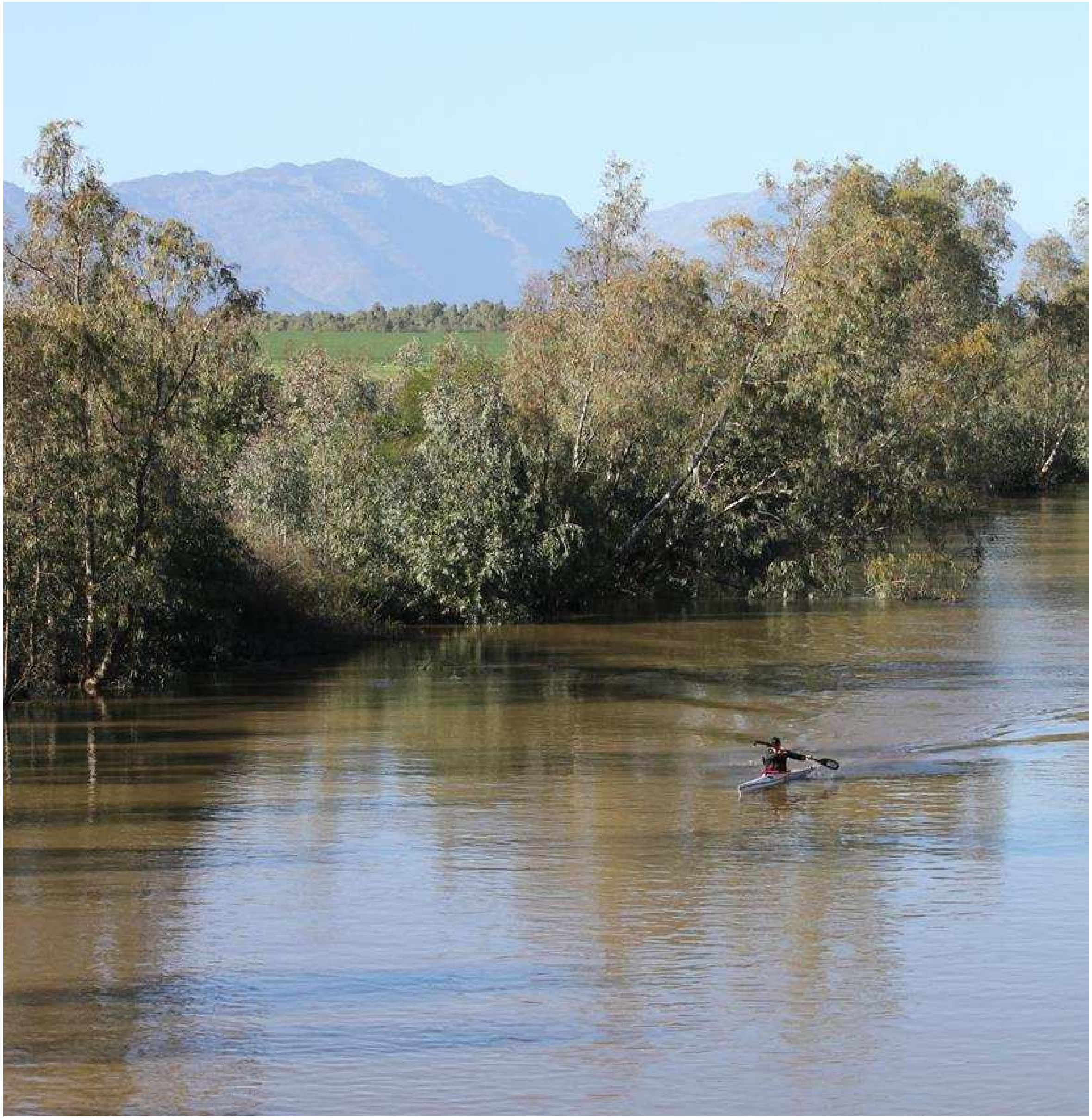

Determination of Water Resources Classes and Resource Quality Objectives in the Berg Catchment

June 2018

Revision: Final

Evaluation of Scenarios Report

No: RDM/WMA9/00/CON/CLA/0417

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Prepared by:

Aurecon South Africa (Pty) Ltd in sub-consultancy association with Southern Waters Ecological Research and Consulting, Anchor Environmental and Delta-H Water Systems Modelling

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Chief Director: Water Ecosystems

Document Index

Reports that will be produced as part of this Study are indicated below.

Bold type indicates this Report.

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List of Abbreviations

CBA	Critical Biodiversity Area
CCT	City of Cape Town
WCWSS	Western Cape Water Supply System
DWAF	(Previous) Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category (A to E based on Kleynhans *et al.* 1996)
EHI	Estuary Health Index
EGSA	Ecosystem Goods, Services and Attributes
EIS	Ecological Importance and Sensitivity
ESA	Ecological Support Area
ESBC	Ecologically Sustainable Base Configuration
EWR	Ecological Water Requirements
FEPA	Freshwater Ecosystem Priority Area
GRAII	Groundwater Resource Assessment Phase 2
GRU	Groundwater Resource Unit
GW	Groundwater
GWBF	Groundwater Contribution to Baseflow
IUA	Integrated Unit of Analysis
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
NBA	National Biodiversity Assessment
nMAR	natural Mean Annual Runoff
NWA	National Water Act
PES	Present Ecological Status
REC	Recommended Ecological Condition
Rm/Yr	Millions of Rand per Year
RQOs	Resource Quality Objectives
SANBI	South African National Biodiversity Institute
SW	Surface Water
SWSAs	Strategic Water Source Areas
TEC	Target Ecological Category
TMGA	Table Mountain Group Aquifer
WARMS	Water Authorisation Registration and Management System
WC/WDM	Water conservation and water demand management
WCBSP	Western Cape Biodiversity Spatial Plan
WCWSS	Western Cape Water Supply System
WMA	Water Management Area
WR2000	Water Resources of South Africa 2000
WR2012	Water Resources of South Africa 2012
WRC	Water Research Commission
WRCS	Water Resources Classification System
WRYM	Water Resources Yield Models

Executive Summary

Introduction

The Chief Directorate: Water Ecosystems of the Department of Water and Sanitation has commissioned a study to determine Water Resource Classes and associated Resource Quality Objectives for all significant water resources in the Berg Catchment. A 7-step procedure is described for determining the recommended class for each water resource (DWAF, 2007a). This report focuses on Step 4-7: Determining and evaluating the classification scenarios. Steps 5 and 6 represent an iterative process, whereby the determined scenarios are evaluated with stakeholders and feedback is integrated into the process to result in the final recommended scenario and Water Resource Classes. The Resource Quality Objectives (RQOs) are then determined to give effect to the recommended water resources classes.

Scenarios Considered

Different approaches were required to the evaluation of scenarios for the IUAs in the Berg River catchment (i.e. G1 Secondary Drainage Region) and the Coastal and Peninsula IUAs (e.g. G2 Secondary Drainage Region). The scenarios considered for the G1 catchments were analysed in terms of the potential impact of various target ecological conditions for the EWR sites on the Berg River on the historical firm yield from the Western Cape Water Supply System (WCWSS).

The scenarios considered are shown in the table below. These include both current and future infrastructure scenarios, as well as the potential impacts of climate change based on a selected future drying scenario. The future infrastructure scenarios include the Voelvlei Augmentation Scheme (VAS), the West Coast Managed Aquifer System and re-use of all treated effluent from Paarl and Wellington wastewater treatment works which would otherwise contribute return flows to the Berg River. The impact of the EWR scenarios were then determine in terms of the Historical Firm Yield using the Water Resources Yield Model.

Scenario Name	Scenario Description
Scenario 1 (PES)	Current day infrastructure with 0.5 m^3/s minimum flow requirement to the estuary.
Scenario 1b (PES-FI)	Future (2040) infrastructure with 0.5 m^3/s minimum flow requirement to the estuary.
Scenario 1c (PES-CC)	Future (2040) infrastructure and reduced streamflow due to potential impacts of climate change with 0.5 m^3/s minimum flow requirement to the estuary.
Scenario 2 (ESBC)	Current Day infrastructure with ESBC baseflow EWRs and 0.5 m^3/s flow to the estuary.
Scenario 3 (REC)	Current day infrastructure with REC baseflow EWRs and 0.6 m^3 flow to the estuary.
Scenario 4 (ESBC-FI)	Future infrastructure with ESBC baseflow EWRs and 0.5 m^3 flow to the estuary.
Scenario 5 (REC-FI)	Future infrastructure with REC baseflow EWRs and 0.6 m^3/s flow to the estuary.
Scenario 6 (No EC-FI)	Future infrastructure with no Environmental Constraints
Scenario 7 (ESBC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, ESBC baseflow EWRs and 0.5 m^3/s minimum flow requirement to the estuary
Scenario 8 (REC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, REC baseflow EWRs and 0.5 m^3/s minimum flow requirement to the estuary
Scenario 9 (No EC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, and no Environmental Constraints

For the estuaries and coastal catchments (G2) a large proportion of the current day flow comprises the return flows from wastewater treatment works (WWTW). The most significant development likely to impact on the flow in the rivers and estuaries is considered to be changes in these return flows as re-use of treated effluent becomes more of a significant contributor to the future water supply to the City of Cape Town.

There are a few potential bulk water infrastructure development projects that have been identified in some of these catchments including on the Lourens River, but these are not considered to be likely to be implemented before 2040. The only other significant future development is likely to be changes in land use, but this is not modelled in the current hydrology. The scenarios considered are shown in the table below.

Scenario Name	Scenario Description
Natural	Reference condition
Present	Present day flows and conditions
Scenario 1	Present day flows but all effluent from WWTWs to be treated to DWS Special Standards
Scenario 2	Reduce inputs from the WWTWs by 50% and treat the remainder to DWS Special standards
Scenario 3	Reduce inputs from the WWTWs by 75% and treat the remainder to DWS Special standards
Scenario 4	Zero inputs from wastewater treatment works (WWTW)

For the estuaries that were not directly impacted by the return flows from WWTW (e.g. Langebaan, Lourens and Zandvlei), alternative scenarios were considered based either on other changes to surface or groundwater flow or physical developments that could affect the functioning and condition of the estuary.

Current and future groundwater developments were considered in terms of the potential impacts on the groundwater stress (use/recharge) for all catchments and groundwater resource units. In addition, the results of previous studies considering the impacts of various development scenarios on the West Coast Aquifers (Langebaan Road and Elandsfontein) and the Cape Flats Aquifers were also considered.

Evaluation of Scenarios

The impacts of the various flow, development and EWR scenarios where considered in terms of the impacts on the overall ecological status of the individual nodes and the catchment as a whole, as well as the impact that this might have on the availability of water, particularly in terms of the yield from the Western Cape Water Supply System (WCWSS). The potential impacts on water quality were also considered. These were then used to determine the overall impacts on ecosystem goods, services and attributes (EGSAs).

The impact of the different scenarios on the overall ecological condition is shown in Figure 0-1.

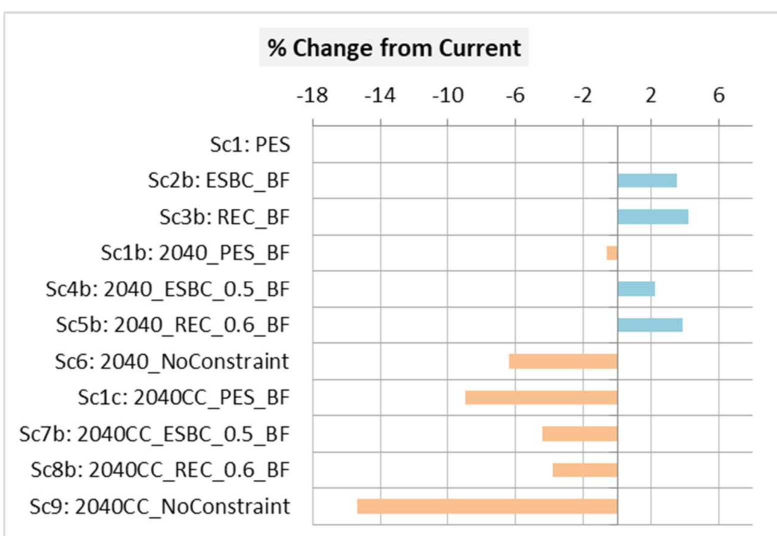

Figure 0-1: Change in the overall ecological condition of the catchment under each scenario

The overall socio-economic impacts were evaluated in terms of the difference between the costs of providing alternative water supply such as desalination to augment the reduction in yield from the WCWSS and the net present value (NPV) of the changes in the EGSA. In the case of the G2 coastal catchments the impact of future changes in the volume and condition of treated effluent was the primary focus and the cost of re-use of this treated effluent was determined based on recent estimates for the City of Cape Town.

Recommended Water Resource Classes

Based on the evaluation of scenarios the recommended water resource class is based on the REC scenario, but considering only the baseflow conditions as minimum with the flood EWRs being met on average and not necessarily every year. This is essentially the same recommended EWR scenario as previously considered for the implementation of the Berg River Dam and for the feasibility study for the Voelvlei Augmentation Scheme. Hence while this scenario does result in a historical firm yield (HFY) less than the present condition and also for the scenarios with no environmental constraint it represents the best trade-off of environmental and ecological conditions, particularly recognising the importance of maintaining flow to the Berg River Estuary, for mitigating the water quality risk and recreational use of the Berg River.

The recommended water resources classes for each IUA are defined in terms of the following:

Class I	**Natural** – minimal impact of humans, natural water quality and safe for most uses.
Class II	**Moderately used/impacted** – slightly altered from natural due to human activity
Class III	**Heavily used/impacted** – significant change from natural due to human activity

The recommended water resource Class is based largely on the number of river and estuary nodes with the different ecological conditions in each IUA and are presented in Table 0-1 and shown in Figure 0-2.

Table 0-1 Recommended class for IUAs

IUA Name	IUA Code	Recommended Class
Upper Berg	D8	II
Middle Berg	D9	III
Berg Tributaries	C5	II
Lower Berg	B4	III
Berg Estuary	A1	II
Langebaan	A2	II
West Coast	A3	III
Diep	D10	III
Peninsula	E11	II
Cape Flats	E12	III
Eerste	D6	III
Sir Lowry's	D7	II

The recommended water resource class also takes into consideration critical water resource areas such as the strategic water source areas (SWSA) which cover a large portion of the upper reaches of some of the IUAs including the Upper Berg IUA and the area covered by the Table Mountain National Park (TMNP) which makes up more than half of the Peninsula IUA. These areas should receive additional protection while the remainder of the IUA is located in a heavily impacted urban or rural area. This is provided in terms of the target ecological category for individual nodes and the Resource Quality Objectives (RQOs).

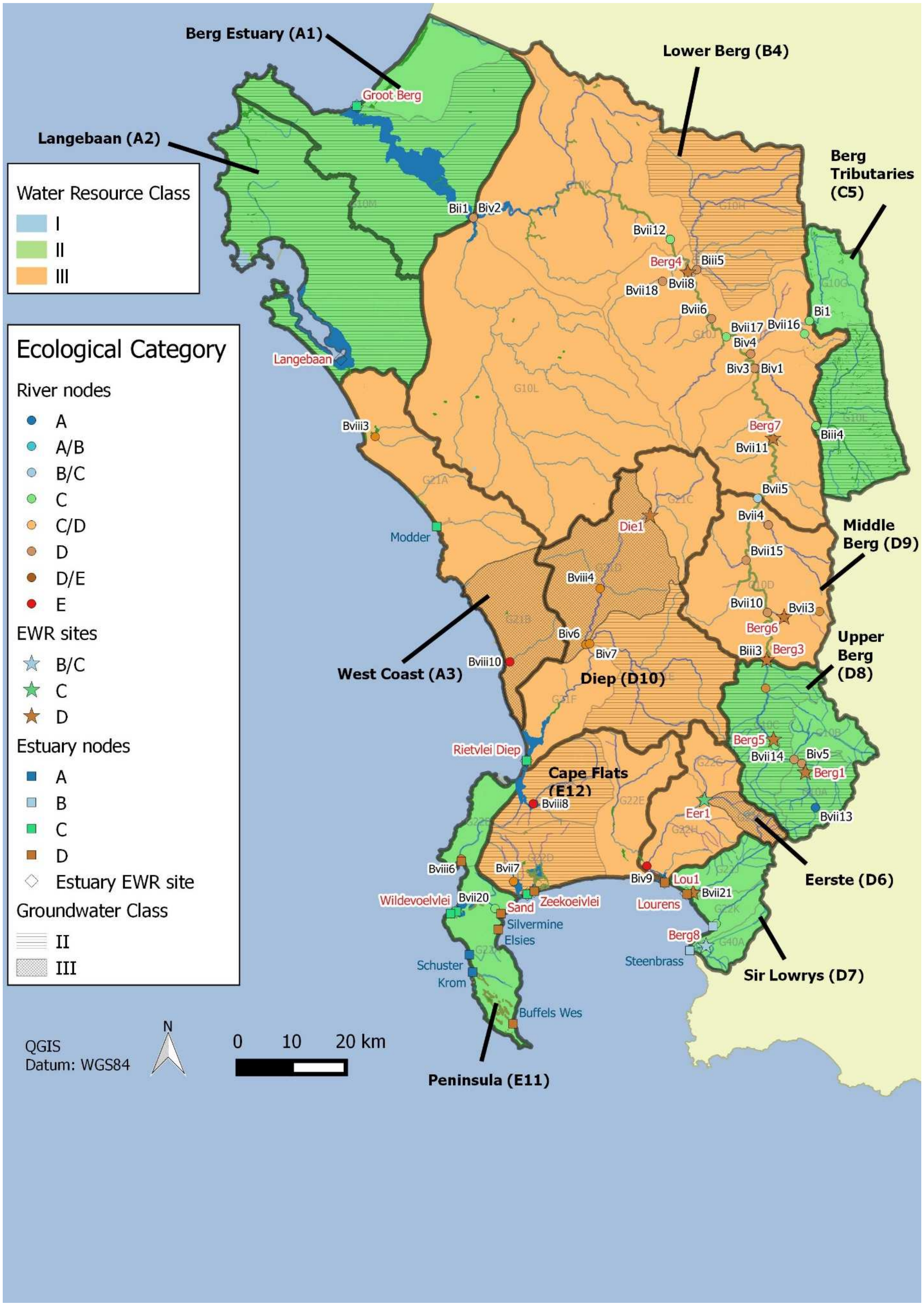

Figure 0-2 Map showing target ecological conditions, recommended water resource classes and resulting groundwater stress levels based on the future development scenario considered for the Berg catchment.

Implications of the Recommended Water Resource Classes

The final recommended water resource classes and target EWRs for the river and estuary nodes represent a balance between maximising the sustainable use of water in the catchment with maintaining critical ecological systems that contribute significantly to the social and economic conditions in the catchment.

The final section of this report provides a short summary of the overall ecological and socio-economic impacts of the proposed water resource classes for each IUA. The next step in the process is to develop specific resource quality objectives (RQOs) for priority river, estuary, wetland and groundwater resource units that are in line and give force to the recommended water resource classes for the Berg Catchment.

Target Ecological Condition and Ecological Water Requirements

Based on the analysis of alternative scenarios for the river and estuary nodes in the Berg catchment, it is recommended that the recommended ecological condition (REC) scenario be considered at the main EWR nodes and at the significant estuaries as this represents the best balance between ecological, economic and social benefits for the whole catchment area. The Target EC and EWRs are given in the table below.

Table 0-2 Proposed Target Ecological Condition (TEC) for the river EWR sites.

Site	Node	IUA	Quat	Name	PES	TEC	% nMAR (Reserve) (excludes floods)
Berg1	Bviii1	D8	G10A	Upper Berg River	C	C	31%
Berg3	Bvii5	D8	G10D	Lower Berg River	D	D	33%
Berg4	Bvii6	B4	G10J	Heuningberg, upstream of Misverstand Dam	D	D	21%
Berg5	Bvii12	B4	G10J	Nuwedrif, downstream of Misverstand Dam	D	D	24%
Berg6	Bvii3	D9	G10D	Kromme River	D/E	D	14%
Berg7	Bviii11	D9	G10D	Pombers River	D	C	21%
Berg8	Bvii22	B4	G40A	Steenbras River	B/C	B/C	14%
Die1	Bv1	D10	G21D	Diep River	E	D	14%
Eer1	Biii6	D6	G22F	Jonkershoek River	C	C	23%
Lou1	Bvii21	D7	G22J	Lourens River	D	D	15%

With IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; TEC = Target Ecological Category; EIS = Ecological Importance and Sensitivity; VH = Very High; H = High; M = Moderate.

Table 0-3 Proposed Target Ecological Condition (TEC) and EWRs for the estuary nodes

Node	IUA	Quat	Name	PES	TEC	EIS	Minimum %MAR to achieve TEC Current WQ	Minimum %MAR to achieve TEC Improved WQ
Bxi1	**A1**	**G10M**	**Berg River Estuary**	**C**	**C**	**H**	**46**	**33**
Bxi3	**A2**	**G10M**	**Langebaan Estuary**	**B**	**B**	**VH**	**94**	**94**
Bxi12	A3	G21A	Modder Estuary	C	C	M	n/a	33
Bxi7	**D10**	**G21F**	**Rietvlei/Diep Estuary**	**D**	**C**	**H**	**n/a**	**33**
Bxi9	**E12**	**G22K**	**Zandvlei Estuary**	**D**	**C**	**H**	**n/a**	**56**
Bxi20	**E12**	**G22D**	**Zeekoe Estuary**	**E**	**D**	**U**	**110**	**60**
Bxi10	E11	G22B	Hout Bay Estuary	E	D	U	35	26
Bxi11	E11	G22A	Silvermine Estuary	D	D	U	35	26
Bxi19	E11	G22A	Elsies Estuary	E	D	U	35	26
Bxi18	E11	G22A	Buffels Wes Estuary	F	D	U	66	67
Bxi17	E11	G22A	Krom Estuary	A	A	U	95	95
Bxi16	E11	G22A	Schuster Estuary	A	A	U	95	95
Bxi15	E11	G22A	Bokramspruit Estuary	C	C	U	65	42
Bxi14	**E11**	**G22A**	**Wildvoëlvlei Estuary**	**D**	**C**	**M**	**79**	**62**
Bxi3	**D6**	**G22H**	**Eerste Estuary**	**E**	**D**	**M**	**61**	**26**
Bxi4	**D7**	**G22J**	**Lourens Estuary**	**D**	**D**	**U**	**69**	**56**
Bxi6	D7	G22K	Sir Lowry's Pass Estuary	E	D	U	35	26
Bxi6	D7	G40A	Steenbras estuary	B	B	U	97	35

With IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; TEC = Target Ecological Category; VH = Very High; H = High; M = Moderate; U = Undefined. BAS = Best attainable state. n/a indicates that it is not possible to improve the Ecological State of the estuary by increasing flows only (WQ also needs to be improved).

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1 Introduction

1.1 Background

Chapter 3 of the National Water Act (NWA) lays down a series of measures which are together intended to ensure protection of the critical water resources of the country. In accordance with these measures, the Department of Water and Sanitation (DWS), in line with Section 12 of the NWA, established a Water Resources Classification System (WRCS) that is formally prescribed by Regulations 810 dated 17 September 2010.

The WRCS provides guidelines and procedures for determining Water Resource Classes, Reserve and Resource Quality Objectives (RQOs) for all water resources in the country.

Section 13 of the NWA states that "as soon as reasonable practicable after the Minister prescribed a system for classifying water resources, the Minister must, subject to subsection (4), by notice in the gazette, determine for all or part of every significant water resource:

- A Class in accordance with the prescribed classification system; and
- Resource quality objectives based on the class determined in terms of paragraph (a).

In accordance with the above section of the NWA, the Chief Directorate: Water Ecosystems of the Department of Water and Sanitation (DWS) has commissioned a study to determine Water Resource Classes and associated Resource Quality Objectives (RQOs) for all significant water resources in the Berg Catchment as part of the Berg-Olifants Water Management Area (WMA) in the Western Cape.

The Berg River is the largest catchment in the Study Area, which also includes a number of smaller catchments such as the Diep, Kuils, Eerste, Lourens, Sir Lowry's, Steenbras, as well as various small catchments on the Cape Peninsula and along the West Coast. The study area is shown in Figure 1-1.

1.2 Objectives of the study

The main objectives of the Study are to undertake the following:

- Co-ordinate the implementation of the WRCS, as required in Regulation 810 in Government Gazette 33541, by classifying all significant water resources in the Berg Catchment.
- Determine RQOs using the DWS Procedures to Determine and Implement RQOs for all significant water resources in the Berg Catchment.

The 7-step WRCS procedure is prescribed in the WRCS Overview Report (DWAF, 2007) leading to the recommendation of the class of a water resource (the outcome of the Classification Process).

This report presents the **Evaluation of Scenarios** for the study area and is part of a series of reports that are being prepared as part of determining the water resource classes.

- Linking the Value and Condition of the Resource report
- Quantification of the Ecological Water Requirements and changes in Ecological Goods, Services and Attributes (EGSA) report
- Ecologically sustainable base configuration scenario (ESBC) report
- **Evaluation of Classification Scenarios report**

The evaluation of Scenarios forms Step 5 of the 7-step process and is followed by the evaluation of scenarios with stakeholders. The final step in the WRCS is the recommend Classes to be Gazetted by DWS. This final step, however will be finalised only after finalisation of the Resource Quality Objectives (RQOs), as the two processes are strongly dependent on each other and there may be a need for iteration of scenarios.

Figure 1-1 Map of the study area.

1.3 Integrated Units of Analysis

Integrated Units of Analysis (IUAs) were determined for the study area based on a combination of hydrological, ecological and socio-economic factors. Twelve IUAs were identified and are shown in Figure 1-2 and outlined in Table 1-1. In addition, 45 biophysical river nodes were defined according to the procedures prescribed by DWS (DWAF, 2007f). Nineteen estuary nodes were also identified and eight of these were considered to be priority estuary nodes. The delineation of IUAs and identified river and estuary nodes are described in the Resource Units and Integrated Units of Analysis Delineation Report (DWS, 2016b).

Table 1-1 Socio-economic zones and Integrated Units of Analysis (IUAs) delineated for the study area.

Socio-economic Zone	Zone Code	IUA Name	IUA Code	Quaternary Catchments
West Coast	A	Berg Estuary	A1	G30A, G10M
		Langebaan	A2	G10M
		West Coast	A3	G21A, G21B
Lower Berg	B	Lower Berg	B4	G10K, G10L. G10J, G10H, G10F
Tulbagh Fruit Area	C	Berg Tributaries	C5	G10G, G10E
Winelands	D	Eerste	D6	G22G, G22H, G22F
		Sir Lowry's	D7	G22J, G22K. G40A
		Upper Berg	D8	G10C, G10B, G10A
		Middle Berg	D9	G10D
		Diep	D10	G21C, G21D, G21E, G21F
Cape Town	E	Peninsula	E11	G22B, G22A
		Cape Flats	E12	G22C, G22D, G22E

1.4 Identification of River Nodes and Additional Reserve sites

Eleven "tiers" of information were sequentially assessed, and rules applied, in order to establish biophysical river nodes for each tier. Nodes were added sequentially for Tiers I to Tier VIII, where-after rationalisation rules were applied to eliminate nodes for which EWRs were not required, e.g., impoundments (Tier VII). Then additional nodes were added as required for Tiers V-IX, and rationalisation rules were applied again to eliminate nodes for which appropriate hydrological information was not available and/or nodes that were too close to each other (Tier IX). Thereafter, nodes were again added where additional information was likely to be needed at a particular sub-quaternary catchment level for planning or allocation purposes.

There are already eight sites in the study area for which high confidence Reserve determinations have been done and high confidence EWRs have been determined. These are listed in Table 1-2. These sites are all located in the Berg River Catchment (Secondary Drainage Region G1) and were considered sufficient for EWR information to be extrapolated to all other river nodes in the G1 area. It was, however, noted that there were no existing Reserve sites in the many smaller catchments of Secondary Drainage Region G2 and it was requested that additional sites be identified in these catchments for which at least a Rapid Level III reserve determination study should be undertaken. Additional EWR sites were identified in the Eerste, Diep and Lourens river as described in the EWRs Report and indicated in Table 1-2.

A field trip and rapid Level III Reserve determination studies were undertaken for the Diep, Lourens and Eerste Rivers. The results of this study and a summary of the previous Reserve determination studies are presented in the EWRs Report. In addition, field visits were undertaken at all existing Reserve sites and river nodes in the study area and used to update the Present Ecological Status (PES) for each river node.

The details of the delineated Reserve sites for the study area are shown in Table 1-2 and on Figure 1-2.

Table 1-2 The existing and new Reserve sites for the study area

Site	Node	IUA	Quat	Name	PES	REC	EIS	Ref
Berg1	Bviii1	D8	G10A	Upper Berg River	C	C	H	DWAF, 1996
Berg3	Bviii5	D8	G10C	Lower Berg River	D	D	H	
Berg4	Bvii8	B4	G10J	Heuningberg, upstream of Misverstand Dam	D	D	M	DWAF, 2000
Berg5	Bvii18	B4	G10J	Nuwedrif, downstream of Misverstand Dam	D	D	H	
Berg6	Bvii3	D9	G10D	Kromme River	D/E	D	H	DWA, 2010c
Berg7	Bviii11	D9	G10D	Pombers River	D	C	H	
Berg8	Bvii22	B4	G10J	Steenbras River	B/C	B/C	VH	
Die1	Bv1	D10	G21D	Diep River	E	D	M	This study
Eer1	Biii6	D6	G22F	Jonkershoek River	C	C	H	
Lou1	Bvii21	D7	G22J	Lourens River	D	D	M	

With IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; REC = Recommended Ecological Category; EIS = Ecological Importance and Sensitivity; VH = Very High; H = High; M = Moderate.

1.5 Estuary Nodes

Twenty-two estuary nodes have been identified in the study area. Eight of these are considered to be significant estuary nodes for which EWRs were determined (highlighted in bold in Table 1-3). Field visits and a specialist workshop were undertaken to determine the EWRs, PES and RECs for these estuaries.

Table 1-3 Estuary nodes considered for EWRs in the study area

Node	IUA	Quat	Name	PES	REC	EIS
Bxi1	**A1**	**G10M**	**Berg River Estuary**	**C**	**C**	**H**
Bxi3	**A2**	**G10M**	**Langebaan Estuary**	**B**	**A**	**VH**
Bxi12	A3	G21A	Modder Estuary	C	C	M
Bxi7	**D10**	**G21F**	**Rietvlei/Diep Estuary**	**D**	**C**	**H**
Bxi9	**E12**	**G22K**	**Zandvlei Estuary**	**D**	**C**	**H**
Bxi20	**E12**	**G22D**	**Zeekoe Estuary**	**E**	**D**	**U**
Bxi10	E11	G22B	Hout Bay Estuary	E	D	U
Bxi11	E11	G22A	Silvermine Estuary	D	D	U
Bxi19	E11	G22A	Elsies Estuary	E	D	U
Bxi18	E11	G22A	Buffels Wes Estuary	F	D	U
Bxi17	E11	G22A	Krom Estuary	A	A	U
Bxi16	E11	G22A	Schuster Estuary	A	A	U
Bxi15	E11	G22A	Bokramspruit Estuary	C	C	U
Bxi14	**E11**	**G22A**	**Wildvoëlvlei Estuary**	**D**	**D**	**M**
Bxi3	**D6**	**G22H**	**Eerste Estuary**	**E**	**D**	**M**
Bxi4	**D7**	**G22J**	**Lourens Estuary**	**D**	**D**	**U**
Bxi6	D7	G22K	Sir Lowry's Pass Estuary	E	D	U
Bxi6	D7	G40A	Steenbras estuary	B	B	U

IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; REC = Recommended Ecological Category; VH = Very High; H = High; M = Moderate; U = Undefined. Significant estuaries highlighted in red.

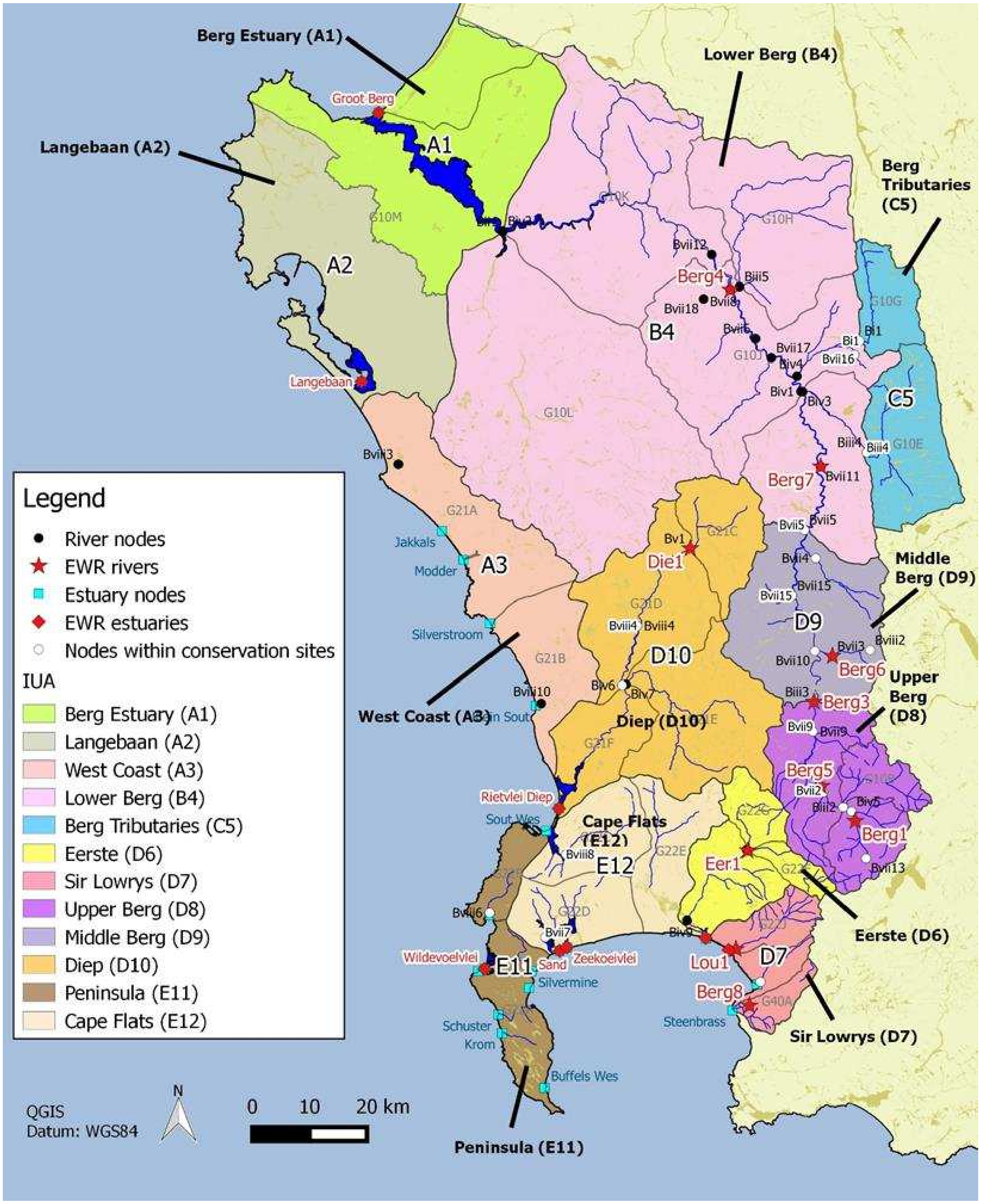


Figure 1-2 Integrated Units of Analysis (IUAs) and biophysical nodes for the Berg catchment.

2 Methodology

The methodological approach for the evaluation of scenarios was as follows:

1. Define the scenarios to be analysed
2. Determine surface flows and ecological categories
3. Quantify impacts on ecosystem health and biodiversity
4. Determine impacts on available yield and water supply
5. Estimate impacts on groundwater condition
6. Quantify impacts on ecosystem goods, services and attributes
7. Determine overall socio-economic impacts

The results of the analysis (surface water; ecosystem health and biodiversity; groundwater condition; and socio-economics) were then used to determine the recommended Water Resource Classes for each IUA.

2.1 Scenarios Considered

A different approach was followed for the evaluation of scenarios in the G1 and G2 parts of the Study Area.

The G1 area, i.e. the Berg River Basin, is characterised by the regulation and management of streamflow and water supply as part of the Western Cape Water Supply System (WCWSS). The G2 area, i.e. numerous small coastal catchments, is characterised by the coastal estuaries' water requirements as well as the effluents from the major wastewater treatment works (WWTWs) for the City of Cape Town and the surrounding smaller towns.

Given the importance of groundwater as a future supply source, we considered not only the overall status of groundwater across the Study Area under current and future development scenarios, but also for specific areas of interest, such as the increased abstractions from the West Coast Aquifers and the Cape Flats Aquifers.

Prior to consideration of individual scenarios for the different focus areas, an overall Ecological Sustainable Base Configuration (ESBC) scenario for the whole study area was considered. This is presented in the ESBC Report, and also summarised here, as it provides the motivation for the additional scenarios considered.

The final recommended classification scenario was derived from an analysis of the various individual scenarios and in particular the Recommended Ecological Condition (REC) scenario, but also taking into consideration key areas of concern or importance identified by various stakeholders during the project's consultation processes.

A summary of the main consequences of the final recommended classification scenario is also presented.

2.1.1 G1 Catchment Scenarios – Berg River and WCWSS

Flow in the Berg River is determined largely by the operation of the dams and water supply distribution system of the WCWSS. This also includes six large dams and inter-basin transfers into Berg River Dam from Theewaterskloof Dam in the Breede Catchment. The impact of the different scenarios considered for the G1 catchments were determined using the Water Resources Yield Model (WRYM) of the WCWSS.

There are four EWR sites on the main stem of the Berg River and their respective ecological conditions are presented in Table 2-2. These existing EWR recommendations where used in the scenario evaluation.

Table 2-1 EIS, PES, REC and ESBC ecological conditions for EWR sites along the Berg River (G1)

Site	Node	IUA	Quat	Name	PES	REC	ESBC	EIS	Reference
Berg1	Bviii1	D8	G10A	Upper Berg River	C	C	D	H	DWAF, 1996
Berg3	Bvii5	D8	G10D	Lower Berg River	D	D	D	H	
Berg4	Bvii6	B4	G10J	Heuningberg, upstream of Misverstand Dam	D	D	D	M	DWAF, 2000
Berg5	Bvii12	B4	G10J	Nuwedrif, downstream of Misverstand Dam	D	D	D	H	

IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; REC = Recommended Ecological Category; EIS = Ecological Importance and Sensitivity; VH = Very High; H = High; M = Moderate.

Note that the REC is the same as the PES and for all but one site also the same as the ESBC; hence the scenarios considered only one target EWR condition for the river nodes, namely the REC. A minimum dry-season flow requirement for the Berg River estuary was also incorporated in the scenario analysis.

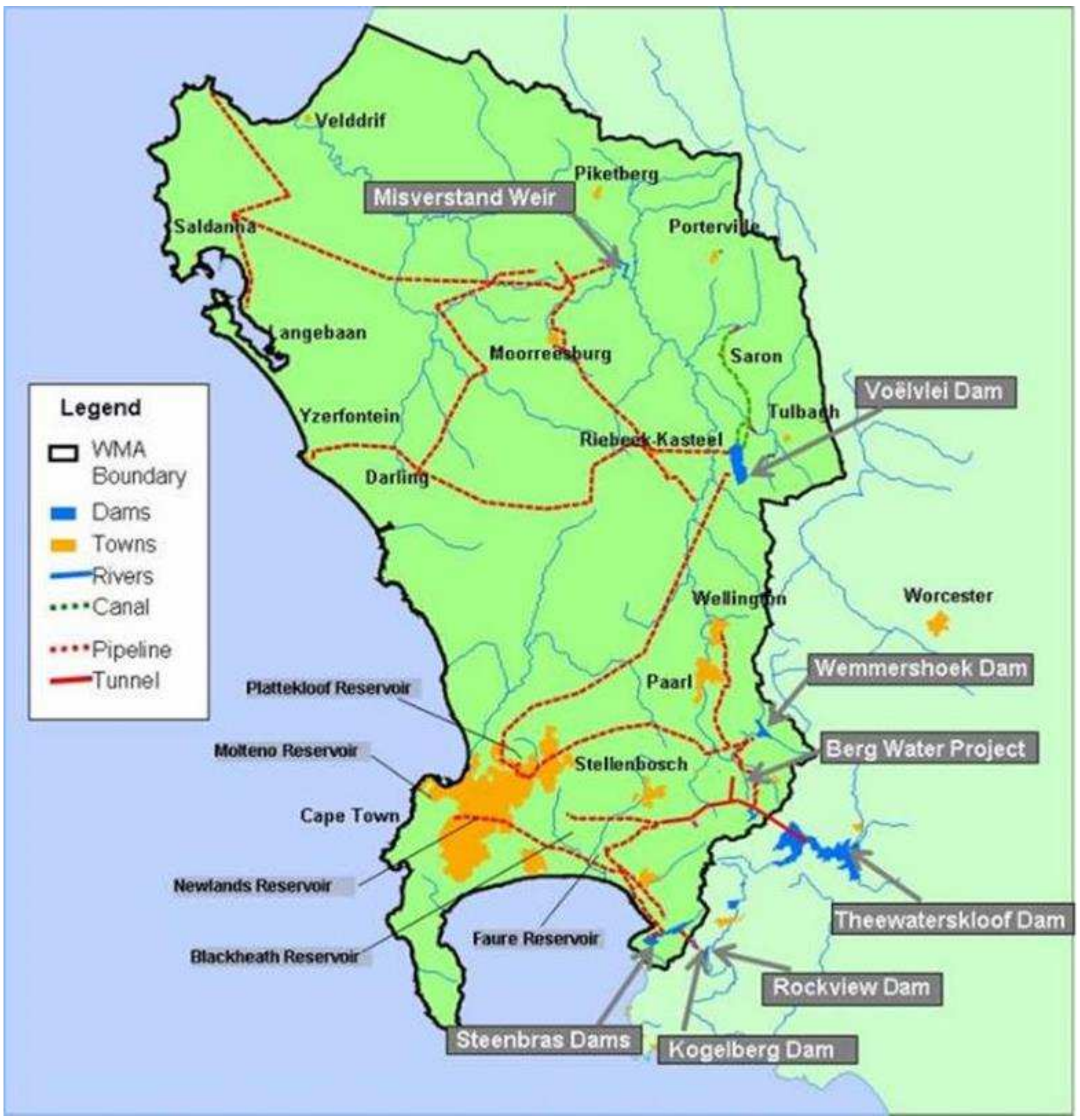


Figure 2-1 Bulk water infrastructure of the WCWSS (from DWS, 2014).

The current and future infrastructure scenarios and demands on the WCWSS are described in Section 2.3.

Additional bulk infrastructure developments considered in the future scenario for the WCWSS are the Voëlvlei Augmentation scheme (VAS), for which the Environmental Impact Assessment (EIA) has already been completed and the proposed increased use of the West Coast Aquifer for managed aquifer recharge and water banking. In addition, the future scenarios assumed that all future return flows from the wastewater treatment plants along the Berg River would be fully utilised as an alternative future water supply source.

The following scenarios were considered in modelling the impacts on the WCWSS for the G1 catchments:

Scenario Name	Scenario Description
Scenario 1 (PES)	Current day infrastructure with 0.5 m^3/s minimum flow requirement to the estuary.
Scenario 1b (PES-FI)	Future (2040) infrastructure with 0.5 m^3/s minimum flow requirement to the estuary.
Scenario 1c (PES-CC)	Future (2040) infrastructure and reduced streamflow due to potential impacts of climate change with 0.5 m^3/s minimum flow requirement to the estuary.
Scenario 2 (ESBC)	Current Day infrastructure with ESBC baseflow EWRs and 0.5 m^3/s flow to the estuary.
Scenario 3 (REC)	Current day infrastructure with REC baseflow EWRs and 0.6 m^3 flow to the estuary.
Scenario 4 (ESBC-FI)	Future infrastructure with ESBC baseflow EWRs and 0.5 m^3 flow to the estuary.
Scenario 5 (REC-FI)	Future infrastructure with REC baseflow EWRs and 0.6 m^3/s flow to the estuary.
Scenario 6 (No EC-FI)	Future infrastructure with no Environmental Constraints
Scenario 7 (ESBC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, ESBC baseflow EWRs and 0.5 m^3/s minimum flow requirement to the estuary
Scenario 8 (REC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, REC baseflow EWRs and 0.5 m^3/s minimum flow requirement to the estuary
Scenario 9 (No EC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, and no Environmental Constraints

2.1.2 G2 Catchment Scenarios – Coastal Rivers and Estuaries

For the estuaries and coastal catchments (G2) a large proportion of the current day flow comprises the return flows from wastewater treatment works (WWTW). The most significant development likely to impact on the flow in the rivers and estuaries is considered to be changes in these return flows as re-use of treated effluent becomes more of a significant contributor to the future water supply to the City of Cape Town.

There are a few potential bulk water infrastructure development projects that have been identified in some of these catchments including on the Lourens River, but these are not considered to be likely to be implemented before 2040. The only other significant future development is likely to be changes in land use, but this is not modelled in the current hydrology. The scenarios considered are shown in the table below.

Scenario Name	Scenario Description
Natural	Reference condition
Present	Present day flows and conditions
Scenario 1	Present day flows but all effluent from WWTWs to be treated to DWS Special Standards
Scenario 2	Reduce inputs from the WWTWs by 50% and treat the remainder to DWS Special standards
Scenario 3	Reduce inputs from the WWTWs by 75% and treat the remainder to DWS Special standards

For the estuaries that were not directly impacted by the return flows from WWTW (e.g. Langebaan, Lourens and Zandvlei), alternative scenarios were considered based either on other changes to surface or groundwater flow or physical developments that could affect the functioning and condition of the estuary.

2.1.3 Groundwater Scenarios

For this study the groundwater status related to use was determined at both quaternary catchment scale as well as groundwater resource unit scale, for both the current status and based on anticipated future groundwater demand. The groundwater present status related to groundwater quality was also determined.

In addition to the consideration of current and future groundwater status, additional scenarios derived from previous studies were used to consider the potential impact of specific groundwater developments for key areas of concern. The selected areas include groundwater developments where impacts of abstraction may influence sensitive receptors (environmental or human), and where this information is available.

A summary of the scenarios considered are given below.

- Current and Future Groundwater Status and Stress
  - Present day GW status related to use and to groundwater quality (as per Status Quo report)
  - Planned GW developments from All Towns Study II and their impact on GW status related to use
  - Planned development scenarios + additional demands to meet shortfalls (this study) and their impact on GW status related to use

The purpose of incorporating potential groundwater impacts of the development scenarios considered in the scenario assessment, and in the socio-economic assessment, is not to specifically influence water resource planning. Given the scale of this study, and the inability to predict development-specific without information on the abstraction locations, this study cannot influence water resources planning, and nor is that the intention. Groundwater condition is influenced by development and conservation driven scenarios, and these impacts will be taken into account in the prioritisation of resource units for development of RQOs.

2.2 The Basin Configuration Scenario Tool

Note that, for the reasons given in Section 2.1, for the most part, the basin configuration tool was used to estimate resulting ecological conditions of the flow and other modelled scenarios rather than in setting or determining flows and conditions.

The basin configuration tool is an Excel based model that routes flows through river nodes to the estuaries. Nodes represent various points of interest in the study area. The tool was created to model how changes in flow affect the ecological condition of rivers and estuaries. To achieve this, the tool calculates the ecological condition at the nodes as the flows are increased or decreased, relative to flows of the current day. It is important to note that Reserves (in terms of ecological water requirements - EWRs) for rivers and estuaries were calculated based on percentage change from natural flows, *viz.* NOT relative to the present day.

There are various inputs into the tool:

- The location of each node relative to the other nodes, up- and downstream respectively.
- Naturalised monthly streamflow series (cumulative and incremental flows), calculated as volumes in million m^3.
- Present day hydrological monthly time series' (cumulative and incremental flows), calculated as volumes in million m^3.
- Monthly Reserve (EWR) streamflow series (cumulative and incremental flows), calculated as volumes in million m^3 for a range of ecological categories.
- The current (generally, 2014) ecological condition of each node (river and estuary).

Flows are linked together in a downstream direction toward their receiving estuary. The tool calculates the cumulative flows for each node by taking into account nodes that deliver flow from upstream. The cumulative natural and current day flows at each node is the primary data sources against which all other flow and ecological condition calculations are made.

The Reserve flows provide for a range of ecological categories where rivers and estuaries in higher conditions (e.g. B) generally have higher flows, relative to natural, than those in lower condition (e.g. D). The Reserve flows were calculated using naturalised streamflow series at each node in the Desktop Model (Hughes and Hannart, 2003) that quantifies Reserve flows based on flow sequences from prior Reserve studies, and/or through the use of regional specific settings.

The Desktop Model only calculates intra-annual flows, *viz.* flows that include the small intra-annual floods (that occur every year) and excludes the larger inter-annual floods (1:2, 1:5, 1:10 year recurrence intervals, etc.). Therefore, for comparison with naturalised, current-day and other scenarios' flows, which are TOTAL flows (inclusive of all floods), it was necessary to first "put back" the inter-annual floods into the Reserve streamflow series prior to any comparative calculations.

The present ecological status (PES / baseline) of each node is the ecological condition (EC) of each (river and estuary) node, as taken from the 2014 PES EIS data base (DWS, 2014a), adjusted in some cases based on more recent information or Reserve studies. In the Western Cape these data were derived from field-based studies, or the applicable relevant Reserve study, or from updates made during the study (DWS, 2017). The links between flow and ecological condition were included in the tool based on:

- Ecological categories after Kleynhans and Louw (2007, Table 2-2).
- Flow categories, based on percentage differences to naturalised flow.
- Changes in flow were linked to changes in ecological condition in a non-linear manner such that nodes in good ecological condition were more responsive to changes in flow, whereas nodes in poor ecological condition were less responsive to changes in flow (i.e. bigger changes in flow would be required to shift the reach into another better or worse condition). The premise here is that poor ecological conditions often result from a combination of impacts, not just from flow alone (e.g. due to water quality or habitat impacts), and where this is the case, an improved ecological condition requires multiple interventions additional to possible flow manipulation.

Table 2-2 Ecological categories and associated PES scores (Kleynhans et al., 2008)

Ecological Category	PES Score	Description of the Habitat
A	92-100	Still in a Reference Condition.
A/B	87-92	
B	82-87	Slightly modified from the Reference Condition. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
B/C	77-82	
C	62-77	Moderately modified from the Reference Condition. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
C/D	57-62	
D	42-57	Largely modified from the Reference Condition. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
D/E	37-42	
E	22-37	Seriously modified from the Reference Condition. The loss of natural habitat, biota and basic ecosystem functions is extensive.
E/F	17-2	
F	0-17	Critically/Extremely modified from the Reference Condition. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.

The tool calculates how the cumulative flows at each node downstream of a change are affected relative to current-day flow, and whether the change in flow will change the Ecological Category. The results presented per node include:

- current ecological condition
- scenario ecological condition
- current-day seasonal (wet and dry seasons) average monthly flow volume as a percentage of natural

- scenario seasonal (wet and dry seasons) average monthly flow volume as a percentage of natural
- surplus/deficit seasonal (wet and dry seasons) flow volumes relative to the current day.

In the tables of results from the tool, colouring is used to guide description and highlight changes. The ecological condition categories are coloured in the standard fashion, blue for better conditions, and red for poorer conditions, and green and orange in between. Other shading is used for the percentages of flow relative to natural mean annual runoff (nMAR) in the tables that follow). Here, from light pink (indicating a small decrease from natural) to red (indicating a large decrease relative to natural), and from light blue (a small increase relative to natural), and dark blue (a large increase relative to natural). Lastly, the surplus or deficit volumes per node, are also colour coded where pink indicates a deficit and blue indicates a surplus. Very small changes are not colour coded.

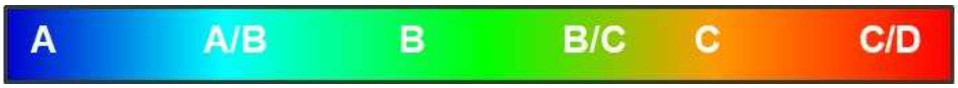


Figure 2-2 Illustration of the distribution of Ecological Categories on a continuum of change.

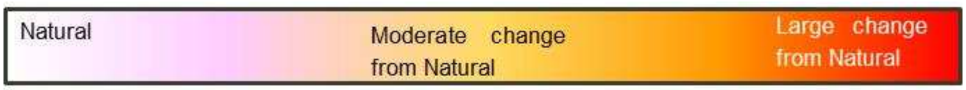


Figure 2-3 Illustration of the distribution of percentages of flow relative to natural.

Figure 2-4 Illustration of the distribution of deficit or surplus flows.

2.3 Determining surface water flows

2.3.1 Natural and present-day conditions

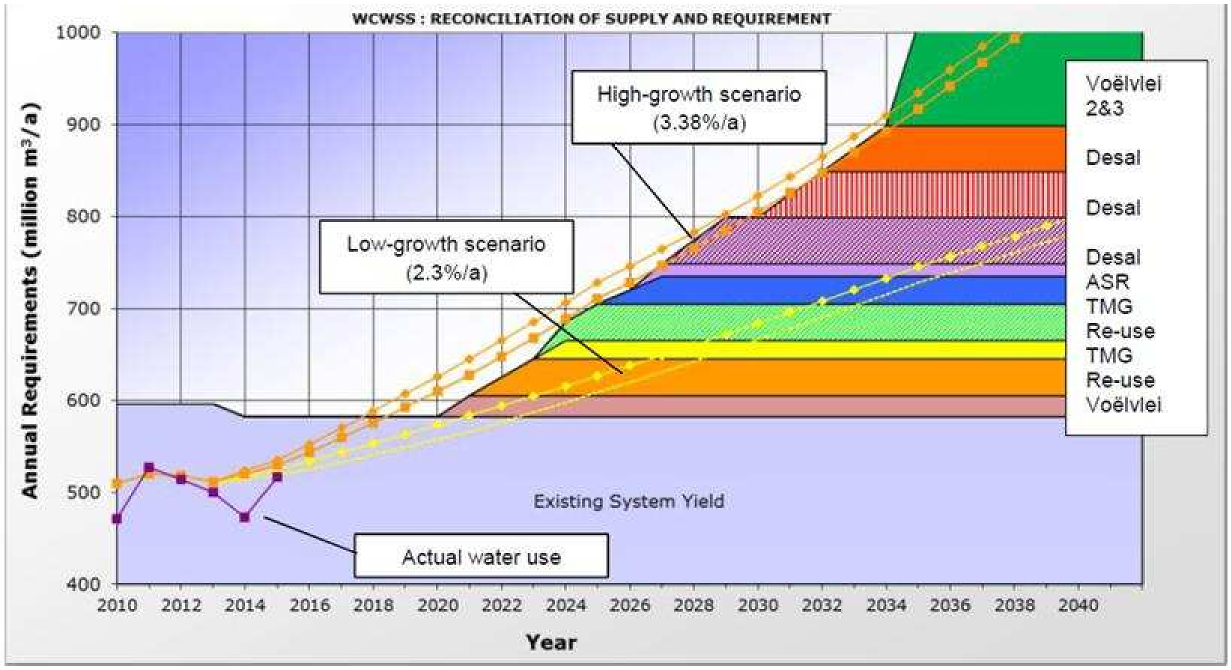
As stated in the "*Linking the Value and Condition of the Water Resource*" Report (DWS, 2017a), DWS updated earlier WCWSS configurations of the Water Resources Yield Model (WRYM) as part of the recently-completed project: *Development of Integrated Annual and Real Time Operating Rules for the Western Cape Water Supply System* (DWA, 2014).

In the current study, we used this 2014 configuration of the WCWSS WRYM system yield model for yield and water supply analyses for Secondary Drainage Region G1. For catchments of Secondary Drainage Region G2 which do not form part of the WCWSS, the WR2012 Pitman rainfall-runoff catchment model configurations (Water Research Commission, 2016) was implemented for yield and water supply analyses.

The above WRYM and WR2012 Pitman configurations were further sub-divided to reflect the river and estuary nodes identified in this study and monthly streamflow sequences were then generated at all the river and estuary nodes for natural and current-day development scenarios. Where applicable effluent return flows downstream of WWTWs were added to the current-day scenario configurations.

2.3.2 Quantifying surface water flows under future (2040) demands

Initially, we planned to base the 2040 development scenario on the "Planning Scenario" projections of potential water requirement growth and concomitant new bulk water supply infrastructure according to the latest WCWSS Reconciliation Strategy Status Report (DWS, 2016), as illustrated in Figure 2-5. For a number of years, the total WCWSS water use allocation used to be about 606 million m3/a, including river and distribution losses. However, Figure 2-5 shows that actual annual water use (urban and agricultural) over hydrological years 2010 to 2015 fluctuated around an average of about 500 million m^3/a.



Note: The insert on the right-hand side indicates the preferred sequence of planned long-term bulk water supply interventions and their respective incremental system yield contributions

Figure 2-5 Reconciliation of water supply and requirement for the "Planning Scenario" of the most recently available WCWSS Reconciliation Strategy Report (DWS, 2016).

Since the onset of the ongoing drought in the region in 2015, total water use in the WCWSS has been steadily declining due to increasingly severe water restrictions and active water saving measures. For example, recently, the City of Cape Town put additional measures in place to enforce a reduction in average daily urban water consumption of about 40% (500 Ml/d), compared with pre-drought consumption. Similarly, agricultural water use has also undergone curtailments that have gradually been increased up to the current 30% enforced restrictions.

It can be expected that this situation of curtailed water use in the WCWSS will continue for a number of years and that, even after the drought is finally over, water saving attitudes and actions will have become imbedded among many urban water users. This will likely result in a relatively gradual return to pre-drought urban water use and, into the future, in relatively lower growth in urban water use.

It is clear that, given the above context, the water requirement projections for the Western Cape Water Supply System (WCWSS) need to be modified. To this end, we formulated the following assumptions:

- Severe water restrictions for urban and agricultural use maintained for 2017/18 and 2018/19.
- Urban water use restrictions relaxed in 2019/20 and further relaxed in 2020/21.
- Agricultural water use restrictions relaxed in 2019/20.
- Agricultural water use allocations for commercial farmers for 2020/21 rising to the WCWSS's long-standing capped total of 170 million m^3/a; for emerging farmers water use allocations of 20 million m^3/a for 2020/21 growing to 40 million m^3/a by 2039/2040.
- River and distribution losses set at about 10% of agricultural allocations.
- Resulting from the current severe drought, water savings lessons/water use behaviour changes will render the high-growth scenario for urban water consumption used in the WCWSS Reconciliation Strategy as highly unlikely. Consequently, we considered only a medium-growth (at 2.8%/a) scenario.

Table 2-3 presents the newly projected quantitative progression of annual water requirements from the WCWSS from 2017/18 to 2039/40 in line with the above assumptions.

Table 2-3 Progression of projected annual water requirements (million m3/a) from 2017/18 to 2039/40 according to the above assumptions

Water Requirement Sector (million m^3/a)	2017/18	2018/19	2019/20	2020/21	2039/40 Medium-Growth Urban (2.8%/a)
CoCT + Other Municipalities	193	210	275	330	560
Agriculture	93	110	135	190	210
Losses	11	12	14	20	20
Total	**297**	**332**	**424**	**520**	**790**

Figure 2-5 presents, according to the "Planning Scenario" of the WCWSS Reconciliation Strategy (DWS, 2016), a likely sequence of planned long-term bulk water supply interventions and their respective incremental system yield contributions. The diagram shows that, in order to meet a total WCWSS water requirement of 790 million m3/a by 2039/40, up to seven new bulk water supply interventions needed.

Table 2-4 presents the respective nominal yields of these schemes.

Table 2-4 New bulk water supply interventions for the WCWSS needed by 2039/40 (DWS, 2016)

Bulk Water Supply Intervention	Yield (million m^3/a)
Berg River-Voëlvlei Dam Diversion	23
Wastewater Re-Use - 1	40
TMG Aquifer – 1	20
Wastewater Re-Use - 2	40
TMG Aquifer – 2	30
West Coast Aquifer Recharge	14
Seawater Desalination - 1	50

The above 2039/40 development scenario was super-imposed on the current-day WRYM model configuration for the WCWSS, followed by simulation of monthly streamflow sequences at all the river and estuary nodes. The increase in treated effluent due to increased urban/industrial water use was included in the future development scenario simulations. This resulted in increased simulated streamflow downstream of the respective wastewater treatment works (WWTWs), which then potentially mitigated any demand shortfalls further downstream. The exceptions were the Zandvliet, Cape Flats, Bellville, Potsdam and Drakenstein WWTWs, which have been identified as candidates for effluent re-use. On average about 85% of the treated effluent can be reclaimed from the WWTWs, while the rest will be discarded as brine – either to the ocean or to evaporation ponds. This is based on an industry average for re-use and could vary for individual plants once a more detailed feasibility study is undertaken for each targeted plant.

2.3.3 Surface water availability under climate change

Potential changes to surface water availability due to climate change over the whole of South Africa were examined at quaternary catchment scale by Cullis *et al.* (2015) by application of more than 300 climate change impact models for different carbon emission scenarios. For this study, the proportional quaternary catchment monthly streamflow changes relative to present day (known as "deltas"; delta means change in mathematics) for a relatively severe "dry" scenario – namely, the 10^{th} percentile case - were selected from the "drying" side of the spectrum of outcomes for the study area from Cullis *et al* (2015). These quaternary "deltas" were super-imposed on all the incremental inflow files in the 2039/40 WRYM model configuration, followed by simulation of monthly streamflow sequences at all the river and estuary nodes.

2.4 Ecological condition of rivers, wetlands and estuaries

2.4.1 Rivers

For each scenario, the monthly flows from the yield model were entered into the Configuration Tool and routed down the system. The resulting ecological condition, in terms of ecological category (EC), A to F, of each node was determined by comparing the resulting flows to current flows and condition, and to the EWR requirements for each node

2.4.2 Wetlands

The Status Quo report (DWS, 2016b) defined the Wetland Regions within the study area according to the spatial framework of Ecoregions. Nested within Wetland Regions are the Wetland Resource Units, defined by vegetation type and Hydrogeomorphic (HGM) unit and prioritised according to Ecological Importance and Ecosystem Services. As the HGM unit is defined by landform it is important to understand the location of a wetland in the landscape and the underlying geological controls.

Defining the Wetland Regions provides a foundational understanding of the controls of wetland formation in the study area. Typical wetland types found in each Wetland Region are as follows:

- **South Western Coastal Belt_Sand** (WR1) and **South Western Coastal Belt_Shale** (WR2) Wetland Regions typically have floodplain wetlands
- **Western Folded Mountains** (WR3) Wetland Region typically have small valley bottom and seep wetlands
- **Southern Folded Mountains** (WR4) Wetland Region typically has seeps and valley bottom wetlands
- **Southern Folded Mountains_Peninsula** (WR5) Wetland Region ranges from mountain seeps, riverine systems and isolated depressions

From an RDM perspective, important wetlands include those that have both ecological importance for the maintenance of biodiversity ecosystem integrity, as well as those that provide ecosystem services. In terms of ecosystem services, wetland prioritisation needs to consider both the ability of a wetland to provide services as well as the demand for such services within the catchment. These two aspects define the importance of wetlands in terms of ecosystem services.

The prioritisation of Wetland Resource Units occurs within each Wetland Region, and is based on those wetlands that have been defined as important in terms of ecological importance and for provision of ecosystem services (Figure 2-6).

The methodology proposed for assessment is therefore as follows:

- Wetland Resource Units will be assessed qualitatively at individual river/estuary nodes in terms of impacts from surface and groundwater usage
- Wetland Resource Units will be assessed qualitatively at the catchment scale for all scenarios in terms of indirect impacts

2.4.2.1 Surface and groundwater usage impacts to wetlands

According to MacFarlane *et al.* (2009) hydrology, in terms of the movement of surface and subsurface water into, through and out of a wetland, is a key component of assessment of wetland health. The hydrological condition of a wetland impacts many important processes, including anaerobic conditions in the soil, availability of nutrients and other solutes and sediment fluxes; which in turn influence which fauna and flora inhabit a wetland. Hydrology of a wetland may be altered through human modifications (in terms of quantity and timing of water inputs) to the wetland catchment; as well as through direct modifications to the wetland which alter the distribution and retention patterns of water within the wetland.

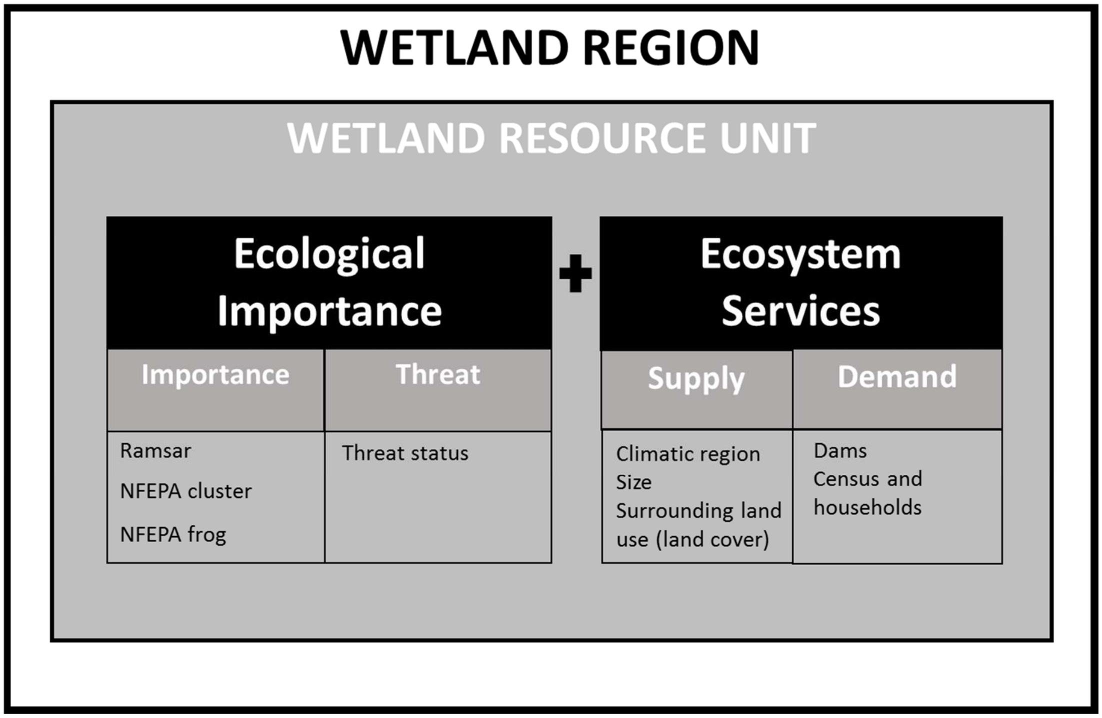


Figure 2-6 Conceptualisation of how Wetland Resource Units are nested within Wetland Regions

Sensitivity to changes in hydrology is different depending on the wetland type, in general the characteristics of wetland types in terms of hydrology are as follows:

- **Floodplains**

  Floodplains generally receive most water during high flow events when waters overtop the streambank. They are considered important for flood attenuation because of the nature of vegetation and topographic setting. Flood attenuation is likely to be high early in the season until the floodplain soils are saturated, whilst in the late season flood attenuation is reduced. The nature of clayey soils in floodplains means that soils retain water, thus limiting contribution to streamflow and groundwater recharge. As flood waters overtop streambanks the waters drop sediments, and nutrient bound sediments, which are left behind to accumulate.

- **Channelled valley-bottom wetlands**

  Channelled valley-bottom wetlands have less active deposition than floodplains and tend to be narrower with steeper gradients. Groundwater input to the main stem channel is also generally greater.

- **Non-channelled valley-bottom wetlands**

  Stream channel inputs are spread diffusely across the wetland even at low flows, resulting in high levels of soil organic matter. This aids nitrate and toxicant removal, particularly if there is groundwater contribution.

- **Hillslope seep wetlands**

  Normally associated with groundwater discharge, although there are additional contributions from surrounding runoff. Contribute streamflow regulation early in the season, until soils are saturated. Good provision of nitrate removal, but poor at erosion control owing to location on steep slopes.

- **Depressions (pans)**

  Can receive both surface and groundwater flows, which accumulate in the depression owing to the impervious underlying layer which prevents water from draining away. Temporary pans allow for the precipitation of minerals, although these deposited minerals can be transported out of a system by wind.

- **Flats**

  A wetland flat is not fed by water from a river channel, and is typically situated on flat land (often on a coastal plain). The primary source of water is precipitation, although on coastal plains groundwater may rise to or near the ground surface. Water typically exits via evapotranspiration and infiltration.

2.4.2.2 Indirect impacts to wetlands

Indirect impacts to wetlands are linked to future development scenarios unrelated to water use. Future development is likely to include increased population density and associated infrastructure growth in urban/agricultural areas. A change or intensified land use would impact the hydrology, geomorphology and vegetation of wetlands. Increased hardened surfaces would increase the surface water contribution to wetlands due to the increased stormwater discharge. Wetland vegetation health may change completely through transformation for the development of infrastructure, substantially for croplands/plantations or moderately for abandoned lands. Increased development would also increase or decrease the input of sediment to wetlands. Reduction of sediment inputs through the development of upstream dams, or increasing sediment through increased upstream erosion would impact the geomorphological stability of wetlands.

Particular threats and sensitivity to change are as follows:

- **Floodplains**

  Upstream dams, or dams within wetlands as well as channel straightening and infilling through construction of bridges or through wetland “reclamation” are the greatest impacts in floodplains. Floodplains are generally resilient to changes in sediment inputs as the system is dominated by fluvial processes. The main impact will be when harmful erosion is occurring due to a change in the natural dynamic (i.e. dam upstream removing sediment). Floodplain size, and manner of releasing water back into the wetland is also important.

- **Channelled valley-bottom wetlands**

  Channel straightening and infilling through construction of bridges or through wetland “reclamation” are the greatest impacts in channelled valley-bottom wetlands. Changes in runoff characteristics and erosional, depositional features and loss of organic material are also important. Channel straightening steepens channel slope, and thus promotes headward erosion. The effect of headward erosion will be attenuated over a longer distance. The infilling of a wetland confines flow and geomorphic activity to a localised area.

- **Non-channelled valley-bottom wetlands**

  Changes in runoff characteristics through increased stormwater inputs and increased erosional/deposition are important in non- channelled wetlands.

- **Hillslope seep wetlands**

  The location on slopes means that hillslope seeps are sensitive to erosion. Habitat transformation through agricultural use is also likely.

- **Depressions (pans) and Flats**

  Depression wetlands and Wetland flats are sensitive to increased stormwater inputs as this impacts the seasonality of the wetlands. Habitat transformation is also likely.

2.4.3 Estuaries

Response curves were derived for each estuary that described the relationship between flow and estuary health (as defined by the Estuary Health Index, EHI) and positive correlations were found to exist between the EHI and a number of ecosystem characteristics (in particular, fish health, bird health and macrophyte health). Using these relationships, matrices were created that allow for prediction of proportional changes in fish, bird and macrophyte abundance with changing EHI class (Table 2-5, Table 2-6 and Table 2-7).

Table 2-5 Matrix of proportional changes between Present Ecological State and Assigned Ecological Category used to model changes in Macrophyte Habitats

		Assigned Ecological Category					
		A	**B**	**C**	**D**	**E**	**F**
PES	A	1.0	0.9	0.7	0.5	0.3	0.1
	B	1.2	1.0	0.8	0.6	0.3	0.1
	C	1.4	1.2	1.0	0.7	0.4	0.1
	D	2.0	1.7	1.4	1.0	0.6	0.1
	E	3.5	3.0	2.5	1.8	1.0	0.2
	F	16.1	13.9	11.2	8.1	4.6	1.0

Table 2-6 Matrix of proportional changes between Present Ecological State and Assigned Ecological Category used to model changes in estuarine fish populations.

		Assigned Ecological Category					
		A	**B**	**C**	**D**	**E**	**F**
PES	A	1.0	0.9	0.7	0.5	0.3	0.0
	B	1.2	1.0	0.8	0.6	0.3	0.1
	C	1.4	1.2	1.0	0.7	0.4	0.1
	D	2.0	1.7	1.4	1.0	0.5	0.1
	E	3.7	3.2	2.6	1.8	1.0	0.2
	F	23.0	19.8	15.9	11.3	6.2	1.0

Table 2-7 Matrix of proportional changes between Present Ecological State and Assigned Ecological Category used to model changes in estuarine waterbird populations

		Assigned Ecological Category					
		A	**B**	**C**	**D**	**E**	**F**
PES	A	1.0	0.9	0.7	0.5	0.3	0.1
	B	1.2	1.0	0.8	0.6	0.4	0.1
	C	1.4	1.2	1.0	0.7	0.4	0.1
	D	1.9	1.7	1.4	1.0	0.6	0.2
	E	3.2	2.8	2.3	1.7	1.0	0.3
	F	10.4	9.0	7.3	5.4	3.2	1.0

These matrices were applied to fish, bird and macrophyte abundance data for each estuary derived from the National Biodiversity Assessment (NBA) (Turpie *et al.* 2012). While these data are not necessarily the most recently-collected data for each estuary, the dataset provides the only complete and consistently collected dataset across the country. This dataset includes areas of different estuarine macrophytes groups including inter- and supratidal saltmarsh, submerged macrophytes and reeds and sedges.

For the NBA for South Africa, biodiversity targets were set for estuarine species and habitats (Turpie *et al.* 2012). Targets for estuarine macrophytes such as saltmarsh, reeds and sedges were set at 20% of their natural extent conserved for each different habitat type (Turpie *et al.* 2012). Population targets for fish and bird species under conservation were set at 50% for red-data species/over-exploited species, 40% for exploited species and 30% for the rest (Turpie *et al.* 2012). The aim was to secure protection status for target populations for each of these groups (macrophytes, fish and birds) by establishing a protected area network comprising of the minimum number of estuaries required to achieve this target.

The primary analysis undertaken for the NBA (Turpie *et al.* 2012) identified 133 estuaries that would need to be incorporated into a national network of protected estuaries to meet biodiversity targets defined for this study, some of these were already partially or wholly protected. In all, 61 were identified as requiring full protection (i.e. 100% of the estuarine habitat to be protected) and 72 as requiring partial protection (at least

50% of estuarine habitat to be protected). This amounted to about 46% of the total number of estuaries in the country and 79% of estuarine area.

While protecting the estuaries themselves help meet these goals, the condition of the protected estuaries was not taken into consideration, although this clearly also plays a role in determining whether or not these biodiversity conservation goals are met (note that it was simply assumed for the purposes of the NBA study that any estuary under conservation would be maintained in a good state of health – mostly “A” or “B” category). However, since the flow of water into these estuaries plays a large role in determining their health, it is also important to consider how the contribution of the Berg catchment estuaries might change under different flow scenarios in the absence of any changes to the protection status.

Thus, for the purposes of this study, we examined how the total extent and quality of estuarine habitat would change and how populations of priority species (fish and birds) in the Berg catchment would change relative to present day under the different scenarios evaluated in this classification study and also how these indicators would change for the significant estuaries selected in the NBA (Turpie *et al.* 2012).

For all scenarios the Ecological Category (EC) for each estuary was determined using modelled relationships between %MAR and EC that were developed for this study and have been included in the basin configuration tool (Figure 2-7). The reader is referred to Volume 7 of this report series (Report no. RDM/WMA9/00/CON/CLA/0217: Quantification of the EWR and changes in EGSAs) for more details on this.

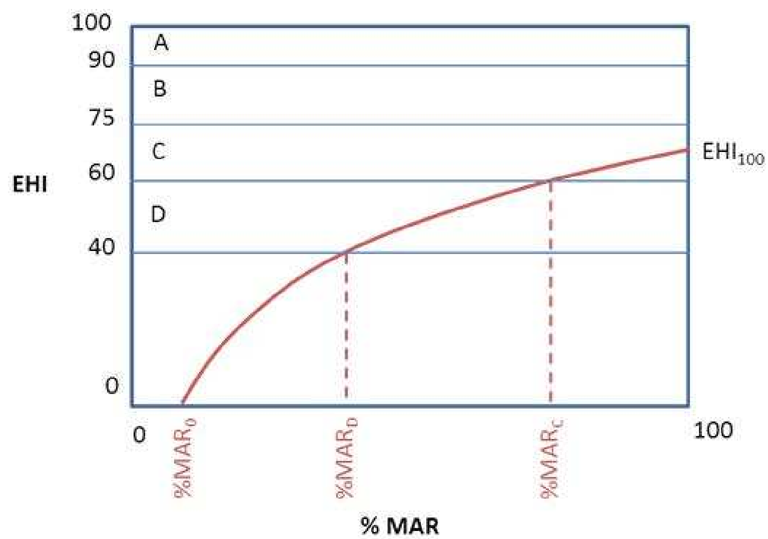


Figure 2-7 Example of the relationships between %MAR and estuary health (EHI) for the (typical) situation where flows are reduced compared to natural (Turpie in prep., DWS 2017)

2.5 Water Quality Impacts

The present status of water quality was described in the *Status Quo Report* in terms of the fitness for use; i.e. whether observed key water quality parameters met with various national water quality guidelines. In the analysis of scenarios, the potential impact of each scenario on the water quality status in each IUA is evaluated based on the anticipated changes in flow and the considered impact this will have on water quality. The assessment considered the continued or changed impacts of point and nonpoint sources of pollution on the mainstem river.

2.6 Impacts on surface water yield and water availability

2.6.1 Impact on Yield from the Western Cape Water Supply System

As described in Section 2.3, the impacts of the different scenarios on the yield from the WCWSS were determined by super-imposing each scenario successively on the existing configuration of the WCWSS in the WRYM model. For each scenario, the penalty structure of the WRYM was iteratively adjusted until the historically-determined EWRs at five river EWR sites as well as at the estuary were fully satisfied during the simulation period of 1928 to 2004. This enabled us to quantify each scenario's impact on the historical firm yield (HFY) of the WCWSS as well as the average annual minimum flow to the Berg River estuary.

In addition, the resulting monthly streamflow sequences at all nodes in the system were then extracted from the outputs of the WRYM and processed in the basin configuration scenario tool outlined in **Section 2.1**.

An important consideration in terms of determining the potential impact on the yield from the WCWSS is to acknowledge that there is already a Reserve that has been approved for the Berg River following the construction of the Berg River Dam. The cost of including the existing EWRs is therefore already incorporated into the current as well as proposed augmentation options for the WCWSS. The REC scenario is based on the existing EWR scenarios and therefore becomes the baseline reference scenario.

2.6.2 Impact on Water Availability from the Coastal Catchments

For the coastal catchments (G2), various streamflow scenarios were considered, relating primarily to changes in the volume of treated effluent return flows to the estuaries which currently makes up a significant proportion of the current flows. The availability of surplus water or deficits in terms of meeting the targeted ecological conditions at the estuaries and any upstream river nodes were determined from the basin configuration scenario tool which included the various EWR thresholds for all nodes included in the model.

These surpluses and deficits were calculated on both an annual and a seasonal basis for all nodes and used to evaluate the impacts of the different scenarios, the potential for increased use of treated effluent as a future supply option, particularly during the summer months, and any nodal deficits that may require augmentation. As a first order estimate it was assume these shortfalls would be met from groundwater.

2.7 Current and Future Groundwater Stress Status

The present status of groundwater is formally defined in relation to the alteration from the pre-development condition. The present status is therefore a function of groundwater use, and of the various impacts that are assumed to be caused by that level of groundwater use (Table 2-8, and Dennis *et al.* 2013). However, in practice it is common to link the present status directly and only to groundwater use as a portion of recharge (the stress index). Perhaps the reason for this is that use/recharge provides a readily applicable quantitative assessment, and the other impacts of groundwater use are rarely quantifiable or represented in regional datasets.

An implicit assumption of using the stress index, and of relating the present status to the level of use, is that abstraction causes negative impacts, and that these increase as the portion of use compared to recharge increases. To attribute changes in river flow to groundwater use would require long term monitoring (pre-abstraction, and current) with more than three piezometers close to a river, at regular distances in river reaches where groundwater is thought to discharge to surface. Alternatively, it would require high-confidence surface water modelling in which all other factors (runoff, return flow, surface water use and interflow) are well known such that the change in Groundwater Contribution to Baseflow (GWBF) can be accurately determined.

Groundwater stress categories can also be used as spatial compliance categories for groundwater; for example, if 20-65% of the quantified units (i.e. quaternaries) in an area (i.e. IUAs) are moderately used, then the groundwater status can be considered as Level II, i.e. moderately used (Dennis *et al.* 2013).

Groundwater quality, and departure from acceptable limits in an area (whether they be drinking water limits or the regional background) is also used as a numerical indicator of the present status (Table 2-10). Variations in groundwater quality in the same aquifer in different areas may be a natural phenomenon, related to recharge rates, and may not be related to use. One aquifer may therefore have a present status related to use that is different to the present status related to groundwater quality. The limitations of the definition of groundwater status/condition based on aquifer stress include:

- Aquifer stress (if defined as Use/Recharge) usually does not take into account groundwater's role in meeting the EWR (i.e. GWBF). An aquifer with significant contribution to the ecological Reserve (high GWBF/EWR) could be over-exploited with a low aquifer stress index, whilst the reverse is true for an aquifer that does not contribute significantly to GWBF and therefore EWR (Riemann, 2013)

- As with most water balance approaches the calculation of aquifer stress uses mean annual recharge, and when used to make decisions on groundwater availability, could lead to over-abstraction for aquifers in arid climates with episodic recharge, and under development of aquifers with high storage capacity and long response time (Riemann, 2013).

- Related to the challenges of water balance approaches, there is no spatial consideration: abstraction close to a river, in an aquifer with low stress, could significantly impact the ability to meet groundwater's contribution to EWR. Likewise, a particular wellfield may be causing negative impacts locally (reduced discharge to a nearby spring), whereas the aquifer (or quaternary) as a whole may have minimal use.

- There is an implicit assumption that a heavily used aquifer (high use/recharge based in Table 2-8) has negative impacts (those listed in Table 2-9), and that alteration or impact is directly proportional to use/recharge. However, the volume abstracted does not directly relate to the same reduction in discharge (this depends on flow regime, distance to river, and access to storage).

- To 'ground truth' the results from a stress index, and determine alteration from pre-development state would ideally require indicators for aquifer storage depletion, discharge depletion, and recharge enhancement (rarely available). Comparison with water level data alone will only indicate storage reduction, which is a certainty in response to pumping, hence is not necessarily an indication of "stress" or level of alteration.

Acknowledging the limitations, in line with other studies, (DWA, 2012; DWS, 2015a) and current guidelines, (Dennis *et al.* 2013), the **present status related to use** is calculated for each quaternary catchment, based on the stress index Use/Recharge. In addition, however, the occurrence of declining water quality trends and declining groundwater level trends is used as an indicator of negative impacts of abstraction. These trends are considered in the prioritisation of resource units for development of RQOs. In addition, the **present status related to groundwater quality** was assessed by comparing the groundwater quality per aquifer per quaternary catchment, with to the regional background groundwater quality of that aquifer in the wider area, and applying the criteria from Table 2-10.

Table 2-8 Definition of groundwater Stress/Classification Status (from Dennis et al. 2013)

Present Status	Generic Description	Affected Environment
Minimally used (I)	The water resource is minimally altered from its pre-development condition	No sign of significant impacts observed
Moderately used (II)	Localised low level impacts, but no negative effects apparent	Temporal, but not long-term significant impact to: -spring flow -river flow -vegetation -land subsidence -sinkhole formation -groundwater quality
Heavily used (III)	The water resource is significantly altered from its pre-development condition	Moderate to significant impacts to: -spring flow -river flow -vegetation -land subsidence -sinkhole formation -groundwater quality

Table 2-9 Recharge/Use as an Indicator of Groundwater Status (from Dennis et al. 2013)

Present Status	Description	Use/ Recharge (Stress)
I	Minimally used	≤20%
II	Moderately used	20-65%
III	Heavily used	>65%

Table 2-10 Groundwater quality as an Indicator of Groundwater Status (from Dennis et al. 2013)

Present Status	Description	Compliance (spatial / temporal)
I	DWA class 0 or 1 or natural background	95%
II	DWA class 2 (95 % compliance) or natural background (75 % compliance)	75%
III	DWA class 3 or 4 or natural background (<75 % compliance)	<75%

Given surface water resources are close to the limit of their use in the catchment, increases in groundwater demand in future are certain to support development. In addition, groundwater use may increase to meet future requirements where there is a surface water deficit based on surface water flows having to meet a required ecological flow. The proposed or required increases are assessed in the groundwater balance model developed for this study. The resulting change in use/recharge ratio (or stress) leads to a change in groundwater status related to use (compared to the present groundwater status), and this potential future groundwater status is also reported on for each scenario (e.g. from I to II). The future scenarios involve increases in groundwater use, and therefore only the present status related to use is reported on. The present status related to groundwater quality is not expected to change in any of the scenarios. However, increased urbanisation may have detrimental impacts on groundwater quality, and this is considered under threats to groundwater resources as part of the resource unit prioritisation stage.

There are a number of known future groundwater developments in the study area. Included in this is the City of Cape Town which is considering the development of a number of bulk groundwater schemes to augment the current and future water supply system. These are summarised in Table 2-11 (DWS, 2018).

Table 2-11 Planned Future Groundwater Development from the City of Cape Town (DWS, 2018)

Project/Aquifer	Phase 1 (hm^3/a)	Phase 2 (hm^3/a)	Phase 3 (hm^3/a)
Cape Flats Aquifer	20	25	30
Atlantis & Silwerstroom	14	20	29
Southern Planning District	8	12	14
Helderberg Basin	3.6	5.5	7.3
Berg River Valley	3.6	5.5	7.3
Steenbras	12	20	35
Nuweberg & Klipfontein	10	31	56
Wemmershoek	2	3	3
Voelvlei	3	6	6

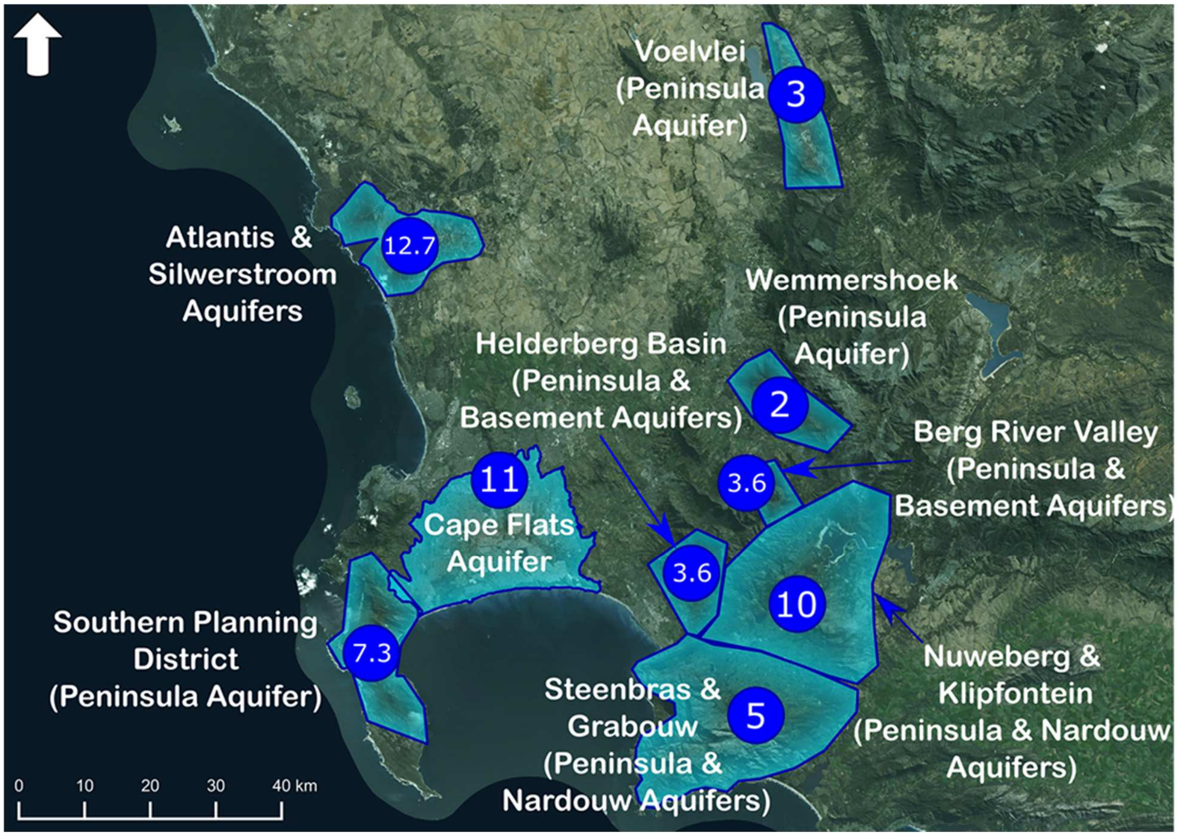


Figure 2-8: General locations of proposed additional groundwater developments by the City of Cape Town. The numbers indicate the anticipated yield (hm^3/a) from the first phase (Umvoto, 2018).

A number of other towns in the study area are likely to require water supply augmentation in the future and most of these towns are considering groundwater as a potential future water supply option, according to the information in the DWS All Towns Study (Phase 2). Several of these towns are currently experiencing water shortages due to the drought. The West Coast District Municipality is planning to increase abstraction at the Langebaan Road Wellfield, and private developments are planned that impact the Elandsfontein aquifer systems. Other towns including Stellenbosch, Franschhoek and Paarl, are also developing groundwater resources. In essence, the development of groundwater resources has been brought earlier than some of the predictions in the All Towns Studies and is still relevant for the future (2040) scenario.

In some cases, groundwater is not the first option with many towns hoping to secure additional water through increased allocations from the Western Cape Water Supply System (WCWSS). However as has been discussed in previous sections, the yield from the WCWSS is already fully allocated and there are only limited additional augmentation options. Added to this is the potential reduction in yield due to the climate change and additional flow requirements to meet the targeted EWRs for the Berg River and other EWR sites. As a first order estimate we have assumed therefore that all future demands will be met from groundwater where this is available (dictated by the groundwater balance values derived previously in this study). This at least will give us a first order estimate of the potential impact on future groundwater status.

2.8 Ecosystem Goods, Services and Attributes (EGSAs)

Impacts of changes in Ecological Condition are estimated on the basis of assumed relationships between ecosystem health and capacity to supply provisioning, regulating and cultural services, and the value of these services. The main types of ecosystem services considered are summarised in Table 2-12, along with the flow-related characteristics that are likely to be the main drivers of these values. These variables are all assessed in the scoring of estuaries using the Estuary Health Index (EHI) which are considered to have a much greater EGSAs value than corresponding river nodes. Additional details are given in the *Ecological Water Requirements and EGSAs* Report (DWS, 2017b).

Table 2-12 Main ecosystem services provided by rivers, wetlands and estuaries used in the analysis.

Category of service	Types of values	Description of EGSA	Independent variables related to estuary condition
Goods (Provisioning services)	Subsistence fishing	Invertebrates and fish collected on a subsistence basis for consumption or bait	Invertebrate abundance Freshwater fish abundance Estuary line- and net fish abundance
Services (Regulating services)	Nursery value	Contribution to marine fish catches due to the nursery habitat provided by estuaries	Abundance of estuary-dependent marine fish
Attributes (Cultural services)	Tourism value & property value	A river, wetland or estuary's contribution to recreation/ tourism appeal of a location	Overall health Line fish abundance Water quality

In order to inform this analysis, the relationships between abiotic and biotic scores and the overall health score for estuaries were explored. In general, it was found that the component scores were strongly correlated with the overall health scores, with all having a slope close to unity. Variation was highest for birds, which are influenced by non-flow disturbance factors, fish, which are influenced by fishing, and macrophytes, which are influenced by habitat loss through development. Nevertheless, it suggests that the overall relationships are generally consistent with the Ecological Health Index (EHI) score.

2.9 Socio-economic Impacts

2.9.1 Additional Water Supply Infrastructure Costs

As discussed in Section 2.3.2, for this study we have accepted the latest recommended "Planning Scenario" proposals by the Water Reconciliation Strategy process (DWS, 2016) for additional water supply infrastructure to meet the so-called medium-growth water demands by 2040.

The following generic "unit costs" of water supply (capital + engineering) in R/m^3 (2016 Rand; where m^3 is the yield) were derived from inflation-escalated costs compiled in relatively recent feasibility studies for each type of intervention and on the basis of the demand met by of each of these interventions (Ninham Shand, 2007, 2009; Aurecon, 2009; 2012; 2014).

- Small local groundwater scheme: R5/m^3
- Large groundwater scheme: R8/m^3
- TMG ground water scheme: R12.50/m^3
- Large surface water pump scheme: R8/m^3
- Surface water storage scheme: R13/m^3
- Treated wastewater plant effluent re-use: R13/m^3
- Desalination: R17.50/m^3.

These unit costs were then used to cost the appropriate interventions needed to cover the respective overall reduction in the yield from the WCWSS and any additional nodal deficits in meeting the EWRs. The individual intervention costs were then consolidated per IUA. It should be noted that these generic costs do not include allowances for operation and maintenance and will vary based on site specific conditions.

2.9.2 Overall Economic Impacts of Scenarios

The overall economic impact of each scenario was estimated as the value of aquatic ecosystem services generated less the opportunity costs incurred in order to maintain the Reserve. The latter were taken to be the additional water supply costs that would need to be incurred in order to meet current and future water demands. For the current situation, this was in addition to the existing water supply infrastructure.

For the 2040 projections, this was in addition to all the planned surface water infrastructure for the WMA. The planned infrastructure was identified from various technical reports.

Costs and benefits were compared over the period 2017 to 2040, based on estimated scenario implications in 2040. The values of ecosystem services were assumed to grow over time in proportion to population and economic growth, at the same overall rate of growth as estimated for water demand under the high growth scenario. The changes in value in each time period were reduced to a net present value using a discount rate of 6% (the rate advocate by World Bank). Sensitivity analysis was performed using discount rates of 3% (social rate of discount) and 9%.

The total infrastructure investments required to meet 2040 water demands under each scenario were costed using 2016 costs. It was assumed that the infrastructure investments would be spread over a 20-year period. The annual values were then discounted to present value terms as described above.

The overall economic impact of each scenario was expressed in terms of the direct gains and losses of ecosystem goods, services and attributes and water supply costs, expressed in present value terms.

2.9.3 Social Implications for Scenarios

Implementation of the ecological Reserve does not have major social implications in terms of meeting basic human needs for households in the form of water for domestic use or access to resources harvested for subsistence uses in the study area. This is because only a very small percentage of households in the study area fall into this category, and the number of these households is decreasing through improvements in service provision. This is a significant difference compared to other parts of the country with a more rural population.

The main social impacts of the scenarios are likely to be in the form of changes in the recreational usage and spiritual values of aquatic ecosystems to households. These values are very difficult to quantify, but can make a major difference to household wellbeing. The relative impacts of the different scenarios on these types of values is likely to follow the same pattern as for the tourism values described above. Thus, social values are maximised where the condition of ecosystems is closest to natural.

In the economic analysis, it is assumed that allocating more water to the Reserve is balanced by investing in measures to increase the supply of water in order to meet demands. The marginal costs of these measures increase with increasing supply. In the analysis, it is assumed that these costs are largely borne by the state (at the expense of some other public service), and would not incur significant additional costs to the users. However, if the costs were to be passed onto the users, then this could eventually have a more significant impact, which would also have social ramifications such as increased unemployment.

The above analysis does not take into account potential public willingness to pay for maintaining aquatic ecosystems in a good condition, whether the REC or a better level of health that supports more biodiversity, and has a more secure conservation outcome. This existence value has a bearing on the welfare of current and future generations. Existence value and other unquantified social costs and benefits will be evaluated in non-monetary terms during of the overall evaluation of the final recommended classification scenario.

3 Results

3.1 Approach to the Analysis of Scenarios

Present-day modelled dry-season flows in the Berg River (G1) are much higher than natural flows at many of the river nodes. This is due to the releases made from Berg River and Voëlvlei Dams to meet irrigation and other demands downstream, as well as the impacts of effluents from WWTWs.

This situation also exists at a number of the smaller estuaries in the G2 catchments, such as the Diep, Sout (Wes), Wildevoëlvlei, Zeekoei, Kuils and Eerste, which are dominated by the effluents from WTWWs. In these cases, it may not be feasible to route Reserve flows at these locations as this would practically mean dampening the maintenance low flows during the dry season, effectively *shutting off* the releases made for irrigation or from WTWWs, to revert to a natural seasonality whereby flows are lower in the dry season. The condition of the rivers and estuaries are maintained by the present-day flow regime. The current impact of return flows, particularly on the ecological conditions at the estuaries, results in the observation that flows may in fact need to be *reduced* at some locations to achieve an improved ecological condition.

This indicates a potential for synergies between future alternative water supply options, particularly through the treatment and re-use of effluent which will need to be considered as part of the future scenarios.

3.2 Berg River Catchment (G1) Scenarios (IUAs: A1 Berg Estuary, B4 Lower Berg, D9 Middle Berg and D8 Upper Berg)

3.2.1 System yield and flows to the Berg River estuary

The resulting impact of the different EWR and infrastructure scenarios on the firm yield from the WCWSS and the corresponding mean annual runoff (MAR) reaching the Berg River estuary are given in **Table 3-4** and in Figure 3-1. The impact of the different scenarios on the mean monthly flow reaching the estuary is shown in Figure 3-2. A zoom in on the critical flows during the summer months is shown in Figure 3-3.

These results are used to determine the social, economic and environmental impacts of the alternative scenarios in terms of the requirements to provide alternative augmentation options, such as desalination or direct potable re-use, to offset the changes in the yield from the WCWSS and the corresponding impact in terms of a changes in the value of the EGSAs provide by the estuary including for fisheries, tourism and property values.

Table 3-1 Impact of EWR and Infrastructure Scenarios on the yield from the Western Cape Water Supply System and resulting flow to the Berg River estuary

Scenario Name	Scenario Description	Summer low flow requirement at the estuary (m3s-1)	Historic Firm Yield (Million.m3)	Estuary MAR (1928-2004) (Million.m3)	Percentage of natural MAR reaching estuary
Scenario 1 (PES)	Baseline – Current day infrastructure with 0.5 m^3/s minimum flow requirement to the estuary.	0.5	535	464	50%
Scenario 1b (PES-FI)	Future (2040) infrastructure with 0.5 m^3/s minimum flow requirement to the estuary.	0.5	755	419	46%
Scenario 1c (PES-CC)	Future (2040) infrastructure and reduced streamflow due to potential impacts of climate change with 0.5 m^3/s minimum flow requirement to the estuary.	0.5	711	304	33%
Scenario 2 (ESBC)	Current Day infrastructure with ESBC baseflow EWRs and 0.5 m^3/s flow to the estuary.	0.5	487	502	54%
Scenario 3 (REC)	Current day infrastructure with REC baseflow EWRs and 0.6 m^3 flow to the estuary.	0.6	487	509	55%
Scenario 4 (ESBC-FI)	Future infrastructure with ESBC baseflow EWRs and 0.5 m^3 flow to the estuary.	0.5	698	480	51%
Scenario 5 (REC-FI)	Future infrastructure with REC baseflow EWRs and 0.6 m^3/s flow to the estuary.	0.6	694	487	52%
Scenario 6 (No EC-FI)	Future infrastructure with no Environmental Constraints	0.0	775	415	45%
Scenario 7 (ESBC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, ESBC baseflow EWRs and 0.5 m^3/s minimum flow requirement to the estuary	0.5	620	386	41%
Scenario 8 (REC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, REC baseflow EWRs and 0.5 m^3/s minimum flow requirement to the estuary	0.6	617	391	42%
Scenario 9 (No EC-CC)	Future infrastructure with reduced streamflow due to potential climate change impacts, and no Environmental Constraints	0.0	716	299	32%

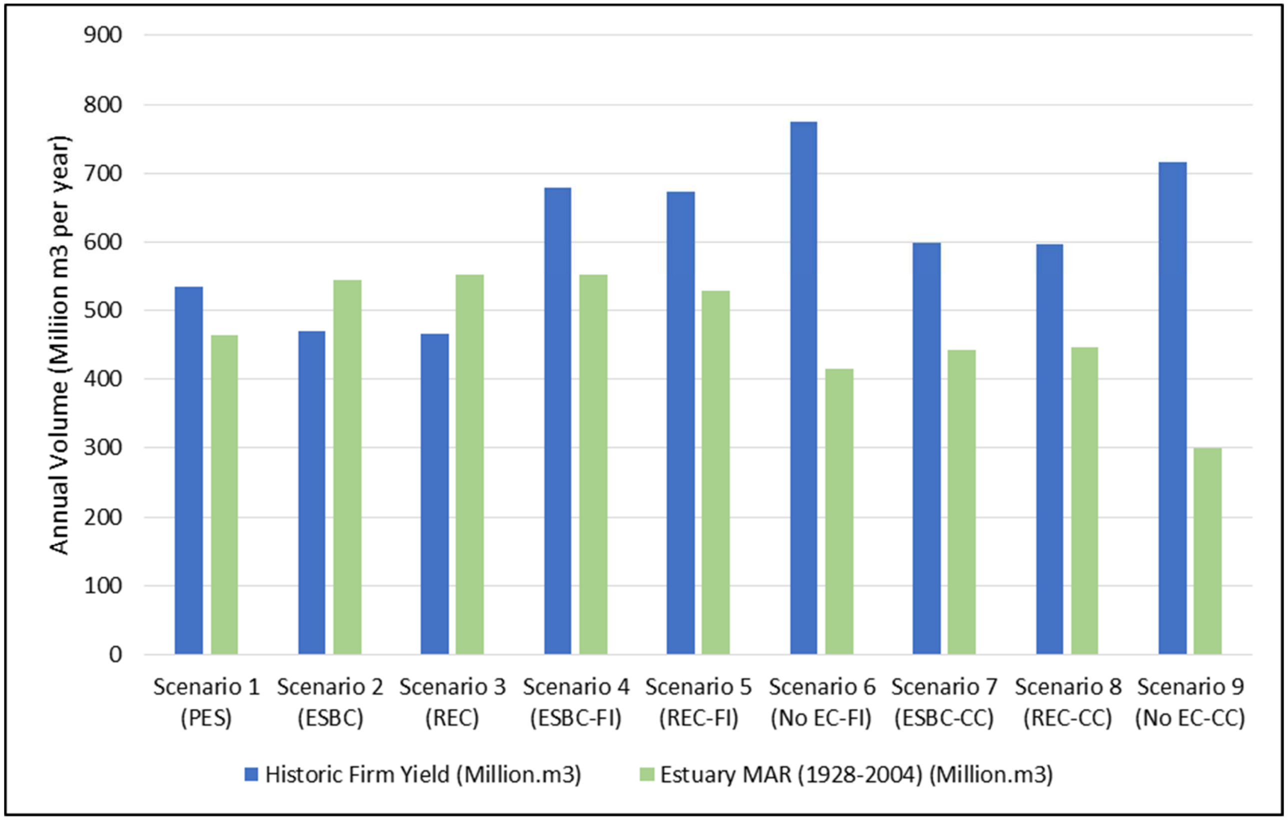


Figure 3-1 Impact of different scenarios on the yield of the WCWSS and average annual flow to the Berg River Estuary

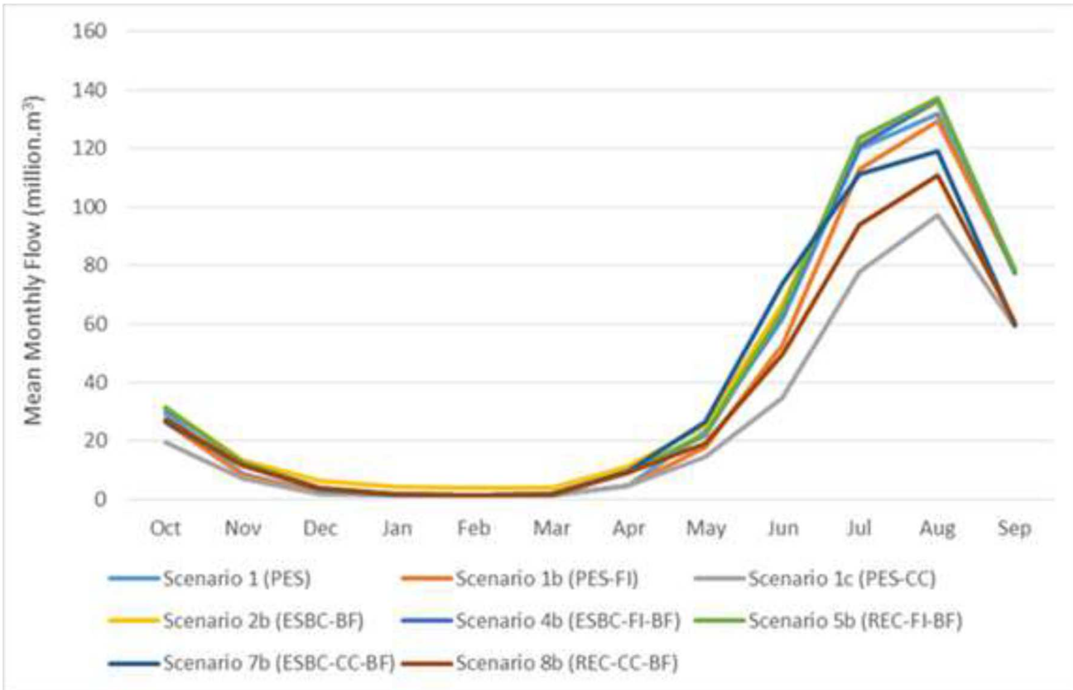


Figure 3-2 Mean monthly flow at the Berg River Estuary for different scenarios.

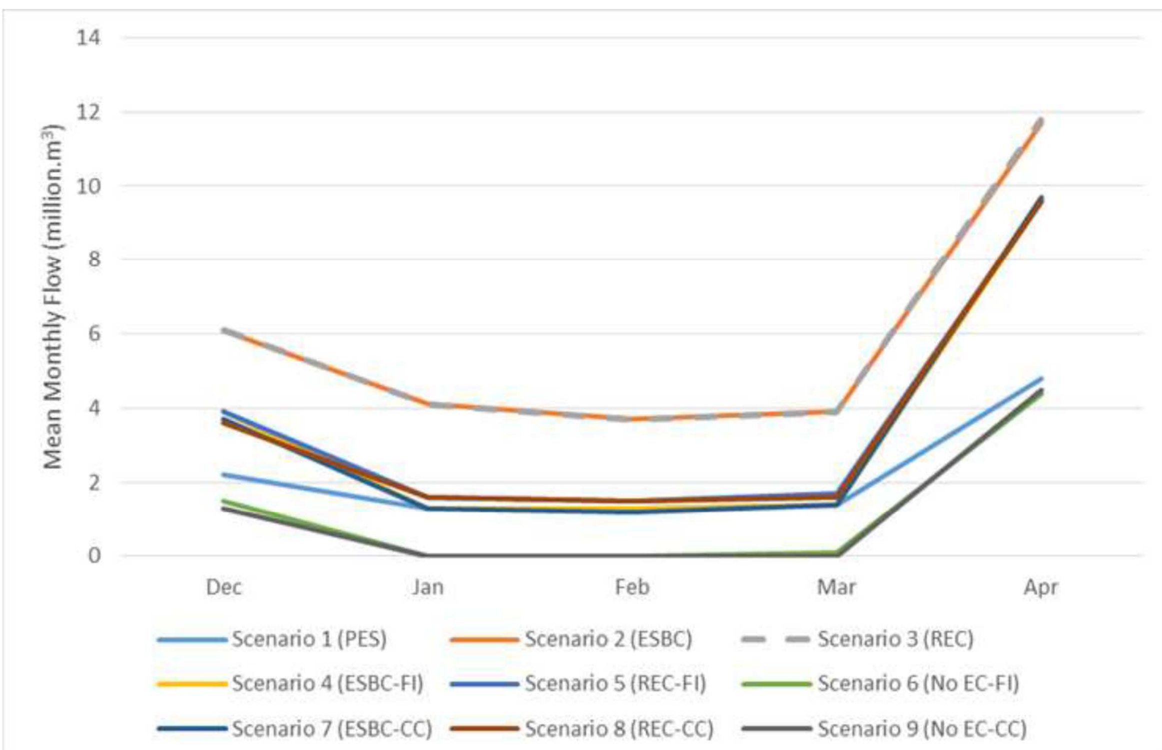


Figure 3-3 Mean monthly flow at the Berg River Estuary for different scenarios (Dec-Apr).

3.2.2 Water Quality Impacts

A summary of water quality risks and the potential impacts of the scenarios are given below for each IUA.

3.2.2.1 Berg Estuary IUA (A1)

Water quality in the Berg estuary is affected by seawater intrusion and tidal effects, therefore TDS, EC, chloride concentrations are high and the water unsuitable for irrigation agriculture. There is a salinity gradient with salt concentrations being highest near the river mouth (near seawater quality) and decreasing in an upstream direction up to the inflow into the estuary where the salinity approaches that of the lower Berg River. The DWS as well as the Western Cape Province are monitoring water quality in the estuary.

Table 3-2 Present day "fitness for use" categories for selected water quality variables at selected water quality sampling points in the Berg Estuary IUA (A1).

		Chloride		TDS		EC		NO3+NO2-N		pH		PO4-P		SO4	
Station	IUA	50	95	50	95	50	95	50	95	50	95	50	95	50	95
G1H023Q01	A1														
G1HO24Q01	A1														
BERG R27	A1														
BE-05 KER	A1														
BE-01 LAA	A1														

Note: 50 = median or 50th percentile, 95 = 95th percentile. Categories: Blue = Ideal, Green = Acceptable, Yellow = Tolerable, and Red = Unacceptable, Blank = No data

3.2.2.2 Lower Berg IUA (B4)

Salinity in the Lower Water Berg River increases in a downstream direction; compare for example G1H013Q01 at Drieheuwels to the downstream G1H031 at Misverstand Weir. This increase is as a result of irrigation return flows and naturally saline tributaries such as the Matjies River (G1H035Q01) and Moreesburgspruit (G1H034Q01). The Leeu River (G1H029Q01) that drains from the Great Winterhoek Mountains has very good water quality and is one of the sources of high flow transfers into the off-channel storage dam, Voëlvlei Dam, which is a water source to the City of Cape Town and towns in the Swartland. Elevated phosphate concentrations occur in the Lower Berg IUA.

Table 3-3 Present day "fitness for use" categories for selected water quality variables at selected water quality sampling points in the Lower Berg IUA (B4).

		Chloride		TDS		EC		NO3+NO2-N		pH		PO4-P		SO4	
Station	**IUA**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**
G1H013Q01	B4														
G1H029Q01	B4														
G1H031Q01	B4														
G1H034Q01	B4														
G1H035Q01	B4														
G1H040Q01	B4														
G1H043Q01	B4														
G1R001Q01	B4														
G1R003Q01	B4														
DIE BOORD	B4														
SARON	B4														
GROEN R307	B4														
SOUT R307	B4														
SOUT TRIB	B4														
SOUT R45	B4														

		Chloride		TDS		EC		NO3+NO2-N		pH		PO4-P		SO4	
Station	**IUA**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**	**50**	**95**
BOESMANS	B4														
G103/01A1	B4														
G103/02A1	B4														
G103/03A1	B4														

Note: 50 = median or 50th percentile, 95 = 95th percentile. Categories: Blue = Ideal, Green = Acceptable, Yellow = Tolerable, and Red = Unacceptable, Blank = No data

3.2.2.3 Berg Tributaries IUA (C5)

Overall water quality in the Berg River tributaries is good except in the upper reaches of the Boontjies River G1H009Q01 and G1H010Q01 which could be affected by irrigation return flows, as well as fruit processing facilities to the north of the Wolseley area. Elevated phosphate concentrations in some of the effluent stream sampling points are high. However, the quality of water that is transferred from the Klein Berg River (G1H008Q01) into Voëlvlei Dam is slightly impacted. Concerns have been expressed about agrochemicals in the Klein Berg River because its catchment is an intensive fruit growing region (Dabrowski, 2015). Agrochemicals are not routinely monitored and concerns are based data of pesticide usage. There is therefore insufficient data to quantify the problem or to determine the impacts. It is recommended that National Toxicity Monitoring Programme be implemented in the Berg CMA to determine the magnitude and extent of agrochemical impacts on rivers.

Table 3-4 Present day "fitness for use" categories for selected water quality variables at selected water quality sampling points in the Berg Tributaries IUA (C5).

		Chloride		TDS		EC		NO3+NO2-N		pH		PO4-P		SO4	
Station	IUA	50	95	50	95	50	95	50	95	50	95	50	95	50	95
G1H008Q01	C5														
G1H009Q01	C5														
G1H010Q01	C5														
G1H012Q01	C5														
G1H021Q01	C5														
G1H028Q01	C5														
KBERG TULBAGH	C5														
EDELWEIZZ	C5														
LA PLAISA	C5														
RIOOL RIV	C5														
EILANDPLA	C5														
OEWERBRUG	C5														
RIOOLPLAA	C5														

Note: 50 = median or 50th percentile, 95 = 95th percentile. Categories: Blue = Ideal, Green = Acceptable, Yellow = Tolerable, and Red = Unacceptable, Blank = No data

3.2.2.4 Upper Berg IUA (D8)

Water quality in the upper Berg IUA is good although some concerns have been expressed by water quality in the Franschhoek River (G1H003Q01) which is situated downstream of the Franschhoek WWTW, some informal settlements and Stiebeuel River which is affected by runoff from dense settlements at Franschhoek (Petersen *et al*., 2008). An examination of E coli data collected as part of the Berg River Improvement Project (Western Cape Government) indicated high counts in the Stiebeuel River which was then carried over into the Franschhoek River (B17) (Table 3-5). The E coli counts improve between Franschhoek and Paarl (B18, B20, B14) due to bacterial die-off and dilution with releases from Berg River Dam. In Paarl and Wellington (B13, B12, B11), the E coli counts increase substantially, largely as a result of urban runoff in stormwater canals draining Mbekweni and high density and informal settlements (Table 3-5). Downstream of Wellington the E coli counts decrease as a result of bacterial die-off.

The Franschhoek WWTW has been decommissioned and does not affect the river anymore. Wastewater is now treated at the new Wemmershoek WWTW which would only impact the Berg River if there is a plant failure or noncompliance to effluent standards. The Berg River Improvement Plan (Western Cape Government, 2012) was developed in 2012 which included upgrading the Langrug and Klein Mooiwater informal settlements to reduce E coli and waste loads to receiving rivers. Efforts to address the non-point source pollution impacts such as the Genius of Place project in Langrug should be considered as potential complementary approaches to addressing the water quality risks.

Table 3-5 Present day "fitness for use" categories for selected water quality variables at selected DWS and BRIP water quality sampling points in the Upper Berg IUA (D8).

		Chloride		TDS		EC		NO3+NO2-N		pH		PO4-P		SO4		E coli	
Station	IUA	50	95	50	95	50	95	50	95	50	95	50	95	50	95	50	95
G1H003Q01	D7																
G1H004Q01	D7																
G1H019Q01	D7																
G1H020Q01	D7																
G1H038Q01	D7																
G1H064Q01	D7																
G1R002Q01	D7																
FRANSCHHOEK	D7																
DIEP ODPB	D7																
BRIP B17	D7																
BRIP B18	D7																
BRIP B20	D7																
BRIP B14	D7																
BRIP B13	D7																
BRIP B12	D7																
BRIP B11	D7																

Note: 50 = median or 50th percentile, 95 = 95th percentile. Categories: Blue = Ideal, Green = Acceptable, Yellow = Tolerable, and Red = Unacceptable, Blank = No data

3.2.2.5 Water Quality Impacts of Scenarios

A summary of the likely water quality impacts for the different scenarios considered are presented in **Table 3-6.**

Table 3-6 Likely water quality impacts for the scenarios in the Berg River Catchment (G2)

Scenario	Likely Water Quality Impact of Scenario
Sc 1 (PES)	Under the baseline scenario and current day infrastructure, present day water quality trends will continue. These include the spatial trends of increasing salinity from the headwaters to the inflow into the estuary, and especially in the Lower Berg IUA. The spatial trends observed in E coli counts and nutrient concentrations will probably continue (high near Franschhoek, general improvement towards Paarl, significant increases in Paarl/Wellington, general slow improvement downstream of Paarl/Wellington). The temporal trends of increasing concentrations during the dry season, followed by a decrease in concentrations during the wet season would also continue. Upgrades to WWTWs will probably improve the nutrient and microbiological status downstream of the Paarl/Wellington area but urban runoff will remain a concern. Changes in dryland agricultural practices will in the long term probably lead to lower export of salts in the Swartland region.

Scenario	Likely Water Quality Impact of Scenario
Sc 2 (ESBC)	Under the Ecologically Sustainable Base Configuration scenario the increase in baseflow during the dry season would probably result in dilution of salt and nutrient concentrations in the middle and lower Berg IUAs. The high dry-season peaks in concentrations would probably be reduced. On average, wet season concentrations would probably be slightly lower as recommended floods flow down the Berg River.
Sc 3 (REC)	As in Scenario 2, the increase in baseflow during the dry season would probably result in dilution of salt and nutrient concentrations in the middle and lower Berg IUAs due to the slightly higher minimum flow to the estuary. The high dry-season peaks in concentrations would probably be reduced due to dilution. The increase in flow during the wet season would probably result in moderately lower concentrations compared to present day conditions.
Sc 4 (ESBC-FI)	The present-day water quality trends in the upper and middle Berg River may deteriorate as effluent discharges become fully utilised as alternative water supply sources, and poor quality urban runoff continues unabated. These trends will continue up to Zonquasdrift where water will be abstracted during the high-flow wet season for the Voëlvlei Augmentation Scheme. Downstream of Zonquasdrift the water quality situation will likely deteriorate further during the dry season as less dilution of high salinity inflows from the Matjies and Moreesburgspruit would take place. Downstream of the abstraction point for the West Coast Aquifer recharge scheme (possibly at Misverstand Dam), even higher salt concentrations would occur leading to a deterioration in quality of the Lower Berg IUA. During the wet season the situation in the lower Berg IUA would probably improve moderately but perhaps not to the same level as present day wet season concentrations.
Sc 5 (REC-FI)	The water quality trends in the upper and middle Berg River may deteriorate as effluent discharges become fully utilised as alternative water supply sources, and poor quality urban runoff continues unabated. These trends will continue up to Zonquasdrift where water will be abstracted during the high-flow wet season for the Voëlvlei Augmentation Scheme. Maintaining the baseflow during the dry season, and floods during the wet season would slightly moderate the impacts on water quality. Downstream of Zonquasdrift the water quality situation will deteriorate during the dry season and will probably be similar to those in Scenario 4 and 5 described above. However, during the wet season the situation in the lower Berg IUA would probably be better than the wet-season status described in Scenario 4 and 5, as well as present day wet season concentrations.
Sc 6 (No EC-FI)	With no ecological constraints and maximum reuse of WWTW return flows, the water quality trends in the upper and middle Berg River will probably deteriorate substantially as water resources are used to its maximum leaving little flow in the river to dilute other point and nonpoint sources of salts, nutrients and bacteria. Downstream of the Voëlvlei Augmentation Scheme at Zonquasdrift the water quality situation will probably deteriorate further during the dry season as summer flows will be at its lowest of all the scenarios. During the wet season the situation in the lower Berg IUA would probably improve slightly but the poor dry-season quality will probably continue later into the wet season.
Sc 7 (ESBC-CC)	Under a climate change scenario, flows in the Berg River and its tributaries would be lower, and water temperatures would be 1-2 °C warmer. Increased water temperatures could affect, inter alia, the quality of water for irrigation, dissolved oxygen content of water, the rates of chemical and biological reactions in water as well as have wide-ranging repercussions in the health sector through the creation of favourable conditions for the incubation and transmission of water-borne diseases. The present-day water quality trends in the upper and middle Berg River may deteriorate further as effluent discharges become fully utilised as alternative water supply sources, and poor quality urban runoff continues unabated, and lower river flows. These trends will continue up to Zonquasdrift where water will be abstracted during the high-flow wet season for the Voëlvlei Augmentation Scheme. Downstream of Zonquasdrift the water quality situation will likely deteriorate further during the dry season as even less dilution of concentrated high salinity inflows from the Matjies and Moreesburgspruit would take place. Downstream of the abstraction point for the West Coast Aquifer recharge scheme (possibly at Misverstand Dam), even higher salt concentrations would occur leading to a further deterioration in quality of the Lower Berg IUA. During the wet season the situation in the lower Berg IUA would probably improve moderately but perhaps not to the same level as present day wet season concentrations.
Sc 8 (REC-CC)	Under a climate change and future infrastructure scenario, the wet-season water quality trends in the upper and middle Berg River will probably be similar to those described in Scenario 5 but the dry-season concentrations will probably be higher than under Scenario 5 due to lower flows in the tributaries. In the lower Berg IUA, downstream of Zonquasdrift and the Voëlvlei Augmentation Scheme, the water quality situation will deteriorate further during the dry season and will probably be worse than those in Scenario 5 due to the overall reduction in flow. However, during the wet season the situation in the lower Berg IUA may be similar to the wet-season status described in Scenario 5.

Scenario	Likely Water Quality Impact of Scenario
Sc 9 (No EC-CC)	Under a climate change scenario, no ecological constraints, and maximum reuse of WWTW return flows, the water quality trends in the upper and middle Berg River will probably deteriorate substantially as water resources are used to its maximum leaving very little flow in the river to dilute other point and nonpoint sources of salts, nutrients and bacteria. Downstream of the Voëlvlei Augmentation Scheme at Zonquasdrift the water quality situation will probably deteriorate even further during the dry season as summer flows will be at its lowest of all the scenarios. During the wet season the situation in the lower Berg IUA would probably improve slightly but there could be a substantial first flush deterioration in quality during the wet season as salts that have accumulated during the dry season are mobilized and washed off into the Berg River.

3.2.3 Ecological Condition of Rivers

A summary of the ecological conditions at all the river nodes for the Berg River Catchment (G1) for each scenario is shown in Table 3-7. In the table, the river nodes are grouped per IUA, and EWR sites are indicated along with their Recommended Ecological Categories (REC) from the relevant Ecological Reserve study. The average seasonal flow volumes (as a percentage of natural seasonal flow) resulting from each scenario are reported at each node in Table 3-8 and Table 3-9.

There is little difference between the first three scenarios, PES (Sc1), ESBC(Sc2b) and REC(Sc3b). Most of the river nodes are in a D category in the PES scenario and there are some changes when applying the ESBC and the REC scenario, often due to changes in the seasonal distribution of flows relative to current, because of the release of Reserve flows (Table 3-8 and Table 3-9**)**. For example, Bvii5 (EWR site 3 on the Berg River at Hermon), and Bvii11 downstream, both improve in condition with increased summer flows. This effect is also noticeable at Biv2 upstream of the estuary and at the estuary itself, where summer flows increase and the condition improves.

The future infrastructure scenarios with constraints (scenarios1b, 4b, 5b), also show slight improvements relative to PES (at Bvii5, Bi1, and Bvii11), because of improved seasonal distributions of flows. Ecological conditions are much worse in the future condition scenario with no ecological constraint (Scenario 6) where EWR site 1 on the Berg River downstream of the Berg River Dam (Bviii1) drops to an E/F category, and the node leading into the estuary (Biv2) and the estuary itself drop to and E/F and a C/D respectively.

The future infrastructure with climate change results (Scenarios 1c, 7b, 8b and 9) are similar to the future use without climate change scenarios, but are worse in places, for example dropping to C/D from C at Bvii17 on the Sandspruit River and at the estuary in both Sc7b (ESBC) and Sc8b (REC). The future infrastructure with climate change and no ecological constraints scenario (Scenario 9) is worse in turn compared to Scenario 6 (without climate change), with Bvii13 dropping to an A/B (from A in all other scenarios), Bi1 dropping to a C/D (compared to B/C in Scenario 6), Bvii17 dropping to a C/D (from C in Scenario 6), Bvii6, Bvii8, Bvii12 dropping to D/E (from D), and the estuary dropping to an E (from C/D).

The conditions scores per scenario are repeated in Table 3-8 and Table 3-9 along with the Mean Annual Runoff at each node and the scenario flows as percentages of natural flow for the wet and the dry seasons. The flows are colour coded with % scores lower than current day being orange and red and % scores higher than current day being blue.

The number of nodes in different ECs, for the Berg River basin (G1), is summarised in Figure 3-4. The No Constraint scenarios of future use with and without climate change (Scenario 6 and 9) are considerably worse than the other scenarios reporting higher numbers of D, D/E and F conditions and fewer B to C/D conditions. The overall change in ecological condition across the whole Berg River catchment (G1) is shown in Figure 3-5.

Table 3-7 Changes in ecological condition and percentage of natural MAR for all nodes per scenario in the Berg River catchment (G1)

				Current infrastructure						2040 Infrastructure								2040 Infrastructure with climate change							
			EWR REC	Sc1: PES		Sc2b: ESBC_BF		Sc3b: REC_BF		Sc1b: 2040_PES_BF		Sc4b: 2040_ESBC_0.5_BF		Sc5b: 2040_REC_0.6_BF		Sc6: 2040_NoConstraint		Sc1c: 2040CC_PES_BF		Sc7b: 2040CC_ESBC_0.5_BF		Sc8b: 2040CC_REC_0.6_BF		Sc9: 2040CC_NoConstraint	
IUA	Node	River		EC	%	EC	%	EC	%	EC	%	EC	%	EC	%	EC	%	EC	%	EC	%	EC	%	EC	%
Upper Berg	Bvii13	Berg		A	98.20	A	98.20	A	98.20	A	98.20	A	98.20	A	98.20	A	98.20	A/B	90.99	A/B	90.99	A/B	90.99	A/B	90.99
	Bviii1	**Berg**	C	C	27.35	C	34.35	B/C	43.10	C	36.00	C	37.61	B/C	45.75	E/F	13.47	C	33.94	C	38.73	B/C	46.37	E/F	11.38
	Biv5	Franschhoek		D	82.46	D	82.46	D	82.46	D	82.46	D	82.46	D	82.46	D	82.46	D	75.92	D	75.92	D	75.92	D	75.92
	Biii2	Wemmershoek		D	28.40	D	28.45	D	28.29	D	27.78	D	28.49	D	28.46	D	28.23	D	24.06	D	24.98	D	24.89	D	24.60
	Bvii14	Dwars		C	72.70	C	73.01	C	72.90	C	72.73	C	73.06	C	72.97	C	73.03	C	63.99	C	64.22	C	64.20	C	64.23
	Biii3	Berg		E	53.92	E	59.75	E	61.81	E	53.25	E	60.58	E	62.43	E	47.72	E	46.89	E	56.14	E	57.49	E	41.23
Middle Berg	**Bviii11**	**Pombers**	C	D	366.03	D	366.03	D	366.02	D	366.02	D	366.02	D	366.02	D	366.03	D	344.93	D	344.93	D	344.93	D	344.92
	Bvii3	**Kromme**	D	D/E	89.92	D/E	89.92	D/E	89.92	D/E	89.92	D/E	89.92	D/E	89.92	D/E	89.92	D/E	70.53	D/E	70.53	D/E	70.53	D/E	70.53
	Bvii10	Berg		D	53.24	D	58.54	D	60.42	D	52.63	D	59.30	D	60.98	D	47.60	D	45.16	D	53.57	D	54.80	D	40.00
	Bvii15	Doring		D	66.84	D	66.75	D	66.71	D	66.83	D	66.75	D	66.77	D	66.48	D	47.34	D	47.25	D	47.27	D	47.15
	Bvii4	Kompanjies		D	74.01	D	74.01	D	74.01	D	74.01	D	74.01	D	74.01	D	74.02	D	54.52	D	54.52	D	54.52	D	54.52
	Bvii5	**Berg**	D	D	49.70	C	52.82	C	54.44	D	49.18	C	53.48	C	54.92	D	44.83	D	40.04	C	45.77	C	46.83	D	35.59
Berg Tribs	Biii4	Klein Berg		C	82.03	C	82.03	C	82.03	C	82.03	C	82.03	C	82.03	C	82.03	C	64.94	C	64.94	C	64.94	C	64.94
	Bi1	Vier-en-Twintig		C	23.59	C	23.93	C	24.05	B/C	24.96	B/C	24.75	B/C	24.96	B/C	24.80	C/D	17.93	C	18.68	C	18.83	C/D	17.66
	Bvii16	Leeu		C	12.69	C	12.98	C	13.08	C	13.88	C	13.69	C	13.88	C	13.74	C	9.60	C	10.25	C	10.38	C	9.36
Lower Berg	Bvii11	Berg		D	50.51	C	54.00	C	55.56	D	40.94	C	44.17	C	45.48	D	37.69	D	31.75	C	36.06	C	37.02	D	28.59
	Biv1	Berg		D	58.27	D	62.37	D	63.62	D	53.41	D	62.40	D	63.34	D	50.20	D	42.84	D	55.10	D	55.80	D	39.68
	Biv3	Klein-Berg		D	53.65	D	53.74	D	53.83	D	56.18	D	55.91	D	56.22	D	55.77	D	39.42	D	39.96	D	40.41	D	39.28
	Biv4	Vier-en-twintig		D	29.28	D	29.56	D	29.67	D	30.44	D	30.26	D	30.44	D	30.31	D	20.64	D	21.28	D	21.40	D	20.40
	Bvii17	Sandspruit		C	88.51	C	88.51	C	88.51	C	88.51	C	88.51	C	88.51	C	88.51	C/D	57.47	C/D	57.47	C/D	57.47	C/D	57.47
	Bvii6	**Berg**	D	D	52.26	D	54.99	D	55.85	D	49.51	D	55.40	D	56.09	D	47.31	D/E	37.98	D	46.29	D	46.83	D/E	35.82
	Biii5	Matjies		D	81.54	D	81.54	D	81.54	D	81.54	D	81.54	D	81.54	D	81.54	D	61.64	D	61.64	D	61.64	D	61.64
	Bvii8	Berg		D	53.19	D	55.72	D	56.54	D	50.46	D	56.11	D	56.78	D	48.35	D/E	38.49	D	46.47	D	46.99	D/E	36.41
	Bvii18	Moreesburgspruit		D	100.0	D	100.0	D	100.0	D	100.0	D	100.0	D	100.0	D	100.0	D	61.19	D	61.19	D	61.19	D	61.20
	Bvii12	**Berg**	D	D	51.09	D	53.16	D	53.96	D	47.61	D	52.93	D	53.63	D	45.47	D/E	35.54	D	43.24	D	43.78	D/E	33.40
	Bii1	Sout		D	99.40	D	99.40	D	99.40	D	99.40	D	99.40	D	99.40	D	99.40	D	77.60	D	77.60	D	77.60	D	77.60
	Biv2	Berg		D	48.84	C	52.95	C	53.73	D	45.90	D	50.64	D	51.35	E/F	43.49	D	33.61	D	40.68	D	41.24	E/F	31.23
	Bxi1	**Berg estuary**	C	C	48.84	B	52.95	B	53.73	C	45.90	C	50.64	C	51.35	C/D	43.49	C/D	33.61	C/D	40.68	C/D	41.24	E	31.23

Table 3-8 Changes in ecological condition, seasonal flow (as percentage of natural), and MAR at all nodes for scenarios 1 to 6 in the Berg River catchment (G1)

				Current infrastructure												2040 Infrastructure															
			EWR REC	Sc1: PES				Sc2b: ESBC_BF				Sc3b: REC_BF				Sc1b: 2040_PES_BF				Sc4b: 2040_ESBC_0.5_BF				Sc5b: 2040_REC_0.6_BF				Sc6: 2040_NoConstraint			
IUA	Node	River		EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR
UpperBerg	Bvii13	Berg		A	98.3	98.7	83.32	A	98.3	98.7	83.32	A	98.3	98.7	83.32	A	98.3	98.7	83.32	A	98.3	98.7	83.32	A	98.3	98.7	83.32	A	98.3	98.7	83.32
	Bviii1	**Berg**	C	C	27.4	42.2	39.13	C	34.4	28.9	49.15	B/C	43.1	40.7	61.66	C	36.0	42.2	51.50	C	37.6	28.9	53.81	B/C	45.7	40.7	65.44	E/F	13.5	0.0	19.27
	Biv5	Franschhoek		D	82.5	3.7	31.01	D	82.5	3.7	31.01	D	82.5	3.7	31.01	D	82.5	3.7	31.01	D	82.5	3.7	31.01	D	82.5	3.7	31.01	D	82.5	3.7	31.01
	Biii2	Wem-mershoek		D	28.4	2.1	25.72	D	28.4	2.1	25.76	D	28.3	2.1	25.62	D	27.8	2.1	25.16	D	28.5	2.1	25.80	D	28.5	2.1	25.77	D	28.2	2.1	25.57
	Bvii14	Dwars		C	72.7	58.7	31.73	C	73.0	59.1	31.87	C	72.9	59.1	31.82	C	72.7	59.1	31.75	C	73.1	59.1	31.89	C	73.0	59.1	31.85	C	73.0	59.1	31.88
	Biii3	Berg		E	53.9	204.0	225.99	E	59.7	262.0	250.39	E	61.8	262.0	259.04	E	53.3	204.0	223.17	E	60.6	262.2	253.89	E	62.4	262.1	261.61	E	47.7	204.0	199.97
MiddleBerg	**Bviii11**	**Pombers**	C	D	366.0	3063.1	6.67	D	366.0	3063.1	6.67	D	366.0	3063.0	6.67	D	366.0	3063.0	6.67	D	366.0	3063.0	6.67	D	366.0	3063.0	6.67	D	366.0	3063.1	6.67
	Bvii3	**Kromme**	D	D/E	89.9	1.9	16.55	D/E	89.9	1.9	16.55	D/E	89.9	1.9	16.55	D/E	89.9	1.9	16.55	D/E	89.9	1.9	16.55	D/E	89.9	1.9	16.55	D/E	89.9	1.9	16.55
	Bvii10	Berg		D	53.2	143.6	245.55	D	58.5	196.7	269.97	D	60.4	196.7	278.62	D	52.6	143.6	242.73	D	59.3	196.8	273.48	D	61.0	196.8	281.20	D	47.6	143.6	219.50
	Bvii15	Doring		D	66.8	0.0	2.88	D	66.7	0.0	2.88	D	66.7	0.0	2.87	D	66.8	0.0	2.88	D	66.8	0.0	2.88	D	66.8	0.0	2.88	D	66.5	0.0	2.86
	Bvii4	Kompanjies		D	74.0	0.5	18.33	D	74.0	0.5	18.33	D	74.0	0.5	18.33	D	74.0	0.5	18.33	D	74.0	0.5	18.33	D	74.0	0.5	18.33	D	74.0	0.5	18.33
	Bvii5	**Berg**	D	D	49.7	17.9	266.38	C	52.8	46.1	283.12	C	54.4	46.1	291.79	D	49.2	17.9	263.60	C	53.5	46.2	286.66	C	54.9	46.2	294.38	D	44.8	17.9	240.31
BergTrib	Biii4	Klein Berg		C	82.0	128.2	69.09	C	82.0	128.2	69.09	C	82.0	128.2	69.09	C	82.0	128.2	69.09	C	82.0	128.2	69.09	C	82.0	128.2	69.09	C	82.0	128.2	69.09
	Bi1	Vier-en-Twintig		C	23.6	33.2	29.61	C	23.9	33.2	30.02	C	24.0	33.2	30.18	B/C	25.0	33.2	31.32	B/C	24.7	33.2	31.06	B/C	25.0	33.2	31.32	B/C	24.8	33.2	31.13
	Bvii16	Leeu		C	12.7	35.0	2.73	C	13.0	35.0	2.80	C	13.1	35.0	2.82	C	13.9	35.0	2.99	C	13.7	35.0	2.95	C	13.9	35.0	2.99	C	13.7	35.0	2.96
LowerBerg	Bvii11	Berg		D	50.5	16.4	281.75	C	54.0	46.8	301.20	C	55.6	46.8	309.93	D	40.9	16.4	228.37	C	44.2	43.1	246.39	C	45.5	43.1	253.69	D	37.7	16.4	210.23
	Biv1	Berg		D	58.3	112.9	331.99	D	62.4	132.5	355.35	D	63.6	132.5	362.43	D	53.4	107.3	304.26	D	62.4	151.4	355.48	D	63.3	152.1	360.83	D	50.2	105.6	285.99
	Biv3	Klein-Berg		D	53.6	126.8	54.58	D	53.7	126.8	54.67	D	53.8	126.8	54.76	D	56.2	126.8	57.15	D	55.9	126.8	56.88	D	56.2	126.8	57.19	D	55.8	126.8	56.74
	Biv4	Vier-en-twintig		D	29.3	13.1	49.53	D	29.6	13.1	50.01	D	29.7	13.1	50.19	D	30.4	13.1	51.50	D	30.3	13.1	51.20	D	30.4	13.1	51.50	D	30.3	13.1	51.28
	Bvii17	Sandspruit		C	88.5	83.1	8.19	C	88.5	83.1	8.19	C	88.5	83.1	8.19	C	88.5	83.1	8.19	C	88.5	83.1	8.19	C	88.5	83.1	8.19	C	88.5	83.1	8.19
	Bvii6	**Berg**	D	D	52.3	87.5	449.46	D	55.0	98.5	472.97	D	55.8	98.5	480.33	D	49.5	82.5	425.85	D	55.4	110.3	476.51	D	56.1	110.7	482.47	D	47.3	81.5	406.95
	Biii5	Matjies		D	81.5	70.6	26.85	D	81.5	70.6	26.85	D	81.5	70.6	26.85	D	81.5	70.6	26.85	D	81.5	70.6	26.85	D	81.5	70.6	26.85	D	81.5	70.6	26.85
	Bvii8	Berg		D	53.2	81.2	476.40	D	55.7	89.8	499.08	D	56.5	89.8	506.44	D	50.5	73.5	451.94	D	56.1	101.7	502.60	D	56.8	102.0	508.56	D	48.3	72.6	433.04
	Bvii18	Moreesburg-spruit		D	100.0	100.0	3.27	D	100.0	100.0	3.27	D	100.0	100.0	3.27	D	100.0	100.0	3.27	D	100.0	100.0	3.27	D	100.0	100.0	3.27	D	100.0	100.0	3.27
	Bvii12	**Berg**	D	D	51.1	75.8	459.58	D	53.2	60.9	478.29	D	54.0	60.9	485.43	D	47.6	61.9	428.29	D	52.9	79.2	476.22	D	53.6	80.9	482.44	D	45.5	58.4	409.03
	Bii1	Sout		D	99.4	100.0	15.65	D	99.4	100.0	15.65	D	99.4	100.0	15.65	D	99.4	100.0	15.65	D	99.4	100.0	15.65	D	99.4	100.0	15.65	D	99.4	100.0	15.65

				Current infrastructure												2040 Infrastructure															
	Biv2	Berg		D	48.8	15.9	448.16	C	53.0	49.2	485.92	C	53.7	49.2	493.07	D	45.9	15.6	421.16	D	50.6	18.6	464.73	D	51.4	21.3	471.21	E/F	43.5	2.1	399.12
	Bxi1	**Berg estuary**	C	C	48.8	15.9	448.16	B	53.0	49.2	485.92	B	53.7	49.2	493.07	C	45.9	15.6	421.16	C	50.6	18.6	464.73	C	51.4	21.3	471.21	C/D	43.5	2.1	399.12

Table 3-9 Changes in ecological condition, seasonal flow (as percentage of natural), and MAR at all nodes for Sc1 and scenarios 1c to 9 in the Berg River catchment (G1)

				Current infrastructure				2040 Infrastructure with climate change															
			EWR	Sc1: PES				Sc1c: 2040CC_PES_BF				Sc7b: 2040CC_ESBC_0.5_BF				Sc8b: 2040CC_REC_0.6_BF				Sc9: 2040CC_NoConstraint			
IUA	Node	River	REC	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR	EC	Wet	Dry	MAR
Upper Berg	Bvii13	Berg		A	98.3	98.7	83.32	A/B	91.1	87.7	77.21	A/B	91.1	87.7	77.21	A/B	91.1	87.7	77.21	A/B	91.1	87.7	77.21
	Bviii1	**Berg**	C	C	27.4	42.2	39.13	C	33.9	41.3	48.56	C	38.7	28.9	55.41	B/C	46.4	40.7	66.34	E/F	11.4	0.0	16.29
	Biv5	Franschhoek		D	82.5	3.7	31.01	D	75.9	3.0	28.55	D	75.9	3.0	28.55	D	75.9	3.0	28.55	D	75.9	3.0	28.55
	Biii2	Wemmershoek		D	28.4	2.1	25.72	D	24.1	1.7	21.79	D	25.0	1.7	22.62	D	24.9	1.7	22.54	D	24.6	1.7	22.28
	Bvii14	Dwars		C	72.7	58.7	31.73	C	64.0	51.0	27.93	C	64.2	51.0	28.03	C	64.2	51.0	28.02	C	64.2	51.0	28.04
	Biii3	Berg		E	53.9	204.0	225.99	E	46.9	204.0	196.52	E	56.1	262.4	235.28	E	57.5	262.4	240.94	E	41.2	204.0	172.79
Middle Berg	**Bviii11**	**Pombers**	C	D	366.0	3063.1	6.67	D	344.9	3050.0	6.29	D	344.9	3050.0	6.29	D	344.9	3050.0	6.29	D	344.9	3049.9	6.29
	Bvii3	**Kromme**	D	D/E	89.9	1.9	16.55	D/E	70.5	1.1	12.98	D/E	70.5	1.1	12.98	D/E	70.5	1.1	12.98	D/E	70.5	1.1	12.98
	Bvii10	Berg		D	53.2	143.6	245.55	D	45.2	143.6	208.28	D	53.6	197.0	247.05	D	54.8	197.0	252.72	D	40.0	143.6	184.48
	Bvii15	Doring		D	66.8	0.0	2.88	D	47.3	0.0	2.04	D	47.2	0.0	2.04	D	47.3	0.0	2.04	D	47.1	0.0	2.03
	Bvii4	Kompanjies		D	74.0	0.5	18.33	D	54.5	0.1	13.50	D	54.5	0.1	13.50	D	54.5	0.1	13.50	D	54.5	0.1	13.50
	Bvii5	**Berg**	D	D	49.7	17.9	266.38	D	40.0	17.9	214.62	C	45.8	46.4	245.36	C	46.8	46.4	251.03	D	35.6	17.9	190.75
Berg Trib	Biii4	Klein Berg		C	82.0	128.2	69.09	C	64.9	118.9	54.69	C	64.9	118.9	54.69	C	64.9	118.9	54.69	C	64.9	118.9	54.69
	Bi1	Vier-en-Twintig		C	23.6	33.2	29.61	C/D	17.9	27.1	22.51	C	18.7	27.1	23.45	C	18.8	27.1	23.64	C/D	17.7	27.1	22.16
	Bvii16	Leeu		C	12.7	35.0	2.73	C	9.6	28.8	2.07	C	10.3	28.8	2.21	C	10.4	28.8	2.24	C	9.4	28.8	2.02
Lower Berg	Bvii11	Berg		D	50.5	16.4	281.75	D	31.7	16.4	177.08	C	36.1	43.2	201.16	C	37.0	43.2	206.50	D	28.6	16.4	159.46
	Biv1	Berg		D	58.3	112.9	331.99	D	42.8	108.3	244.08	D	55.1	152.9	313.91	D	55.8	153.5	317.91	D	39.7	106.3	226.06
	Biv3	Klein-Berg		D	53.6	126.8	54.58	D	39.4	117.2	40.10	D	40.0	117.2	40.65	D	40.4	117.2	41.11	D	39.3	117.2	39.96
	Biv4	Vier-en-twintig		D	29.3	13.1	49.53	D	20.6	10.5	34.91	D	21.3	10.5	36.00	D	21.4	10.5	36.21	D	20.4	10.5	34.51
	Bvii17	Sandspruit		C	88.5	83.1	8.19	C/D	57.5	72.8	5.31	C/D	57.5	72.8	5.31	C/D	57.5	72.8	5.31	C/D	57.5	72.6	5.31
	Bvii6	**Berg**	D	D	52.3	87.5	449.46	D/E	38.0	81.1	326.65	D	46.3	109.2	398.12	D	46.8	109.6	402.79	D/E	35.8	79.9	308.09
	Biii5	Matjies		D	81.5	70.6	26.85	D	61.6	64.6	20.30	D	61.6	64.6	20.30	D	61.6	64.6	20.30	D	61.6	64.6	20.30
	Bvii8	Berg		D	53.2	81.2	476.40	D/E	38.5	71.9	344.71	D	46.5	100.4	416.19	D	47.0	100.7	420.85	D/E	36.4	70.7	326.15
	Bvii18	Moreesburg spruit		D	100.0	100.0	3.27	D	61.2	89.9	2.00	D	61.2	89.9	2.00	D	61.2	89.9	2.00	D	61.2	90.1	2.00
	Bvii12	**Berg**	D	D	51.1	75.8	459.58	D/E	35.5	61.0	319.69	D	43.2	78.4	389.00	D	43.8	80.0	393.83	D/E	33.4	57.1	300.51
	Bii1	Sout		D	99.4	100.0	15.65	D	77.6	91.3	12.22	D	77.6	91.3	12.22	D	77.6	91.3	12.22	D	77.6	91.2	12.22
	Biv2	Berg		D	48.8	15.9	448.16	D	33.6	15.3	308.44	D	40.7	18.2	373.28	D	41.2	20.8	378.41	E/F	31.2	1.6	286.61
	Bxi1	**Berg estuary**	C	C	48.8	15.9	448.16	C/D	33.6	15.3	308.44	C/D	40.7	18.2	373.28	C/D	41.2	20.8	378.41	E	31.2	1.6	286.61

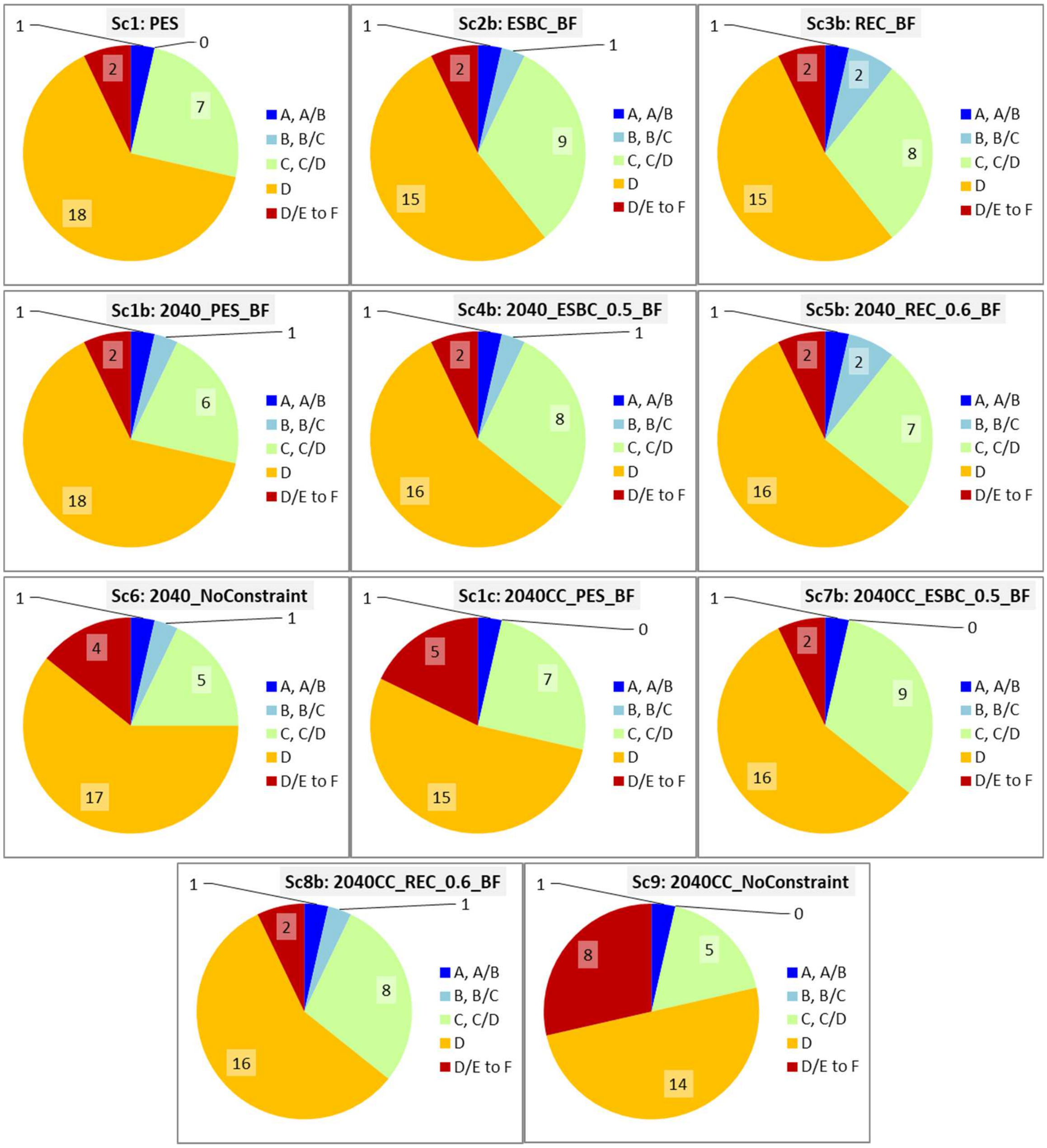


Figure 3-4 Number of nodes in each ecological category (EC) per scenario for the Berg River basin (G1)

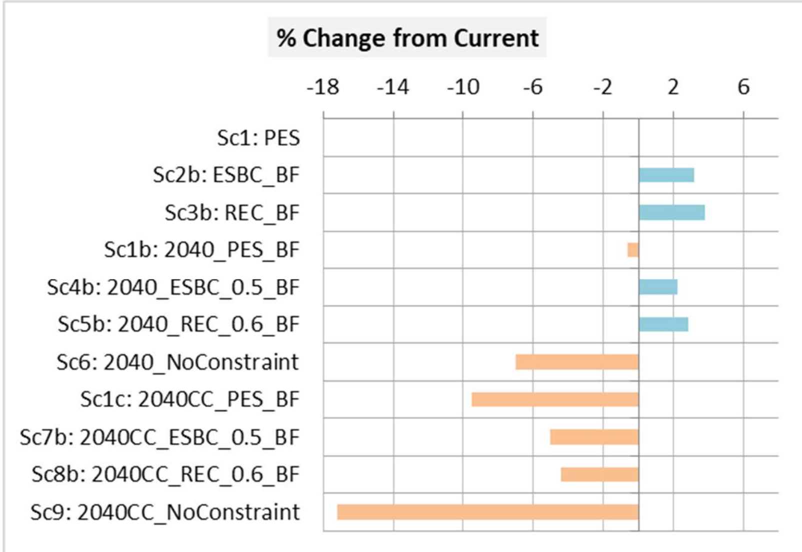


Figure 3-5 Change in the overall ecological condition of the catchment under each scenario

3.2.4 Wetlands

The Wetland Regions associated with the Berg River catchments (G1, excluding Langebaan) are the South Western Coastal Belt_sand (WR1) and South Western Coastal Belt_shale (WR2) as well as the Western Folded Mountains Wetland Region (WR3). These are shown in Figure 3-6 and summarised below.

South Western Coastal Belt_Sand (WR1) Wetland Region

- The South Western Coastal Belt_Sand Wetland Region stretches along the coast and is associated with Aeolian sedimentary deposits of the Kalahari Group.
- The Berg Estuary occurs within this Wetland Region, with associated wetlands occurring along the Berg River. There are also priority NFEPA wetland clusters (Southwest Sand Fynbos Unchanneled Wetlands) in the riparian area of the Berg River Estuary.
- Alluvial floodplains are highly threatened by water abstraction, which is threatening the seasonal inundation of the floodplain, and the persistence of floodplain vegetation.

South Western Coastal Belt_Shale (WR2) Wetland Region

- The South Western Coastal Belt_shale Wetland Region is typified by the Berg floodplain wetland (West Coast Shale Renosterveld_Floodplain), which is considered to be ecologically important due to the vegetation type being critically endangered and priority NFEPA frog status. There are also NFEPA priority wetland clusters in the upper Boesmans River (Southwest Sandstone Fynbos Seep & Northwest Fynbos Seep).
- Water abstraction is the main threat to floodplain wetlands in this Region, with the expansion of towns and urban areas likely increasing pressure due to habitat degradation and pollution.
- Wemmershoek wetland has had rehabilitation efforts by Working for Wetlands.

Western Folded Mountains (WR3) Wetland Region

- There are limited wetlands in this Region although small valley bottom and seep wetlands persist. These wetlands occur in a Strategic Water Source Area and Seeps contribute the source of rivers flowing out of the mountains.
- The main impact in this region are transformation of wetlands for agriculture.

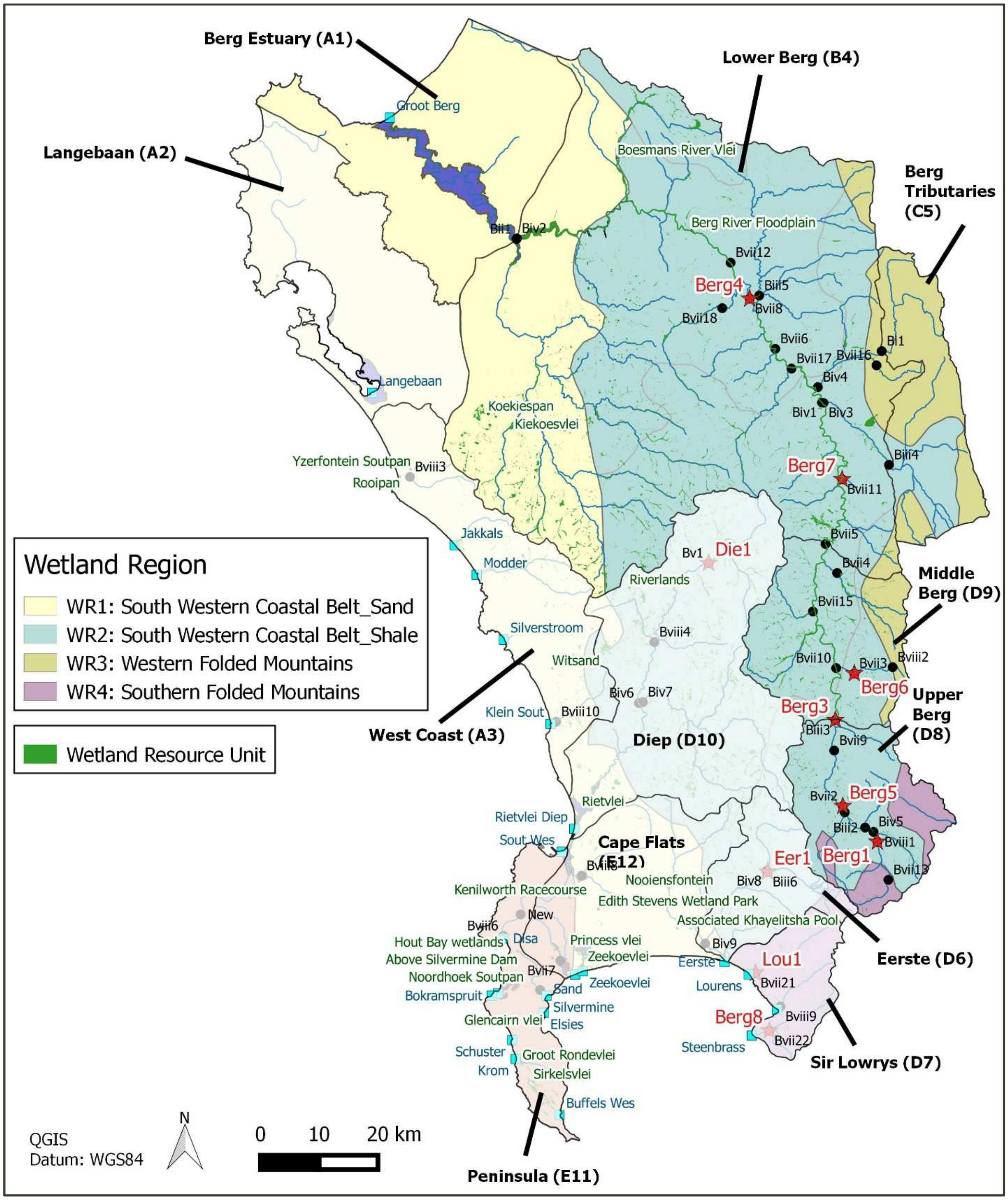


Figure 3-6 The wetland Regions and Wetland Resource Units associated with the Berg River Catchment (G1)

3.2.4.1 Wetland impacts of Scenarios

A summary of the likely wetland impacts for the different scenarios considered are presented in **Table 3-6**.

Table 3-10 Likely wetland impacts for the scenarios in the Berg River Catchment (G2)

Scenario	Likely surface usage impact	Likely indirect impact
Sc 1 (PES)	The present-day wetland impacts will continue.	The present-day wetland impacts will continue.
Sc2 (ESBC)	The increase in baseflow during the dry and wet season would probably result in increased inundation of floodplain wetlands on the Berg River in the middle and lower Berg IUAs. Along the Berg River the river nodes had an improvement of EC at node Bvii5, EWR 7 (node Bvi11), EWR 5 (node Bvi12) and Berg Estuary (node Bxi1).	**No catchment management:** The present-day wetland impacts will continue.
Sc3 (REC)	The increase in baseflow during the dry and wet season would probably result in increased inundation of floodplain wetlands on the Berg River in the middle and lower Berg IUAs. The improvement to river nodes is similar as that defined in Sc2 (ESBC).	**No catchment management:** The present-day wetland impacts will continue.
Sc4 (ESBC-FI)	The increase in baseflow during the dry and wet season would probably result in increased inundation of floodplain wetlands on the Berg River in the middle and lower Berg IUAs. The improvement to river nodes is similar as that defined in Sc2 (ESBC), although river node Biv2 reduces and Berg Estuary is less than what it was in Sc2/Sc3.	**No catchment management:** Future development without catchment management will mean that although floodplain wetlands may become inundated, alien invasive vegetation may decrease the diversity of vegetation in riparian areas which would reduce the effectiveness of floodplains. An increase in population and increased agriculture will also increase the indirect impacts through "wetland reclamation" and increased erosion/depositional features. Channelled valley-bottom wetlands and seeps will become transformed, especially in agricultural areas. Important wetlands such as the NFEPA cluster wetlands in the headwaters of Boesmans River will be at risk of being degraded. And wetlands such as Koekispan and Kiekoesvlei will also likely be degraded.
Sc5 (REC-FI)	Similar impacts to Sc4.	**With catchment management:** Future development with catchment management will conserve wetlands other than just floodplain wetlands. Removing alien invasive vegetation will increase the diversity of the floodplain wetlands, and improving the management of runoff of the surrounding farms will reduce the erosion and degradation of valley-bottom and seep wetlands.
Sc6 (No EC-FI)	The main impact to wetlands will be to floodplain wetlands due to increased abstraction. The present-day wetland trends in the upper and middle Berg River will continue up to Zonquasdrift where water will be abstracted for the Voëlvlei Augmentation Scheme. Downstream of the abstraction inundation of floodplain wetlands will decrease. The river nodes Bvii11 and Biv2 are in an unacceptable condition and the estuary node (Bxi1) is also below PES. This Scenario does not consider baseflow and flood EWRs therefore abstraction has the largest impact to floodplain wetlands.	**No catchment management:** Flow impacts, as well as lack of catchment management will have large impacts on all wetlands in the area. An increase in population and increased agriculture will also increase the non-flow related impacts through "wetland reclamation" and increased erosion/depositional features. Channelled valley-bottom wetlands and seeps will become transformed, especially in agricultural areas. Important wetlands such as the NFEPA cluster wetlands in the headwaters of Boesmans River will be at risk of being degraded. And wetlands such as Koekispan and Kiekoesvlei will also likely be degraded.

Scenario	Likely surface usage impact	Likely indirect impact
Sc7 (ESBC-CC)	The same impacts as for Sc4 would be expected. Although certain river nodes degrade further (Bi1, Bvii17, Bvii6, Bvii12, Biv2), the estuary node remains at PES.	**No catchment management:** A drying scenario in terms of climate change will reduce the flow from hillslope seeps and depression wetlands will dry up quicker.
Sc8 (REC-CC)	The same impacts as for Sc4 would be expected. With certain river nodes degrading further (Bi1, Bvii17, Bvii6, Bvii12, Biv2) although less so than in Sc7, the estuary node remains at PES.	**With catchment management:** Catchment management will increase the resilience of hillslope seeps and depression wetlands to the impacts of drying up under the increased drying scenario of climate change.
Sc9 (No EC-CC)	Similar impacts to Sc6, but more river nodes in an unacceptable condition.	**No catchment management:** A drying scenario in terms of climate change will reduce the flow from hillslope seeps and depression wetlands will dry up quicker.

The current and future groundwater scenarios were assessed in terms of the usage impacts, in particular for wetlands linked to a river, as well as in terms of indirect impacts, for wetlands not associated with a river (Table 3-11). The Groundwater Resource Units that relate to the Berg Catchment are the Paarl-Upper Berg; Tulbagh; 24 Rivers; Piketberg and West Coast Groundwater Resource Units.

Table 3-11 Likely wetland impacts for the scenarios in the Berg River Catchment (G2)

Scenario	Likely groundwater usage impact	Likely indirect impact
Current	The Groundwater Resource Units associated with the Berg River floodplain wetland (i.e. Paarl-Upper Berg; Tulbagh; 24 Rivers; Piketberg and West Coast Groundwater Resource Units) are currently in a Class I (water resource is minimal altered from its pre-development condition). There is minimal impact on groundwater input to these wetlands. This is also the case for Valley-bottom wetlands.	Hillslope seeps are normally associated with groundwater discharge. Most hillslope seeps occur in the Western Folded Mountain Wetland Region, which are predominantly within protected areas. Depression wetlands within the South Western Coastal Belt_Shale and Southern Folded Mountains Wetland Regions may also receive groundwater flows. The depression wetlands associated with Wemmershoek Dam in the headwaters of the Berg River, pump station and gauging weirs along the Berg River will remain in current state. Kiekoesvlei and Koekiespan in the South Western Coastal Belt_Sand Wetland Region will also remain in current state. The important hillslope seeps associated with Boesmans River in the South Western Coastal Belt_sand Wetland Region are within the Piketberg Groundwater Resource Unit (GRU9), which is Class II (localised low level impacts) which has temporal but not long-term significant impact.
Langebaan (Future)	Increased abstraction from the Langebaan Road Wellfield will increase the Class from I to II (moderately used) for the Quaternary catchment G10M. Drawdown will not impact the Berg River floodplain. Western Strandveld and Southwest Sand Fynbos channelled valley bottom wetlands will be impacted, although these do not have significant ecological importance.	Drawdown will impact Western Strandveld and Southwest Sand Fynbos depression wetlands although these do not have significant ecological importance.

Scenario	Likely groundwater usage impact	Likely indirect impact
Elandsfontein (Future)	Simulations indicate that groundwater flow direction from the mine is towards the Langebaan lagoon (Ramsar site) and associated Geelbek wetland (Western Strandveld Unchanneled Valley Bottom Wetland). Impacts are predicted to be small, although there are uncertainties in predictions. Due to the Ramsar designation of Langebaan, it is important to ensure limited impacts in terms of groundwater.	There are no other wetlands impacted by the project in the surrounding area.

3.2.5 Ecosystems Goods, Services and Attributes

A primary contributor to the ecosystems goods services and attributes (EGSA) in the Berg River Catchment (G1) is the Berg River estuary itself. The estimated annual contributing value for EGSAs from the estuary under different flow and ecological condition is determined in terms of provisioning services (i.e. subsistence fishing), regulating services (i.e. nursery value) and attributes (i.e. tourism value and property value) summarised in Table 3-12.

The tourism value for the Berg River estuary in its current condition was estimated to be around R31 million/a, while the value of the property market associated with the estuary was estimating to be around R11 million/a. Both factors are likely to change as a result of the changing ecological health of the estuary. There is relatively little difference in the condition of the estuary under most scenarios, apart from Scenario 4, where it drops a full category to a D. The change from a condition C to D was estimated to lead to a 10% reduction in tourism value and 30% reduction in property values.

Similarly, the change in status from a category C to D for the estuary is estimated to lead to a 30% reduction in fishing and nursery value. The total value of the subsistence linefish catch from the Berg estuary, under current conditions, was estimated to be around R228 000 per year while the nursery value was estimated at around R8.1 million per year, given that it is considered to be a major contributor to the sustainability of West Coast fish stocks.

Overall, increasing the estuary to a B/C condition is estimated to lead to an increase in value of about R2.4 m per annum, whereas its deterioration to a D category under Scenario 9 would result in a loss of almost a fifth of its value (R8.9 m). Given that these values would increase over time with population and income growth, it is estimated that the present value of these losses ranges up to R157.7 million for the worst-case scenario (Table 3-12).

Table 3-12 Summary of EGSA benefits (and drawbacks) for different scenarios in the Berg River Catchment (G1)

Scenario	Estuary MAR (million m^3)	% natural estuary MAR	Ecological Condition of the estuary (Current WQ)	Estimated value of EGSA benefits (R million/a)					NPV change in EGSAs (R million)
				Sub-sistence Fishing	Nursery Value	Tourism value & property value	Property value (estuary premium, annualised)	Total	
Sc 1 (PES)	464	50%	C	0.2	8.1	31.1	11.0	50.4	42.3
Sc 2 (ESBC)	545	58%	B/C	0.3	8.9	32.7	11.0	52.8	42.3
Sc 3 (REC)	551	59%	B/C	0.3	8.9	32.7	11.0	52.8	0.0
Sc 4 (ESBC-FI)	552	56%	DC	0.2	8.1	31.1	11.0	50.4	0.0

Scenario	Estuary MAR (million m^3)	% natural estuary MAR	Ecological Condition of the estuary (Current WQ)	Estimated value of EGSA benefits (R million/a)					NPV change in EGSAs (R million)
				Sub-sistence Fishing	Nursery Value	Tourism value & property value	Property value (estuary premium, annualised)	Total	
Sc 5 (REC-FI)	528	57%	C	0.2	8.1	31.1	11.0	50.4	-78.9
Sc 6 (No EC-FI)	415	45%	C/D	0.2	6.9	29.5	9.4	46.0	0.0
Sc 7 (ESBC-CC)	442	47%	C	0.2	8.1	31.1	11.0	50.4	0.0
Sc 8 (REC-CC)	447	48%	C	0.2	8.1	31.1	11.0	50.4	-157.7
Sc 9 (No EC-CC)	299	32%	D	0.2	5.7	28.0	7.7	41.5	42.3

3.2.6 Socio-economic Impacts of Scenarios

As discussed in Section 2.3.2, it was assumed for this study that, to meet medium-growth future water demand up to 2040, additional bulk water supplies to the WCWSS would primarily be met through a mix of treated effluent re-use, desalination and groundwater extraction. It follows that, for the theoretical exercise of costing additional water supply infrastructure to cover EWR-related shortfalls at river and estuary nodes, a similar mix of augmentation interventions need to be considered. As a worst-case, we have assumed that the shortfall in the yield from the WCWSS due to scenario EWRs would be met through increased use of desalination at an average cost of R18/m^3. It is important to note that in reality alternative, cheaper options for meeting the future demand could be identified, but we have used this as a measure of the ultimate marginal costs for augmenting any losses (or gains) in the system yield due to the various EWR scenarios.

The historical firm yield (HFY) for the Western Cape Water Supply System (WCWSS) are shown in Table 3-13 for the different scenarios. The impact in terms of the change in the HFY due to the various EWR scenarios is then calculated in terms of the relative current and future base scenario case. In the current situation the base scenario is the PES scenario with only a minimum flow requirement for the estuary. For the future infrastructure scenario, however, the REC EWR requirements have already been taken into account in the feasibility study for the Voelvlei Augmentation Scheme (VAS), which is the only additional major planned surface water augmentation option. In this case the REC scenario is for baseflow only, with the flood flow requirements been met on average and not every year to allow for reduced EWR requirements during drought periods. Hence the REC with baseflow only scenario is the relevant reference scenario to be used when determining the impact of the other future scenarios on the HFY from the system.

Table 3-13 Historical firm yield (change from baseline in million m^3 per year) under the different scenarios.

	Time and climate		
Scenario	Present (Scenarios 1,2,3)	2040, no climate change (Scenarios 1b,4,5,6)	2040 with climate change (Scenarios 1c,7,8,9)
PES	535 (present baseline)	755 (+61)	711 (+37)
ESBC	491 (-44)	698 (+4)	620 (-74)
REC	487 (-48)	694 (future baseline)	617 (-77)
No EC	-	775 (+81)	716 (+22)

3.3 Coastal River Catchment Scenarios (G2)

The coastal river catchments (G2) are relatively short and largely highly developed, but with no major bulk water supply infrastructure (i.e. dams) likely to be development in these catchments. There are however a number of smaller existing dams that supply water to parts of Cape Town located on Table Mountain and above Glencairn and Simonstown and some farm dams that capture local runoff. There are also no new dams likely to be developed in these catchments. There are however a number of wastewater treatment works (WWTW) that discharge into these rivers. Hence the classification of water resources in these catchments will be largely dominated by water requirements to maintain the coastal estuaries and also in terms of the likely future scenarios for changes in the volume of return flows from the WWTWS. Table 3-14 presents a summary of the ecological importance score (EIS) and the ecological category and associated flow requirements for the PES, REC and ESBC scenarios for the estuaries of the coastal catchments.

Table 3-14 Ecological Category for different scenarios for the estuaries of the coastal catchments

Node	IUA	Quat	Name	PES	REC	ESBC	EIS
Bxi12	A3	G21A	Modder Estuary	C	C	D	M
Bxi7	D10	G21F	Rietvlei/Diep Estuary	D	C	D	H
Bxi9	E12	G22K	Zandvlei Estuary	D	C	D	H
Bxi20	E12	G22D	Zeekoe Estuary	E	D	D	U
Bxi10	E11	G22B	Hout Bay Estuary	E	D	D	U
Bxi11	E11	G22A	Silvermine Estuary	D	D	D	U
Bxi19	E11	G22A	Elsies Estuary	E	D	D	U
Bxi18	E11	G22A	Buffels Wes Estuary	F	D	D	U
Bxi17	E11	G22A	Krom Estuary	A	A	D	U
Bxi16	E11	G22A	Schuster Estuary	A	A	D	U
Bxi15	E11	G22A	Bokramspruit Estuary	C	C	D	U
Bxi14	E11	G22A	Wildvoëlvlei Estuary	D	D	D	M
Bxi3	D6	G22H	Eerste Estuary	E	D	D	M
Bxi4	D7	G22J	Lourens Estuary	D	D	D	U
Bxi6	D7	G22K	Sir Lowry's Pass Estuary	E	D	D	U
Bxi6	D7	G40A	Steenbras estuary	B	B	D	U

With IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; REC = Recommended Ecological Category; VH = Very High; H = High; M = Moderate; U = Undefined.

For each significant estuary, a detailed Reserve determination study had previously been undertaken which included consideration of a number of development scenarios. In particular, these scenarios considered the likely impact of changes in the volume of treated effluent contributing to the estuary systems, as these form a major part of the current flow conditions with many estuaries experiencing much higher flows than natural during the summer months. An important consideration for is the impact that increased use of treated effluent would have on the flow volumes entering these systems as this could potentially have a positive impact on ecological conditions.

In the following sections a summary of the scenarios considered for each of the eight significant estuary is presented.

3.3.1 Langebaan Lagoon

3.3.1.1 Estuary functional zone and activities

The size of the estuary functional zone for Langebaan lagoon is 260.8 ha, making it the second largest estuary in the Berg WMA (Figure 3-7). Unlike the other estuaries within the Berg WMA, surface water runoff is not the primary source of freshwater for the Langebaan Lagoon. Classification of the 16-km long Langebaan Lagoon that adjoins Saldanha Bay on the West Coast about 100 km north of Cape Town, has been debated for some time. Langebaan Lagoon has many of the characteristics of an estuary, including calm coastal waters that are protected from marine wave action and a biota that includes many of species typically found in estuaries. However, the system lacks a conventional estuarine salinity gradient due to the absence of any inflowing river, although there is groundwater that feeds into certain sections of the lagoon.

At 3-4 km wide, with channels up to 5 m deep, Langebaan is much larger and deeper than conventional coastal lagoons which are usually small and shallow. Whitfield (2005) suggested that the term “coastal embayment” type of estuary be used to describe Langebaan owing to the fact that it does receive freshwater inflow from land drainage (aquifer input), and also has typical estuarine biota. This would place it in a class of its own; separate from “estuarine bays”, all of which are fed by rivers.

Figure 3-7 Extent of the Langebaan Lagoon.

The area directly surrounding Langebaan Lagoon is mainly under natural vegetation, waterbodies or wetlands, some of which falls within the West Coast National Park. Outside of the National Park, cultivated land makes up the next most common land use (Figure 3-8).

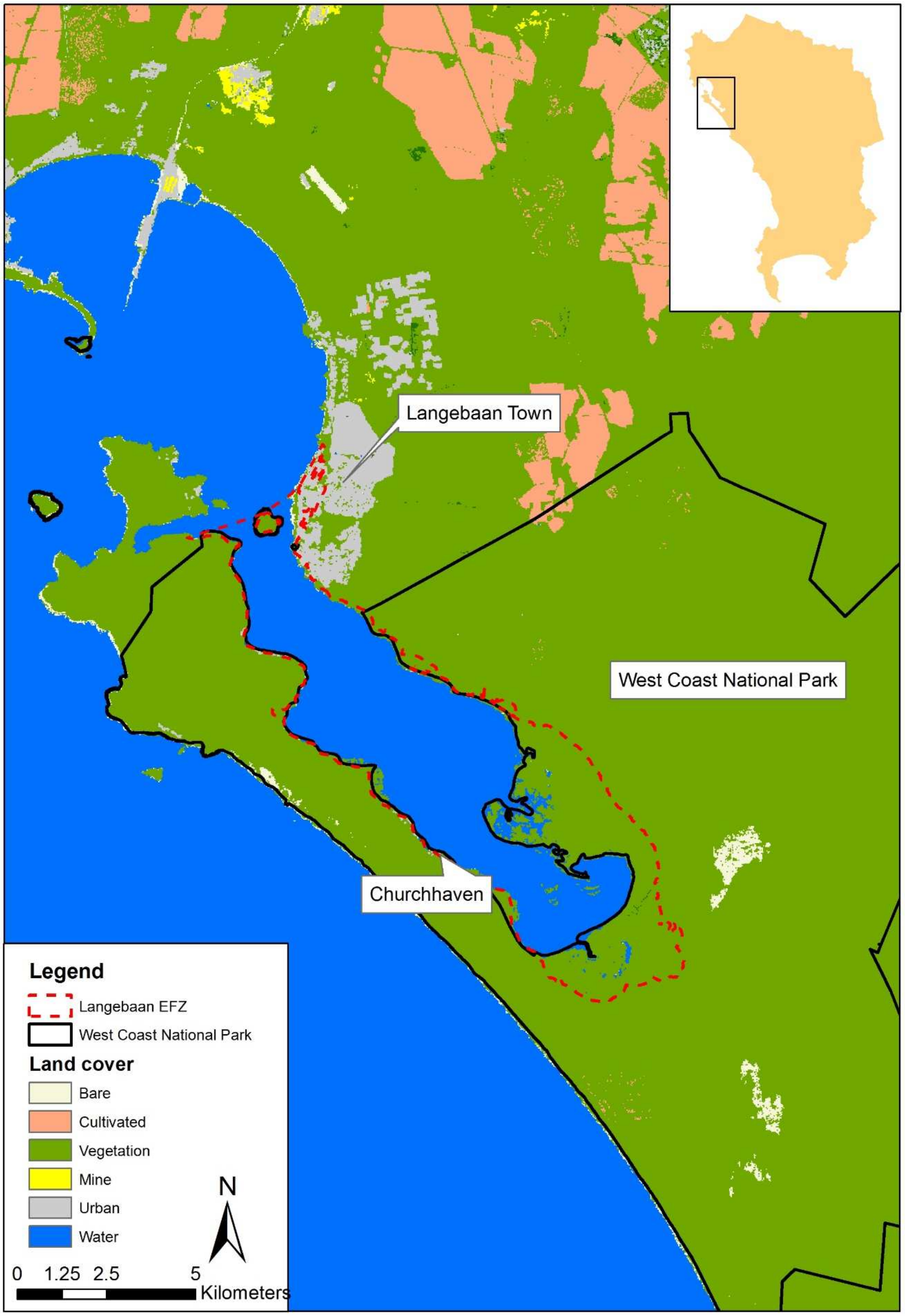


Figure 3-8 Location of the Langebaan Lagoon in relation to Langebaan town, Churchhaven and the West Coast National Park including dominant land cover types.

Most of the freshwater runoff to Langebaan Lagoon is derived from the Elandsfontein Aquifer System (EAS) (Weaver & Wright 1994, Valiela *et al.* 1990, Burnett *et al.* 2001), which comprises of a Lower Aquifer Unit that lies on a basement rock formation and an Upper Aquifer Unit located in variably consolidated sands and calcretes which are separated by an impermeable layer of clay (DWAF 2008). A steep hydraulic gradient exists where the Elandsfontein aquifer intersects with the lagoon, and coupled with presence of the clay beneath the lagoon, forces groundwater to flow towards the surface at the lagoon edge resulting in significant groundwater outflow to the lagoon.

3.3.1.2 Scenarios Considered

Groundwater flow to Langebaan Lagoon has been estimated by Seyler et al. (2016) for a base case prior to any abstraction, with a series of steady state scenarios designed to replicate future states of dynamic equilibrium under a range of specified abstraction regimes at the West Coast District Municipality wellfield (Langebaan Road Aquifer System and Langebaan Road wellfields). The volume abstracted increased from around 4.94 million m^3/a under the base case scenario to a combined 18.53 million m^3/a under Scenario 5 (Table 3-15).

Table 3-15 Historic and future groundwater abstraction scenarios for the West Coast District Municipality (WCDM) and the Langebaan Road wellfields. (Source: Seyler et al. 2016.)

Scenario	WCDM wellfield abstraction (million m^3/a)	Dispersed abstraction (million m^3/a)
Base case	0	4.94
Scenario 1	1.35	6.53
Scenario 2	3.5	6.53
Scenario 3	5.5	6.53
Scenario 4	7	6.53
Scenario 5	12	6.53

Impacts of these increases in abstraction on the depth of the water table for the Upper Aquifer Unit (UAU) and Lower Aquifer Unit (LAU) near the lagoon edge and outflow rates to the lagoon from each of these aquifer systems is presented in Table 3-16 and Table 3-17, respectively.

Table 3-16 Modelled change in water level in the UAU and LAU in the vicinity of Langebaan Lagoon under different abstraction scenarios (Source Seyler et al. 2016).

	Base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Drawdown at Langebaan Lagoon LAU (m)	n/a	<0.1	<0.1	<0.1, increasing to 0.1-0.5 ~680m from water	<0.1, increasing to 0.1-0.5 ~500m from water	<0.1, increasing to 0.1-0.5 500m from water
Drawdown at Langebaan Lagoon UAU (m)	n/a	<0.1	<0.1	<0.1	<0.1	<0.1

Table 3-17 Modelled groundwater flow results for base case and future scenarios. (Source Seyler et al. 2016).

Aquifer Flux	Base case	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	million m^3/a	million m^3/a	% Change	million m^3/a	% Change	million m^3/a	% Change	million m^3/a	% Change	million m^3/a	% Change
Langebaan Lagoon UAU net	-0.6	-0.6	0%	-0.6	-1%	-0.6	-1%	-0.6	-1%	-0.6	-2%
Langebaan Lagoon LAU net	-5.1	-5.1	-1%	-5	-2%	-5	-3%	-5	-3%	-4.9	-4%
Langebaan Lagoon net	-5.7	-5.7	-1	-5.6	-3	-5.6	-4	-5.6	-4	-5.5	-6%

Net outflow to the lagoon from the Upper Aquifer Unit (UAU) and Lower Aquifer Unit (LAU) barely changes under the various scenarios, dropping from around 5.7 Mm^3/a under the base case to around 5.5 Mm^3/a under Scenario 5. For water level, the model predicts no change in the level of the Upper Aquifer Unit (UAU) between the base case and the most extreme abstraction scenario modelled, and a very modest change in the water level for the Lower Aquifer Unit (LAU) at the waters' edge. This increases 500 m from the water's edge for Scenario 5. Thus, while the base case scenario incorporates abstraction of some 4.94 Mm^3/a from the Langebaan Road wellfields, it is likely that this corresponds closely with the Reference condition.

Hydrological health for Present day and the EWR scenarios was assessed on the basis of the change in the depth of the Upper Aquifer Unit (UAU) and the outflow of groundwater to the lagoon. Results are presented in Table 3-18. Confidence in this assessment was rated as low as simulated flows have not been properly calibrated against gauged data.

Table 3-18 Similarity scores for hydrology for Present and EWR scenarios relative to the Reference condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Conf
a. Change in water level in the UAU	99	99	99	99	99	99	L
b. Change in outflow	97	96	94	93	93	91	L
Score (min + average (a: b)/2)	**97**	**96**	**94**	**93**	**93**	**91**	**L**
Score min (a to b)	**98**	**97**	**95**	**95**	**95**	**93**	**L**

3.3.1.3 Hydrodynamics and Groundwater Impacts

Since the construction of the causeway and the iron ore jetty in Saldanha Bay during the early 1970s, various alterations to the coastline in the area of the Langebaan Lagoon mouth were observed, including erosion of Langebaan Beach located near the town of Langebaan. Sediment entering the lagoon from the southern edge is minimal and trapped by the wetlands located in this area. Thus, the source of available sediments is mostly fine, unconsolidated quarzitic sand particles located in Saldanha Bay. Beaches located in the Langebaan Lagoon have been stabilized by the vegetation, however, at the entrance to the lagoon major development activities have resulted in the removal of vegetation near the coastline, which increases the risk of erosion of these beaches. Thus, when investigating the sediment transport conditions in the Langebaan Lagoon, especially at the entrance to the lagoon, an understanding of the dynamics of Saldanha Bay is required. Alterations in the hydrodynamic conditions in Saldanha Bay, including variations in the tidal levels and wave properties, could have major impacts on the Langebaan Lagoon.

The town of Langebaan has expanded since the 1960s. Development of beachfront properties has resulted in the removal of vegetation along the northern beach. This encroachment of housing, due to an increase in tourism and recreational attractions, and additional access roads to the beach possibly resulted in instability of the shoreline and were potentially a cause for the major shoreline problems. This encroachment interrupts the land-shore sediment interchange, which results in less material available for cross-shore sediment transport due to wave action and thus the erosion of the beaches which also results in steeper slopes in the beach areas.

Various interventions have been considered for reducing the on-going erosion and rehabilitation of the beaches that have experienced erosion. The most appropriate methods had to include natural restoration of the beaches by altering local hydrodynamics to prevent further erosion. In 2003, two structures were designed to alter the local hydrodynamics in an attempt to rehabilitate Langebaan Beach. These structures, known as groynes, consisted of Geotextile Sand Containers (GCS's) and are similar to erosion protection structures often used in river systems to counter scouring at locations where high velocities are expected. The local hydrodynamics along the coastline, due to wave action, are altered in an attempt to dissipate energy by decreasing flow velocities and result in the deposition of sediments which were transported by means of littoral drift. This deposition is expected, in the long term, to result in the rehabilitation of the beaches. Weise (2013) investigated the possible impact these structures had on the hydrodynamics and sediment transport of the Saldanha Bay and Langebaan Lagoon systems, focusing on the entrance to the Langebaan Lagoon. Results indicated that no major impact on the hydrodynamics and sediment transport were experienced due to the construction of the causeway and the jetty. During the investigation of the impact of various extreme water level and extreme wind conditions, it has been observed that a 1 in 100-year wind velocity across the longest fetch towards Langebaan Beach resulted in the greatest velocities prior and after construction of the causeway and the jetty, and that tidal storms, or storm surge, generated the greatest velocities and thus the most sediment transport in the main channels of the mouth of the Langebaan Lagoon.

Hydrodynamic health scores for Langebaan Lagoon are presented in Table 3-19.

Table 3-19 Hydrodynamic health scores for Present Day and the four alternative scenarios relative to the Reference Condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Conf
a. Hydrodynamics	95	95	95	95	95	95	L
b. Groundwater level	95	95	95	95	95	90	L
Score (min + average (a: b))/2	95	95	95	95	95	90	**L**
Score min (a to b)	95	95	95	95	95	91	**L**

Sediment processes under Scenario 1 to 5 are similar to that of the present. Table 3-20 below provides a summary of the EHI scores for the physical habitat of the Langebaan estuary system.

Table 3-20 Similarity scores for physical habitats under different scenarios.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Conf
a. Supratidal area and sediments	90	90	90	90	90	90	L
b. Intertidal areas and sediments	95	95	95	95	95	95	L
c. Subtidal area and sediments	95	95	95	95	95	95	L
d. Estuary bathymetry/water volume	95	95	95	95	95	95	L
Score (min + average (a: b))/2	**92**	**92**	**92**	**92**	**92**	**92**	**L**
Score min (a to b)	90	90	90	90	90	90	**L**

3.3.1.4 Water Quality

Within the Estuary Functional Zone (EFZ) demarcated for the Langebaan Lagoon, water quality assessment studies have shown little impact from anthropogenic influences on the larger Saldanha Bay/Langebaan system (Anchor Environmental, 2015). Salinity at the lagoon mouth is similar to that of the adjacent sea with values in the order of 34.5-35psu (Krug 1999). Deeper into the lagoon, solar heating, strong southerly winds enhance evaporation and long residence times result in hypersaline conditions with salinity frequently reaching values in excess of 37 psu (Krug, 1999). Extreme values of temperature and salinity have been measured in the salt marshes at the head of the lagoon, with temperature and salinity reaching maxima of 30.5 °C and 43 psu in January, respectively (Krug 1999). Drops in the salinity can briefly occur as a result of precipitation in winter.

The lagoon can be separated into three sections, each having defined temperature and salinity properties:

- At the inlet, the lagoon is essentially marine;
- At distances more than 2 km from the mouth (but typically less than 6 km), the lagoon behaves like a thermal estuary, with density decreasing as temperature increases with distance from the inlet;
- South of that region, density starts increasing due to higher salinity values, giving the lagoon water characteristics similar to that of a hypersaline inverse estuary (Largier et al. 1997}.

The increase in temperature and salinity with distance from the lagoon mouth is particularly pronounced during the summer months, when solar heating is strongest. Concerns have been raised of possible enrichment in certain areas (e.g. trend of increasing faecal coliform levels at Leentjiesklip and Langebaan Main Beach) which may also have suggested potential concern for nutrient enrichment. However, within the scale of the EFZ and the strong tidal flushing, such enrichment remains localised. Thus, nutrient concentrations in the Lagoon are expected to remain near-pristine. As a result of the shallow depth, strong wind mixing and tidal flushing, the Lagoon is expected to remain well-oxygenated as it was in the reference state. Total suspended solids (TSS) are also considered low, similar to reference conditions. Slight non-similarity in the water quality scoring is to reflect possible localised effects around the periphery of the Lagoon. Water quality conditions are not expected to change within the larger EFZ under any of the projected future scenarios (Table 3-21).

Table 3-21 Similarity scores for water quality for Present and EWR scenarios relative to the Reference condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Confidence
1. Salinity	95	95	95	95	95	95	L
2. Other WQ							
Inorganic nutrients	95	95	95	95	95	95	L
Dissolved oxygen	100	100	100	100	100	100	L
Total SS	95	95	95	95	95	95	L
Toxic substances	95	95	95	95	95	95	L
WQ Score	96	96	96	96	96	96	**L**

**Score = (0.6 x S + 0.4 x min (a to d))*

3.3.2 Present Ecological Status

Using minimum scores for each component, the overall present ecological status was found to be 85 (B category), with abiotic scores being notably higher than biotic scores. Scores obtained using average-minimum method were similar for PES and the scenarios and are not summarised here.

Table 3.22. Present ecological status of the Langebaan Lagoon.

Component	Score
Hydrology	99
Hydrodynamics and mouth condition	95
Water quality	95
Physical habitat alteration	92
Habitat health score	**95**
Microalgae	90
Macrophytes	90
Invertebrates	90
Fish	50
Birds	50
Biotic health score	**74**
Estuary Health Score	**85**
Ecological Category	**B**

3.3.3 Recommended Ecological Category

Recommended Ecological Category is decided on the basis of conservation importance, using a set of rules. Conservation importance, in turn, comprises biodiversity importance, a score which is taken from an existing dataset, and functional importance, which is decided in the specialists' reserve determination workshop.

Table 3.23. Estuary importance score.

Biodiversity importance score	Score	Wt	Estuary Importance (look up remaining scores)	Score	Wt
Plants	100	30	Size	100	15
Invertebrates	100	10	Zonal Type Rarity	100	10
Fish	100	30	Habitat diversity	80	25
Birds	100	30	Biodiversity	100	25
Weighted mean	**100**		Functional importance	100	25
Max	**100**				
Biodiversity Importance Score	**100**		**ESTUARY IMPORTANCE SCORE**	**95**	

The biodiversity importance score for Langebaan Lagoon is 100. The functional importance was estimated to be 100 as well, given its large size and the dearth of other large permanently open estuaries on the South African West coast. Using these scores in conjunction with national scores on size, zonal type rarity, and habitat diversity, the overall importance score for the Langebaan Lagoon is 95. This puts it in the category of "highly important".

Since the estuary is located within the West Coast National Park and an MPA, the rule for REC is to improve health to an A category or Best Attainable State (BAS). It is estimated that 99% of the anthropogenic impacts on the system are non-flow related (see Section 1.12.3 below) and thus restoring flow is unlikely to improve health of the system in any measurable way. Biota of the system that display the lowest health scores at present include fish and birds. Rehabilitation efforts would thus need to focus on the components and would need to include national and international conservation efforts as well as local interventions such as controlling reduce kite surfing and other activities that may affect the avifauna and increase protection from fishing.

3.3.4 Relative contribution of flow and non-flow related impacts on health

Impacts on Langebaan Lagoon under its current state are considered to be almost entirely non-flow related for all components (100% non-flow related for all components except macrophytes where were rated at 90% non-flow related). If non-flow related impacts were removed, the health score for Langebaan Lagoon is expected to increase to 99% (A category).

3.3.5 Implications of different scenarios for estuary health

Increases in abstraction form the Langebaan Road and Elandsfontein aquifers considered in this study were all fairly modest and had minimal effect on Langebaan Lagoon (although the localised impact on critical wetlands such as Geelbek in the West Coast National Park could be significant). Scenario 1 had no impact on the overall health status of the lagoon as a whole, while Scenarios 2-5 resulted in a reduction in a one point reduction in health score (change from 85 to 84) but no change in the health category (estuary remained in a B category).

Table 3.24. Estuary health scores of alternative flow scenarios for the Langebaan Lagoon.

Component	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5
Hydrology	99	99	99	99	99	99
Hydrodynamics and mouth condition	95	95	95	95	95	91
Water quality	95	95	95	95	95	95
Physical habitat alteration	92	92	92	92	92	92
Habitat health score	**95**	**95**	**95**	**95**	**95**	**94**
Microalgae	90	90	90	90	90	90
Macrophytes	90	90	88	88	85	85
Invertebrates	90	90	90	90	90	90
Fish	50	50	50	50	50	50
Birds	50	50	50	50	50	50
Biotic health score	**74**	**74**	**74**	**74**	**73**	**73**
Estuary Health Score	**85**	**85**	**84**	**84**	**84**	**84**
Ecological Category	**B**	**B**	**B**	**B**	**B**	**B**

It is not recommended that any attempt be to extrapolate these results in respect of any further increases in groundwater abstraction from the Langebaan Road and Elandsfontein aquifers in future, as responses in the health of Langebaan Lagoon to such further increases is likely to be non-linear and results of such extrapolation would not be valid. More detailed modelling of localised groundwater impacts is required.

3.3.6 Diep/Rietvlei Estuary (IUA D10)

3.3.6.1 Catchment Area and activities

The catchment of the Diep/Rietvlei estuary system (Figure 3-10) lies mainly within the City of Cape Town and Swartland Municipalities, however also partially extends into the Drakenstein and Stellenbosch Municipalities. The Diep River catchment is approximately 1 495 km^2 and extends from the Riebeek Kasteel Mountains in the north-east to the Durbanville Hills in the south-west.

Figure 3-9 Extent and main components of the Diep estuary system showing the estuary functional zone (EFZ, blue line, http://bgis.sanbi.org/) in relation to the undeveloped EFZ (dotted red line).

The main tributaries of the Diep River are the Mosselbank, Swart and Riebeek Rivers. All these tributaries enter the Diep River before it reaches the coastal plain where it then discharges into the sea via Milnerton Lagoon, which is situated approximately 5 km north of Cape Town. Historically, the Salt river also used to be connected to this Diep estuary via Zoarvlei. Zoarvlei is still connected to the Milnertion lagoon (discharges into Milnerton lagoon via a pipeline under the road) but it no longer receives and water input from the Salt River.

The catchment falls within the Fynbos Biome, but the predominant land use within the catchment is agriculture, while the area immediately surrounding the estuary is mainly urban residential and industrial areas. The catchment is located within the winter rainfall region, although orographic rain originating from the mountain ranges close to the coast results in local concentrations of rainfall (Heinecken & Damstra, 1983).

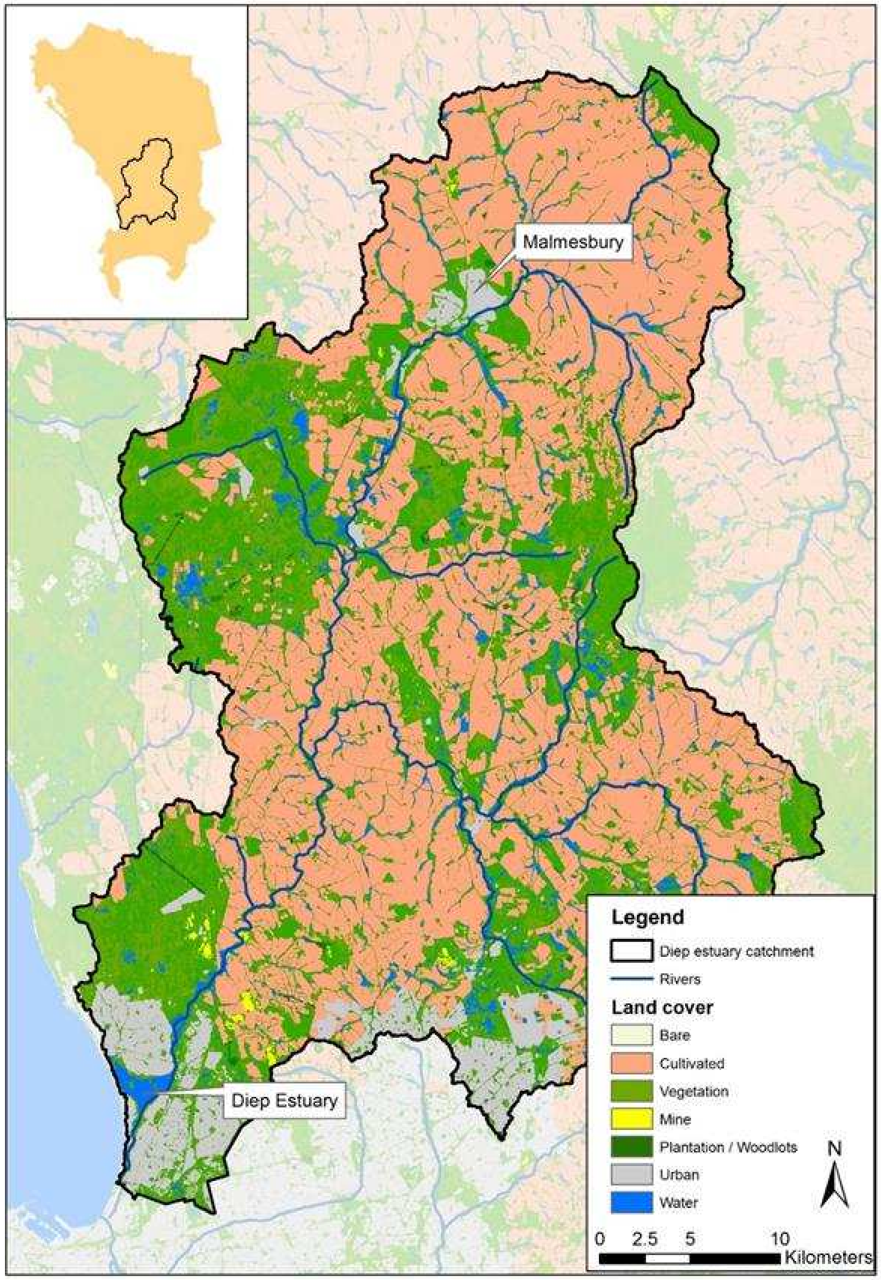


Figure 3-10 Diep/Rietvlei estuary catchment showing major land cover classes.

The banks of the Diep River were cultivated from as early as 1690, and the removal of riparian vegetation, combined with poor land management, has resulted in extensive erosion from the surrounding farmlands and the silting up of the river, vlei and estuary. Agriculture (primarily grain, but also livestock and vines) is the main land use in the catchment (over 50%), while urban development is limited to the coastal plain (6% of the catchment). In the 1960s, the Potsdam Wastewater Treatment Works (WWTW) was constructed on the north-east bank of the Rietvlei. This WWTW, originally designed to handle 30 Ml/day was expanded in 2004 to a capacity of 47 Ml/day. The early effluent was discharged directly into Rietvlei, however in the 1990s a channel was constructed to carry the treated effluent from the WWTW into Milnerton Lagoon.

Despite the large catchment, mean annual runoff (MAR) is relatively low and the Diep River dries up completely in summer months. Heavy agriculture in the catchment has led to high levels of erosion which has in turn caused siltation within the Diep River and estuary. Water abstraction within the catchment for agriculture has also decreased the volumes of water entering the system.

3.3.6.2 Anthropogenic developments within the estuary system

One of the earliest maps of the area, drawn by Barbier in 1786, shows the Diep River in the same location as present, with the exception of the lower estuary section, which joined up with the Liesbeek River and Black River along the alignment of the present-day Zoarvlei before flowing out to sea. The mouth of the system was located some 3 km south of its present position (Brown & Magoba, 2008).

Historical survey plans of the Diep Estuary indicate Rietvlei basin silting up between 1858 and 1906, as evidenced by the labelling of "quicksand" on the later maps, while earlier maps indicated the channel was too deep for guns and cavalry to cross. The 1858 map also shows that a new mouth had opened up close to its present-day position, resulting in a complex Diep-Salt estuarine system.

In 1905 steam dredgers were used to deepen parts of the Diep Estuary for rowing regattas. The decreased depths in Rietvlei also contributed to reduced tidal volume and thus reduced scouring action by tidal waters moving into the lagoon. By 1920 a sandbar had developed that closed the mouth. Boating activities were seriously curtailed by the shallowing of the system and in 1928 attempts were made to address the problem by building a weir across the river mouth to increase water levels. The weir was not a success, as it caused floodwaters to back up and flood the adjacent residential areas. It was eventually demolished after it was damaged during floods in the 1940s (Grindley & Dudley, 1988, Brown & Magoba, 2008).

Today, the lagoon, with its confined channel stabilised by road embankments and bridges, has a maximum width of 150 metres and the current channel bed is below MSL. The mouth now migrates between a gabion (rock basket) structure and concrete wall to the south and a natural high area about 250 metres to the north.

In the past, the City of Cape Town artificially breached the estuary to prevent flooding of low-lying development. The Woodbridge Island development raised the ground level between the lagoon and the sea. This was accomplished by filling with material dredged from the estuary and left the mouth permanently open for some time (Grindley & Dudley, 1988, Brown & Magoba, 2008).

Originally, Rietvlei was a series of extensive saline seasonal pans connected to the lower estuary. In the early 1970s, a section of Rietvlei was dredged to a depth of nine metres to provide fill for the building of the Ben Schoeman container berth. The resultant deep-water area, now known as Flamingo Vlei (which comprises North Vlei and South Vlei), became an important water-sport recreational area. Water sports are now only permitted in North vlei, though, south vlei being reserved as a conservation area.

Today, Rietvlei is relatively fresh with an elevation of +1.0 - +2.0 m MSL. The decreased depths can be attributed to increased erosion from the catchment and the resultant increased sedimentation occurring when the river overtopped into the seasonal wetland area. In the last 6 to 8 years, this has been exacerbated by dust-control practices that were initiated in late summer to prevent the Flamingo Vlei residents being blanketed in fine silt on exceptionally windy days. The dust control measures currently being used involve pumping water from North Vlei onto the Central Pan during dry periods to keep this area damp. This activity limits the removal of sand and silt from the system. In the long term, the rise in level will transform Rietvlei into a dry land habitat (Brown & Magoba, 2008).

3.3.6.3 Scenarios Considered

Although there are no firm plans for increased (or decreased) utilisation of water in the Diep River catchment, a number of hypothetical scenarios were constructed to examine likely impacts of improving the quality and/or reducing the volume of effluent discharged into the Diep catchment on the health of the estuary. It was assumed that reductions in flow could be achieved through recycling or diversion of waste water out of the catchment and improvements in waste water quality achieved through implementation of improved treatment technology and or upgrading of the WWTW. The following scenarios were considered:

- **Natural**: Reference condition
- **Present**: Present day flows and conditions
- **Scenario 1:** Maintain present day flows but all effluent from WWTW to be treated to DWS Special Standards.

- **Scenario 2:** Reduce inputs from the WWTW by 50% reduction and treat the remainder to DWS Special standards
- **Scenario 3**: Reduce inputs from the WWTW by 75% reduction and treat the remainder to DWS Special standards
- **Scenario 4**: Divert/recycle 100% of effluent from WWTW

Present day flows reaching the estuary from the catchment (37.3 million m^3/a) have been reduced considerably from natural (60.8 million m^3/a, 39% reduction) mostly due to abstraction of water for agriculture. However, inflows from the catchment are supplemented by waste water releases from the Potsdam Waste Water Treatment Works (WWTW. 20.7 Million m^3/a) which brings total freshwater input back up to 58.0 million m^3/a) or 95% of Reference condition. A summary of the scenarios considered are given in Table 3-25.

Table 3-25 Summary of scenarios considered for the Diep River Estuary

Scenario name	Description	MAR (million m^3/a)	Percentage of natural flows
Natural	Reference condition	60.804	100%
Present	Present day flows	57.957	95%
Scenario 1	Present day flows + special WWTW standards	57.957	95%
Scenario 2	50% reduction in contribution from WWTW + special standards	47.627	78%
Scenario 3	75% reduction in contribution from WWTW+ special standards	42.462	70%
Scenario 4	Zero input from WWTW	37.297	61%

3.3.6.4 Hydrodynamics

Information from the 1940s and 1950s indicates that the estuary was closed during most summers. Salinity in the estuary was very variable, i.e. fresh during high flow periods to high salinities in isolated pools when the estuary dried up. Since construction of the Potsdam WWTW in 1960, a gradual increase in wastewater discharges over the years has contributed to less mouth closure and lower salinities in the system. Currently the estuary is nearly permanently open, partly as a result of the dredging activities that resulted in the formation of the island now developed as Woodbridge Island, and partly because of discharges from Potsdam WWTW. Rietvlei is triangular in shape with a maximum width of over 2 kilometres in an east-west direction and 1.5 kilometres in a north-south direction (Grindley & Dudley 1988). The Diep River enters the vlei at the north-eastern corner.

Rietvlei originally comprised a series of seasonally flooded pans. These were inundated during the early winter when the Diep River would break its banks. Water and silt that had washed into the pans, gradually dried up through evaporation. The pans generally stood empty for several months in late summer before the return of the winter floods. Silt deposited during the wet phase was removed during the dry phase through strong winds lifting dust and sand from the dry pans (Grindley & Dudley 1988, Brown & Magoba 2008). At present, Rietvlei is fresh and elevated at 1 to 2 m above MSL, with the exception of Flamingo Vlei, which was dredged in the mid-1970s. Based on the above information, the Diep Estuary hydrodynamics were defined in terms of three abiotic states (Table 3-26 and Table 3-27).

Table 3-26 Characteristic abiotic state in the Diep Estuary.

Abiotic State	Water level (m MSL) associated with abiotic state	Tidal range	Connectivity	Salinity Structure
Closed	2.0-2.5 m	none	None	Well mixed
Open, Marine	1.0 -1.5 m	0.5 – 1.0	Good tidal exchange	Horizontally stratified
Open, Fresh water dominated	1.0 - 1.5 m	1.0 – 1.5	Significant river input and good tidal exchange	Nearly fresh, can be vertically stratified in mouth region

Table 3-27 The occurrence of the Abiotic States under the Reference conditions (includes inflows from the Salt River), Present day conditions and Scenarios 1 to 4.

Abiotic State	Flow range (m^3/s)	% Occurrence					
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4
Closed	<0.2	7.3	0.0	0.0	0.0	4.4	40.8
Open, marine	0.02-3.0	72.1	89.4	89.4	90.9	86.9	51.2
Open, freshwater dominated	> 3.0	20.6	10.6	10.6	9.1	8.6	8.0

Hydrodynamic health scores for the Diep estuary are presented in Table 3-28.

Table 3-28 Hydrodynamic health scores for Present Day and the four alternative scenarios relative to the Reference Condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Conf-idence
a. Mouth condition	93	93	93	97	64	L
b. Abiotic states as proxy for hydrodynamic shifts	83	83	81	85	66	L
Score (min + average (a: b))/2	**86**	**86**	**84**	**88**	**65**	**L**
Score min (a to b)	**83**	**83**	**81**	**85**	**64**	**L**

3.3.6.5 Water Quality

For this study, the open water area of the Diep estuary system was sub-divided into four zones:

- Milnerton Lagoon
- Channel (channel upstream of Otto du Plessis Bridge)
- Rietvlei (wetland area between canal and Flamingovlei)
- Flamingovlei (two deeper pools).

Taljaard *et al.* (1992) sampled the Diep Estuary under winter (1.2 m^3/s river inflow) and summer (no flow) conditions. The winter data are representative of an open brackish state, while the summer observations are representative of the Closed State. The winter data show that the upper reaches of the estuary are very responsive to flow, i.e. fresh in the shallower upper reaches, while the lower reaches are highly stratified with a plug of saline water trapped in the deeper areas near the mouth. The summer sampling condition represents a typical closed state, with lower water levels and a reverse salinity gradient. Data collected by the City of Cape Town also shows significant salinity penetration in the lower and middle reaches of the Milnerton Lagoon. No salinity information is available on the historical condition of the system. However, based on a hydrodynamic conceptual model of how the system could have functioned, the available salinity data, and expert opinion the following salinity model was developed (Table 3-29).

Table 3-29 Salinity model for the Diep estuary.

State	Reference			Present		
Physical driver	The Estuary was deeper and saline water could penetrate further upstream. Base flows were lower. The Rietvlei wetlands were at lower elevations and subjected to back-flooding at regular intervals.			At present the estuary is shallower and the tidal influences are more restricted. Base flow ranges are elevated. The Rietvlei wetlands are elevated well above the average tide conditions, with little possibility of back-flooding under the closed state.		
State	**Closed**	**Open, brackish**	**Open, freshwater dominated**	**Closed**	**Open, brackish**	**Open, freshwater dominated**
Lagoon	40	30	5	40	15	1
Channel	20	5	0	15	0	0
Rietvlei	15	0	0	0	0	0
Deep pools (e.g. Flamingo Vlei)	0	0	0	2	2	2

No measured data on the reference water quality (i.e. prior to anthropogenic influences) could be obtained for this estuary. However, considering the catchment of the system, it can be assumed that, on average, its open water areas were clear, well-oxygenated and oligotrophic. Upwelling may have increased DIN and DIP concentrations in estuary during open marine state. Historical data on the system (after anthropogenic influence) is available from in Grindley & Dudley (1988) and Taljaard *et al.* (1992). However, due to rapid urbanisation in the area the estuary is now subject to major anthropogenic impacts on water quality, specifically diffuse runoff from urbanised area in the catchment around the systems, as well as WWTW effluent (Potsdam WWTW) (Peak Practice 2008). Available data best representative of present water quality (2010 – 2016) is summarised in Table 3-30 (City of Cape Town, Candice Haskins, pers. comm.)

Table 3-30 Available water quality data representative of present state Diep/Rietvlei Estuary

Location	Period	Salinity	DO	TSS	NOx-N	NH4-N	DIN*	PO4-P**
			mg/ℓ	mg/ℓ	µg/ℓ	µg/ℓ	µg/ℓ	µg/ℓ
Diep River inflow (RTV01)	2010-2016	2	4.6	20	411	596	1007	860
Flamingovlei (RTV02)	**2010-2016**	**2**	**9.0#**	**23**	**67**	**73**	**140**	**32**
Channel (RTV05)	**2010-2016**	**1**	**3.3**	**17**	**1254**	**886**	**2133**	**1026**
Upper Lagoon (RTV09)	2010-2016	12	7.6	30	1155	365	1515	811
Lower Lagoon (RTV10)	2010-2016	19	8.2#	39	494	231	720	357
Average Lagoon (RTV09,10)	**2010-2016**	**15**	**8.0#**	**35**	**824**	**298**	**1117**	**584**

* *Dissolved inorganic N* = sum of NOx-N and NH4-N

*** Dissolved inorganic P = Dissolved ortho-phosphate (PO4-P)*

 # Assume supersaturation thus diurnal DO fluctuations expected

For the Present State, water quality conditions in the various zones in the system were based on average measured data. For all future scenarios the water quality conditions in the deep pools and wetlands (wetland assumed similar to deep pools as no measured data were available for this zone) were set similar to present, as none of the Scenarios are expected to change water quality in these zones. To estimate water quality conditions for the future scenarios in the canal and estuary, proportional contributions of WWTW and river inflow were used to calculate DIN, DIP and TSS concentrations. Dissolved oxygen, however, could not be estimated in this manner for future scenarios, being strongly non-conservative, and concentrations were therefore based on available data and expert opinion. Present concentrations of nutrients in effluent for the Potsdam WWTW for the period 2010 to 2016, together with estimated future water quality concentrations under different scenarios are presented in Table 3-31. For Scenarios 1, 2 and

3 effluent concentrations were set as per the General Authorisation Standards under the National Water Act (Special Limits) (DWA, 2013). Measured river water quality for the Diep River is as per Table 3-30.

Table 3-31 Estimated volume and water quality from WWTW effluents under various scenarios, as well as estimated river water quality

Parameter	Present WWTW (2010-2016)	WWTW (Sc 1)	WWTW (Sc 2)	WWTW (Sc 3)	No WWTW (Sc 4)	River (present)
Flow (m^3/s)	0.66	0.66	0.33	0.16	0	
Total NH_4-N (µg/ℓ)	1300	2000	2000	2000	-	596
NOx-N (µg/ℓ)	2900	1500	1500	1500	-	411
DIN (µg/ℓ)	**4200**	**3500**	**3500**	**3500**	**-**	**1007**
DIP (µg/ℓ)	**2700**	**1000**	**1000**	**1000**	**-**	**860**
SS (mg/ℓ)	**10**	**10**	**10**	**10**	**-**	**20**

Based on the above approach, the estimated water quality conditions for abiotic states under each of the future scenarios - should these occur - were estimated.

The water quality scores and summary of changes are presented in Table 3-32 and Table 3-33.

Table 3-32 Summary of changes and calculation of the water quality health score

Variable		Present	Sc 1	Sc 2	Sc 3	Sc 4	Conf
1	**Salinity**	42	42	42	49	72	L
2	**General water quality**						
a	Nutrient (DIN/DIP) concentrations	28	29	30	30	31	L
b	Dissolved oxygen	80	82	81	83	81	L
c	Total suspended solids	41	46	46	45	44	L
d	Toxic substances	30	30	35	40	45	L
	Water quality score*	**36**	**38**	**39**	**40**	**41**	**L**

**Score = (0.6 x S + 0.4 x min (a to d))*

Table 3-33 Summary of expected changes in the various water quality parameters under the future flow scenarios.

Parameter	Summary of Changes
Salinity	Sc 1 to 3 ⇩ as a result of increased baseflows flow relative to Reference and infilling of the wetlands. Sc 3 and 4 a slight ⇩ as a result of decrease in WWTW flow.
Inorganic nutrients (DIN/DIP) in estuary	⇧⇧ due to nutrient input from WWTW effluent and urban runoff. The variation in scores of future scenarios relates to the fraction of WWTW effluent to total inflow, higher inflow equals lower score.
Dissolved oxygen in estuary	⇩⇩ due to organic and nutrient loading from urban and WWTW runoff, as well as algal growth (in Flamingovlei, Rietvlei and Milnerton Lagoon)
Suspended solids in estuary	⇧⇧ due to urban runoff and WWTW input, as well as phytoplankton biomass (in deep pools, wetland and estuary)
Toxic substances in estuary	⇧⇧ due to urban runoff and WWTW input

3.3.6.6 Overall Estuary Health Score for Scenarios

The resulting overall estuary health score is determined for the different scenarios in terms of a number of factors including hydrology, hydrodynamics, water quality, microalgae, macrophytes invertebrates, fish and birds. The results of the analysis for the Rietvlei/Diep estuary are shown in Table 3-34. The overall estuary health score improves to a maximum of 50% under Scenario 3 (75% reduction in waste water inputs) but drops down to 47% under Scenario 4 due to loss of freshwater input and impacts on mouth dynamics (increased closure).

Table 3-34 Estuary health scores for alternative flow scenarios for the Diep estuary

Component	Present	Sc1	Sc2	Sc3	Sc 4
Hydrology	59	59	59	59	59
Hydrodynamics and mouth condition	83	83	81	85	64
Water quality	38	39	40	42	47
Physical habitat alteration	30	30	30	30	30
Habitat health score	**52**	**53**	**52**	**54**	**50**
Microalgae	45	45	45	48	50
Macrophytes	30	32	35	38	40
Invertebrates	16	20	20	24	40
Fish	40	40	45	55	30
Birds	61	61	63	64	61
Biotic health score	**38**	**40**	**42**	**46**	**44**
Estuary Health Score	**45**	**46**	**47**	**50**	**47**
Ecological Category	**D**	**D**	**D**	**D**	**D**

The alternative scenarios that were evaluated in this study do not significantly improve the health of the estuary owing to the extremely high nutrient and suspended solid levels in the waste water from the Potsdam WWTW and also those from the catchment, and the reduction in runoff from the catchment.

As such, maintaining status quo (D category) is considered the Best Attainable State (BAS), and hence the REC for this system.

Additional non-flow related measures that could be implemented to improve the current state of health of the system include the following:

- reducing abstraction of freshwater from the catchment,
- establishment of riparian buffers in the catchment;
- improving the quality of stormwater entering the system especially from informal settlements,
- dredging Milnerton lagoon to improve tidal exchange but only once water quality issues have been addressed to prevent problems with anoxia (under the present situation dredging will most likely reduced flushing time and may result in deoxygenation of the bottom waters in the estuary which is highly undesirable);
- reduction of illegal fishing (by recreational fishers and poachers using gill nets),
- removing alien plants from the catchment and estuary functional zone (EFZ),
- remove any remaining portions of the weir that was constructed near the mouth of Milnerton lagoon in 1928
- consider introducing hippos to control vegetation in the EFZ.

3.3.7 Wildevoëlvlei Estuary (IUA E11)

3.3.7.1 Catchment area and activities

The Wildevoëlvlei estuary catchment (Figure 3-11) is relatively small and lies within the City of Cape Town Metropolitan Municipality. The catchment consists of a low-lying basin surrounded by Chapman's and Noordhoek peaks to the north and the Brakkloof ridge in the south. The catchment is separated from the Silvermine/Clovelly catchment by the Spitskop and Dassenberg peaks in the east. Wildevoëlvlei estuary comprises the two Wildevoëlvleis, a 0.75 km estuary channel and the backshore lagoon on the southern half of Noordhoek beach. There is no defined river that feeds into Wildevoëlvlei although there is evidence that a relic connection existed between Wildevoëlvlei, the Lakes (previously the Noordhoek saltpans) and Papkuilsvlei (Heinecken, 1985). The estuary is separated from other low-lying areas in the north by some higher-lying dune areas. These systems are also most likely linked via groundwater.

The Wildevoëlvlei estuary system is divided into four main sections, upper vlei, lower vlei, the backshore lagoon and the channel connecting the lower vlei to the lagoon and/or sea (Figure 3-12).

The estuary functional zone (EFZ) includes the open water area, estuarine vegetation and floodplain areas, with the 5-m contour line acting as a guideline to delimit the latter. The EFZ for Wildevoëlvlei (http://bgis.sanbi.org/) included the Goeiehoop estuary and backwater lagoon at the north of Noordhoek beach as well as the areas below 5 m behind this estuary. Although these areas may once have been hydrologically linked to Wildevoëlvlei, this is no longer the case, and were thus separated for the purposes of this study. The boundary was drawn along some higher lying ground between the two estuaries. The portion of the EFZ for Wildevoëlvlei estuary system considered in this study (266.4 ha) is shown in Figure 3-12. Open water area for this system is estimated at 22.0 ha. The mouth area was also decreased to exclude the rocky shore.

Figure 3-11 Wildevoëlvlei estuary system catchment.

Figure 3-12 Extent of the Wildevoëlvlei/Goeiehoop estuary system function zone (EFZ; blue line; http://bgis.sanbi.org/) in relation to the area considered in this study (dotted red line).

The Wildevoëlvlei catchment falls within the Fynbos Biome with natural vegetation making up the largest land use type in the catchment (~60%). Urban residential and industrial areas make up the next most predominant land use (29% of the catchment). The catchment is located within the winter rainfall region, although orographic rain originating from the mountain ranges close to the coast result in local concentrations of rainfall (Heinecken & Damstra, 1983).

3.3.7.2 Anthropogenic developments within the estuary system

Under natural conditions Wildevoëlvlei estuary system comprised a series of seasonal pans. Data collected in the 1970s showed the pans to be hypersaline (TDS >150 mg/l) and nearly empty (Heinecken, 1985). Since the construction of the waste-water treatment works (WWTW) in 1976, Wildevoëlvlei has contained water perennially, with nearly all the summer inflow attributed to treated effluent (Heinecken, 1985). Natural runoff from the catchment has not been reduced significantly compared to the reference flow (94%) and the catchment is mostly (74%) vegetation with 25% urban development. Prior to the construction of the WWTW, sea water penetration into Wildevoëlvlei occurred during high tides with saline waters, seaweed and other marine flotsam present (Heinecken, 1985). The estuary has become increasingly freshwater-dominated with monthly average wastewater volumes of 0.28 million m^3 limiting sea water penetration, which is now mostly to the backshore lagoon area. The mouth does still close when a sandbar forms during the summer months, and the estuary then drains into the backshore lagoon.

The Noordhoek beach is 4 km long, 500 m wide and very flat (Heinecken, 1985). The north and south beaches are divided by a central dune area which separates two large, shallow seasonal backshore lagoons. The southern lagoon is fed by an overflow channel from Wildevöelvlei and the northern lagoon by seasonal storm water drainage from the Papkuilsvlei. Both lagoons are fed by overwash from the sea during winter storms and spring tides. The foreshore is wider at the northern beach and therefore the northern backshore lagoon is only connected to the sea when it is full and has broken open at this end.

During sea storms and high spring tides large amounts of marine debris (e.g. kelp, wood) are driven up the connecting channel into the lower vlei and on occasions even through to the upper vlei.

Historical maps and charts (1786, 1790, 1822, 1890, 1901, 1964, and 1978) show that human influence over the years has significantly altered the drainage pattern of the system – there were more feeder streams and better-established connections between the vleis and the pans. The vleis were originally fed by runoff from the southern mountains and sub-surface seepage, over the years flow to the vleis has been augmented by stormwater discharges from Ocean View (1970 onwards), the light industrial areas of Fish Eagle Park and Heron Park (1980 onwards), Masiphumelele informal settlement (1995 onwards) and Sun Valley (the latter flows through reed beds before it reaches the vleis). The most significant flow is, however, received from the adjacent Wildevoëlvlei WWTW, which serves Noordhoek, Kommetjie and Fish Hoek, and which discharges polished effluent into the eastern vlei.

The area presently covered by the backshore lagoons used to be dune field. At present the alien vegetation planted to stabilise this dune field covers all but the central dune areas.

The only obstructions to water flowing into the wetlands are the bridges on the roads which cross the various water courses draining the surrounding mountain slopes. None of these bridges, which are all minor structures, seems to impede flow to a great extent.

Currently the estuary is subject to major anthropogenic impacts on water quality, specifically surface runoff from urbanised area around the systems (Heinecken, 1985; Gassner, 1999), as well as effluent from the Wildevoëlvlei WWTW being discharged into the upper vlei area.

Elevated flows from the WWTW are likely to maintain artificially high-water levels in the vleis throughout the year, as well as persistent outflow through the Southern backshore lagoon.

3.3.7.3 Scenarios Considered

Although there are no firm plans for increased (or decreased) utilisation of water in the Wildevoëlvlei catchment, a number of hypothetical scenarios were constructed to examine likely impacts of improving the quality and/or reducing the volume of effluent discharged into the catchment on the health of the estuary. It was assumed that reductions in flow could be achieved through recycling or diversion of waste water out of the catchment and improvements in waste water quality achieved through implementation of improved treatment technology and or upgrading of the WWTW. The following scenarios were considered:

- **Natural**: Reference condition
- **Present**: Present day flows and conditions

- **Scenario 1:** Maintain present day flows but all effluent from WWTW to be treated to DWS Special Standards
- **Scenario 2:** Reduce inputs from the WWTW by 50% and treat the remainder to DWS Special standards
- **Scenario 3:** Reduce inputs from the WWTW by 75% and treat the remainder to DWS Special standards
- **Scenario 4:** Divert/recycle 100% of effluent from WWTW

A summary of the scenarios considered are given in Table 3-35.

Table 3-35 Summary of scenarios considered for the Wildevöelvlei Estuary (IUA E11)

Scenario	Description	MAR (million m^3/a)	Percentage of natural flows
Natural	Reference condition	6.299	100%
Present	Present day flows	9.269	147%
Scenario 1	Present day flows + special WWTW standards	9.269	147%
Scenario 2	50% reduction in WWTW flows + special WWTW standards	7.584	120%
Scenario 3	75% reduction in WWTW flows + special standards	6.742	107%
Scenario 4	Zero input from WWTW	5.899	94%

3.3.7.4 Hydrodynamics

The Noordhoek beach is 4 km long, 500 m wide and very flat (Heinecken, 1985). The north and south beaches are divided by a central dune area which separates two large, shallow seasonal backshore lagoons. The southern lagoon is fed by an overflow channel from Wildevöelvlei and the northern lagoon by seasonal storm water drainage from the Papkuilsvlei. Both lagoons are fed by overwash from the sea during winter storms and spring tides. The foreshore is wider at the northern beach and therefore the northern backshore lagoon is only connected to the sea when it is full and has broken open at this end. During sea storms and high spring tides large amounts of marine debris (e.g. kelp, wood) are driven up the connecting channel into the lower vlei and on occasions even through to the upper vlei.

Historical maps and charts (1786, 1790, 1822, 1890, 1901, 1964, and 1978) show that human influence over the years has significantly altered the drainage pattern of the system – there were more feeder streams and better-established connections between the vleis and the pans. The vleis were originally fed by runoff from the southern mountains and sub-surface seepage, over the years flow to the vleis has been augmented by stormwater discharges from Ocean View (1970 onwards), the light industrial areas of Fish Eagle Park and Heron Park (1980 onwards), Masiphumele informal settlement (1995 onwards) and Sun Valley (the latter flows through reed beds before it reaches the vleis). The most significant flow is, however, received from the adjacent Wildevöelvlei WWTW, which serves Noordhoek, Kommetjie and Fish Hoek, and which discharges polished effluent into the eastern vlei.

The area presently covered by the backshore lagoons used to be dune field. At present the alien vegetation planted to stabilise this dune field covers all but the central dune areas.

The only obstructions to water flowing into the wetlands are the bridges on the roads which cross the various water courses draining the surrounding mountain slopes. None of these bridges, which are all minor structures, seems to impede flow to a great extent. Elevated flows from the WWTW are likely to maintain artificially high-water levels in the vleis throughout the year, as well as persistent outflow through the Southern backshore lagoon. While little hard data exits, it is assumed that elevated and stable water levels represent the most significant altered hydrodynamic variable. Therefore, as the waste water into the system are reduced from Scenario 1 to 4 a concomitant reverting to reference water levels is anticipated.

3.3.7.5 Water Quality

For the purposes of this study, the Wildevöelvlei estuary system is sub-divided in to four zones (Figure 3-12). Under the Reference conditions the salinities of the various water bodies fluctuated considerably according to the seasons. This was attributed to high evaporation losses from the shallow pans during the hot windy summers and fresh water input from the catchments in the winter (Heinecken, 1985). At present the Wildevöelvleis are mostly fresh, with salinity confined to the channel and backwater lagoons.

No measured data on the reference of the other water quality parameters could be obtained for this estuary. However, considering the catchment of the system, it can be assumed that, on average, its water bodies were clear, well-oxygenated and oligotrophic. Currently the estuary is subject to major anthropogenic impacts on water quality, specifically surface runoff from urbanised area around the systems (Heinecken 1985, Gassner 1999), as well as effluent from the Wildevöelvlei WWTW being discharged into the upper vlei area. Available data best representative of present water quality was used for the current water quality situation.

As a result of anthropogenic influence (urban development and WWTW effluent), water quality in the systems has been highly modified. Inorganic nutrient concentrations have increased markedly, resulting in regular algal blooms. Associated with the algal blooms, supersaturation in dissolved oxygen has been recorded mainly attributed to high photosynthetic rates associated with dense algal activity.

However, such supersaturation often also results in an equally marked reduction of oxygen as a result of respiration at night. Thus, under the present state high fluctuation in dissolved oxygen is expected, ranging from supersaturation during the day to hypoxia/anoxia during night time, especially in the lower and upper vleis. The high total suspended solid concentrations recorded in the estuary are mainly attributed to high phytoplankton biomass dominated by Cyanophyceae and Chlorophyceae rather than high total suspended entering from freshwater inflow or WWTW effluent.

Proportional contributions of WWTW inflow and freshwater flow were used to calculate resultant DIN and DIP concentrations in inflow to the system, and ultimately the concentration in the estuary for future scenarios. Dissolved oxygen and TSS, however, could not be estimated in this manner, being strongly non-conservative parameters (e.g. reliant on algal biomass and not inflow). DO and TSS concentrations, therefore, were derived from available data. Using this approach, as well as expert opinion, average water quality concentrations under the reference, present and future scenarios for the Wildevöelvlei estuary system were estimated in Table 3-36. Water quality scores for the present and future scenarios are presented in Table 3-36 and the rationale is provided in Table 3-38.

Table 3-36 Estimated water quality concentrations under reference, present and future scenarios for the Wildevöelvlei estuary system.

Salinity	Reference	Present	Scenario 1 (present WWTW; Special limits)	Scenario 2 (50% ⇩ WWTW; Special limits)	Scenario 3 (75% ⇩ WWTW; Special limits)	Scenario 4 (no WWTW)
Backshore lagoon	20	10	10	10	15	20
Channel to Lower vlei	15	5	5	5	7.5	15
Lower vlei	10	0	0	0	2	10
Upper vlei	2	0	0	0	1	2
DIN (µg/ℓ)	**Reference**	**Present**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Backshore lagoon	50	200	200	200	200	200
Channel to lower vlei	50	1300	750	750	500	250
Lowervlei	50	2098	1500	1500	1000	500
Upper vlei	50	1543	1500	1500	1000	500

DIP (µg/ℓ)	Reference	Present	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Backshore lagoon	10	50	50	50	50	50
Channel to lower vlei	10	900	225	150	100	50
Lowervlei	10	847	450	300	200	100
Upper vlei	10	951	450	300	200	100
DO (mg/ℓ)	**Reference**	**Present**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Backshore lagoon	8	6	6	6	6	6
Channel to lower vlei	8	4	5	6	6	6
Lowervlei	8	3	4	5	5	6
Upper vlei	8	3	4	5	5	6
TSS (mg/ℓ)	**Reference**	**Present**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Backshore lagoon	5	10	10	10	10	10
Channel to lower vlei	5	74	60	50	40	30
Lowervlei	5	169	130	100	80	60
Upper vlei	5	111	90	70	50	40

Table 3-37 Summary of changes and calculation of the water quality health score

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Confidence
1 Salinity						
Similarity in salinity	34	34	34	67	97	L
2. General water quality						
a. Nutrient (DIN/DIP) concentrations	12	14	16	18	27	L
b. Dissolved oxygen	65	74	81	81	86	L
c. Total suspended solids	23	25	27	30	33	L
d. Toxic substances	40	45	50	55	60	L
Water quality score*	**24**	**27**	**30**	**32**	**39**	**L**

**Score = (0.6 x S + 0.4 x min (a to d))*

Table 3-38 Summary of changes of the water quality health parameters.

Parameter	Summary of Changes
Salinity	Scenario 1 to 3: Backshore lagoon ⇩ than reference due to nutrient input from WWTW effluent and urban runoff, but an ⇧ in the channel as the City of Cape Town have deepened it as remedial action to increase salinity penetration. Scenario 4: Backshore lagoon and channel very similar to reference due to removal of WWTW effluent.
Inorganic nutrients (DIN/DIP) in estuary	⇧⇧ due to nutrient input from WWTW effluent and urban runoff. The variation in score of future scenarios related to the fraction of WWTW effluent to total inflow.
Dissolved oxygen in estuary	⇩ due to diurnal variation associated with eutrophication caused by nutrient input from anthropogenic sources (e.g. WWTW effluent and urban runoff)
Suspended solids in estuary	⇧⇧ due to high phytoplankton biomass associated with nutrient inputs

Parameter	Summary of Changes
Toxic substances in estuary	⇧⇧ due to urban runoff and WWTW input to the estuary.

3.3.7.6 Overall Estuary Health Score for Scenarios

All of the alternative scenarios considered in this assessment (progressive reductions in the volume and/or improvements in the quality of waste water discharged to the system) resulted in an improvement in health, culminating in Scenario 4 where the health improved to 70% (C category). Further improvements could also be achieved by opening up the channel between the lagoon/beach and Wildevöelvlei, clearing some of the reeds in the vlei and channel, and dredging some of the accumulated sludge from the bottom of the system.

Table 3-39 Estuary health scores of alternative flow scenarios for the Wildevoëlvlei estuary system.

Component	Present	Sc1	Sc2	Sc3	Sc4
Hydrology	74	74	90	94	94
Hydrodynamics and mouth condition	40	40	55	75	90
Water quality	26	28	31	39	51
Physical habitat alteration	50	50	50	50	50
Habitat health score	**47**	**48**	**56**	**65**	**71**
Microalgae	20	20	25	35	45
Macrophytes	45	45	50	60	70
Invertebrates	38	45	55	65	85
Fish	30	30	40	55	75
Birds	54	54	58	71	76
Biotic health score	**37**	**39**	**46**	**57**	**70**
Estuary Health Score	**42**	**43**	**51**	**61**	**71**
Ecological Category	**D**	**D**	**D**	**D**	**C**

3.3.8 Zandvlei Estuary (IUA E12)

3.3.8.1 Catchment area and activities

The Zandvlei catchment (Figure 3-14) lies within the City of Cape Town Metropolitan Municipality. The catchment of Zandvlei is approximately 92 km^2 and bordered by Muizenberg Mountain, Silvermine Plateau and Constantiaberg to the West, Wynberg Hill to the North and a smaller, less noticeable eastern boundary. The main streams draining the catchment are the Keysers River and Sand River Canal as well as the smaller Westlake Stream and Langvlei Canal. The estimated contribution of flow is about 45%, 43% and 12% from the Keysers, Sand and Westlake rivers, respectively (Coastal & Environmental Consulting 2010). The current MAR is estimated to be 93% of natural MAR and there are no WWTWs discharging into the estuary or its source rivers. Under natural conditions the estuary was temporarily open and during the open mouth phase, there would have also been a significant tidal influence through the estuary mouth. This tidal influence is now greatly altered due to canalization, weir construction and artificial mouth management.

The estuary functional zone (EFZ) includes the open water area, estuarine vegetation and floodplain areas, with the 5-m contour line acting as a guideline to delimit the latter. Based on the EFZ (http://bgis.sanbi.org/) the 5-m contour around Zandvlei includes extensive area around the upper reaches and to the east (Marina da Gama) of this system that have been completely transformed by residential development. These areas contain little or no estuarine vegetation or fauna and are no longer functionally linked to the estuary.

More than half of the catchment is urbanised. The next most common land use is natural vegetation, mainly in Table Mountain National Park and covered with fynbos vegetation (Figure 3-14). There is also a small amount of agriculture (mainly wine grapes) as well as forestry occurring in the catchment in the suburbs of Constantia and Tokai. Substantial development has occurred within the Zandvlei Estuary EFZ, including the residential developments such as Marina da Gama, as well as recreational areas, roads and bridges.

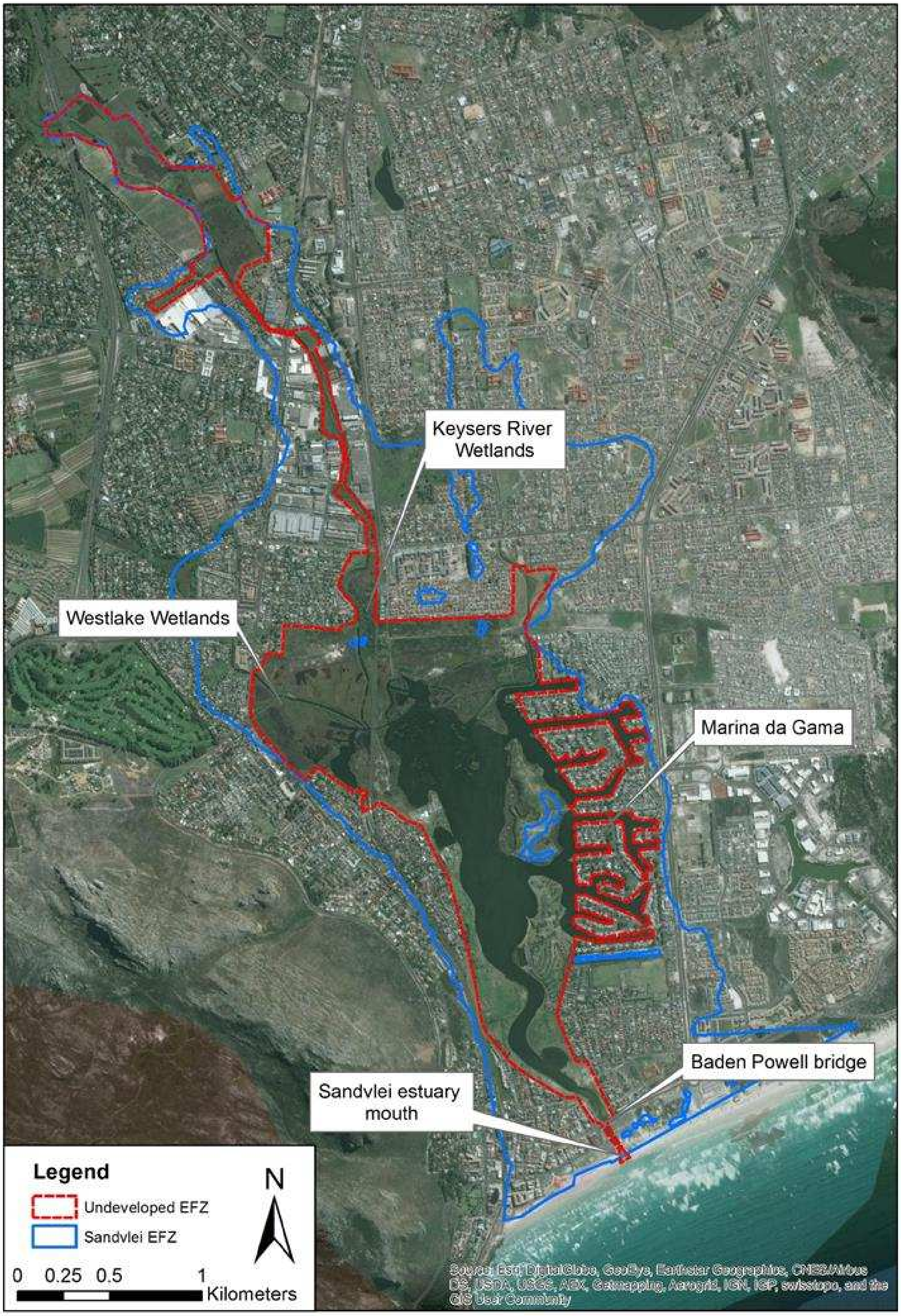


Figure 3-13 Extent of Zandvlei Estuary functional zone (EFZ; blue line; http://bgis.sanbi.org/) in relation to the undeveloped EFZ (red-dotted line).

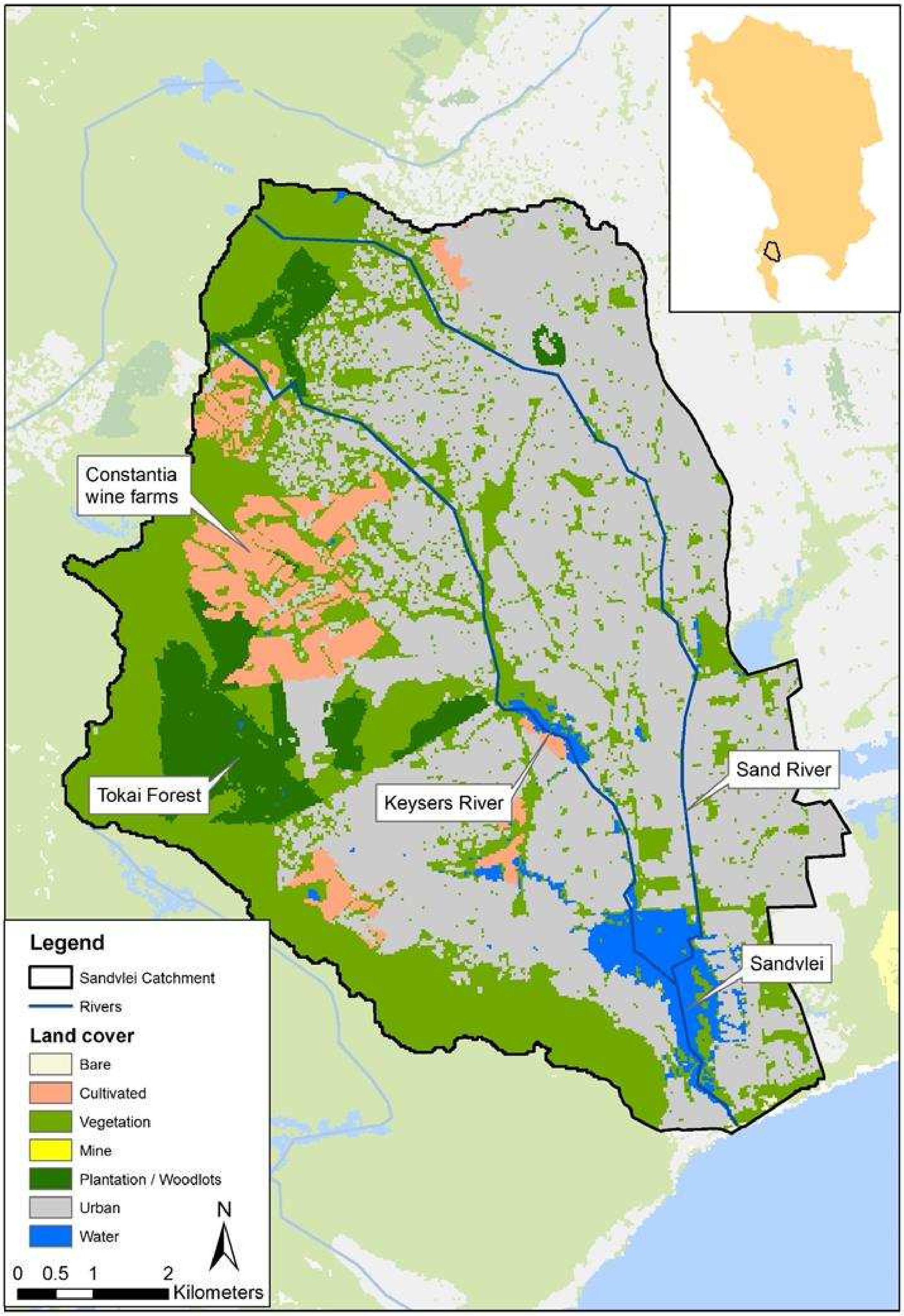


Figure 3-14 The Zandvlei Estuary catchment showing main inflowing rivers and surrounding land cover including some remaining pine plantations.

3.3.8.2 Anthropogenic developments within the estuary system

Zandvlei lies on the south-westerly extremity of the Cape Flats. The western shore lies close to the steep sandstone slopes of Muizenberg Mountain, while the eastern and northern shores are bounded by the remains of the sand dunes which formerly dominated the area. The present form of Zandvlei bears little resemblance to the original. Under Reference Conditions the shore gradient of the system was gentle and the water was surrounded by extensive muddy marshlands (Morant & Grindley, 1982).

The physical habitat of Zandvlei has been severely altered as the result of decades of human modifications to both the vlei and the catchment feeding it. Historical maps show a wide-open mouth (Morant & Grindley, 1982). Mouth closure is expected to have occurred towards the end of summer. Currently the mouth of Zandvlei is subjected to contingency management in order to maintain the water levels as close as possible to the design levels for Marina da Gamaand to assist with faunal movement into and out of the estuary and water quality improvement

The bathymetry of Zandvlei is complex since the vlei has been subjected to a number of dredging programmes since 1947. Currently much of the vlei does not exceed 1.0 m in depth. Two 2 m deep dredge channels have been excavated in the main basin of the vlei. Dredging has also been undertaken between the Imperial Yacht Club and Caravan park where the depth varies between 1 and 2 m.

Historical records indicate no gradation of the bottom material particle size from the head of the estuary to the mouth. This is likely due to the severe disturbance of the bottom material caused by the extensive dredging operations undertaken in 1947 and 1961. Under Reference Conditions, there was likely a gradation of particle sizes from fine muds in the upper reaches to coarse sand at the entrance channel and mouth. During a survey in May/June 1982 coarse grain shelly sand was found at the mouth of the channel, while at the adjacent beaches the sand was fine. Historical engineering reports indicate that beach grain size was in the fine to medium range (Morant & Grindley, 1982).

3.3.8.3 Scenarios Considered

There are no firm plans for increased (or decreased) utilisation of water in the Zandvlei catchment, and opportunities for this are limited aside from informal unregulated utilisation of water from streams by private landowners. Even complete clearing of all forest and aliens in the Zandvlei catchment (about 7.3 km^2) is not expected to result in a significant change in flow in this catchment (increase by 1.5 million m^3/a). Sources of pollution in the catchment are almost all non-point sources (e.g. stormwater and urban drainage) and are not easy to address. Thus, it was agreed that alternative scenarios for this system must focus on habitat restoration and restoration of hydrodynamic functioning rather than flow or water quality. It was assumed that other mouth management practices would continue (i.e. artificial opening and closure of the mouth for a few days each spring tide). The following scenarios were considered:

- **Natural**: Reference condition
- **Present**: Present day flows and conditions
- **Scenario 1**: Complete removal of the rubble weir and other obstructions (pipelines) at mouth of the estuary to allow improved tidal flushing.
- **Scenario 2**: Remove bank stabilisation (concrete banks in lower reaches of the estuary and reshape banks) to create more shallow water marginal habitat.
- **Scenario 3**: Dredge the upper reaches of the vlei to -2.0 m MSL to remove accumulated silt and organic material.
- **Scenario 4**: Combination of interventions for Scenario 1 and 2

Present-day flows into the estuary are estimated to be 93% of flows under natural (Reference) conditions, and no change is expected for any of the future scenarios. The 1:50 year floods are estimated to be 98% similar to Reference condition.

3.3.8.4 Hydrodynamics

Zandvlei is a long, shallow estuarine system. It is 2.5 km long and 0.5 kilometres wide at its widest point, excluding Marina da Gama, and has a depth of between 0.5 and 1.5 metres. In its current configuration, Zandvlei can be divided into four basic components: the estuary entrance channel, the main basin, the Marina da Gama canal system and the wetlands to the north of the system associated with the inflowing rivers. Although naturally a wholly estuarine system, today the system is only semi-estuarine as a result of changes to its catchment and mouth configuration. The exit to the sea consists of a 20-m wide, concrete channel.

The water level in the estuary is controlled either by a rubble weir situated in the estuarine channel or by a sand bar which periodically closes the mouth. The purpose of the rubble weir is to assist with water level management and to prevents scour which could damage the sewer pipeline which is located upstream of the weir and traverses the bed of the estuary from the west to east. In addition to the rubble weir the most important obstruction is the 700-m long railway embankment running north-south across the north-western part of the vlei. A single culvert allows the passage of water from the Keysers and Westlake Rivers into the main body of the vlei. The Baden Powell bridge spans the canalised outlet of the System some 200 m from the sea.

Under the Reference condition the vlei dried out during drought conditions when the river inflow in summer was exceeded by evaporation during the closed state. Under these conditions it is likely that evaporation would have caused hypersaline conditions to prevail for a while and, if the drought persisted, nearly the entire vlei would have eventually dried up. Under the Reference conditions, water levels of 2.5 to 3.0 m MSL were often reached before the sand berm at the mouth was breached, and in the process a large area around Zandvlei was flooded. After breaching, large amounts of sediments were flushed from the mouth region resulting in a wide, open mouth with channel depths below MSL.

Under the Reference Condition strong tidal exchange occurred and the mouth would have stayed open for long periods because of the greater tidal flows. No record exists of historical mouth conditions, but given the reference monthly flow regime (this study) and a surface area of about 100 ha it is estimated that a monthly volume greater than 2.0×10^6 m^3 represents potential open mouth conditions, therefore, the system could have been open between 30 to 40% of the time in winter under the Reference state. Longer periods of open mouth conditions would have resulted in an increase in the salinity concentrations in the vlei.

Until about 1920, the lower part of the vlei was still strongly influenced by high tides and there was a large area of open water. However, after the mouth of the vlei was constricted by a weir and canalised under the Muizenberg Promenade, the lake bed gradually filled in in the lower reaches and in many summers the vlei was almost dry. By 1946, the increased siltation and weed infestation was so bad that the yacht club had to disband. Work on dredging the vlei and stabilising its water level started in 1947 and was completed in 1961 when the western bank was reclaimed, stabilised and extensive recreation areas established. The yacht club was reconstituted and other boating organisations were established. The vlei was further modified in the 1970s when Marina da Gama was built on its eastern shores.

Under the Present State, low-lying developments, especially Marina da Gama, necessitate artificial breaching while the water level in the vlei is between 1.1 and 1.4 m MSL. This situation is further exacerbated by the presence of the rubble weir (used to maintain a high-water level for boating and to protect a sewage pipe), which prevents the water levels from dropping low enough to allow significant scouring and an adequate influx of seawater. Consequently, flushing of sediments after breaching is insufficient to open the mouth properly and maintain a prolonged connection to the sea. The result is considerable sedimentation in the vlei, particularly directly upstream of the weir where a sand plume has developed, which has reduced the open water area in the lower reaches.

Table 3-40 Highest and lowest water level in Zandvlei under the Reference and present Conditions.

	Highest water level (m MSL)	Lowest water level (m MSL)
Reference	2.5-3.0	0.0-0.3
Present	1.3-1.4	0.6-0.4

At present the system is only open for a few days at a time over the spring tide, but this actual period over which this mouth manipulation is required is spread over more months as the lower water levels require earlier (and potentially later) interventions than under the Reference conditions. However, as the estuary is now only allowed to remain open for a few days at a time, open mouth conditions are now estimated at 10 to 30% of the time.

Little information exists on the salinity structure of Zandvlei. Noble & Hemens (1978) reported that Zandvlei water was fresh to saline with no vertical stratification. However, Benkenstein (1982) stated that a salt wedge can be detected in the main basin. Salinity stratification mainly occurs in the winter when the estuary mouth is open and seawater penetrates the vlei under the outflowing fresh water (Morant & Grindley 1982).

The prevailing wind regime is an important driver of the hydrodynamic processes in Zandvlei. With both the South-Easterlies and North-Westerlies, in combination with the system's shallow bathymetry, the vlei is usually well mixed unless the mouth is open with a strong outflow. The exception here is the deeper and more sheltered Marina da Gama channels, where a halocline can form relatively easily, especially during the calmer winter months (Morant & Grindley 1982).

Under scenario 1 (removal of rubble weir) circulation and tidal flushing in the entrance channel and main basin is expected to improve significantly, with the increase in tidal variation. Scenario 2 will not affect the hydrodynamics of the system significantly. However, should the main basin of Zandvlei be dredged to deeper than 2 m under Scenario 3, the circulation patterns in the system are expected to change considerably. Under this scenario there is a high probability of stratification developing throughout the main basin, which in turn, will increase retention of the bottom waters and is associated with poor water quality conditions. This need to be assessed properly through a hydrodynamic modelling study, though.

Based on the above information Zandvlei hydrodynamics were defined in terms of two mouth states – "open" and "closed".

Table 3-41 The occurrence of the open mouth conditions under the Reference Condition, Present State and Scenarios 1 to 3.

Mouth State	Estimated % Occurrence					
	Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4
Closed	80	75	80	80	80	80
Open	20 (few days over Spring tide)	25 (few days over Spring tide)	20 (few days over Spring tide)	20 (few days over Spring tide)	20 (few days over Spring tide)	20 (few days over Spring tide)

Table 3-42 Hydrodynamic health scores for Present Day and the four alternative scenarios relative to the Reference Condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Conf
a. Mouth condition	30	40	30	30	40	VL
b. Tidal variation	20	50	20	20	50	M
c. Salinity structure	50	60	50	30	60	M
Score (min + average (a: b))/2	**27**	**45**	**27**	**23**	**45**	**M**
Score min (a to b)	**20**	**40**	**20**	**20**	**40**	**M**

3.3.8.5 Water Quality

For the purposes of this study, the open water area of Zandvlei Estuary was sub-divided into four zones:

- Lower estuary;
- Main basin;
- Marina da Gama;
- Upper wetlands.

No measured data on the reference water quality could be obtained for this estuary. However, considering the catchment of the system, it can be assumed that, on average, its open water areas were clear, well-oxygenated and oligotrophic. The decrease in tidal flushing from reference to present has resulted in mostly brackish salinities being recorded in the system in the 1980s and 1990s. In an attempt to rectify the salinity gradient in Zandvlei Estuary, the City of Cape Town has implemented artificial breaching during high spring tides which have proved to be very effective. This significantly increased the salinity gradient in the system are now regularly recorded after openings. Historical data on the system (after anthropogenic influence) is available from Morant & Grindley (1982). However, due to rapid urbanisation in the area the estuary is now subject to major anthropogenic impacts on water quality, specifically diffuse runoff from urbanised areas in the catchment around the systems (Coastal Environmental Consulting 2010).

Available data on relevant water quality parameters for the periods 2000-2009 and 2010-2016 are available. As a result of anthropogenic influence, water quality in the system has been highly modified as reflected by the water quality data. However, average DIN and DIP concentrations showed a marked decrease from the period 2000-2009 to the period 2010-2016, both in river inflows and in the different zones in the Zandvlei Estuary. This decrease is most likely a result of improved management practices in the catchments. Increased uptake by submerged macrophytes and microalgae can also contribute to lower ambient concentrations and re-suspension of fines, but this needs to be confirmed through more detailed studies.

Supersaturation in dissolved oxygen (DO) has been recorded, as a result of high photosynthetic rates associated with macrophyte and algal blooms, especially in the main basin and marina. However, such supersaturation hints to an equally marked reduction of oxygen as a result of respiration at night. Thus, high fluctuations in DO probably occur in these zones, ranging from supersaturation during the day to hypoxia/anoxia at night (mainly in summer). Recent observation in the wetland zones (S Lamberth, pers. comm.) recorded hypoxia in these areas. Elevated TSS concentrations are mostly linked to contamination from urban catchments (as reflected by TSS in river inflow).

For the purposes of this study present WQ conditions for different zones in Zandvlei were derived mainly from average data for the period 2010-2016. Based on available data and expert opinion, water quality concentrations in the different zones of Zandvlei Estuary, under the reference, present and future scenarios were also estimated (Table 3-43).

Table 3-43 Summary of changes and calculation of the water quality health score.

SALINITY	**Lower Estuary**	**Main Basin**	**Marina**	**Upper Wetland**
Reference	25	20	20	5
Present	15	7	10	0
Scenario 1	20	15	15	0
Scenario 2	15	7	10	0
Scenario 3	15	12	10	0
Scenario 4	20	7	10	0
DIN (µg/ℓ)	**Lower Estuary**	**Main Basin**	**Marina**	**Upper Wetland**
Reference	50	50	50	50
Present	130	180	70	170
Scenario 1	100	150	70	70
Scenario 2	130	180	70	170
Scenario 3	130	180	70	170
Scenario 4	100	150	70	70

DIP (µg/ℓ)	Lower Estuary	Main Basin	Marina	Upper Wetland
Reference	10	10	10	10
Present	110	80	60	80
Scenario 1	90	90	60	80
Scenario 2	110	80	60	80
Scenario 3	110	80	60	80
Scenario 4	90	90	60	80
DISSOLVED OXYGEN (mg/ℓ)	**Lower Estuary**	**Main Basin**	**Marina**	**Upper Wetland**
Reference	8	8	8	8
Present	6	6	6	5
Scenario 1	7	7	6	5
Scenario 2	6	6	6	5
Scenario 3	6	5	6	5
Scenario 4	7	7	6	5
TSS (mg/ℓ)	**Lower Estuary**	**Main Basin**	**Marina**	**Upper Wetland**
Reference	5	5	5	5
Present	40	30	25	40
Scenario 1	30	20	25	40
Scenario 2	40	30	25	40
Scenario 3	40	30	25	40
Scenario 4	30	20	25	40

The water quality scores and changes under future scenarios are presented in Table 3-44 and Table 3-45. A recent study by the CSIR (2015) shows some toxic accumulation in the system, but not severe.

Table 3-44 Summary of changes and calculation of the water quality health score.

Variable		Present	Sc 1	Sc 2	Sc 3	Sc 4	Conf
1	**Salinity**						
	Salinity	48	65	48	54	65	L
2	**General water quality**						
a	Nutrient (DIN/DIP) concentrations	40	47	40	40	47	L
b	Dissolved oxygen	84	87	84	81	87	L
c	Total suspended solids	27	31	27	31	31	L
d	Toxic substances	70	75	70	70	75	L
	Water quality score*	41	46	41	43	46	*L*

**Score = (0.6 x S + 0.4 x min (a to d))*

Table 3-45 Summary of changes to water quality health under different scenarios.

Parameter	Summary of Changes
Salinity	⇩⇩ due to artificial manipulation of the mouth. Scenario 1 shows an increase associated with increased flushing. Scenario 2 similar to present. Scenario 3 slight increase in salinity in main basin.
Inorganic nutrients (DIN/DIP) in estuary	⇧ due to nutrient input from urban runoff/sewage overflow. Slight improvement under Scenarios 1 and 4 relates to stronger tidal flushing in the estuary, main basin compared with present

Parameter	Summary of Changes
Dissolved oxygen in estuary	⇩ due to organic and nutrient loading from urban runoff and high primary production (diurnal fluctuation). Slight improvement under Scenarios 1 and 4 relates to stronger tidal flushing in the estuary, main basin compared with present. Reduction in main basin during Scenario 3 is due to deeper dredged areas potentially developing hypoxia.
Suspended solids in estuary	⇧⇧ due to urban runoff. Slight improvement under Scenarios 1 and 4 relates to stronger tidal flushing in the estuary, main basin compared with present
Toxic substances in estuary	⇧ due to urban runoff. Slight improvement under Scenario 1 and 4 relates to stronger tidal flushing in the estuary, main basin compared with present

3.3.8.6 Overall Estuary Health Score for Scenarios

Scenario 1 and 2 both allows for a small improvement in health (55 and 50, respectively, compared to the current 45), but the estuary remains in a D category. Scenario 3 could result in stratification in the estuary and possible hypoxia and must be investigated in more detail using a hydrodynamic modelling study before it can be implemented. Scenario 4 (a combination of interventions considered under Scenarios 1 and 2) resulted in the best improvement in health to 57 but the estuary remained in a D category.

Table 3-46 Estuary health scores of alternative flow scenarios for Zandvlei.

Component	Present	Sc1	Sc2	Sc3	Sc4
Hydrology	93	93	93	93	93
Hydrodynamics and mouth condition	20	40	20	20	40
Water quality	43	49	43	45	47
Physical habitat alteration	10	15	20	10	25
Habitat health score	**41**	**49**	**44**	**42**	**51**
Microalgae	45	61	50	45	65
Macrophytes	25	35	35	25	35
Invertebrates	68	83	75	68	85
Fish	45	55	50	40	55
Birds	63	72	70	65	75
Biotic health score	**49**	**61**	**56**	**49**	**63**
Estuary Health Score	**45**	**55**	**50**	**45**	**57**
Ecological Category	**D**	**D**	**D**	**D**	**D**

Other interventions that are worth considering to further improve the health of the estuary include improve management of the Westlake Wetlands and any interventions that would improve the quality of influent stormwater. Consideration should also be given to a more modest dredging intervention than the one considered in this study – dredging of parts of the upper vlei to -1 m or -1.5 MSL and also of a channel linking this area to the mouth region. This may assist in entraining more salt water into the estuary and hence improving the salinity structure and further diluting nutrient inputs from the catchment and improving the nursery function of the system. However, the impacts of this intervention on the hydrodynamic functioning and water quality would need to be investigated in detail using a hydrodynamic model before such a measure can be implemented.

3.3.9 Zeekoe Estuary (IUA E11)

3.3.9.1 Catchment area and activities

The estuary functional zone (EFZ) includes the open water area, estuarine vegetation and floodplain areas, with the 5-m contour line acting as a guideline to delimit the latter. The Zeekoe EFZ includes Zeekoevlei, Rondevlei, and the channel down to the mouth (http://bgis.sanbi.org/). Portions of the Cape Flats WWTW ("Strandfontein Sewage Works") and landfill sitefall within the 5-m contour, as well as some other low-lying developed areas, but it is recommended that these be formally excised from the EFZ for this estuary. Excluding these areas, the total remaining area of the undeveloped Zeekoe estuary EFZ is estimated at 366.48 ha, while the open water area was almost the same size (327.34 ha) (Figure 3-15).

The Zeekoe estuary and its catchment (Figure 3-16) fall within the City of Cape Town Metro in the Western Cape Province. The Zeekoe catchment is drained by the Big and Little Lotus Rivers, Zeekoevlei and Rondevlei. The catchment of the Zeekoe estuary is almost 60 km^2. It extends from Kenilworth, across to Weltevreden. The catchment encompasses most of the Philippi farming area as well as suburban and industrial areas of Ottery, Lotus River and Grassy Park. While almost 40% of the Zeekoe estuary catchment is built up urban areas, 22% remains vegetated. Approximately 25% of the catchment is under small-scale agriculture in the Philippi Horticultural Area.

Seaward of Zeekoevlei and Rondevlei the predominant southerly winds have built sand dunes which range from 10 to 35 m in height. However, siltation does not appear to be a major problem in the water courses of the catchments. Some sediment deposition has occurred where the Big and Little Lotus rivers enter the vleis, necessitating dredging from time to time (Bickerton, 1982).

Wind-blown sand used to enter Zeekoevlei from the south-east. Artificial stabilisation of the dunes surrounding the system commenced in 1936. This stemmed the movement of sand into the vlei from the 1950s onwards. Development in and around the EFZ also prevents the free movement of sediments into and around the vleis. At present the vleis do not dry out, which in turn prevents the removal of sediment by means of wind erosion, possibly contributing to long term siltation in some areas.

In Zeekoevlei, dead algae and mud has accumulated up to 2 m thick on the bottom of the vlei. During the 1982, a dredging programme was undertaken to remove some of the accumulated organics. However, only a part of the vlei was dredged during that time, leaving large volumes of the sludge in places.

The City of Cape Town at times straightens the estuary mouth channel to prevent extensive beach migration which threatens Baden Powell Drive, thus preventing the development of a backwater lagoon and the free migration of the mouth.

The cut-off drain that was excavated to prevent groundwater from the Cape Flats WWTW from draining into Zeekoevlei is indicated as a dotted yellow line.

Figure 3-15 Extent of the Zeekoe undeveloped estuary functional zone (undeveloped EFZ; red dotted line) in relation to the entire EFZ (blue lines, http://bgis.sanbi.org/) showing the location of the Cape Flats WWTW and coastal dump.

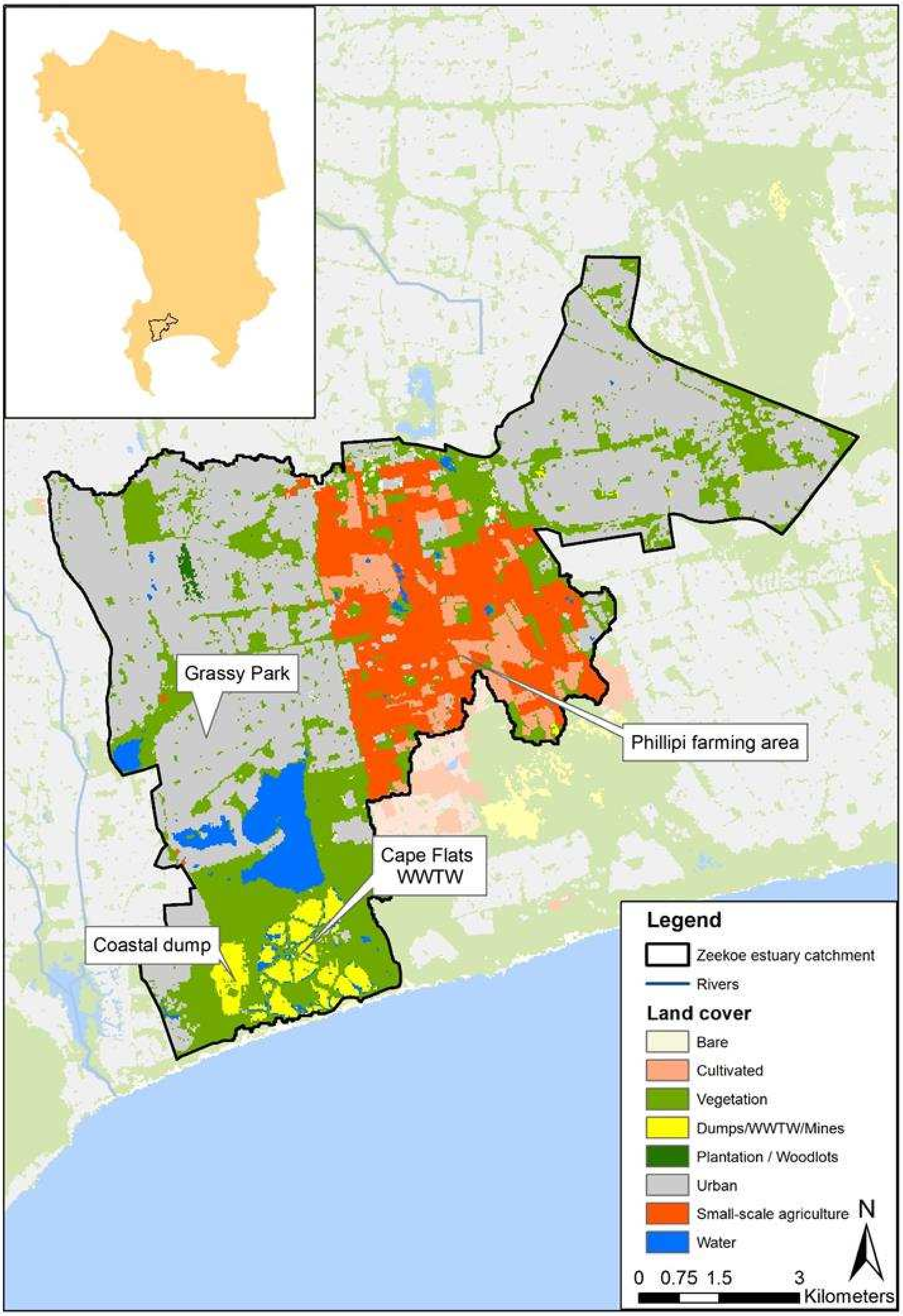


Figure 3-16 Zeekoe estuary catchment showing main landcover categories in the catchment as well as location of major features.

3.3.9.2 Anthropogenic developments within the estuary system

Under historical conditions, estuarine biota such as mullet, white steenbras and eels, are thought to have moved into both Zeekoevlei and Rondevlei (Bickerton, 1983). The connection between the vleis and the 3-km long estuary channel has now been all but cut off by the construction of weirs below Zeekoevlei and Rondevlei. Both Rondevlei and Zeekoevlei are intensively managed, the former as a nature reserve, maintaining its ephemeral nature, and the latter as a recreational and residential area with management focused on maintaining water quality through manipulation of water levels as well as maintaining water levels suitable for recreation. Zeekoevlei has therefore largely lost its ephemeral nature.

The weirs at Zeekoevlei and Rondevlei are opened for an extended period each April in order to drawdown the vlei and assist with water quality improvement. After several consecutive years that this has been done, the residents bordering Zeekoevlei have reported that the expanse of exposed mud has changed from being black to being white sand which suggests that the drawdown is assisting with entrainment of anoxic nutrient enriched sediments.

The Zeekoe EFZ is surrounded by City infrastructure including the Coastal Park Landfill Site to the north and the Cape Flats WWTW to the east. Baden Powell Drive crosses the mouth of the estuary. The Cape Flats WWTW was first constructed in 1956 and extended three times, most recently in 1997.

There are no major natural water courses entering the vleis or the lower estuary, instead only stormwater canals known as the Big and Little Lotus Rivers that drain the surrounding urban area. There has been little reduction in MAR from reference conditions (current runoff is estimated at 93% of reference), but the estuary receives a considerable volume of effluent from the Cape Flats WWTW via the Zeekoe outlet channel that enters approximately 400 m upstream from the estuary mouth. This additional nutrient enriched freshwater input (a monthly average of 3.6 million m^3) severely limits sea water penetration up the estuary and effectively precludes the development of estuary conditions above this point. These additional flows also ensure that the Zeekoe mouth remains permanently open.

The Zeekoe estuary also receive runoff from the “cut-off drain” (Figure 3-15), a channel that was excavated between the Cape Flats WWTW and Zeekoevlei in 2008 to intercept nutrient enriched groundwater seepage flow from the WWTW that would otherwise flow into Zeekoevlei due to differences in elevation of these two features. Water quality into this canal is extremely poor owing to the fact that the settlement ponds adjacent to the canal contain effluent that has been mostly subject to primary treatment only.

3.3.9.3 Scenarios Considered

Although there are no firm plans for increased (or decreased) utilisation of water in the Zeekoe River catchment, a number of hypothetical scenarios were constructed to examine likely impacts of improving the quality and/or reducing the volume of effluent discharged into the Zeekoe estuary on the health of the system. It was assumed that reductions in flow could be achieved through recycling or diversion of waste water out of the catchment and improvements in waste water quality achieved through implementation of improved treatment technology and or upgrading of the WWTW. The following scenarios were considered:

- **Natural**: Reference condition
- **Present**: Present day flows and conditions
- **Scenario 1:** Maintain present day flows but effluent from Cape Flats WWTW to be treated to DWS Special Standards
- **Scenario 2:** Reduce inputs from the Cape Flats WWTW by 50% and treat the remainder to DWS Special standards
- **Scenario 3:** Reduce inputs from the Cape Flats WWTW by 75% and treat the remainder to DWS Special standards
- **Scenario 4:** Divert/recycle 100% of effluent from WWTW
- **Scenario 5:** Flows as for Scenario 1 above but facilitate access by marine and estuarine fish into Zeekoevlei and Rondevlei through (1) construction of fish ladders at the Zeekoevlei and Rondevlei weirs and at the causeway beneath the main effluent line running to the Cape Flats WWTW, (2)

maintaining the channel between the estuary mouth and the weirs free of water hyacinth, and (3) diversion of water from the cut-off drain back into the WWTW. (Note that effluent quality of water in this canal is extremely poor with ammonia levels above that which can be tolerated by most fish species.)

- **Scenario 6:** Flows as for Scenario 4 above but facilitate access by marine and estuarine fish into Zeekoevlei and Rondevlei through (1) construction of fish ladders at the Zeekoevlei and Rondevlei weirs and at the causeway beneath the main effluent line running to the Cape Flats WWTW, (2) maintaining the channel between the estuary mouth and the weirs free of water hyacinth, and (3) diversion of water from the cut-off drain back into the WWTW. (Note that effluent quality of water in this canal is extremely poor with ammonia levels above that which can be tolerated by most fish species.)

A summary of the scenarios considered are given in Table 3-47.

Table 3-47 Summary of scenarios considered for the Zeekoevlei Estuary (IUA E11)

Scenario name	Description	MAR* (million m^3/a)	Percentage of natural flows	Effluent from Cape Flats WWTW (million m^3/a)
Natural	Reference condition	18.36	100%	-
Present	Present day flows	17.14	93%	42.49
Scenario 1	Scenario 1 (Present flow, Treat effluent from WWTW to Special Standards)	17.14	93%	42.49
Scenario 2	Scenario 2 (50% reduction in vol of WWTW inputs, treat remainder to Special standards)	17.14	93%	21.25
Scenario 3	Scenario 3 (75% reduction in vol of WWTW inputs, treat remainder to Special standards)	17.14	93%	10.62
Scenario 4	Scenario 4 (Divert/recycle 100% of effluent from WWTW)	17.14	93%	-
Scenario 5	Scenario 5 Flows as for Sc 1 but facilitate access by marine and estuarine fish into Zeekoevlei and Rondevlei through construction of a fish ladder	17.14	93%	42.49
Scenario 6	Scenario 6 Flows as for Sc 4 but facilitate access by marine and estuarine fish into Zeekoevlei and Rondevlei through construction of a fish ladder	17.14	93%	-

3.3.9.4 Hydrodynamics

Zeekoevlei (surface area ~ 2.56 km^2) is U-shaped, with a central peninsula dividing the lake into North and South basins. Most of the present-day surface inflow is into the North basin via the Big and Little Lotus "rivers", while the outflow to the sea occurs at the southwestern corner of the South basin through the Zeekoe Canal. It has been established that the vlei is also fed by an aquifer that extends as far as the Royal Cape Golf Course, Youngsfield and towards Southfield (Brown & Magoba 2009). Rondevlei is considerably smaller than its neighbour, covering an area of approximately 0.45 km^2.

The surface inflow is mainly via the road canals, and the outflow to the Zeekoe Canal is in the south-east corner where outflow is controlled by a weir structure. Rondevlei is thought to be the remnants of a historic bay of Zeekoevlei. A natural link existed between the two vleis and, indeed, an outlet weir and connection that allowed intermittent flow between the two was still in place until 1943, when it was closed permanently and an outlet from Rondevlei was constructed to connect to the Zeekoevlei outlet canal (Brown & Magoba 2009).

The whole Zeekoe estuary system including Zeekoevlei and Rondevlei would have been a temporarily open/closed estuary system under natural conditions. While little information exists on the Reference

Condition, it is envisaged that the system would have functioned in a similar way to an estuarine lake taking a year or more to fill up and breaching once higher water levels facilitated a cut-through of the coastal dune system. The resultant high outflow would have enabled the scouring of a deep and wide outflow channel that could have remained open for months at a time (e.g. 3 to 6 months). After breaching, saline water would have penetrated the system freely. The system would have been tidal during the open phase (possibly 10-20 cm on average). After a prolonged open period, mouth closure would have occurred that initially would be associated with low water level and even seasonally drying out of parts of the system, followed by a period of elevated water level once the systems started filling up during winter. The mouth of the system would have migrated significantly from its present fixed position.

Old maps show an outlet from Zeekoevlei to the sea, but this closed during the first quarter of the last century. Old inhabitants reported that sea and estuarine fish had been common before the original opening closed. In the past, water levels fluctuated greatly and in summer large marginal areas of the vlei became dry white sandflats. The water was brackish and formed a salt crust where it evaporated on the shore. The development of the Grassy Park area increased peak runoff and caused flooding of houses around the vlei.

There are a number of obstructions in the system that currently prevent natural fluctuations in water level:

- The weir at the south-eastern corner of Rondevlei
- The weir at the south-western corner of Zeekoevlei.
- Constricted channel and bridge protecting Baden Powell Drive.

At present, outflow from Zeekoevlei and Rondevlei is constrained to a narrow canal through the dune field to the mouth. The mouth of the canal is situated approximately 8 km from Muizenberg and fixed by the Baden Powell Drive road bridge. The system often dams up behind the 2 to 3 m high beach bar and forms a shallow longshore lagoon. Because of the high beach elevation, this lagoon is mostly perched and non-tidal. At times the meanders of the beach canal threaten the road infrastructure and are straightened out by the City of Cape Town, which significantly reduces the back-water area. To assist the river in cutting through the beach bar in a straight line from the bridge to the edge of the sea, a section of the canal was once lined with concrete.

The Cape Flats WWTW discharges effluent into the channel below the weir. The elevated inflows ensure that the mouth of the Zeekoe estuary is now permanently open and remain as well flushed as possible.

In 1997, a management scheme was initiated to improve water quality in Zeekoevlei that involved opening the sluice gates in the Zeekoevlei weir in late summer (April) to draw down the water levels of the vlei. The previously solid weir was altered through the construction of six openings that permitted adjustment of water levels in the vlei. These openings allow for the release of up to three million of the estimated five million cubic metres of water in Zeekoevlei. The contribution of low-nutrient water from the aquifer to Zeekoevlei increases during the drawdown when an approximately 1.2-meter ‘head’ is removed as the vlei’s water level is dropped. The first drawdown improved the functioning of the vlei through a reduction in the phytoplankton and improved light penetration. Residents, including freshwater ecologists (L Day and J Ewart Smith), have also reported an apparent improvement in water quality in the past three to five years - increased exposure of white shoreline sands as opposed to black anoxic mud, increased zooplankton activity and short periods of clear water in an otherwise heavily Cyanophyceae-dominated state.

The sluice gates on the weir were upgraded in 2007 so that the outflow will mostly comprise the more contaminated bottom water. In addition, low-flow diversion weirs were constructed in the Lotus River catchment upstream of Zeekoevlei in an effort to reduce the amount of pollution entering the vlei in the summer months.

Figure 3-17 Weir at Zeekoevlei that maintains water level in the system but prevents connectivity with the sea.

Based on the above, estuary hydrodynamics are estimated at about 20% similar to that of the Reference condition, with a focus on connectivity of the system to sea. Connectivity will be similar to the present state under Scenario 1 to 3, but connectivity will be further reduced under Scenario 4.

Table 3-48 Hydrodynamic health scores for Present Day and the four alternative scenarios relative to the Reference Condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
a. Mouth condition	20	20	20	20	10	20	10	L
Hydrodynamics and mouth conditions score	20	20	20	20	10	20	10	

3.3.9.5 Water Quality

For the purposes of this study, the Zeekoe estuary system is sub-divided in to three zones (Figure 3-15):

- Rondevlei
- Zeekoevlei
- Channel (below weir).

No salinity information is available on the historical condition of the system. However, based on the hydrodynamic conceptual model of how the system could have functioned, a conceptual salinity model was developed based on expert opinion (Table 3-49).

Table 3-49 Conceptual salinity model for the Zeekoe estuary system.

State	Reference	Present
Physical driver	Outflow channel was deeper and wider, with significant salt penetration during the open phase in the lower channel. Zeekoevlei would have been brackish, with the possibility of hyper salinity developing in some areas as the system dried out. Rondevlei would only have had limited salt input during times when the combined water level of the system was high.	Outflow channel perched with only occasional overwash entering the Lower channel. In addition, elevated flows from WWTW prevent any significant ingress of salt water. No salt penetration past the weirs into Zeekoevlei and Rondevlei.
Rondevlei	1	0
Zeekoevlei	5	0
Estuary channel	15	1 (Present, Sc 1 to 3) 5 (Sc 4)

No measured data on the reference water quality could be obtained for this estuary. However, considering the catchment of the system, it can be assumed that, on average, its water bodies were clear, well-oxygenated and oligotrophic (e.g. De Villiers & Thiart 2007).

Currently the estuary is subject to major anthropogenic impacts on water quality, specifically surface runoff from urbanised area around the system and in its catchment (Bickerton 1982), as well as effluent from the Cape Flats WWTW being discharging into the estuary channel. Available data on relevant water quality parameters for the periods 2000-2009 and 2010-2016 were provided to the project team by the CoCT. These are provided for river inflows, Rondevlei, Zeekoevlei, as well as inflow to the estuary channel.

As a result of anthropogenic influence (urban development and WWTW effluent), water quality in the system has been highly modified as reflected by the WQ data. While WQ in Rondevlei DIN and DIP concentrations in Rondevlei showed a decrease in DIN and DIP between 2000-2009 and 2010-2016, DIN and DIP concentrations in Zeekoevlei and in the inflow to the estuary channel improved markedly from the early 2000s to present. Improvement could be as a result of reduced inputs (e.g. from rivers or from diffuse sources along the banks), or increased uptake by submerged macrophytes and microalgae. However, a more detailed assessment is required to explain these improvements in greater detail.

Supersaturation in dissolved oxygen (DO) has been recorded (e.g. DO >9 mg/ℓ), as a result of high photosynthetic rates associated with macrophyte and algal blooms. However, such supersaturation (i.e. photosynthesis during the day) hints to an equally marked reduction of oxygen (resulting in hypoxia, even anoxia) as a result of respiration at night. Thus, high fluctuation in DO probably in Zeekoevlei, ranging from supersaturation during the day to hypoxia/anoxia at night. Supersaturation levels in DO increased in both Zeekoevlei 2000-2009 to 2010-2016, most likely associated with increased primary production. Average DO levels in Rondevlei do not suggest regular supersaturation, averaging ~6 mg/ℓ. The high total suspended solid (TSS) concentrations recorded in the system, especially Zeekoevlei, is mainly attributed to high phytoplankton biomass. TSS levels largely similar over both periods in Zeekoevlei but increase markedly in Rondevlei over the period 2010-2016, possibly indicating increased phytoplankton activity (but this is not reflected in DO concentrations, i.e. no supersaturation).

For the purposes of this study water quality conditions in Rondevlei and Zeekoevlei were derived from the measured data for present and all the future scenarios. Proportional contributions of Cape Flats WWTW inflow (discharging into the lower channel which is disconnected from the vlei area by a weir) and present catchment flow (0.54 m^3/s) were used to calculate resultant DIN, DIP and TSS concentrations in the lower channel, both for the present and all future scenarios. Dissolved oxygen could not be estimated in this manner, being strongly non-conservative parameters. DO concentrations were thus estimated based on expert opinion derived from available data. Using this approach, as well as expert opinion average water quality concentrations under the reference, present and future scenarios for the Zeekoe estuary system were estimated as indicated in Table 3-50. Water quality scores for the present and future scenarios are presented in Table 3-51. Das et al (2008) show some toxic accumulation (e.g. trace metal) in Zeekoevlei. Seepage from the land fill site next to the lower canal is also a concern in this regard.

Table 3-50 Average estimated water quality concentrations under the reference, present and future scenarios for the Zeekoe system.

Salinity	Volume fraction	Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
Estuary channel	0.2	15	1	1	1	1	5
Zeekoevlei	0.4	5	0	0	0	0	0
Rondevlei	0.4	1	0	0	0	0	0
DIN (µg/ℓ)	**Volume fraction**	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Estuary channel	0.2	50	12700	2750	2300	1850	800
Zeekoevlei	0.4	50	740	740	740	740	740
Rondevlei	0.4	50	1200	1200	1200	1200	1200
DIP (µg/ℓ)	**Volume fraction**	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Estuary channel	0.2	10	6430	800	680	560	290

Zeekoevlei	0.4	10	390	390	390	390	390
Rondevlei	0.4	10	90	90	90	90	90
DO (mg/ℓ)	**Volume fraction**	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Estuary channel	0.2	8	6	6	5	4	4
Zeekoevlei	0.4	8	4	4	4	4	4
Rondevlei	0.4	8	5	5	5	5	5
TSS (mg/ℓ)	**Volume fraction**	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Estuary channel	0.2	5	45	30	45	55	85
Zeekoevlei	0.4	5	75	75	75	75	75
Rondevlei	0.4	5	85	85	85	85	85

Table 3-51 Summary of changes and calculation of the water quality health score.

Variable		Present	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Conf
1	Salinity								
	Similarity in salinity	30	30	30	30	35	30	35	L
2	General water quality								
a	Nutrient (DIN/DIP) concentrations	9.2	9.7	9.8	10	11	9.7	11	L
b	Dissolved oxygen	75	75	73	71	71	75	71	L
c	Total suspended solids	13	5	13	13	12	5	12	L
d	Toxic substances	50	50	50	55	55	50	55	L
	Water quality score*	**24**	**22**	**25**	**25**	**26**	**22**	**26**	

*Score = (0.6 x S + 0.4 x min (a to d))

Table 3-52 Summary of changes in key water quality parameters in the Zeekoe estuary system.

Parameter	Summary of changes
Salinity	⇩ under present, scenario 1 to 3 due to the influence of the weirs, diversion of outflow channels, elevated flows through the mouth. Scenario 4 salinity ⇧ from present in entrance channel as result of no WW inflow.
Inorganic nutrients (DIN/DIP) in estuary	⇧⇧ due to nutrient input from urban runoff (as well as WWTW effluent in lower channel). The variation in score of future scenarios related to the fraction of WWTW effluent to total inflow in the lower channel
Dissolved oxygen in estuary	⇩ due to organic loading and diurnal variation associated with eutrophication caused by nutrient input from anthropogenic sources (e.g. WWTW effluent and urban runoff). Incremental decrease in lower canal over Scenarios 2 to 4 linked to longer retention with less flow
Suspended solids in estuary	⇧⇧ due to high phytoplankton biomass associated with nutrient inputs, especially in Zeekoevlei. Incremental increase in TSS in lower canal over Scenarios 2 to 4 linked to stronger proportional influence of turbid inflow from above weir
Toxic substances in estuary	⇧⇧ due to urban runoff and WWTW input

3.3.9.6 Overall Estuary Health Score for Scenarios

Scenario 1 did not allow for any measurable improvement in the health of the estuary as nutrient levels in Zeekoevlei and Rondevlei remain in spite of improvements in the quality of effluent water from the WWTW due to high nutrient loading in the stormwater entering these two water bodies. Scenarios 2-4 (which allowed for progressive reductions in waste water input of 50, 75 and 100%, respectively) yielded very small improvement in health (health scores: 29, 31 and 33, respectively), but did not push the estuary up out of an E category.

Scenario 5 (same flows as for Sc 1) yielded no improvement in health (high volumes of effluent water entering the lower estuary under this scenario still present a significant barrier to upstream movement of fish), while Scenario 6 (same flows as for Scenario 4) yielded another small increase (score = 35) but the health category did not change. It is important to note that improvements anticipated under scenarios 5 & 6 are only likely to be realised should the bypass drain no longer discharge into the estuary channel, the channel is kept clear of water hyacinth and a fish ladders are installed at the weirs on the lower edge of Zeekoevlei and Rondevlei and over the gabions at the southern bridge that carries a sewer line.

Table 3-53 Estuary health scores of alternative flow scenarios for the Zeekoe estuary system.

Component	Present	Sc1	Sc2	Sc3	Sc4	Sc 5	Sc 6
Hydrology	51	51	82	89	93	51	93
Hydrodynamics and mouth condition	20	20	20	20	10	20	10
Water quality	24	22	25	25	26	22	26
Physical habitat alteration	10	10	10	10	10	10	10
Habitat health score	**26**	**26**	**34**	**36**	**35**	**26**	**35**
Microalgae	25	25	25	25	35	25	35
Macrophytes	25	25	25	25	35	25	35
Invertebrates	10	10	10	10	11	10	11
Fish	5	5	10	20	25	5	30
Birds	52	52	52	52	52	55	65
Biotic health score	**23**	**23**	**24**	**26**	**32**	**24**	**35**
Estuary Health Score	**25**	**25**	**29**	**31**	**33**	**25**	**35**
Ecological Category	**E**	**E**	**E**	**E**	**E**	**E**	**E**

3.3.10 Eerste River Estuary (IUA D6)

3.3.10.1 Catchment area and activities

The EFZ for the Eerste estuary was estimated at 55.6 ha, making it the second smallest significant estuary in the Berg WMA (Figure 3-18). Extensive areas of low lying land to the east of the main channel outlet are included in the EFZ (http://bgis.sanbi.org/) for the Eerste estuary. While these areas are no longer hydrologically or functionally linked with the system due to land transformation and road construction they still form part of the study area (Figure 3-18). The open water area of the estuary is estimated at just 9.0 ha and consists of backshore lagoon, lower and upper estuary.

Figure 3-18 Extent of the Eerste estuary functional zone (EFZ, blue line, http://bgis.sanbi.org/). Main sections of the estuary are labelled, as well as the Macassar WWTW.

The Eerste estuary falls within the City of Cape Town Municipality, however the catchment spans both the CoCT and the Stellenbosch Local Municipalities. The combined catchments of the Kuils and Eerste Rivers that feed the Eerste estuary are approximately 628 km^2, making it the third largest catchment within the Berg WMA (Figure 3-19). The Eerste River meanders through the coastal dunes near Macassar and then forms an elongated lagoon in the slack of the backshore area of the beach. The extent of the lagoon and the location of the mouth are both highly variable depending on outflow as well as wind and wave action.

Present day MAR is estimated at 88% of natural but this excludes the substantial input from five WWTWs within the catchment (one of which discharges directly into the estuary – Macassar WWTW) that together process approximately 75 million m^3/a. Historically the Eerste estuary was a temporary open system and seawater intrusion created estuarine conditions up to 2.5 km from the mouth (CCT 2014). In the present day, however, the mouth of the estuary remains open due to the additional flow provided by the WWTWs, and there is limited tidal influence into the estuary. Sea water can only penetrate into the estuary under certain mouth and river flow conditions.

The Eerste River catchment is comprised of predominantly natural vegetation and agricultural land whilst low income, high-density, urban industrial, commercial and residential areas dominate in the Kuils River catchment. There are also a number of informal settlements located within the Kuils catchment area, some of which border directly on the river. Overall, the combined catchment is made up of approximately 41% natural area, 28% agriculture and 22% urban area, with the remainder wetlands areas and a small amount of forestry.

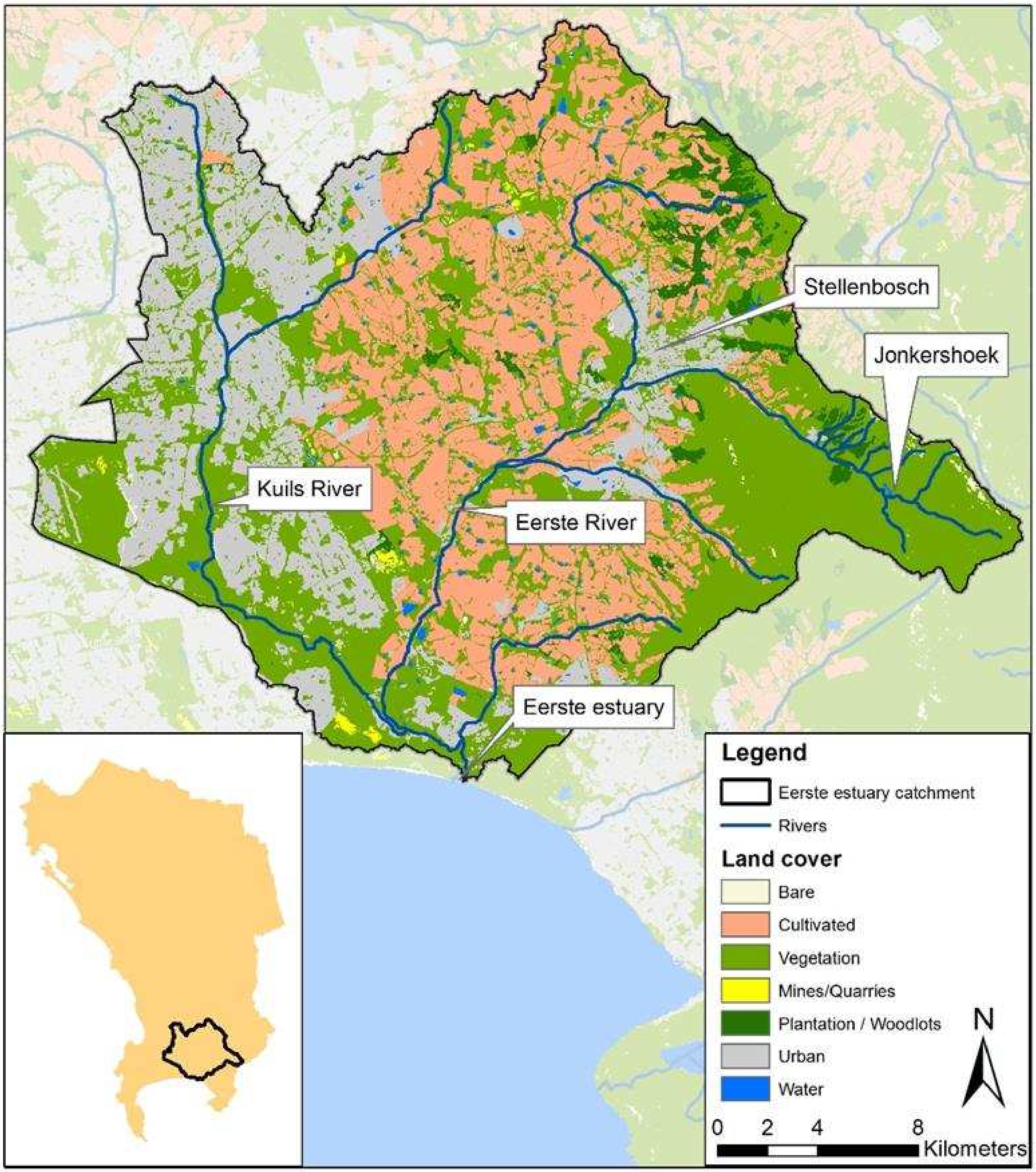


Figure 3-19 Eerste estuary catchment showing major inflowing rivers and dominant land cover types.

3.3.10.2 Anthropogenic developments within the estuary system

The Eerste estuary is located at the eastern end of the large calcrete dune at Macassar. Rocky outcrops of Malmesbury group near the sewage outfall in the channel are a natural obstruction and collect debris and drift wood. Grindley (1982) reported that a short section of fence on the west bank of the estuary 900 m from the mouth at the boundary of the old Kentron controlled area has flood debris adhering to it indicating some degree of obstruction to natural flow patterns.

An embankment and the road causeway on the eastern side of the estuary represent a complete obstruction that isolates a wetland area which historically formed the eastern part of the estuary. The Macassar Sewage Works were constructed in part of the original estuarine flood plain and the 1938 air photograph indicates old distributary channels in that area.

In recent years, the flow into the Eerste estuary has been significantly increased, despite winter abstraction in the catchment. The additional flows mean that the mouth closure now seldom occurs, and even if it did the mouth would have to be artificially breached to prevent flooding of the Macassar Wastewater Treatment Works. Where once the estuary flooded an extensive inter-dune field, and the mouth migrated between its present position and at least a kilometre eastward, the estuary is now an incised and confined system as a result of infilling. The City of Cape Town at times straightens the estuary mouth channel to prevent extensive beach migration.

3.3.10.3 Scenarios Considered

Although there are no firm plans for increased (or decreased) utilisation of water in the Lourens River catchment, a number of hypothetical scenarios were constructed to examine likely impacts of improving the quality and/or reducing the volume of effluent discharged into the Eerste catchment on the health of the estuary. It was assumed that reductions in flow could be achieved through recycling or diversion of waste water out of the catchment and improvements in waste water quality achieved through implementation of improved treatment technology and or upgrading of the various WWTWs in the catchment.

The following scenarios were considered:

- **Natural**: Reference condition
- **Present**: Present day flows and conditions
- **Scenario 1:** Maintain present day flows but all effluent from WWTW to be treated to DWS Special Standards
- **Scenario 2:** Reduce inputs from the WWTW by 50% reduction and treat the remainder to DWS Special standards
- **Scenario 3:** Reduce inputs from the WWTW by 75% reduction and treat the remainder to DWS Special standards
- **Scenario 4:** Divert/recycle 100% of effluent from WWTW

A summary of the scenarios considered are given in Table 3-54 Table 3-25.

Table 3-54 Summary of scenarios considered for the Eerste River Estuary (IUA D6)

Scenario name	Description	MAR (million m^3/a)	Percentage of natural flows
Natural	Reference condition	114.81	100%
Present	Present day flows	176.45	154%
Scenario 1	Present day flows	176.45	154%
Scenario 2	50% reduction in contribution from WWTWs	138.95	121%
Scenario 3	75% reduction in contribution from WWTWs	119.39	104%
Scenario 4	Zero input from WWTW	101.44	88%

3.3.10.4 Hydrodynamics

The Eerste estuary under its reference condition would have naturally been a temporarily open/closed system. While little information exists on its Reference condition, it is envisaged that the system would have been similar in size to the Uilkraals. As the estuary is perched (more exposed and high wave energy at its mouth) river inflow would always have played a dominant role in maintaining an open mouth condition. Observations made by trout fisherman in the 1950s to 1960s tells us that when the estuary closed it formed a water body between 0.8 to 2.5 km long in summer. With the onset of winter rains, flooding at Zandvliet Farm used to be the stimulus to open the estuary artificially.

In recent decades the flow into the Eerste estuary has been significantly increased, despite abstraction in the catchment. The additional flows mean that the mouth closure now seldom occurs, and even if it did, the mouth would have to be artificially breached to prevent flooding of the Macassar Wastewater Treatment Works. Where once the estuary flooded an extensive inter-dune field and the mouth now migrated freely between its present position and at least a kilometre eastward, the channel is now confined and incised. The City of Cape Town at one time straightened the estuary mouth channel to prevent extensive beach erosion. This has not been repeated and the mouth has since been left to migrate naturally back and forth.

Water level recordings are not available for the Eerste estuary. It is known from literature (Grindley 1982) that in the past some saline intrusion sometimes occurred, but data on corresponding river flows is not available. It is therefore very difficult to estimate when (and at what river inflow level) the different abiotic states for the Eerste estuary occur because of the lack of field data. It is also not possible to use data from the Lourens to draw conclusions for the Eerste River, because of the different physical conditions. Important differences exist between the dynamics of the mouths of the Eerste and Lourens estuaries for reasons in CSIR (2001), and summarised below.

The longshore current and the longshore sediment transport is from west to east at the mouth of the Eerste estuary and from East to West at the mouth of the Lourens estuary. The median grain size of the sand on the beach is approximately 200 microns at the mouth of the Lourens Estuary and approximately 1200 micron at the mouth of the Eerste estuary. The result is a much steeper beach slope at the mouth of the Eerste compared to the Lourens. This results in stronger wave action at the mouth of the Eerste estuary, which means that the forces causing mouth closures are also stronger at the Eerste estuary. Based on the above information the estuary hydrodynamics were defined in terms of three abiotic states (Table 3-55).

Occurrence of the different states for Reference, Present and the alternative scenarios is indicated in Table 3-56. Hydrodynamic health scores are presented in Table 3-57. Confidence in these estimates and score are low due to the lack of empirical data.

Table 3-55 Characteristic abiotic state in the Eerste Estuary.

Abiotic State	Water level (m) associated with abiotic state	Tidal range	Connectivity	Salinity Structure
Closed	2.5-3.0 m	None	Closed with raised water level, back flooding into back water areas	Well mixed
Perched, with limited tidal variation	1.5-2.0 m	10 cm	Limited inflow and limited tidal exchange on high tides	Horizontally stratified
Open, tidal	0.5 m	40-60 cm	Significant river input and good tidal exchange	Vertically stratified

Table 3-56 The occurrence of the Abiotic States under Reference Condition, Present State and Scenarios 1 to 4.

Abiotic State	Flow range (m^3/s)	% Occurrence					
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4
Closed	<0.5	20.4	0.0	0.0	0.0	0.0	30.3
Perched, with limited tidal	0.5-3.0	41.7	34.1	34.1	52.3	59.7	35.8
Open, tidal	> 3.0	38.0	65.9	65.9	47.7	40.3	33.9

Table 3-57 Hydrodynamic health scores for Present Day and the four alternative scenarios relative to the Reference Condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Conf
a. Mouth condition	80	80	80	80	88	L
b. Abiotic states as proxy for hydrodynamic shifts	72	72	80	80	90	L
Score (min + average (a: b))/2	**74**	**74**	**80**	**80**	**89**	**L**
Score min (a to b)	**72**	**72**	**80**	**80**	**88**	**L**

3.3.10.5 Water Quality

For the purposes of this study, the Eerste estuary is sub-divided into two zones:

- Upper estuary
- Lower estuary.

Very little salinity data is available for the Eerste estuary. In Table 3-58 the conceptual salinity model was therefore developed based on expert opinion and personal observations is presented.

Table 3-58 Conceptual salinity model developed for the Eerste estuary.

State	Reference		Present	
Physical driver	The estuary was deeper with a well-formed backshore "lagoon" that would have retained seawater much better.		Presently a very perched, short, filled-in backshore "lagoon", mostly fresh with occasional overwash on high tide.	
Zone	Lower	Upper	Lower	Upper
Closed (<0.5 m^3/s)	10	5	5	1
Perched (0.5 – 3 m^3/s)	20	0	10	0
Open (> 3.0 m^3/s)	5	0	0	0

Data collected by the City of Cape Town shows no significant salinity penetration in the lower and middle reaches of the Eerste Estuary. The estimated salinity in the different zones under each of the abiotic states are presented in Table 3-59.

Table 3-59 Estimated salinity for the Eerste Estuary under the three abiotic states in Reference, present and each of the future scenarios.

		Reference	Present	Scn 1	Scn 2	Scn 3	Scn 4
Lower Estuary	State 1: Closed	10	5	5	5	5	5
	State 2: Perched	20	10	10	10	10	10
	State 3: Open	5	0	0	0	0	0
Upper Estuary	State 1: Closed	5	1	1	1	1	1
	State 2: Perched	0	0	0	0	0	0
	State 3: Open	0	0	0	0	0	0
	State 2: Perched	5	20	10	13	14	15
	State 3: Open	5	20	13	14	15	15

No measured data on the reference condition for other water quality could be obtained for this estuary. However, considering the catchment of the system, it can be assumed that, on average, its water bodies were clear, well-oxygenated and oligotrophic).

Available data on relevant water quality parameters for the periods 2000-2009 and 2010-2016 are available. As a result of anthropogenic influence, water quality in the system has been highly modified as reflected by the WQ data. Both in river inflow and in the estuary, DIN concentration increased significantly between the periods 2000-2009 and 2010-2016. This is primarily attributed to inflow from WWTWs in the catchment (probably operating above design capacity in terms of removal of nutrients). Associated with organic loading from anthropogenic sources, dissolved oxygen (DO) decreased at all sites in system, but because of the large volume, residence time is limited which is probably the reason why supersaturation is not observed in this system. Hypoxic conditions increased between 2000-2009 and 2010-2016. Higher total suspended solid (TSS) levels are also associated with increased urban and WWTW inputs. A marked increase was observed in the lower estuary, suggesting higher TSS associated with the Macassar WWTW discharge in this zone.

For the Present State, water quality conditions in the estuary were based on average measured data for the period 2010-2016. To estimate average water quality conditions for the future scenarios, proportional contributions of WWTW and river inflow, were used to calculate DIN, DIP and TSS concentrations. Dissolved oxygen, however, could not be estimated in this manner for future scenarios, being strongly non-conservative, and concentrations therefore were based on available data and expert opinion.

Present concentrations in WWTW effluent for the Macassar WWTW (Cape Town unpublished data), as well as estimated volume and concentrations for future scenarios for all WWTW discharges in the catchment is presented in Table 3-60. For Scenarios 1, 2 and 3. Effluent concentrations were set as per the General Authorisation Standards under the National Water Act (Special Limits) (DWA 2013).

Measured river water quality for the Eerste or Kuils rivers could not be used in the proportional calculations, as these concentrations include input from WWTWs. To obtain river concentrations representative of an urban catchment, but excluding WWTW contribution, data from the Sand River (draining into Zandvlei) was used. River inflow volumes were set as present MAR, excluding WWTWs.

Table 3-60 Estimated volume and water quality from WWTW effluents, as well as estimated river water quality (excluding WWTW contribution)

Parameter	Present WWTW	WWTW (Sc 1)	WWTW (Sc 2)	WWTW (Sc 3)	WWTW (Sc 4)	River
Flow (Mm^3/a)	75.01	75.01	37.5	18.75	0	101.44
Flow (m^3/s)	2.38	2.38	1.19	0.59	-	3.22
Total NH4-N (µg/ℓ)	4900	2000	2000	2000	-	160
NOx-N (µg/ℓ)	2800	1500	1500	1500	-	940
DIN (µg/ℓ)	7700	3500	3500	3500	-	1080
DIP (µg/ℓ)	5200	1000	1000	1000	-	40
SS (mg/ℓ)	15	10	10	10	-	18

Based on the distribution of abiotic state and WWTW inputs for the reference, present and future scenarios, average water quality conditions in the estuary under a specific scenario are presented Table 3-61.

Table 3-61 Estimated average water quality conditions for the Eerste Estuary under the three abiotic states in Reference, present and each of the future scenarios.

Salinity	Reference	Present	Scenario 1 (present WWTW; Special limits)	Scenario 2 (50% ⇩ WWTW; Special limits)	Scenario 3 (75% ⇩ WWTW; Special limits)	Scenario 4 (no WWTW)
Lower Estuary	12	3	3	5	6	5
Upper Estuary	1	0	0	0	0	0
DIN (µg/ℓ)	**Reference**	**Present**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Lower Estuary	50	11 970	2 100	1 750	1 450	1 100
Upper Estuary	50	8 700	2 100	1 750	1 450	1 100
DIP (µg/ℓ)	**Reference**	**Present**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Lower Estuary	10	2 190	450	300	190	40
Upper Estuary	10	1 770	450	300	190	40
DO (mg/ℓ)	**Reference**	**Present**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Lower Estuary	8	5	6	6	7	6
Upper Estuary	8	4	6	6	7	6
TSS (mg/ℓ)	**Reference**	**Present**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**

Salinity	Reference	Present	Scenario 1 (present WWTW; Special limits)	Scenario 2 (50% ⇩ WWTW; Special limits)	Scenario 3 (75% ⇩ WWTW; Special limits)	Scenario 4 (no WWTW)
Lower Estuary	5	60	15	15	15	20
Upper Estuary	5	15	15	15	15	20

The urban and WWTW inputs are assumed to have had a significant influence in terms of introducing toxic substances, assume 30% similarity for Present State and allow incremental improvement as volume of WWTW decrease and water quality condition improve.

The water quality scores and summary of changes are presented in Table 3-62 and Table 3-63.

Table 3-62 Summary of changes and calculation of the water quality health score.

Variable		Present	Sc 1	Sc 2	Sc 3	Sc 4	Conf
1	Salinity	33	33	45	49	55	L
2	General water quality						
a	Nutrient (DIN/DIP) concentrations	1	4	6	8	24	L
b	Dissolved oxygen	72	86	86	93	86	L
c	Total suspended solids	33	50	50	50	40	L
d	Toxic substances	30	35	40	45	50	L
	Water quality score*	**18**	**24**	**26**	**29**	**39**	**L**

**Score = (0.6 x S + 0.4 x min (a to d))*

Table 3-63 Summary of changes to the water quality health score.

Parameter	Summary of Changes
Salinity	Sc1 similar to present ⇩ due to elevated base flows. Sc 2 to 4 ⇧ as a result of a decrease in baseflows. Sc 4 is reduced from Sc 3 as a result of increase mouth closure
Inorganic nutrients (DIN/DIP) in estuary	⇧⇧ due to nutrient input from WWTW effluent and urban runoff. The variation in scores of future scenarios relates to the fraction of WWTW effluent to total inflow. Note that in Scenario 4 the proportion of total NH4-N in DIN is much lower compared to scenarios where WWTW flows were still present
Dissolved oxygen in estuary	⇩ due to organic and nutrient loading from urban and WWTW runoff. The variation in scores of future scenarios relates to the fraction of WWTW effluent to total inflow. The decrease in DO in Sc 4 reflects the increase in mouth closure – i.e. longer residence time
Suspended solids in estuary	⇧ due to urban runoff and WWTW input to the estuary. The variation in scores of future scenarios relates to the fraction of WWTW effluent to total inflow. Decrease in Sc 4 reflect stronger influence of more turbid river inflow
Toxic substances in estuary	⇧⇧ due to urban runoff and WWTW input to the estuary. The variation in scores of future scenarios relates to the fraction of WWTW effluent to total inflow

3.3.10.6 Overall Estuary Health Score for Scenarios

The alternative scenarios that were evaluated in this study allow for only a modest improvement in the health of the estuary owing to the extremely high nutrient and suspended solid levels in the waste water from the WWTWs that augment flow to this system and also those from the catchment, and the reduction in runoff from the catchment. Health improves to a maximum of 48% (D category) under Scenario 4 (diversion of all wastewater from the estuary). Diversion of 75% of waste water inputs also facilitate attainment of a D category (45%). As such, the BAS for the estuary is likely to be a D category.

Table 3-64 Estuary health scores for alternative flow scenarios for the Eerste estuary.

Component	Present	Sc1	Sc2	Sc3	Sc4
Hydrology	35	35	39	43	40
Hydrodynamics and mouth condition	74	74	80	80	89
Water quality	21	26	30	33	42
Physical habitat alteration	30	30	30	30	30
Habitat health score	**40**	**41**	**45**	**46**	**50**
Microalgae	25	25	30	30	35
Macrophytes	35	35	40	40	45
Invertebrates	10	10	15	20	25
Fish	5	5	20	50	50
Birds	65	65	70	75	75
Biotic health score	**28**	**28**	**35**	**43**	**46**
Estuary Health Score	**34**	**35**	**40**	**45**	**48**
Ecological Category	**E**	**E**	**E**	**D**	**D**

Additional non-flow related measures that could be implemented to improve estuary health include:

- reducing abstraction of freshwater from the catchment,
- establishment of riparian buffers in the catchment;
- improving the quality of stormwater entering the system especially from informal settlements,
- dredging the estuary to remove organically rich and anoxic sediments and improve tidal exchange;
- rehabilitate the wetland areas on the eastern side of the estuary that were once integrally linked with the system.
- remove alien plants from the catchment and estuary functional zone (EFZ),
- remove any remaining portions of the weir that was constructed near the mouth of Milnerton lagoon in 1928

3.3.11 Lourens River Estuary (IUA D7)

3.3.11.1 Catchment area and activities

The size of the EFZ for the Lourens estuary is estimated at 38.2 ha, making it the smallest significant estuary in the Berg WMA. Total open water area for this system was estimated at just 2.0 ha. The EFZ (http://bgis.sanbi.org/) for the Lourens estuary included extensive low-lying area to the northwest and southeast of the main channel outlet. The areas to the northwest of the estuary drain into the Lourens via a canal that does not possess any estuarine characteristics, and it is recommended that this area be excised from the EFZ for future assessments. Similarly, the area of the EFZ on the southeast side of the estuary mouth has been completely transformed for urban development and does not possess any estuarine characteristics. It is thus recommended that this area also be excised from the delineation of the estuary in future. Historically, the Lourens used to discharge into the sea much further to the west (i.e. included the Wagenveldsluit), a feature which is still below the 5-m contour and is functionally linked to the estuary. It is recommended that this area be included in the delineation of the EFZ for this estuary (Figure 3-20).

The Lourens estuary and almost all of the catchment falls within the City of Cape Town Metropolitan Municipality while some upper parts of the catchment spans into the Stellenbosch Municipality. The catchment for the Lourens estuary is approximately 92 km^2. The upper reaches of the Lourens River begin in the mountains where the natural vegetation is mainly intact and under conservation in the Hottentots-Holland Nature Reserve. The river then flows through mostly agricultural land, cuts across the flat coastal plain through the towns of Somerset West and Strand before emptying into False Bay (Figure 3-21).

At the mouth of the Lourens River, a small estuary of approximately 0.7 km^2 forms in the slack of the beach bar. The lagoon that forms is usually along the east/west orientation and is approximately 300 m long and 30-40 m wide. The beach sand bar is built up by the strong wave action and often the channel must extend some several hundred metres to find a low-lying course to the sea. Present day runoff is about 85% of reference flows. Historically effluent from the Strand WWTW was discharged into the Lourens River but this WWTW closed in 1978. The estuary mouth is open most of the year, however, is known to close periodically during dry summer months (Cliff & Grindley, 1982).

The catchment of the Lourens estuary is mainly made up of natural vegetation, approximately 55%. The next most common land use is urban areas which make up a further 21%, the reminder being mainly cultivated land and small amounts of forestry.

Figure 3-20 **Extent of the Lourens estuary functional zone (EFZ, blue line, http://bgis.sanbi.org/) in relation to the undeveloped EFZ. Recommended extent of the EFZ is indicated by the red outline.**

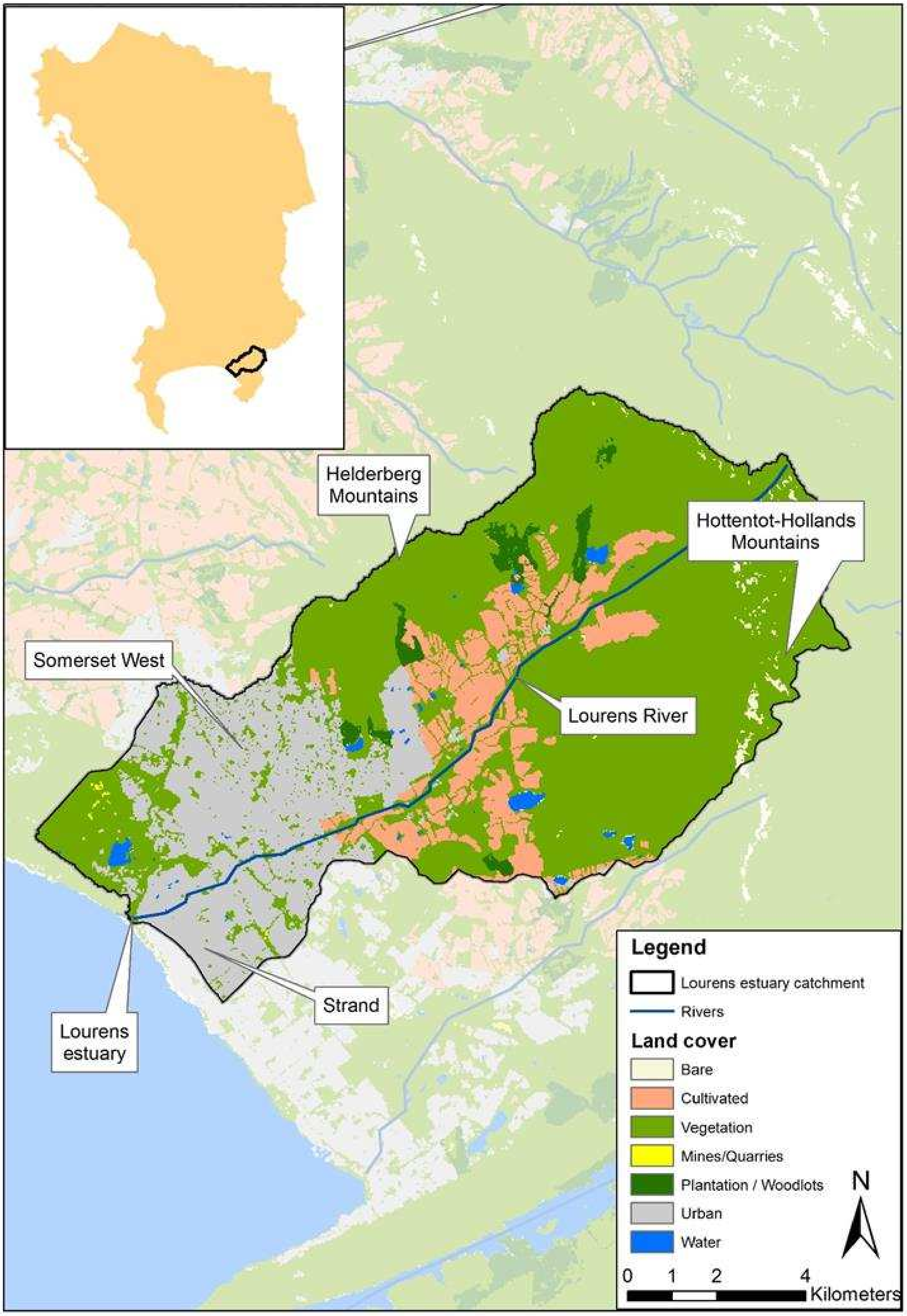


Figure 3-21 Location of the Lourens estuary catchment between the Hottentot-Holland and Helderberg mountains, showing the location of major developments and the Lourens River.

3.3.11.2 Anthropogenic developments within the estuary system

The Lourens estuary is greatly transformed. The estuary flows through a dune belt that is very disturbed by development in and around the Estuary Functional Zone. There has also been significant loss of supratidal habitat in the system.

Concrete retaining walls and boulders have been used along the middle and upper reaches of the estuary to support the banks where erosion has occurred during times of floods. This has contributed to significant loss of intertidal area. Two single-span bridges cross the estuary. At the head of the estuary is a pipe bridge which bears a sewer pipe from Strand and a waterworks pipe from Steenbras Dam to Cape Town (Cliff & Grindley, 1982). The Beach Road bridge supports two sewage pipes leading from pump stations on the beach to the sewer mains (Cliff & Grindley, 1982). While little information is available on the historical configuration of the Lourens estuary, it is assumed that the bridges have led to a more confined channel and a related deepening of the system, especially in the middle reaches.

Sediment processes under Scenario 1 are likely to be similar to that of the present as floods are not significantly altered, with only a slight additional infilling of the subtidal areas as a result of reduced flooding. Under Scenario 2 and 3, a decrease in higher flows/flood frequency will translates into further infilling of the intertidal and subtidal areas, especially in the lower reaches. Sediment processes under Scenario 4 represent a slight improvement on the Present as river flows are higher than at present.

An investigation was undertaken of the historical evolution and stability of the shoreline at the mouth of the Lourens estuary was undertaken by Porter & Clark (2014) as part of an assessment integrated stormwater and ecological management system for the Heartlands property on the western side of the estuary. This study also investigated historic movements of the Lourens estuary mouth and the links between this estuary and the Wagenveldsluit, a wetland feature running parallel to the coast on the seaward margin of the Heartlands site.

3.3.11.3 Scenarios Considered

Although there are no firm plans for increased (or decreased) utilisation of water in the Lourens River catchment, a number of hypothetical scenarios were constructed to examine likely impacts of further decreases (transfers out of the catchment) as well as some increases (restoration) in flow on the health of the Lourens estuary. Restoration of flows was assumed to be achieved through removal of Invasive Alien plants (IAPs) and or reduction in water use for irrigation and/or domestic use.

The following scenarios were considered:

- **Natural**: Reference condition
- **Present**: Present day flows and conditions
- **Scenario 1**: Steady state reduction in baseflow of 0.1 m^3/s (equivalent to reduction in MAR of ~4% from Present and 19% from Reference)
- **Scenario 2**: Steady state reduction in baseflow of 0.3 m^3/s (equivalent to reduction in MAR of ~11% from Present and 24% from Reference)
- **Scenario 3**: Steady state reduction in baseflow of 0.6 m^3/s (equivalent to reduction in MAR of ~19% from Present and 32% from Reference)
- **Scenario 4**: 50% reduction in abstraction from present (8% below Reference)

Scenarios 1-3 are designed to investigate the impact of further reduction in runoff to the estuary resulting from, for example increased run-of-river abstractions. Scenario 4 was designed to investigate the impacts of restoration in baseflow through, for example clearing of alien vegetation in the catchment and our reduction in use of water for irrigation and/or domestic use.

A summary of the scenarios considered are given in Table 3-65.

Table 3-65 Summary of scenarios considered for the Lourens River Estuary (IUA D7)

Scenario name	Description	MAR (million m^3/a)	Percentage of natural flows
Natural	Reference condition	70.027	100%
Present	Present day conditions	59.221	85%
Scenario 1	- 4% from Present	56.793	81%
Scenario 2	- 11% from Present	52.887	76%
Scenario 3	- 19% from Present	47.769	68%
Scenario 4	50% reduction in abstraction from present	64.621	92%

3.3.11.4 Hydrodynamics

The estuary emerges below the road bridge at an angle of 60 degrees from north-east on to the beach where it forms a small elongated east/west orientated water body, dammed up behind the beach bar. This water body can vary significantly in size depending on the location of the mouth and the degree to which the system is perched. The more perched the larger the water body. During the ECRU survey on 7 July 1982, the beach bar was between 0.5 and 2 m high. When the beach bar is built up by high waves, the channel sometimes extends several hundred metres along the shore towards the west until it finds its way down to the foreshore and sea. The area to the west of the mouth is the Helderberg Marine Protected Area (which extends along the coast as far as the Eerste estuary).

At the Lourens estuary, during the high flow season the mouth is scoured by the river outflow and a tidal influence of 40 to 70 cm is clearly detectable. Once river inflow reduces, wave action over a period of months causes sand accumulation in the mouth area, which results in sand build up and restriction of the mouth. Tidal flows become progressively less. As the outflow through the mouth is enough to maintain an open inlet, an equilibrium state is reached where the water level in the estuary keeps up with the rate the sand berm is increasing and/or scour out accumulated sand from the inlet, resulting in a perched mouth condition.

In the “perched state” the mouth of an estuary is open, but only a small outflow channel of a few metres wide and a few centimetres deep is present, with limited sea water intrusion and very little tidal variation occurring (~ 10 cm). This state must also be present for a significant period (about 14 days) to distinguish it from the transition phase between the open and closed mouth states. The perched state must not be confused with overwash by big waves during storm events or spring tides, which only occurs for short periods or under extreme conditions. Reductions in river flow can affect the natural variation in the state of an estuary mouth, and subsequently the ecological character. For example, a small change in river inflow could change the mouth from this open, but constricted state to a closed state.

In this perched state the mouth is located high on the beach and above the influence of the average wave conditions. The result of such a perched or restricted mouth is no or limited tidal variation in the estuary and a relatively high-water level (+1.0- 2.0 m MSL). There are therefore no, or very little, inter-tidal areas exposed at low tide or flooded during high tide. Small fluctuations in water level may occur due to changes in river flow, overwash, water losses and changes in the berm height. The outflow channel, which would be the lowest point on berm wall, would still allow waves through at higher tides (e.g. spring tides) and during storms events. It should also be noted that the runoff associated with this state is so little that it does not prevent big waves, such as those occurring during a storm, with associated greater sediment loads from closing the estuary.

Aerial photographs of the Lourens estuary indicate that the outflow channel is normally only a few metres wide, but often meanders extensively. This is an indication that the perched state has persisted for some time, for if strong tidal interaction was present, the entrance channel would be straight. Field observation show that the depth of the outflow channel during the perched mouth state is normally about 0.2 m or less, e.g. Lourens ~0.15 m in January 2002.

Very little baseflow is required to maintain this state, however, they should need to be high enough to compensate for the loss of water from evaporation (negligible in smaller estuaries) and seepage through the berm wall. The implications of this is that even a relatively small abstraction of water can influence this dynamic resulting in an increase in the frequency of mouth closure, which in turn can impact on juvenile fish and invertebrate migration patterns. Equally, the small increases in baseflow needed to create this state in an estuary can also be produced artificially through for example return flow from sewage plants, return flow from agriculture and stormwater inflows.

The Department of Water and Sanitation (DWS) collected water level data at the mouth of the Lourens Estuary between 2004 and 2016. The following observations were made from these recordings:

- Strong tidal variation is observed during most of the autumn, winter and spring periods. The graphs show that the mouth was wide open and that strong intrusion of seawater undoubtedly occurred. The river flow was probably at times strong enough to flush all saline water out of the estuary, but the influx of seawater would occur again after the river flow was reduced.
- Limited tidal variation was observed in most years during late summer, i.e. January to March. During this period the water level in the estuary is raised, with limited tidal intrusion on spring high tides. Some problems have been experienced with backflooding in the stormwater reticulation network under these conditions.
- These observations show that the estuary is predominately in a perched or open state, with no record of a prolonged closed state.

Based on the above information the Lourens estuary hydrodynamics were defined in terms of three abiotic states.

Table 3-66 Characteristic abiotic state in the Lourens estuary.

Abiotic State	Water level (m) associated with abiotic state	Tidal range	Connectivity	Salinity Structure
Closed, with overwash	2.0-2.5 m	Overwash	Overwash input from the sea every few weeks	Well mixed
Perched, with limited tidal variation	1.-2.0 m	10 cm	Limited inflow and limited tidal exchange on high tides	Horizontally stratified
Open, tidal	0.5 m	40-60 cm	Significant river input and good tidal exchange	Vertically stratified

Table 3-67 The occurrence of the Abiotic States under the Reference Condition, Present State and Scenarios 1 to 4.

Abiotic State	Flow range (m^3/s)	% Occurrence					
		Reference	Present	Sc 1	Sc 2	Sc 3	Sc 4
Closed, with overwash	<0.01	0.0	18.6	25.2	31.1	39.6	0.0
Perched, with limited tidal	0.01-0.2	14.7	20.6	15.9	11.9	5.6	24.5
Open, tidal	> 0.2	85.3	60.8	58.9	56.9	54.7	75.5

Based on the information presented above, scores for hydrodynamic health of the Lourens estuary were allocated as in Table 3-68.

Table 3-68 Hydrodynamic health scores for Present Day and the four alternative scenarios relative to the Reference Condition.

Variable	Present	Sc 1	Sc 2	Sc 3	Sc 4	Conf
a. Mouth condition	81	69	57	51	100	L
b. Abiotic states as proxy for hydrodynamic shifts	76	69	57	51	90	L
Score (min + average (a: b))/2	**77**	**69**	**57**	**51**	**93**	**L**
Score min (a to b)	**76**	**69**	**57**	**51**	**90**	**L**

3.3.11.5 Water Quality

For the purposes of this study, the Lourens estuary is sub-divided into two zones, namely the Upper estuary (~above golf course) and Lower estuary (~below golf course).

Very little salinity data is available for the Lourens estuary. The following conceptual salinity model was therefore developed based on expert opinion and limited data:

- State 1: Open tidal - the lower parts of the estuary can be very close to that of sea water (30-35 PSU), with significant salinity penetration into the middle reaches. The system will have a full salinity gradient, the extent of which will be determined by river inflow. During floods the system may be completely fresh for a few days. During periods of high river inflow, the system is subjected to extreme salinity variation over a tidal cycle, with high salinities on the flood tide and near zero on the ebb tide. On 7 July 1982, for example, salinities of 35 PSU were recorded at the mouth decreasing rapidly to 12 PSU during high tide and 0 PSU during the low tide.
- State 2: Perched State, with limited tidal intrusion - low river inflow facilitates high retention of sea water and the development of strong stratification in the deeper middle reaches of the system above the bridge. Bollmohr *et al.* (2011) measured bottom salinities varying between 25 and 35 PSU and surface salinities varying between 1 and 8 PSU during this state between January and March 2003. In addition, water levels are higher during this state pushing small amounts of saline water (1-2 PSU) into the upper reaches.
- State 3: Closed with overwash - stratification is expected to be less prominent, with salinities similar to that of the State 2 in the lower and middle reaches, but due to elevated water levels saline water is expected to push significantly into the upper reaches, e.g. 5 PSU.

Data collected by the City of Cape Town shows no significant salinity penetration in the lower and middle reaches, but this a function of the monitoring station and monitoring procedures that only focus on surface water quality. As the system is very stratified in the middle reaches this is not a true reflection of the salinity regime of this system. The lower reaches of the Lourens Estuary often stratify, characterised by high bottom water salinity.

Considering the distribution of the 3 abiotic states under the reference, present and future scenarios, average water quality conditions in the estuary are as indicated in Table 3-70.

Table 3-69 Water quality characteristics of the Lourens estuary under different states.

Salinity		Reference and Present	
Lower Estuary	State 1: Closed	15	
	State 2: Perched	15	
	State 3: Open	25	
Upper Estuary	State 1: Closed	5	
	State 2: Perched	1	
	State 3: Open	0	
	State 2: Perched	5	10
	State 3: Open	5	10

No measured data on the reference water quality other than salinity (i.e. prior to anthropogenic influences) could be obtained for this estuary. However, considering the catchment of the system, it can be assumed that, on average, its water bodies were clear, well-oxygenated and oligotrophic. Currently the estuary is subject to major anthropogenic impacts on water quality, specifically diffuse runoff from urbanised areas and a golf course in the lower estuary (Cliff & Grindley, 1982).

Available data on relevant water quality parameters for the periods 2000-2009 and 2010-2016 are summarised in Table 3-70. As a result of anthropogenic influence, water quality in the system has been modified as reflected by the WQ data. Results show that average DIN and DIP concentrations decrease from the period 2000-2009 to the period 2010-2016, both in river inflows and in the lower and upper estuary

(DIN mostly a reduction in NOx-N). This could be attributed to improved catchment practices, e.g. upstream agricultural areas using improved methods re fertilizer application. Average DO levels in the system also did not reflect supersaturation during the 2010-2016 period compared with 2000-2009. TSS is the system remained relatively low compared with other urban systems in the WMA.

Based on available information and expert opinion, estimated average water quality concentration for various zones across scenarios are indicated in Table 3-70.

Table 3-70 Average water quality conditions in the Lourens estuary under different abiotic states.

Salinity	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower estuary	24	22	22	21	21	24
Upper estuary	0	1	1	2	2	0
DIN (µg/ℓ)	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower estuary	50	350	350	400	400	350
Upper estuary	50	350	350	350	350	350
DIP (µg/ℓ)	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower estuary	10	80	80	90	90	80
Upper estuary	10	20	20	20	20	20
DO (mg/ℓ)	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower estuary	8	7	7	6	6	7
Upper estuary	8	7	7	6	6	7
TSS (mg/ℓ)	**Reference**	**Present**	**Scn 1**	**Scn 2**	**Scn 3**	**Scn 4**
Lower estuary	5	9	9	9	9	9
Upper estuary	5	11	11	11	11	11

In terms of toxic substances, Bollmohr *et al.* (2011) also detected pesticide contamination in the estuary attributed to agricultural activities in the catchment.

The water quality scores and summary of changes are presented in Table 3-71.

Table 3-71 Summary of changes and calculation of the water quality health score

Variable		**Present**	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Conf**
1	Salinity						
	Similarity in salinity	77	75	74	72	93	L
2	General water quality						
a	Nutrient (DIN/DIP) concentrations	35	35	33	33	35	L
b	Dissolved oxygen	93	93	86	86	93	L
c	Total suspended solids	67	67	67	67	67	L
d	Toxic substances	70	70	60	60	70	L
	Water quality score*	**60**	**59**	**58**	**56**	**70**	

**Score = (0.6 x S + 0.4 x min (a to d))*

Table 3-72 Summary of changes to the water quality health score

Parameter	Summary of Changes
Salinity	Scenario 1 is similar to present. Scenario 2 to 3 shows a slight ⇩ in salinity, while Scenario 4 is very similar to Reference
Inorganic nutrients (DIN/DIP) in estuary	⇧ due to nutrient input from agricultural and urban runoff (including golf course in lower estuary). Increase in lower estuary is expected in scenarios where the closed state increases significantly e.g. Scenarios 2 and 3 (less flushing with runoff from golf course still entering system)
Dissolved oxygen in estuary	⇩ due to organic and nutrient loading from urban and agricultural runoff (and algal activity) Decrease is expected in scenarios where closed state increases significantly e.g. Scenarios 2 and 3 (less flushing)
Suspended solids in estuary	⇧ limited increase due to urban and agricultural runoff. No marked shift between scenarios as average salinity in zones remain similar (i.e. same influence of “cleaner seawater) and quality of inflow remain similar
Toxic substances in estuary	⇧ due to urban and agricultural runoff. Increase in lower estuary is expected in scenarios where the closed state increases significantly e.g. Scenarios 2 and 3 (less flushing with runoff from golf course still entering system)

3.3.11.6 Overall Estuary Health Score for Scenarios

Progressive reductions in flow envisioned for Scenario 1-3 led to an overall reduction in health from 51 to 40, taking the estuary to an E category for Scenario 3 (Table 3-73). Scenarios 4 (increased flow) increased health to a similar degree, and put the estuary into a C category (score 61).

Table 3-73 Estuary health scores of alternative flow scenarios for the Lourens estuary.

Component	Present	Sc1	Sc2	Sc3	Sc4
Hydrology	85	81	76	68	92
Hydrodynamics and mouth condition	76	69	57	51	90
Water quality	53	52	51	50	58
Physical habitat alteration	30	30	25	20	30
Habitat health score	**61**	**58**	**52**	**47**	**67**
Microalgae	45	45	45	40	65
Macrophytes	25	25	25	20	35
Invertebrates	39	36	34	25	45
Fish	40	40	40	30	65
Birds	53	50	48	45	65
Biotic health score	**40**	**39**	**38**	**32**	**55**
Estuary Health Score	**51**	**49**	**45**	**40**	**61**
Ecological Category	**D**	**D**	**D**	**E**	**C**

3.3.12 Wetland Scenarios for the G2 Catchments

The Wetland Regions associated with the Coastal River Catchment Scenarios (G2 and G40A and Langebaan Lagoon) are the South Western Coastal Belt_sand (WR1) and South Western Coastal Belt_shale (WR2) as well as the Southern Folded Mountains (WRU4 and WRU5) Wetland Regions.

These are shown in Figure 3-22 and summarised in the following sections.

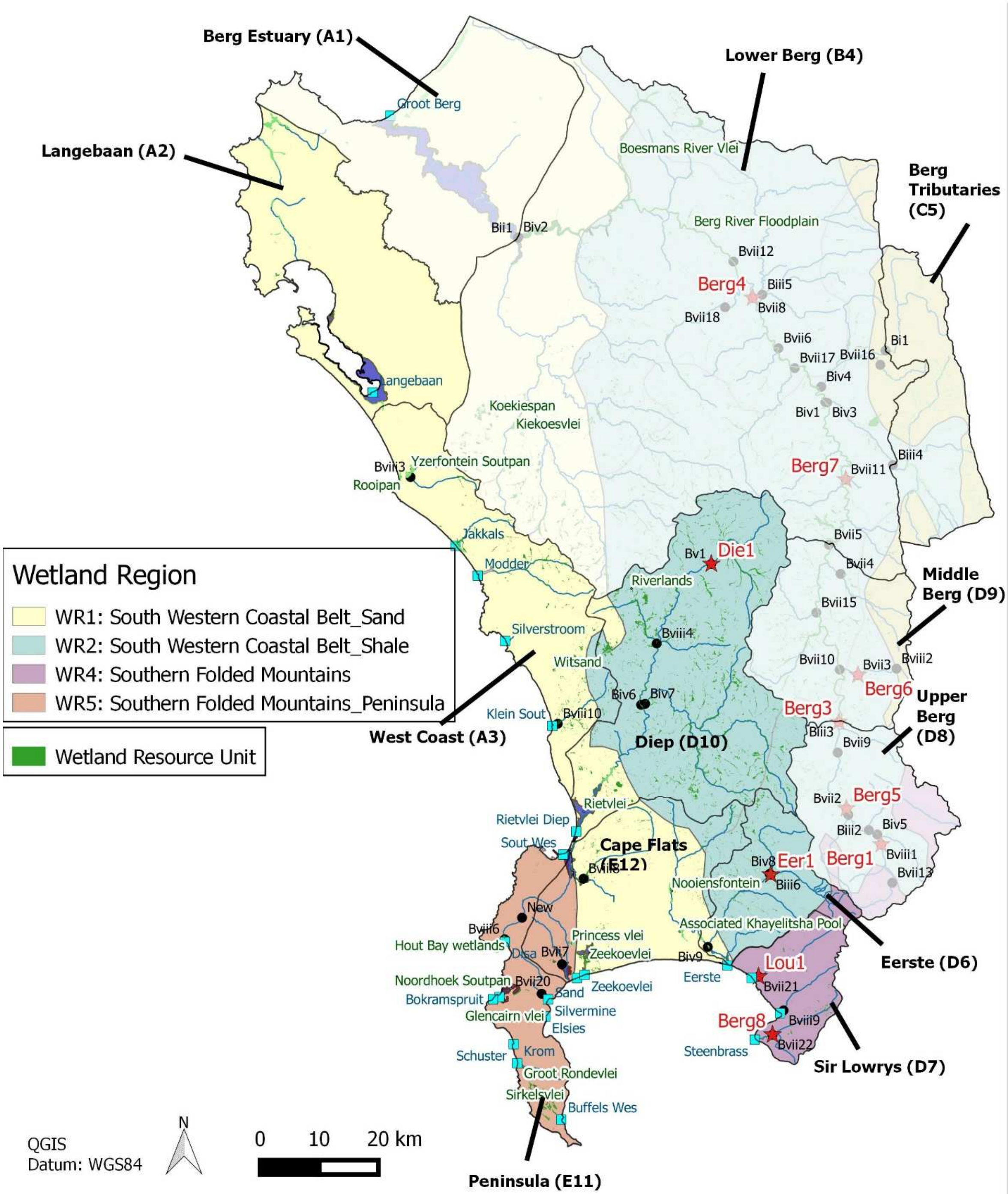


Figure 3-22 The Wetland Region and Wetland Resource Units associated with the G2 catchments and Estuaries

South Western Coastal Belt_Sand (WR1) Wetland Region

- The South Western Coastal Belt_Sand Wetland Region stretches along the coast and is associated with Aeolian sedimentary deposits of the Kalahari Group.
- The Langebaan and False Bay Ramsar sites occur within this Wetland Region.
- Strandveld valley bottom wetlands are located almost exclusively in the Saldanha Peninsula. They are seasonal wetlands, tend to be saline and occur on neutral to alkaline sands or granite-derived soils (Job *et al.*, 2008). As opposed to Langebaan these wetlands are generally fed by hillslope seeps lying on higher ground and are not particularly groundwater dependent (Job *et al.*, 2008).

Threats to these wetlands are both cultivation and urban expansion, with changes to the flow regime being of particular concern.

- The wetlands along the coast consist of a few isolated pans and the Witzand Recharge Aquifer is artificial. Yzerfontein salt pan, a saline depression wetland, is currently being mined for gypsum. Alien invasive vegetation in the area and deepening of the main pan due to dredging activities is degrading the wetland. Two depression wetlands occur on a tributary of the Berg River to the north of Darling. The Koekispan and Kiekoesvlei occur within agricultural lands and are host to a variety of water birds. Koekispan is a saline pan which still bears a berm from salt mining.
- Zeekoeivlei is the largest of the Cape Flats wetlands. Princessvlei is a small, shallow, eutrophic freshwater coastal vlei to the north of Rondevlei (a smaller vlei next to Zeekoevlei). These wetlands (along with the Strandfontein Wastewater Treatment Works) form part of the False Bay Nature Reserve, which was proclaimed as South Africa's 22nd Ramsar site in 2015. The importance of this area stems from the endemic vegetation type and important bird species. Most of the birds within this wetland system are concentrated at the Strandfontein Wastewater Treatment Works due to the wide range of wetland habitats present and the proximity to the ocean (Wright, 2015). Key bird species are in decline, possibly in response to changes in water level and quality (Wright, 2015). Water hyacinth has also invaded some of the settling ponds, impacting the biodiversity.
- The Kuils River in its original state flowed through a flat sandy valley from source until the Cape Flats. In particular the Khayelitsha wetlands have formed as the settlement expanded within the natural wetlands and a large portion of them were bulldozed and flattened (Brown and Magoba, 2009). "New" wetlands have formed as water was displaced and these wetlands form a viable habitat for aquatic animals, for water purification and for the recharge of the Cape Flats Aquifer (Brown and Magoba, 2009).

South Western Coastal Belt_Shale (WR2) Wetland Region

- The Diep River and Eerste River originate in the South Western Coastal Belt_shale Wetland Region which is which is typified by floodplain wetlands.
- Riverlands seep and depression wetlands occur in this region.
- Water abstraction is the main threat to floodplain wetlands in this Region, with the expansion of towns and urban areas likely increasing pressure due to habitat degradation and pollution.

Southern Folded Mountains (WR4) Wetland Region

- Typically, this wetland region has seeps and valley bottom wetlands, in particular acting as strategic water source areas for rivers as they flow out of the mountains.
- Paardevlei lies on the site of a natural, shallow, seasonal vlei. It has been impacted by various changes in use over the years, particularly related to fishing. In recent years it has had several rehabilitation efforts aimed at reinstating indigenous biota (Brown and Magoba, 2009). The surrounding area has been identified for significant mixed-use developments.
- The main impact in this region are transformation of wetlands for agriculture.

Southern Folded Mountains_Peninsula (WR5) Wetland Region

- Most mountain seeps, riverine systems and isolated depressions are within the Table Mountain Nature Reserve area.
- Noordhoek Valley consists of many wetlands scattered about between the developed part of the catchment and the beach. Three permanent waterbodies occur in this area: Lake Michelle (developed from former salt pans) and the Wildevoelvleis. These wetlands are of great conservation importance as they provide refuge to various rare plant and animal species.
- Along the Southern Peninsula towards Cape Point there are numerous seasonal vleis, seeps and streams, which mostly dry up in Summer (Brown and Magoba, 2009). Silvermine River emerges from the Silvermine Valley into the Fish Hoek plain whereby it joins the sea at the Silvermine Estuary. The area at upstream of the Silvermine Dam has a high EIS (5.9) due to the occurrence

of rare plant species and amphibians and the area at the lower Silvermine River floodplain has an even higher EIS (7.3) due to the occurrence of red data species (otters) and as it improves water quality amelioration and reduces flooding (Malan *et al.*, 2015). It also has important recreational value.

- Working for Wetlands has worked on Noordhoek, Prinskasteel and Langvlei wetlands.

3.3.12.1 Wetland impacts of Scenarios

A summary of the likely wetland impacts for the different scenarios considered are presented in Table 3-6.

Note that the potential impacts of alternative development scenarios on the wetlands associated with Langebaan lagoon are addressed in the estuaries sections looking at the impacts for Langabaan Lagoon.

Table 3-74 Likely wetland impacts for the scenarios in the Coastal River Catchment Scenarios

Scenario	Scenario Description	Likely surface water usage impacts	Likely indirect impacts
Diep/Rietvlei	**Scenario 1:** Maintain present day flows but all effluent from WWTW to be treated to DWS Special Standards. **Scenario 2:** Reduce inputs from the WWTW by 50% reduction and treat the remainder to DWS Special standards **Scenario 3:** Reduce inputs from the WWTW by 75% reduction and treat the remainder to DWS Special standards **Scenario 4:** Divert/recycle 100% of effluent from WWTW **Scenario 5:** Achieve REC through catchment management and flow scenario	The wetlands associated with the Diep/Rietvlei (Southwest Sand Fynbos Floodplain and West Coast Shale Renosterveld Floodplain) are floodplain wetlands with important vegetation under threat, and high ecosystem service supply/demand. The important vegetation and provision of ecosystem services of riparian floodplain wetlands (flood attenuation water quality enhancement) needs to be maintained. Reduction of flow through diversion of the WWTW effluent flows beyond 75% would reduce the inundation of floodplain wetlands. Freshwater inputs need to be increased.	**No catchment management:** Flow based scenarios do not significantly improve the health of the estuary due to extremely high nutrient and suspended solid levels in waste water from the WWTW and the catchment. **With catchment management:** Maintaining floodplain wetland vegetation and establishing riparian buffers in the catchment, improving the quality of stormwater entering the system (especially from informal settlements), dredging Milnerton lagoon, removing alien invasive vegetation from the catchment will improve the state of the estuary and floodplain wetlands.

Scenario	Scenario Description	Likely surface water usage impacts	Likely indirect impacts
Wildevoelvlei	**Scenario 1:** Maintain present day flows but all effluent from WWTW to be treated to DWS Special Standards **Scenario 2:** Reduce inputs from the WWTW by 50% and treat the remainder to DWS Special standards **Scenario 3:** Reduce inputs from the WWTW by 75% and treat the remainder to DWS Special standards **Scenario 4:** Achieve REC through catchment management and flow scenario	Wildevoelvlei is a medium sized temporarily open estuary that drains several seasonal wetlands and pans in the Fish Hoek-Noordhoek valley (Southwest Sand Fynbos Unchanneled valley bottom & Floodplain, Southwest Sandstone Fynbos Floodplain, Western Strandveld Floodplain & Unchanneled valley-bottom). These wetlands are of great conservation importance as they provide refuge to various rare plant and animal species. The scenarios considered improved the health of the estuary through reductions of WWTW effluent to upper vlei. This reduction in flow would not impact the surrounding wetlands in the upper catchment as inputs are generally from surrounding runoff.	**No catchment management:** Without additional catchment management it is likely that the health of the estuary and wetlands would degrade in the long term, even if reducing WWTW flows is achieved. **With catchment management:** Opening up the channel between the lagoon and Wildevoelvlei, clearing reeds and dredging accumulated sludge would allow for increased natural flow to the Estuary and in turn allow for increased seasonality and more naturalised sediment regime of surrounding wetlands.
Zandvlei	**Scenario 1**: Complete removal of the rubble weir and other obstructions at mouth of the estuary to allow improved tidal flushing. **Scenario 2**: Remove bank stabilisation to create more shallow water marginal habitat. **Scenario 3**: Dredge the upper reaches of the vlei to -2.0 m MSL to remove accumulated silt and organic material. **Scenario 4**: Combination of interventions for Scenario 1 and 2 **Scenario 5:** Achieve REC through catchment management and flow scenario	No flow scenarios considered.	**No catchment management:** With no catchment management the Estuary and surrounding wetlands will degrade due to increased pressure from the urban environment. **With catchment management:** Although there are no prioritised wetlands near Zandvlei Estuary, there are Working for Wetlands (Prinskasteel Floodplain wetland and Langvlei Channelled Valley Bottom wetland) in the catchment, as well as Princessvlei (Channelled Valley Bottom wetland). Catchment management for these wetlands in terms of erosion management (Working for Wetlands project) and improved stormwater management will benefit the wetlands and estuary by managing the sediment regime.

Scenario	Scenario Description	Likely surface water usage impacts	Likely indirect impacts
Zeekoevlei	**Scenario 1:** Maintain present day flows but effluent from Cape Flats WWTW to be treated to DWS Special Standards **Scenario 2:** Reduce inputs from the Cape Flats WWTW by 50% and treat the remainder to DWS Special standards **Scenario 3:** Reduce inputs from the Cape Flats WWTW by 75% and treat the remainder to DWS Special standards **Scenario 4:** Divert/recycle 100% of effluent from WWTW **Scenario 5:** Flows as for Scenario 1 above but facilitate access by marine and estuarine fish into Zeekoevlei and Rondevlei. **Scenario 6:** Flows as for Scenario 4 above but facilitate access by marine and estuarine fish into Zeekoevlei and Rondevlei **Scenario 7:** Achieve REC through catchment management and flow scenario	Rondevlei and Zeekoevlei are both Western Strandveld Floodplain wetlands within the False Bay Ramsar delineation. They are therefore important ecologically, as well as in terms of ecosystem services as they provide important flood amelioration, groundwater recharge, water quality amelioration and recreational benefits. Inputs to the wetlands are from surrounding stormwater and Big and Little Lotus Rivers (Rondevlei also receives input from Princessvlei). Rondevlei and Zeekoevlei have both had significant changes in terms of sediment inputs and outputs, which has impacted erosion and deposition features in the wetlands. Rondevlei has been managed to maintain a level of seasonality, which allows for the removal of sediments and water. Zeekoevlei is managed with water quality in mind, not seasonality of water flows. Diverting the effluent flows will allow for a seasonality of flow to the wetlands.	**No catchment management:** With no catchment management the Estuary and surrounding wetlands will degrade due to increased pressure from the urban environment which would increase the stormwater inputs, water quality and habitat degradation. **With catchment management:** Continuing the management of removing suspended sediment from Rondevlei allows for the seasonality of deposition to be maintained. Improved stormwater management in the surrounding catchment will also reduce sediment loads, although a certain level of sediment is required to keep the system stable. Improving the biodiversity through improved access by building a fish ladder into the wetlands will be beneficial.
Eerste	**Scenario 1:** Maintain present day flows but all effluent from WWTW to be treated to DWS Special Standards **Scenario 2:** Reduce inputs from the WWTW by 50% reduction and treat the remainder to DWS Special standards **Scenario 3:** Reduce inputs from the WWTW by 75% reduction and treat the remainder to DWS Special standards **Scenario 4:** Divert/recycle 100% of effluent from WWTW **Scenario 5:** Achieve REC through catchment management and flow scenario	Changes to the flow from the WWTW will not impact these wetlands.	**No catchment management:** Eerste Estuary is associated with the South Western Coastal Belt_Sand (WR1) Wetland Region (In particular the Khayelitsha Pool and Nooiensfontein wetlands) and the South Western Coastal Belt_Shale (WR2) Wetland Region. Future developments will likely increase stormwater inputs, water quality and habitat degradation. **With catchment management:** Improved stormwater management and limiting wetland transformation will allow for the continued functioning of the wetlands in the area.

Scenario	Scenario Description	Likely surface water usage impacts	Likely indirect impacts
Lourens	**Scenario 1**: Steady state reduction in baseflow of 0.1 m^3/s (equivalent to reduction in MAR of ~4% from Present and 19% from Reference) **Scenario 2**: Steady state reduction in baseflow of 0.3 m^3/s (equivalent to reduction in MAR of ~11% from Present and 24% from Reference) **Scenario 3**: Steady state reduction in baseflow of 0.6 m^3/s (equivalent to reduction in MAR of ~19% from Present and 32% from Reference) **Scenario 4**: 50% reduction in abstraction from present (8% below Reference) **Scenario 5:** Achieve REC through catchment management and flow scenario	There are no notable wetlands associated with the estuary in the Southern Folded Mountains (WR4) Wetland Region. .	

The current and future groundwater scenarios were assessed in terms of the usage impacts, in particular for wetlands linked to a river, as well as in terms of indirect impacts, for wetlands not associated with a river (Table 3-76). The Groundwater Resource Units that relate to the G2 catchment are the Peninsula, Cape Flats, Helderberg, Malmesbury and Atlantis Groundwater Resource Units.

Table 3-75 Likely wetland impacts for the scenarios in the G2 catchments

Scenario	Scenario Description	Likely groundwater usage impact	Likely indirect impact
Current	Baseline - Present day	The current status of the Atlantis GRU is a Class III (Heavily used). This is indicative that the Depression, Flat and Seep wetlands typical of the South Western Coastal Belt_Sand Wetland region are likely altered from their reference condition. The current status of the Malmesbury GRU is a Class II (Moderately used) although the G21D quaternary catchment is in a Class III. This is indicative that the Depression and Seep wetlands (such as Riverlands) are likely altered from their reference condition. The current status of the Cape Flats GRU is a Class II (Moderately used) indicating that there are localized low level impacts to wetlands in the area.	**No catchment management:** Without catchment management stormwater inputs reduce the seasonality of depression and flat wetlands. **With catchment management:** With catchment management the seasonality of depression and flat wetlands is provided for.

Scenario	Scenario Description	Likely groundwater usage impact	Likely indirect impact
Cape Flats Aquifer	Mitchells Plain: 20 boreholes located between 1.5 – 4km from coastline (18 to 3.7 million m^3/a)	Hypothetical sites therefore location unknown. It is likely that there will be significant impacts on flat and depression wetlands which are groundwater dependent. These wetlands will have a reduced seasonality, if not complete drying up depending on location near cone of depression.	**No catchment management:** Borehole locations near/within wetlands (location is likely to be within a wetland due to surface/groundwater interaction) will transform wetland habitat and increase stormwater flow due to hardened surfaces associated with infrastructure. **With catchment management:** Borehole locations near/within wetlands need to have stormwater management which limits erosion and channelization of flow.
	North Philippi (20 boreholes at 3.7 million m^3/a and 19 boreholes at 2 million m^3/a)		
	Central Philippi and airport (10 million m^3/a)		
	Dispersed abstraction		
	Central Philippi and airport (10 million m^3/a) and dispersed abstraction		

3.3.13 Ecosystem Goods Services and Attributes

The primary EGSA value for the rivers and estuaries in the G2 catchments is in terms of the tourism value and property value as these estuaries are not considered to be major contributors to subsistence fishing or nursery functions for ocean fish stocks. The estimated tourism value and property value for the estuaries are given in Table 3-76 as well as the estimated increase in value for the targeted REC scenario. The resulting net present value (NPV) of the change in the EGSAs value for the REC is also given (NPV: 30 years @ 6% discount rate).

Table 3-76 Estimated change in EGSA values for estuaries in the G2 catchments for the REC scenario.

ESTUARY	Property Value (R million/a)	Tourism Value (R million/a)	Total	PES	REC	Change in Value	Change in Total EGSA Value (R million/a)	NPV of Change in EGSAs (R million)
Langebaan	26.99	136.6	163.59	A	A	1	0.0	0.0
Rietvlei/Diep	32.71	62.4	95.11	D	D	1	0.0	0.0
Wildevoëlvlei	0.19	29.6	29.79	D	D	1	0.0	0.0
Sand	4.74	98.5	103.24	D	C	1.4	41.3	731.2
Zeekoe	1.62	8.2	9.82	E	D	1.8	7.9	139.1
Eerste	1.76	8.9	10.66	E	D	1.8	8.5	151.0
Lourens	0.50	33	33.50	D	D	1	0.0	0.0
TOTAL	**39.81**	**377.2**	**445.71**				**57.7**	**1 021.3**

3.3.14 Socio-economic Impacts of Scenarios

In contrast to most other river and estuaries systems in the country, the major concern from a flow perspective for the G2 catchments is the high summer return flows from the wastewater treatment plants. These are also a major contributor to the water quality challenges for each estuary. Achieving the desired REC for these estuaries therefore requires a reduction in the average flow, particularly during the summer season.

This can be achieved through the use of treated effluent, which is also being considered by the City of Cape Town as a future water supply augmentation option. The current cost of re-use is estimated to be around R13/m^3.

Increased re-use of treated effluent is an option for the Diep, Zeekoei, Eerste and Lourens estuaries as these are located downstream of WWTW targeted by the City of Cape Town for possible re-use projects. Together these represent a possible total surplus during the dry season of around 22 million m^3/a. The infrastructure cost necessary to be able to utilise this volume of water for re-use, i.e. to meet the REC, is around R289 million. However, this actually represents a cost saving, since it saves on the next option for water supply which is desalination. At current prices, this option therefore incurs a saving of R110 million.

For some of the upstream nodes, however there are small seasonal shortfalls which will need to be met. As a first estimate it is assumed that these shortfalls will be met through increased groundwater abstraction. Note that these shortfalls are based on current demands as it assumes no additional allocations to agriculture and that additional demands from urban and industrial users will be met through re-use or augmenting the WCWSS.

In total the dry season shortfall for all the G2 nodes is around 7.64 million m^3/a. The infrastructure cost to provide this shortfall through increased groundwater abstraction, if available, is estimated to be around R31 million.

As indicated in the previous section, the NPV of the increased value from EGSAs for the estuaries in the G2 catchments is at least R1020 million. The REC scenario thus incurs a net saving of R79 million for water supply plus the benefits of improved EGSAs, yielding an overall benefit of some R1100 million. This benefit could offset some of the costs of implementing an REC scenario in the Berg primary catchment.

3.4 Groundwater Development Scenarios

3.4.1 Current and Future Groundwater Status

The present groundwater status was presented in full in the EWR report and are summarised in the tables and figures below. The present status based on groundwater quality is based on data presented in the Status Quo report, and is described in detail in the EWR report. Note that five quaternary catchments with insufficient water quality data are not included Table 3-79 (G10B, G10E, G22B, G22F, G22G).

For the current condition scenario, the results show:

- In terms of present status based on groundwater use:
  - 24 quaternary catchments have a groundwater stress of <20%, and present status I
  - 4 quaternary catchments have a groundwater stress of 20-65%, and present status II
  - 1 quaternary catchment (G21B) has a groundwater stress of >65%, and present status III
  - 1 GRU (Atlantis) has a groundwater stress of >65%, and present status III
- In terms of present status based on groundwater quality:
  - 11 quaternary catchments have a present status I
  - 15 quaternary catchments have a resent status II
  - 3 quaternary catchments have a present status III

For the future development scenario, the results show:

- 19 quaternary catchments (61%) have a groundwater stress of <20%, and future status I
- 9 quaternary catchments (29%) have a groundwater stress of 20-65%, and future status II

- 3 catchments (G21B, G21D, G22F) have a groundwater stress of >65%, and future status III
- 7 quaternary catchments have an increased level of risk with 2 of these increased to future status III.

The catchment with the greatest potential impact is G22F which will go from 6% to 163% stress if all future increases in demand were to be met from groundwater. This is due to the projected future shortfall of around 13.4 million m^3/a for the town of Stellenbosch. The current day balance available from groundwater in this catchment is however only 5.63 million m^3/a after taking into account the estimated groundwater contribution to baseflow (GWBF) of around 2.41 million m^3/a. Hence at least 8.2 million m^3/a will have to come from other sources. These could include improvements in water use efficiency, or increased allocations from the WCWSS or, most likely, the re-use of treated effluent.

A summary of the current groundwater balance, stress and status per GRU is given in Table 3-77.

Table 3-77 Groundwater Balance, Use/Recharge (Stress), and Present Status per GRU

GRU Name	Recharge (million m^3/a)	Use (million m^3/a)	GWBF (million m^3/a)	Balance (million m^3/a)	Use/Recharge (%)	Present Status
GRU-1: Malmesbury	47.19	10.48	10.37	26.34	22%	II
GRU-10: Atlantis	10.43	7.51	1.31	1.61	72%	III
GRU-2: Cape Flats	38.34	11.78	7.57	19.00	31%	II
GRU-3: Peninsula	11.25	0.10	3.93	7.22	1%	I
GRU-4: Paarl-Upper Berg	86.92	10.77	19.79	56.36	12%	I
GRU-5: Helderberg	45.21	3.31	8.25	33.65	7%	I
GRU-6: 24 Rivers	49.85	2.00	8.41	39.45	4%	I
GRU-7: Tulbagh	30.86	5.63	6.51	18.71	18%	I
GRU-8: West Coast	153.50	8.92	5.47	139.11	6%	I
GRU-9: Piketberg	44.19	17.52	1.71	24.95	40%	II

Table 3-78 Groundwater Balance, Use/recharge (Stress), and Present Status per Quaternary catchment

Quaternary	Recharge (million m^3/a)	GWBF (million m^3/a)	Current Day Scenario				Additional GW Demand (by 2040)	Maximum Future Growth Scenario (All Towns)			
			Use (million m^3/a)	Balance (million m^3/a)	Use/Recharge (%)	Present Status		Use (million m^3/a)	Balance (million m^3/a)	Use/Recharge (%)	Future Status
G10A	21.09	7.25	3.9	9.94	18%	I	4.05	7.95	5.89	38%	II
G10B	12.27	5.34	0.36	6.57	3%	I	0.00	0.36	6.57	3%	I
G10C	22.88	2.26	2.64	17.98	12%	I	10.43	13.07	7.55	57%	II
G10D	31.03	5	3.87	22.16	12%	I	0.00	3.87	22.16	12%	I
G10E	16.05	2.25	4.65	9.15	29%	II	1.24	5.89	7.91	37%	II
G10F	15.05	4.33	0.98	9.74	7%	I	0.88	1.86	8.86	12%	I
G10G	8.84	2.73	0	6.11	0%	I	0.00	0.00	6.11	0%	I
G10H	17.18	3.28	1.62	12.28	9%	I	1.86	3.48	10.42	20%	II
G10J	23.74	2.36	0.38	21	2%	I	0.86	1.24	20.14	5%	I
G10K	39.34	1.18	7.5	30.66	19%	I	0.04	7.54	30.62	19%	I
G10L	44.35	1.99	4.17	38.19	9%	I	0.35	4.52	37.84	10%	I
G10M	55.5	5.7	1.97	47.83	4%	I	32.67	34.64	15.16	62%	II
G21A	14.77	0.29	0.77	13.71	5%	I	0.13	0.90	13.58	6%	I
G21B	7.5	0.53	6.33	0.64	84%	III	0.00	6.33	0.64	84%	III
G21C	8.84	1.95	0.57	6.32	6%	I	0.00	0.57	6.32	6%	I
G21D	14.25	3.27	6.97	4.01	49%	II	2.96	9.93	1.05	70%	III
G21E	21.85	4.21	3.97	13.67	18%	I	1.59	5.56	12.08	25%	II
G21F	5.07	1.71	0.13	3.23	3%	I	0.00	0.13	3.23	3%	I
G22A	6.81	3.24	0.06	3.51	1%	I	0.00	0.06	3.51	1%	I
G22B	4.22	0.65	0.04	3.53	1%	I	0.00	0.04	3.53	1%	I
G22C	13.07	2.56	3.54	6.97	27%	II	0.00	3.54	6.97	27%	II
G22D	13.08	2.4	7.31	3.37	56%	II	0.00	7.31	3.37	56%	II
G22E	12.27	2.63	0.92	8.72	7%	I	0.00	0.92	8.72	7%	I
G22F	8.54	2.41	0.5	5.63	6%	I	13.39	13.89	-7.76	163%	III
G22G	6.57	1.1	0.82	4.65	12%	I	0.00	0.82	4.65	12%	I
G22H	14.03	2.08	1.25	10.7	9%	I	0.00	1.25	10.70	9%	I
G22J	11.28	1.58	0.51	9.19	5%	I	0.00	0.51	9.19	5%	I
G22K	4.78	1.06	0.24	3.48	5%	I	0.00	0.24	3.48	5%	I
G30A	27.88	1.19	3.81	22.88	14%	I	0.02	3.83	22.86	14%	I
G30D	15.61	0.62	8.23	6.76	53%	II	0.00	8.23	6.76	53%	II
G40A	15.26	3.17	0	12.09	0%	I	0.00	0.00	12.09	0%	I
TOTAL	**533**	**80.32**	**78.01**	**374.67**	**15%**		**70.46**	**148.47**	**304.21**	**28%**	

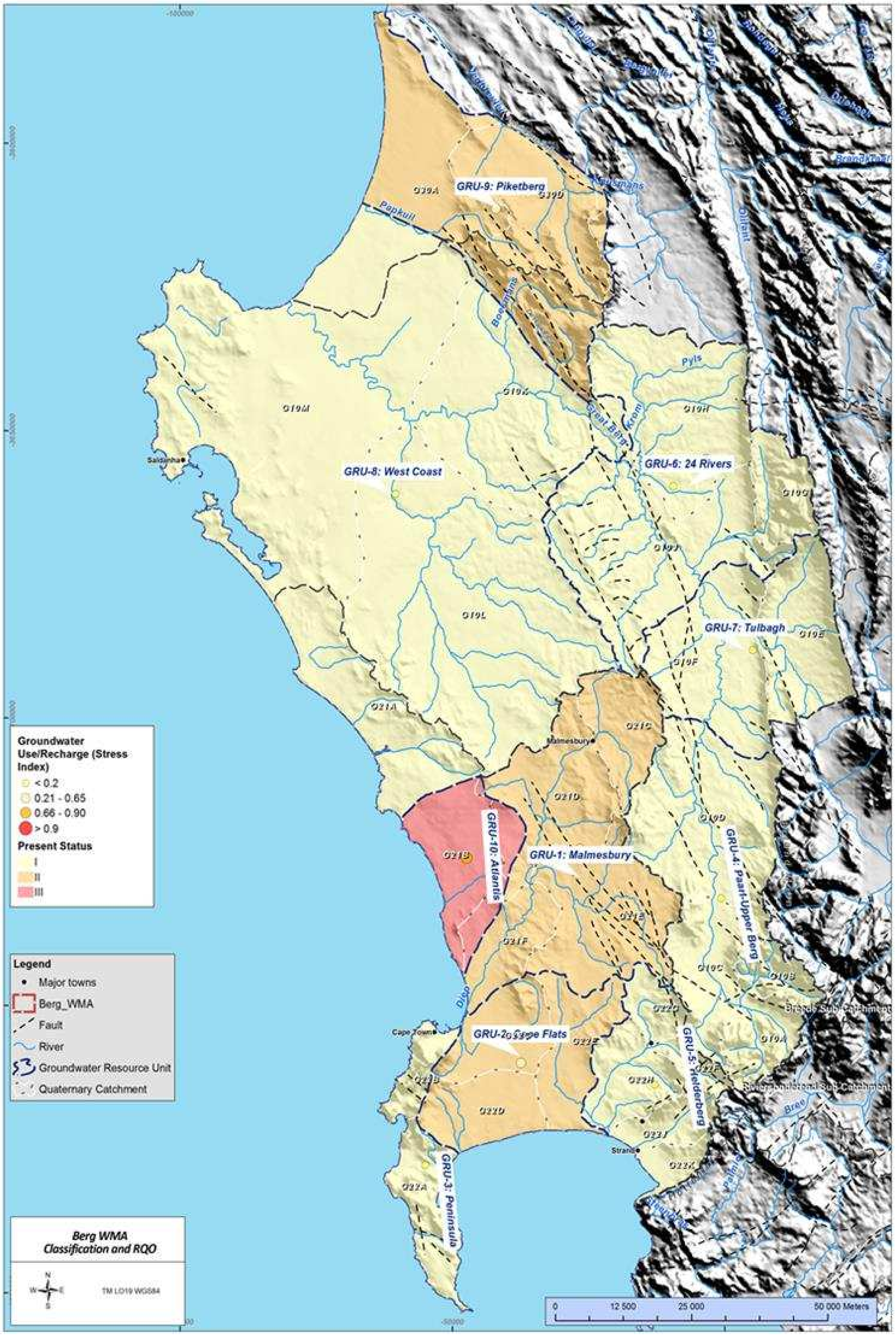


Figure 3-23 Present day level of groundwater stress in the Study Area

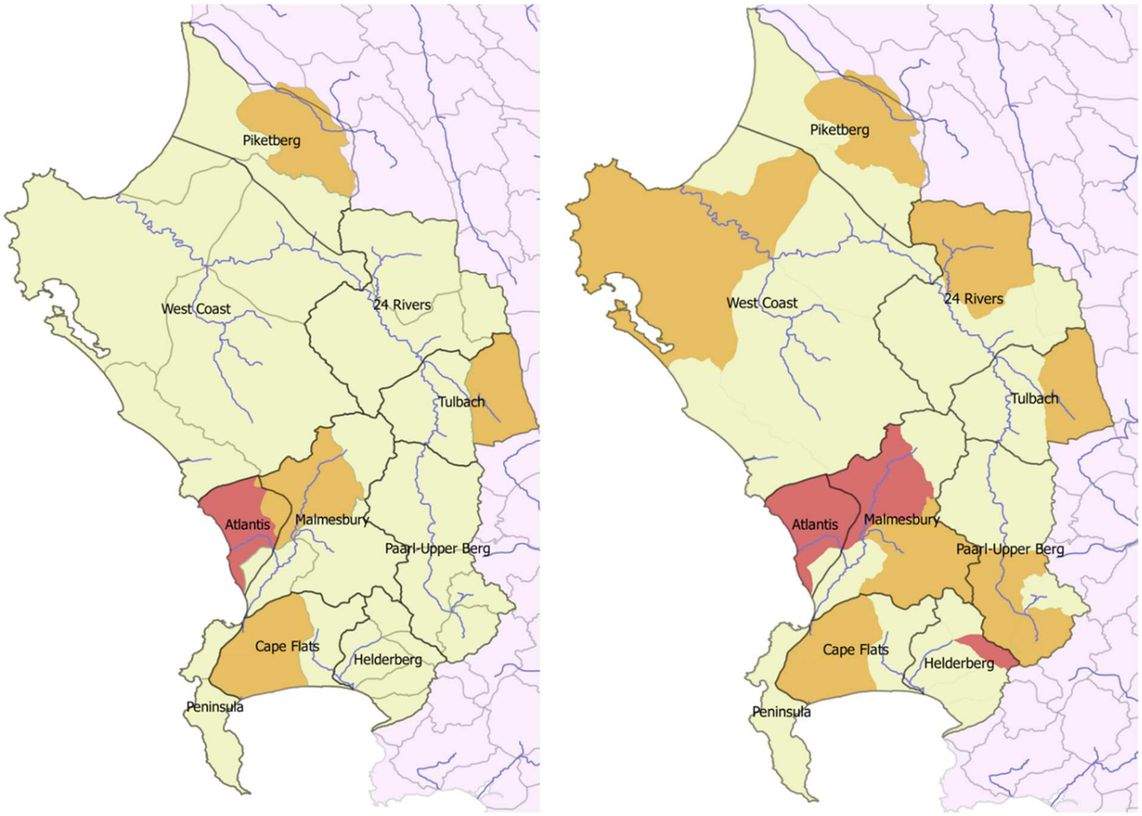


Figure 3-24: Change in groundwater stress level for all quaternary catchments from present status (left) to future (right) assuming future shortfalls from the All Towns study are met from groundwater.

Table 3-79 Present Status related to groundwater quality, per major aquifer per Quaternary catchment

Quaternary Catchment	Aquifer grouping	Category - EC	Category - NO_3 (as N)
G10A	Cenozoic coastal deposits	I	I
	TMG	I	I
	Basement	I	I
G10C	Cenozoic coastal deposits	I	I
	Basement	I	I
G10D	Cenozoic coastal deposits	I	I
	Basement	I	I
G10F	Basement	I	II
G10H	Cenozoic coastal deposits	I	II
	Basement	I	II
G10J	Cenozoic coastal deposits	II	I
	Basement	I	II
G10K	Cenozoic coastal deposits	III	I
	TMG	I	II
	Basement	II	III
G10L	Cenozoic coastal deposits	II	I
	Basement	II	II
G10M	Cenozoic coastal deposits	II	II
	TMG	I	I
	Basement	III	I

Quaternary Catchment	Aquifer grouping	Category - EC	Category - NO_3 (as N)
G21A	Cenozoic coastal deposits	I	I
G21B	Cenozoic coastal deposits	I	I
	Basement	III	III
G21C	Basement	II	III
G21D	Cenozoic coastal deposits	I	I
	Basement	I	II
G21E	Cenozoic coastal deposits	I	I
	Basement	I	I
G21F	Cenozoic coastal deposits	II	III
	Basement	II	II
G22A	Cenozoic coastal deposits	I	II
G22C	Cenozoic coastal deposits	I	I
G22D	Cenozoic coastal deposits	I	II
G22E	Cenozoic coastal deposits	I	I
G22H	Cenozoic coastal deposits	I	II
G22J	Cenozoic coastal deposits	I	II
G22K	Cenozoic coastal deposits	I	I
	Basement	I	I
G30A	Cenozoic coastal deposits	II	I

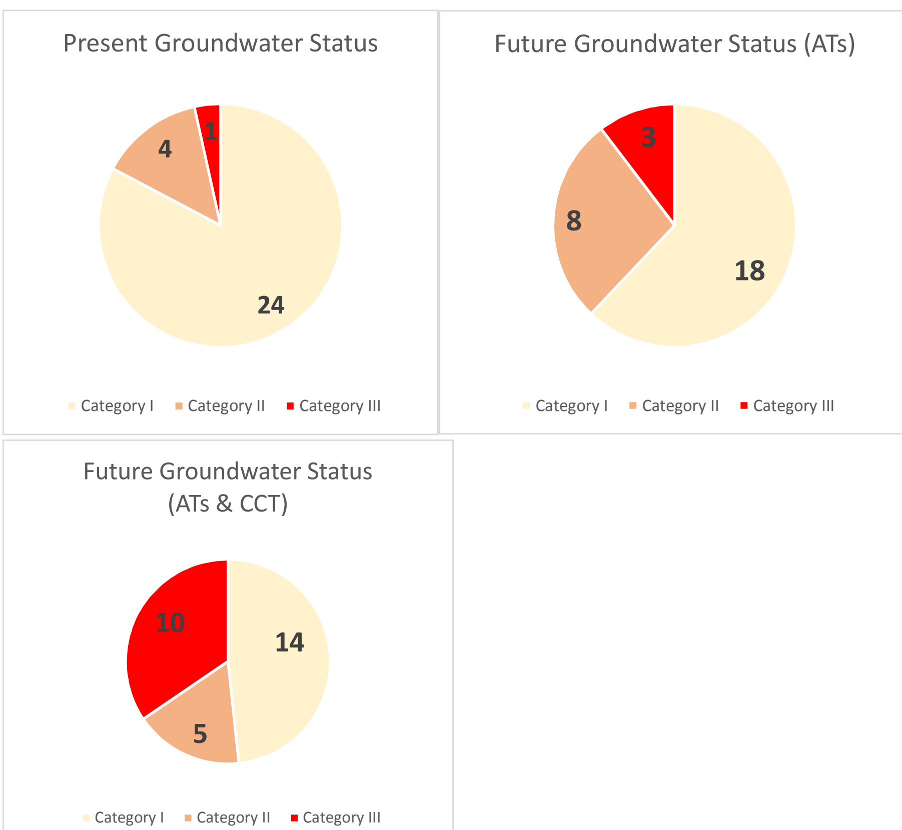


Figure 3-25 Number of catchments in each level of groundwater status (based on use) for present conditions, future condition with maximum All Towns demands (ATs), and future condition with maximum All Towns demands and maximum additional demands from City of Cape Town (CCT).

3.5 Final Evaluation of Scenarios

The resulting water resource Class is based largely on the number of river and estuary nodes with each of the ecological conditions in each IUA as indicated by the percentage in each category in Table 3-80.

Table 3-80 Guidelines for determining the IUA Class based on ecological condition

		Percentage (%) of nodes in the IUA falling into the indicated groups				
		A or A/B	B or B/C	C or C/D	D	< D
Class I		60	40	20	1	-
Class II			60	30	5	-
Class III	Either			70	20	-
	Or				100	-

These were used to determine the overall class for the each IUA under the different scenarios considered.

The results for this analysis are shown in Table 3-81.).

Table 3-81 Resulting water resource class for each IUA for scenarios considered

IUA Name	IUA Code	PES	Future ESBC	Future REC	Future No-EC	Future Climate Change ESBC	Future Climate Change REC	Future Climate Change No EC
Berg Estuary	A1	II	III	II	III	III	II	III
Langebaan	A2	II	III	II	III	III	II	III
West Coast	A3	III	III	III	III	III	III	III
Lower Berg	B4	III	III	III	III	III	III	III
Berg Tributaries	C5	II	III	II	III	III	II	III
Eerste	D6	III	III	III	III	III	III	III
Sir Lowry's	D7	III	III	III	III	III	III	III
Upper Berg	D8	III	III	III	III	III	III	III
Middle Berg	D9	III	III	III	III	III	III	III
Diep	D10	III	III	III	III	III	III	III
Peninsula	E11	II	III	II	III	III	II	III
Cape Flats	E12	III	III	III	III	III	III	III

It is clear from the results of this analysis, that the majority of the study area is already heavily impacted and this is likely to degrade further under future development and climate change scenarios unless the recommended ecological condition (REC) is achieved. In order to better evaluate the critical area of the catchment, however it is necessary to consider individual resource units within each IUA which requires consideration of a finer scale delineation of IUAs to which specific resource classes can be allocated including areas of minimal impact (i.e. Class I). This is addressed in the final section which presents the recommended water resource class for each of these redefined IUAs within the current system of IUAs.

4 Recommended Water Resource Classes and Implications

4.1 Recommended Water Resource Classes

Based on the evaluation of scenarios and in consultation with stakeholders, it is recommended that the REC scenarios be considered for river and estuary nodes within the Berg Catchment. This is considered to be the best trade-off between the benefits of maintaining critical ecological systems, particularly key estuaries, due to the benefits associated with EGSAs and the need to provide additional infrastructure to address any future water demands or shortfalls as a result of the recommended water resource class.

The recommended water resource classes for each IUA are given in Table 4-1 and shown in Figure 4-1.

Table 4-1 Recommended water resource Classes for the Berg Catchment

IUA Name	IUA Code	Recommended Water Resource Class
Upper Berg	D8	II
Middle Berg	D9	III
Berg Tributaries	C5	II
Lower Berg	B4	III
Berg Estuary	A1	II
Langebaan	A2	II
West Coast	A3	III
Diep	D10	III
Peninsula	E11	II
Cape Flats	E12	III
Eerste	D6	III
Sir Lowry's	D7	II

The recommended water resource class also takes into consideration critical water resource areas such as the strategic water source areas (SWSA) which cover a large portion of the upper reaches of some of the IUAs including the Upper Berg IUA and the area covered by the Table Mountain National Park (TMNP) which makes up more than half of the Peninsula IUA. These areas should receive additional protection while the remained of the IUA is located in a heavily impacted urban or rural area. This is provided in terms of the target ecological category (TEC) for individual nodes and the Resource Quality Objectives (RQOs).

The location of some of these critical resource areas are shown in **Figure 4.2**. and will be further defined during the process of RU prioritisation and development of RQOs during the next phase of the study.

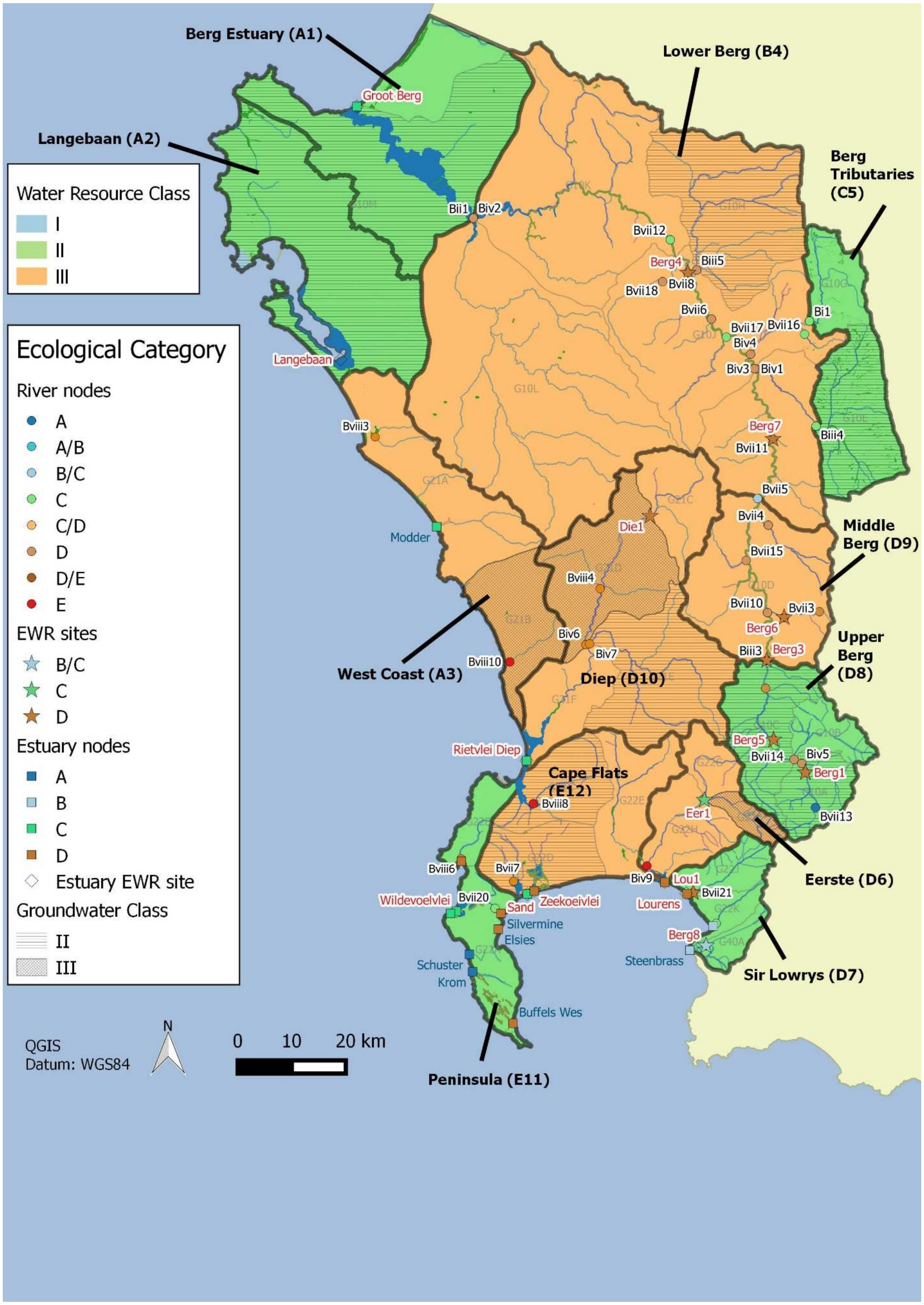


Figure 4-1 Map showing final recommended classification scenario for the Berg catchment and including the areas identified as having potential high levels of groundwater stress under future scenarios.

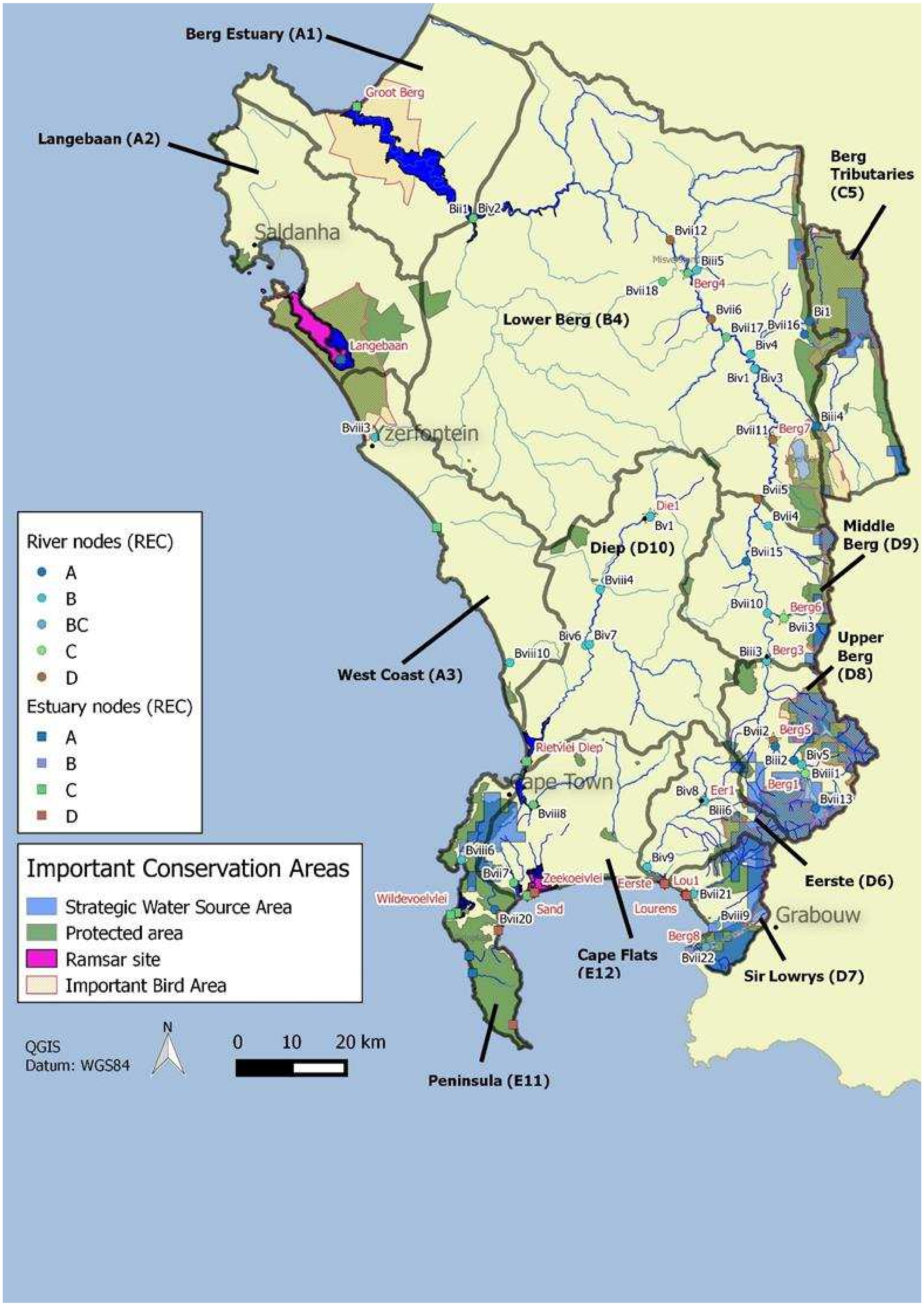


Figure 4-2 Map of the Study Area showing the strategic water source areas and protected areas used to define individual resource units within each IUA for the final recommended water resource class.

4.2 Implications for Recommended Water Resource Classes

The social, ecological and economic implications of the recommended water resource classes for each IUA are described in Table 4-2. These considerations align with concerns expressed by key stakeholders.

Table 4-2 Socio-economic and ecological implications for the recommended water resource Classes.

IUA	Name	Recommended Class	Ecological Implications	Socio-Economic Implications
D8	Upper Berg	II	The upper reaches of the IUA are a strategic water source area. The section of river between Berg River Dam and the Supplement Scheme is also maintained in a good condition by diverting summer releases via the Supplement Scheme and maintaining flood releases.	Fresh water releases are required from the Berg River Dam and Wemmershoek Dam to maintain downstream conditions. The recommended EWRs, however are consistent with what is already included into the Berg River Dam operating rules and hence, even though there is an additional cost that needs to be paid, this is already captured in the cost of the Berg River Dam as well as the feasibility study for the Voelvlei Augmentation Scheme (VAS). Further augmentation to the WCWSS is likely to be from re-use of treated effluent, which will affect return flows in the river, and desalination.
D9	Middle Berg	III	The upper tributaries of the IUA are a strategic water source area. These however constituted a small portion of the IUA and the bulk of the water resources are heavily utilized. Riparian wetland areas along the Berg River are important in terms of flood attenuation and addressing some water quality concerns.	Protecting the upper reaches of this IUA is also of economic importance as these supply the numerous farm dams in this area. The Berg River main stem and tributaries are heavily impacted.
C5	Berg Tributaries	II	Nearly half of this IUA is in a protected area and a strategic water source area (Groot Winterhoek Nature Reserve). The other half of the catchment is impacted by agricultural activities.	Although the economy of this area is dominated by agriculture as a major water user, tourism is also increasing which requires water resources to be maintained in a good condition. The 24 Rivers and the Klein Berg river contribute to the inflows to Voëlvlei Dam which is critical to the economy of Cape Town and the WCWSS.
B4	Lower Berg	III	The upper tributaries of the IUA are a strategic water source area, however they only constitute a small part of the overall IUA, with the bulk of the resource being heavily impacted by urban and agricultural activities in the catchment. The rivers need to be maintained in a minimum sustainable condition. Riparian wetland areas along the Berg River are important in terms of flood attenuation and addressing some water quality concerns.	This is a hard-working river and agricultural area with numerous water quality challenges due to irrigation and highly saline soils. Maintaining minimum flows in the rivers are important for managing the water quality risks, particularly downstream.

IUA	Name	Recommended Class	Ecological Implications	Socio-Economic Implications
A1	Berg Estuary	II	The Berg River estuary should be maintained in a C condition, given the important nursery function and contribution to the local and regional economy. The water resources in this IUA, outside of the estuary are already heavily impacted by development. Development and future water demands in the rest of the IUA should not impact on the condition of the Berg River Estuary itself.	The Berg River Estuary itself is of significant importance to the local economy. Water availability however is limited due to the environmental requirement to maintain flows.
A2	Langebaan	II	Future development and water use in this IUA should not impact on the condition of Langabaan Lagoon Sufficient groundwater flows in particular must be maintained to protect the Geelbek wetlands at the head of the lagoon.	The West Coast aquifers offer sustainable water supply options for Saldanha, but future groundwater abstractions from the Langebaan Road aquifer need to be monitored so as not to negatively impact on flows into the lagoon. Alternative supply options such as seawater desalination and wastewater re-use should be considered if groundwater abstraction is predicted to have unacceptable impact on the lagoon.
A3	West Coast	III	The water resources in this IUA are already heavily impacted by rural development, but there are a number of critical wetlands in the area that need to be protected.	Groundwater is considered to be already stressed in this IUA and needs to be managed carefully to prevent further impacts of abstraction.
D10	Diep	III	The Rietvlei/Diep estuary near Milnerton is important for social, economic and ecological reasons and should be maintained in a minimum of a D condition.	The bulk of this IUA is heavily impacted by agriculture and urban land uses. The Diep River estuary is important for social, economic and ecological reasons and should be protected. Future increased use of treated effluent however may pose increasing water quality risks for the estuary.
E11	Peninsula	II	The water resources in the Table Mountain National Park should be protected for both ecological as well as socio-economic, recreation and cultural benefits. The remaining areas of the Peninsula IUA will need to be very carefully managed particularly with regards to protecting critical wetland areas within the boundaries of the metro area. The Sand River catchment and the Liesbeek River have been included in the Peninsula IUA rather than the Cape Flats IUA as they are more similar and with a recommended Class II rather than Class III.	The bulk of this IUAs is highly developed and as a result water resources are already significantly impacted by current and future development needs to be considered. Table Mountain National Park and the associated rivers, lakes and estuaries together form an important economic asset for the City of Cape Town. Protecting the catchment areas of the City's dams on Table Mountain is also important for water security.

IUA	Name	Recommended Class	Ecological Implications	Socio-Economic Implications
E12	Cape Flats	III	The majority of this IUA is covered by urban and peri-urban developments. This results in a Class III water resource. Strategic water source areas, particularly those in the Table Mountain National Park and including the National Botanical Garden should be maintained in a natural condition. Critical estuaries, vleis and wetlands including the False Bay Coastal Park, Princess Vlei and Zandlvei should also be protected due to the RAMSAR status and EGSAs	The return flows from wastewater treatment plants provide significant flow to the estuaries in this IUA and the potential to use these as a future water resource for the City of Cape Town could have a positive impact as well as providing a cost-effective water source. Careful consideration needs to be given to protecting priority wetlands as well as groundwater-dependent areas such as the Phillipi Horticultural Area (PHA).
D6	Eerste River	III	The upper reaches of the IUA are a Class I strategic water source area. Efforts are being made to improve the condition of the river through Stellenbosch which includes addressing water quality risks.	Future water demands for Stellenbosch will need to be met either through increased allocations from the WCWSS or from direct potable re-use as increased groundwater use could be unsustainable.
D7	Sir Lowry's	II	The upper catchment areas include the strategic water source areas (SWSAs) of the Hottentots Holland Nature Reserve. Flow downstream of the Steenbras Dams is however impacted, but the estuary requires special protection. The middle reaches of the Lourens river (Class II) are in a conservation area and should be protected. The lower portion of the catchment is in a peri-urban area and the estuary is maintained at a D ecological condition.	The Steenbras Dam is a major source of water to the City of Cape Town and it is important the catchment area of this dam is protected. The lower reaches of this IUA are in the built-up area of Somerset West and Gordon's Bay and also receive return flows from WWTWs that contribute to local water quality risks. The lower reaches of the Sir Lowry's Pass River are in an urban area and already heavily impacted.

4.3 Target Ecological Water Requirements

Based on the analysis of alternative scenarios for the river and estuary nodes in the Berg catchment it is recommended that the recommended ecological condition (REC) scenario be considered at the main EWR nodes and at the significant estuaries as this represents the best balance between ecological, economic and social benefits for the whole catchment area. The recommended Target EC and EWRs are given below.

Table 4-3 Proposed Target Ecological Condition (TEC) for the river EWR sites.

Site	Node	IUA	Quat	Name	PES	TEC	% nMAR (Reserve) (excludes floods)
Berg1	Bviii1	D8	G10A	Upper Berg River	C	C	31%
Berg3	Bvii5	D8	G10D	Lower Berg River	D	D	33%
Berg4	Bvii6	B4	G10J	Heuningberg, upstream of Misverstand Dam	D	D	21%
Berg5	Bvii12	B4	G10J	Nuwedrif, downstream of Misverstand Dam	D	D	24%
Berg6	Bvii3	D9	G10D	Kromme River	D/E	D	14%
Berg7	Bviii11	D9	G10D	Pombers River	D	C	21%
Berg8	Bvii22	B4	G40A	Steenbras River	B/C	B/C	14%
Die1	Bv1	D10	G21D	Diep River	E	D	14%
Eer1	Biii6	D6	G22F	Jonkershoek River	C	C	23%
Lou1	Bvii21	D7	G22J	Lourens River	D	D	15%

IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; REC = Recommended Ecological Category; TEC = Target Ecological Category; EIS = Ecological Importance and Sensitivity; VH = Very High; H = High; M = Moderate.

Table 4-4 Proposed Target Ecological Condition (TEC) and EWRs for the estuary nodes

Node	IUA	Quat	Name	PES	TEC	EIS	Minimum %MAR to achieve REC with Current WQ	Minimum %MAR to achieve REC with Improved WQ
Bxi1	**A1**	**G10M**	**Berg River Estuary**	**C**	**C**	**H**	**46**	**33**
Bxi3	**A2**	**G10M**	**Langebaan Estuary**	**B**	**B**	**VH**	**94**	**94**
Bxi12	A3	G21A	Modder Estuary	C	C	M	n/a	33
Bxi7	**D10**	**G21F**	**Rietvlei/Diep Estuary**	**D**	**C**	**H**	**n/a**	**33**
Bxi9	**E12**	**G22K**	**Zandvlei Estuary**	**D**	**C**	**H**	**n/a**	**56**
Bxi20	**E12**	**G22D**	**Zeekoe Estuary**	**E**	**D**	**U**	**110**	**60**
Bxi10	E11	G22B	Hout Bay Estuary	E	D	U	35	26
Bxi11	E11	G22A	Silvermine Estuary	D	D	U	35	26
Bxi19	E11	G22A	Elsies Estuary	E	D	U	35	26
Bxi18	E11	G22A	Buffels Wes Estuary	F	D	U	66	67
Bxi17	E11	G22A	Krom Estuary	A	A	U	95	95
Bxi16	E11	G22A	Schuster Estuary	A	A	U	95	95
Bxi15	E11	G22A	Bokramspruit Estuary	C	C	U	65	42
Bxi14	**E11**	**G22A**	**Wildvoelvlei Estuary**	**D**	**C**	**M**	**79**	**62**
Bxi3	**D6**	**G22H**	**Eerste Estuary**	**E**	**D**	**M**	**61**	**26**
Bxi4	**D7**	**G22J**	**Lourens Estuary**	**D**	**D**	**U**	**69**	**56**
Bxi6	D7	G22K	Sir Lowry's Pass Estuary	E	D	U	35	26
Bxi6	D7	G40A	Steenbras estuary	B	B	U	97	35

IUA = Integrated Unit of Analysis; Quat = Quaternary catchment; PES = Present Ecological Category; REC = Recommended Ecological Category; TEC = Target Ecological Category; EIS = Ecological Importance and Sensitivity; VH = Very High; H = High;

M = Moderate; U = Undefined. BAS = Best attainable state. n/a indicates that it is not possible to improve the Ecological State of the estuary by increasing flows only (WQ also needs to be improved)

Note: Significant estuaries highlighted in red.

Additional comments relevant to the implications of the recommended TECs given above for specific estuaries that will be addressed during the RQOs phase of the project are included below:

- Diep River (TEC = **D) -** The river condition is not necessarily the same as the estuary condition due to different habitat drivers.
- Lourens River (TEC = **D)** – A D condition is not likely achievable through changes in flow only, but would require additional changes.
- Zeekoe Estuary (TEC = **D) -** The minimum allowable EC for a river is D, unless essentially a concrete canal (E/F). Maintaining the Zeekoe estuary in at least a D condition (PES) is preferred, but it is acknowledged that this may be hard to achieve, particularly with current levels of development.
- Silvermine Estuary (TEC = **D) -** The Silvermine estuary is severely modified as a result of development in the Fish Hoek valley which has constrained migration of the estuary mouth. Road and railway crossings severely limited seawater penetration into this system. Achieving a C category is not realistic in our opinion.
- Elsies Estuary (TEC = **D)** – Water Quality is very good in the river. Estuarine quality hampered by physical obstruction which is unlikely to be removed. Minimum allowable EC for an estuary is D.
- Wildvoëlvlei Estuary (TEC = **C) -** The PES for the WIldevoelvlei estuary was determined in the RDM workshop for this system according to the RDM methods for estuaries (= D). The system is located in a protected area (Table Mountain National Park) and hence the REC for the system should be an A or Best Attainable State (BAS). It was determined in the RDM workshop that a C category was achievable through reducing the volume and/or improving the quality of waste water discharged to the system and also by opening up the channel between the lagoon and Wildevöelvlei, clearing some of the reeds in the vlei and channel, and dredging some of the accumulated sludge from the bottom of the system.
- Lourens Estuary (TEC = **D) -** The Lourens estuary is not on the list of existing or desired protected areas (Turpie et al. 2012), thus the rule for REC is to maintain the PES. Therefore, the REC is a D category.

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