency of buffer zones is presented in Table 4.1, below. For further details including the rationale for considering each criteria, together with modifier ratings and the method to be followed in collecting appropriate site-based information, please see section 1.

Table 4.1. Buffer zone characteristics used to refine buffer zone requirements to cater for the variability in pathogen retention efficiency. Default values are highlighted in green.

Slope of the buffer	Category	Very Gentle	Gentle	*Moderate*	Moderately steep	Steep	Very steep
	Score	0.6	0.75	*1*	1.25	1.5	1.75
Vegetation characteristics (basal cover)	Category	Very high	*High*	Moderately low	Low		
	Score	0.75	*1*	1.5	2		
Soil permeability	Category	High	*Moderate*	Moderately low	Low		
	Score	0.75	*1*	1.25	1.75		
Topography of the buffer zone	Category	Uniform topography	*Dominantly uniform topography*	Dominantly Non-uniform topography	Concentrated flow paths dominate		
	Score	0.75	*1*	1.5	2		

15. Potential criteria not included in this assessment

It is worth noting that a range of additional factors also affect the ability of buffer zones to reduce pathogen loads but have not been specifically integrated into the model. These are detailed briefly here:

- **Soil moisture:** Soil moisture levels may also affect buffer zone effectiveness as desiccation is a large contributor to pathogen mortality. Drier soils promote water absorption and desiccation (Biohabitats Inc., 2007) and are therefore generally more effective than moist soils for pathogen removal. To illustrate this point, hookworm disease (*Strongyloidiasis*) and threadworm can survive in the film of moisture surrounding soil particles. Buffer zones with drier soils will carry less of these parasites, reducing infection rates (Cowan, 1995).

  Studies also show that the pathogen removal ability of the buffer is mainly dependent on the physiochemical interactions that occur between the soil and the pathogen. The different chemical characteristics of different soil types will promote the adsorption of different types of pathogens, some pathogens, such as *Cryptosporidium parvum* can actively desorb themselves from particles (Tate et al., 2004).

- **Size and shape of pathogens:** This also plays a role, with small narrow types, such as *E. coli* and *Salmonella* being far more difficult to remove as they can escape entrapment far more easily than larger cylindrical types, including parasitic oocytes (Tate et al., 2004).

- **Survivability:** Even once caught, the survivability of the micro-organisms influences the buffers effectiveness at removing them, as some micro-organisms may survive up to 27 weeks in the soil, enabling them to possibly be dislodged once again and delivered to the water body (Kent, 1994).

It is important to note that while these attributes have not been specifically accounted for, Tate et al. (2004) agreed that when factoring out the attributes specific to the type of micro-organism that attributes that promote sediment retention, including slow flow, greater infiltration and filtration, should be the primary buffer zone characteristics considered when aiming to remove microbes in general. This is consistent with the approach followed in this method.

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Annexure 17 – Overview of the mitigation measures tool

An Excel tool was developed as part of this project to help assessors identify a suite of alternative mitigation measures and management guidelines that can be used to reduce potential impacts on aquatic ecosystems. This tool was developed by Mr. Douglas Macfarlane, with input from Mr. Jeremy Dickens, and was based on a review of close to 70 best-practice guidelines across a range of sectors.

The tool is designed to act as a quick reference for assessors to a wide range of mitigation measures and guidelines which would otherwise need to be accessed through a plethora of different guidelines. References are also linked to specific mitigation measures to help users access relevant supporting documentation if required. The tool is structured according to nine primary threats which are also assessed as part of the buffer zone determination process. These include:

- Alteration to flow volumes;
- Alteration of patterns of flows (increased flood peaks);
- Increase in sediment inputs & turbidity;
- Increased nutrient inputs;
- Inputs of toxic contaminants (including organics & heavy metals);
- Alteration of acidity (pH);
- Increased inputs of salts (salinization);
- Change (elevation) of water temperature; and
- Pathogen inputs (i.e. disease-causing organisms).

The tool includes a list of some 370 mitigation measures that can be used to reduce impacts to aquatic ecosystems and is simply structured to facilitate use. Filters have been set up to allow users to quickly search through the range of mitigation measures for those that are relevant to them. Filters are structured according to the following criteria and can be filtered accordingly:

- **Aspect**: This groups mitigation measures based on common themes such as construction management; site planning; mine management; pollution control and rehabilitation. This allows mitigation measures of a similar type to be quickly located and reviewed.
- **Relevance of management guideline / mitigation measure**: This allows users to filter mitigation measures based on a selected threat type such as “Increase in sediment inputs & turbidity”. Differentiation is made here between mitigation measures with strong relevance and those mitigation measures which may contribute towards mitigating selected threat types but which are not specifically designed to do so.
- **Construction Phase**: This allows users to identify mitigation measures which are specifically designed to address construction-phase impacts. These are grouped according to sector to enable easy access to relevant mitigation measures. In this way, a simple filter can be set up to search for construction-related mitigation measures for any sector such as “Agriculture” or “Mining”.
- **Operational Phase**: As above, but here, mitigation measures relevant to operational activities can be quickly filtered.

While the tool does not represent an exhaustive suite of mitigation measures / management guidelines, it certainly covers a wide variety of these and will help any assessor in better understanding potential mitigation measures that can be used to mitigate potential impacts.

Annexure 18 – Examples of biodiversity information sheets *(electronic copy only – refer to the CD provided)*

Annexure 19 – Guidelines for corridor design *(electronic copy only – refer to the CD provided)*

Annexure 20 – Useful data layers *(electronic copy only – refer to the CD provided)*