**Determination of Water Resource Classes and Associated Resource Quality Objectives for the Berg Catchment (WP10987)**

# Quantification of the Ecological Water Requirements and Changes in Ecosystems Goods, Services and Attributes

October 2017

**Revision**: Final

**No:** DWS REPORT NO:RDM/WMA9/00/CON/CLA/0217

## Department of Water and Sanitation, Chief Directorate: Water Ecosystems

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

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| ***Title:*** | *Quantification of the Ecological Water Requirements and Changes in Ecosystem Goods, Services and Attributes* |
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| ***Project Name:*** | *Determination of Water Resource Classes and Associated Resource Quality Objectives in Berg Catchment* |
| ***DWS Report No:*** | *RDM/WMA8/00/CON/CLA/0217* |
| ***Status of Report**:* | *Final* |
| ***First Issue:*** | *July 2017* |
| ***Final Issue:*** | *October 2017* |

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***Professional Service Providers:*** Aurecon South Africa (Pty) Ltd, Southern Waters Ecological Research and Consulting, Anchor Environmental and Delta-H Water Systems Modelling

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This report is to be cited as:

*Department of Water and Sanitation, South Africa. October 2017. Determination of Water Resource Classes and Associated Resource Quality Objectives in the Berg Catchment: Quantification of the Ecological Water Requirements and Changes in Ecosystem Goods, Services and Attributes. Project Number WP10987. DWS Report NO:RDM/WMA9/00/CON/CLA/0217*

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Project Name: Determination of Water Resource Classes and Associated Resource Quality Objectives in Berg Catchment

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| 17 | RDM/WMA9/00/CON/CLA/0718 | Final Project Close Out Report. |

# List of Abbreviations

| | |
|---|---|
| 1999EC: | Ecological Condition 1999 |
| 2014EC: | Ecological Condition 2014 |
| AECs: | Alternate Ecological Categories |
| AHS: | Abiotic health score |
| BBM: | Building Block Methodology |
| BRIP: | Berg River Improvement Plan |
| CMNT: | Catchment |
| DRIFT: | Downstream Response to Instream Flow Transformation |
| DWA: | Department of Water Affairs (now the Department of Water and Sanitation) |
| DWAF: | Department of Water Affairs and Forestry (now the Department of Water and Sanitation) |
| DWS: | Department of Water and Sanitation |
| D/s: | Downstream |
| ER: | Ecoregion |
| EC: | Ecological Condition |
| EcoSpec: | EcoSpecification |
| EGSAs: | Ecosystems goods, services and attributes |
| EHI: | Estuary Health Index |
| EIS: | Ecological Importance and Sensitivity |
| EWRs: | Ecological Water Requirements |
| EWR-MLF: | Maintenance Low Flow component of Ecological Water Requirements |
| FEPA: | Freshwater Ecosystem Priority Area |
| FSP: | Fine scale planning |
| GEMS | Global Environment Monitoring System |
| GIS | Geographical Information System |
| GDP: | Gross Domestic Product |
| GRAII: | Groundwater Resource Assessment Study |
| GRU: | Groundwater Resource Unit |
| GWBF: | Groundwater Contribution to Baseflow |
| GZ: | Geozone |
| HGM: | Hydrogeomorphic Unit |
| HI: | Hydrological Index |
| IBA: | Important Bird Area |
| IUA: | Integrated Unit of Analysis |
| IWRM: | Integrated Water Resources Management |
| MAR: | Mean annual runoff |
| MCA: | Mountain Catchment Area |

| | |
|---|---|
| NCWQ: | National Chemical Water Quality Network |
| NCMP: | National Chemical Monitoring Programme |
| NFEPA: | National Freshwater Ecosystem Priority Area |
| NGDB: | National Groundwater Database |
| nMAR: | Natural mean annual runoff |
| NWA: | National Water Act |
| PES: | Present Ecological Status |
| QUAT: | Quaternary catchment |
| RC: | Reference Condition |
| RDM: | Resource Directed Measures |
| REC: | Recommended Ecological Class |
| RQO: | Resource Quality Objective |
| RU: | Resource Unit |
| SWSA: | Strategic Water Source Area |
| TMG: | Table Mountain Group |
| U/s: | Upstream |
| WAAS: | Water Availability Assessment Study |
| WARMS: | Water Allocation Registration Management System |
| WMA: | Water Management Area |
| WCWSS: | Western Cape Water Supply System |
| WRCS: | Water Resources Classification System |
| WWTW: | Wastewater Treatment Works |

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# 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 Resource Quality Objectives for all significant water resources in the Berg Catchment in line with Section 12 of the NWA which established a Water Resources Classification System (WRCS) that is formally prescribed by Regulations 810 dated 17 September 2010.

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).

The purpose of this report is to describe the generation of Ecological Water Requirements (EWRs) for the biophysical nodes identified in the study area and to describe the approach to evaluating the changes in ecosystems goods, services and attributes (EGSAs). These data will be used to evaluate the classification scenarios to inform the recommendations for Water Resource Classes and Resource Quality Objectives.

The quantification of EWRs and changes in non-water quality EGSAs are Step 3 of the WRCS procedure.

**ECOLOGICAL WATER REQUIREMENT QUANTIFICATION**

During Step 1 of the WRCS procedure as system of 12 Integrated Units of Analysis (IUAs) were determined for the Berg Catchment. These are described in the *Delineation Report* (DWS, 2016a). The *Delineation Repor*t also identified 10 Groundwater Resource Unit (GRUs) and identified a number of significant wetlands and wetland systems.

A total of 47 biophysical and river allocation nodes where initially identified and then reduced to 45 according to eleven “tiers” of information (DWAF 2007). In addition 19 estuary nodes were also identified in the Study Area as the ultimate outlet node for a number of catchments.

There are a number of reserve determinations that have already been undertaken in this catchment and information from these previous studies was used to determine the Ecological Water Requirements (EWRs) for 8 existing EWR river nodes. In order to address a shortfall of EWRs, particularly in the G2 catchments, additional RDM studies were undertaken as part of this study to determine the EWRs for 8 of the priority estuaries, particularly relating to the coastal catchments in G2 and three additional rivers. Detailed reports on the additional RDM studies for the 8 priority estuaries are presented in the Appendices to this Report.

Additional Rapid Level III Reserve Determination studies were undertaken for the Diep, Lourens and Eerste Rivers. In addition the EIS and PES where updated for all river nodes in both the G1 and G2 catchments.

The EWR requirements for the 11 river nodes and 8 estuary nodes) were then extrapolated to the relevant biophysical nodes according to the procedures outlined in the classification procedure (DWAF, 2007).

The final list of biophysical nodes are given in Table E1 along with a brief description of each node.

In addition to determining the water requirements for each node, each node was also assessed for significance in terms of the Groundwater Contribution to Baseflow (GWBF). The nodes for which the GWBF was estimated to be above 50% of the EWR were identified as significant with regards to surface-groundwater interaction and are highlighted in green as groundwater nodes in Table E2.

The descriptions for each node also includes significant relationships to wetlands for which the identified node are either representative of the flow requirements for wetlands, or are influence by upstream wetland conditions. These nodes with significant connections to wetlands are in green in Table E2.

## CHANGES IN ECOSYSTEM GOODS, SERVICES AND ATTRIBUTES

Determining the changes in ecosystem goods, services and attributes is required as the sectors dependent on aquatic ecosystem services could either shrink or expand as a result of moving to a lower or higher ecological class. The availability and quality of water in rivers, wetlands and estuaries and the overall condition of these natural systems influence their capacity to deliver aquatic ecosystem services. These, in turn, will influence the value of final goods and services generated by activities that depend on them.

In this study, the main impact sectors considered are tourism, property and inshore fisheries. These sectors and their linkages to the aquatic ecosystem services in the study area are explained in more detail in the *Status Quo Report* (DWS, 2016c). Estuaries are the main freshwater-dependent ecosystems that impact on all three of these sectors, but rivers and wetlands can also influence tourism values.

In addition, we also consider the impact of changes in ecosystem condition on the wellbeing of inhabitants of and visitors to these catchments. This requires estimating the relationships between ecosystem condition and the capacity to supply natural resources, as well as amenity values such as recreation and spiritual fulfilment. The main types of ecosystem services considered are summarised in Table E5.

**Table E 5: Main ecosystem services provided by estuaries of the study area, and the main flow-related variables that can be derived from RDM studies to estimate changes in the capacity to deliver these services.**

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

The general approach to how changes in the flow requirements will impact on these different sectors is described in this report and will be the basis for the analysis of future development scenarios.

## THE WAY FORWARD

The data on EWRs and changes in the EGSAs will be used to determine the flow requirements at individual nodes based on the recommended ecological class as well as determining the impact of alternative development scenarios on the ecological condition of individual nodes. The impact in terms of changes in Ecological Goods, Services and Attributes will be used to evaluate the impacts of alternative scenarios.

The approach to the scenario analysis has been described in the *Linking the Value Report* (DWS, 2017a) and will be further developed as part of the *Ecological Sustainable Base Configuration Scenario* report. The analysis of current and future development scenarios will follow resulting in the recommended class for each IUA and the associated flow requirements at each node will be consider when developing flow related resource quality objectives (RQOs) for the significant and prioritized resource units in the study area.

Table E1: List of nodes selected for the scenario analyses

| IUA | NODE | QUAT | EIS | EC | Node type and considerations | Within conservation sites |
|---|---|---|---|---|---|---|
| A1 | **Bxi1** | **G10M** | **H** | **D** | **Berg River estuary EWR site, linked to river node Biv2; Floodplain, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.** | **Berg River Estuary IBA** |
| A2 | **Bxi3** | **G10M** | **VH** | **B** | **Langebaan estuary; Channelled Valley-bottom and Unchannelled Valley-bottom wetlands, significant groundwater contribution.** | **West Coast National Park IBA** |
| A3 | Bxi12 | G21A | M | C | Modder estuary | N/A |
| | Bviii3 | G21A | H | D | Inflow to Yzerfontein salt pan; Depression wetland (Yzerfontein Salt Pan) as well as Unchannelled Valley-bottom wetlands. | N/A |
| | Bviii10 | G21B | H | E | Sout River; Depression and Seep wetlands as well as Floodplain wetlands. | N/A |
| B4 | Biv3 | G10J | VH | D | Klein-Berg River, u/s of confluence with Berg; Channelled Valley-bottom wetlands. | N/A |
| | Biv1 | G10J | M | D | Berg River, u/s of confluence Klein-Berg, d/s Voëlvlei canal; Seep wetlands as well as Channelled Valley-bottom and Floodplain wetlands. | N/A |
| | Bvii16 | G10J | VH | A | Leeu River, gauge, 100% MAR. | N/A |
| | Bvii11 | G10F | H | D | Berg River, u/s of Voëlvlei canal; Depression and Hillslope seep wetlands. | N/A |
| | Biv4 | G10J | H | D | Vier-en-Twintig River, u/s of confluence with Berg; Depression wetlands as well as Channelled Valley-bottom, Unchannelled Valley-Bottom and Flat wetlands. | N/A |
| | Bvii17 | G10J | M | C | Sandspruit River, gauge; Depression wetlands as well as Floodplain and Flat wetlands. | N/A |
| | **Bvii6** | **G10J** | **H** | **D** | **Berg River, d/s of EWR 4, above Misverstand Dam; Depression wetlands as well as Floodplain wetlands.** | N/A |
| | Biii5 | G10J | M | D | Matjies River, gauge; significant groundwater contribution; Depression wetlands as well as Channelled Valley-bottom wetlands. | N/A |
| | Bvii8 | G10J | M | D | Berg River, u/s Misverstand reservoir, d/s Matjies River; Depression wetlands as well as Floodplain wetlands. | N/A |
| | Bvii18 | G10J | M | E | Morreesburg Spruit River, gauge; significant groundwater contribution; Depression wetlands as well as Flat and Channelled Valley-bottom wetlands. | N/A |
| | **Bvii12** | **G10K** | **H** | **D** | **Berg River, 3.5 km d/s Misverstand reservoir, at EWR 5; Depression wetlands and Floodplain wetlands.** | N/A |
| | Bii1 | G10L | M | D | Sout River, u/s of confluence with Berg; Depression wetlands as well as Floodplain, Flat, Channelled Valley-bottom and Unchannelled Valley-bottom. | N/A |
| | Biv2 | G10L | H | D | Berg River, u/s of confluence with Sout, head of estuary; Hillslope seep wetlands as well as Floodplain, Flat and Unchannelled Valley-bottom wetlands. | N/A |
| C5 | Biii4 | G10E | VH | C | Klein Berg River, gauge; Channelled Valley-bottom, Unchannelled Valley-bottom and Flat wetlands. | SWSA |
| | Bi1 | G10G | VH | A | Vier-en-Twintig River, gauge, pristine wilderness 100%. | NFEPA Fish1; Winterhoek MCA |
| D6 | **Biii6** | **G22F** | **H** | **C** | **Jonkershoek River, Eer1 EWR site** | **N/A** |
| | Biv8 | G22G | H | D | Klippies River | N/A |
| | Biv9 | G22H | H | E | Kuils River, u/s confluence Eerste; significant groundwater contribution; Depression and Seep wetlands as well as Floodplain wetlands and Valley-bottom wetlands. | N/A |
| | **Bxi3** | **G22H** | **M** | **E** | **Eerste estuary EWR site, linked to river nodes Biii6, Biv8 and Biv9; Floodplain wetlands.** | **N/A** |

| IUA | NODE | QUAT | EIS | EC | Node type and considerations | Within conservation sites |
|---|---|---|---|---|---|---|
| D7 | **Bvii21** | **G22J** | **H** | **C** | **Lourens River, Somerset West; Seep (Paardevlei) and Depression wetlands as well as Valley-bottom wetlands.** | NFEPA Fish1, SWSA; Lourens River |
| | **Bxi4** | **G22J** | **U** | **D** | **Lourens estuary, linked to river node Bvii21; Floodplain wetlands.** | **N/A** |
| | Bviii9 | G22K | H | C | Sir Lowrys Pass River; Depression and Seep wetlands as well as Valley-bottom wetlands. | NFEPA Fish1, SWSA |
| | **Bxi5** | **G22K** | **U** | **E** | **Sir Lowrys Pass estuary EWR site, linked to river node Bviii9** | **N/A** |
| | Bvii22 | G40A | VH | C | Steenbras River, at EWR 8, u/s of estuary mouth; significant groundwater contribution; Seep wetlands as well as Valley-bottom wetlands. | SWSA; Hottentots Holland MCA |
| | **Bxi6** | **G40A** | **U** | **B** | **Steenbras estuary EWR site, linked to river node Bvii22** | **Hottentots Holland MCA** |
| D8 | Bvii13 | G10A | VH | A | Berg River, gauge u/s Berg River dam, 100% MAR. | NFEPA Fish2; SWSA |
| | **Bviii1** | **G10A** | **H** | **C** | **Berg River, d/s of Berg River dam EWR 1** | SWSA |
| | Biv5 | G10A | H | D | Franschoek River, u/s of confluence with Berg. | N/A |
| | Biii2 | G10B | VH | D | Wemmershoek River, u/s of confluence with Berg; significant groundwater contribution; Depression and Hillslope seep wetlands as well as Channelled Valley-bottom wetlands. | NFEPA Fish1; SWSA |
| | Bvii14 | G10C | VH | C | Dwars River, gauge. | SWSA |
| | Bvii2 | G10C | H | D | Berg River, Berg Water Project pump station; Depression wetlands as well as Floodplain and Channelled Valley-bottom wetlands. | SWSA |
| | Biii3 | G10C | H | E | Berg River, gauge; Depression and Hillslope seep wetlands as well as Floodplain, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands. | SWSA |
| D9 | **Bviii11** | **G10C** | **H** | **D** | **Pombers River, EWR 7 u/s of confluence with Kromme; Flat, Channelled Valley-bottom, Unchannelled Valley-bottom and Floodplain wetlands** | **N/A** |
| | **Bvii3** | **G10D** | **H** | **D** | **Kromme River, North of Wellington, EWR 6; Hillslope seep wetlands as well as Flat, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.** | **NFEPA Fish2; SWSA** |
| | Bvii10 | G10D | H | D | Berg River, d/s of confluence Kromme, gauge; significant groundwater contribution; Hillslope seep and Depression wetlands as well as Floodplain, Channelled Valley-bottom, Unchannelled Valley-bottom and Flat wetlands. | NFEPA Fish2; SWSA |
| | Bvii15 | G10D | VH | D | Doring River, gauge; significant groundwater contribution; Depression wetlands as well as Unchannelled Valley-bottom (Klein Sand vlei and Sand River vlei) and Floodplain wetlands. | SWSA |
| | Bvii4 | G10D | H | D | Kompanjies River, gauge; Hillslope seep and Depression wetlands as well as Channelled Valley-bottom and Floodplain wetlands. | SWSA |
| | **Bvii5** | **G10D** | **H** | **D** | **Berg River, gauge and u/s of EWR 3; Depression (Blouvlei) and Seep wetlands.** | **SWSA** |
| D10 | **Bv1** | **G21D** | **H** | **D** | **Diep River; significant groundwater contribution; Depression and Seep wetlands as well as Flat wetlands.** | NFEPA Fish2 |
| | Bviii4 | G21D | H | D | Swart River, u/s of confluence with Diep; significant groundwater contribution; Depression wetlands as well as Unchannelled Valley-bottom wetlands. | NFEPA Fish2 |
| | Biv6 | G21D | H | D | Diep River; significant groundwater contribution ; Depression and Seep wetlands as well as Valley-bottom wetlands. | NFEPA Fish2 |
| | Biv7 | G21E | H | D | Mosselbank River; significant groundwater contribution; Depression and Seep wetlands as well as Floodplain and Valley-bottom wetlands. | N/A |

| IUA | NODE | QUAT | EIS | EC | Node type and considerations | Within conservation sites |
|---|---|---|---|---|---|---|
| | Bxi7 | G21F | H | D | Rietvlei/Diep estuary EWR site, linked to river nodes Bv1, Bviii4, Biv6, Biv7; Floodplain and Valley bottom wetlands (Rietvlei) as well as Depression wetlands. | N/A |
| | Bviii8 | G22C | M | F | Elsieskraal River, u/s of confluence Black; Depression as well as Valley-bottom wetlands. | N/A |
| | Bvii7 | G22D | H | D | Keysers River, at EWR site; Depression (Princessvlei) and Seep wetlands as well as Floodplain and Valley-bottom wetlands. | N/A |
| E12 | Bxi9 | G22D | H | D | Sand estuary EWR site, linked to river node Bvii7; Depression as well as Floodplain wetlands. | SWSA, False Bay Nature Reserve |
| | Bxi20 | G22D | U | E | Zeekoe estuary; Depression (Zeekoevlei and Rondevlei) and Seep wetlands as well as Floodplain wetlands. | SWSA, False Bay Nature Reserve |
| | Bviii6 | G22B | H | D | Hout Bay River, at EWR site; Seep wetlands as well as Floodplain and Valley-bottom wetlands. | SWSA, NFEPA Fish1 |
| | Bxi10 | G22B | U | E | Hout Bay estuary EWR site, linked to river node Bviii6 | SWSA, Table Mountain National Park |
| | Bvii20 | G22A | U | C | Silvermine River, Fish Hoek, 100% MAR; Seep wetlands. | NFEPA Fish1 |
| | Bxi11 | G22A | U | D | Silvermine estuary EWR site, linked to river node Bvii20 | N/A |
| | Bxi13 | G22A | M | D | Goeiehoop estuary | N/A |
| E11 | Bxi14 | G22A | M | D | Wildevoelvlei estuary; Depression wetlands (Noordhoek Salt Pan and Pick n Pay Reedbeds) as well as Valley-bottom wetlands. | Table Mountain National Park |
| | Bxi15 | G22A | U | D | Bokramspruit estuary (micro-estuary); Depression wetlands as well as Valley-bottom wetlands. | N/A |
| | Bxi16 | G22A | U | A | Schuster estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands. | NFEPA Fish1, Table Mountain National Park |
| | Bxi17 | G22A | U | A | Krom estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands. | Table Mountain National Park |
| | Bxi18 | G22A | U | F | Buffels Wes estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands. | Table Mountain National Park |
| | Bxi19 | G22A | U | E | Elsies estuary (micro-estuary); Depression wetlands as well as Valley-bottom wetlands. | SWSA |

With IUA = Integrated Unit of Analysis; IBA = Important Bird Area; Quat = Quaternary catchment; EIS = Ecological Importance and Sensitivity; EC = Ecological Category; SWSA: Strategic Water Source Area, MCA = Mountain Catchment Area; N/A = Not applicable; NFEPA: National Freshwater Priority Area

Note: Reserve sites in red; blue highlights estuary nodes and green highlights river nodes with significant groundwater contribution

Provisional Recommended Ecological Categories (REC) where determined by the specialists for all river nodes and estuaries (Table E3 for EWR sties and E4 for estuaries). These will be reviewed by stakeholders during the classification scenarios before the final recommend classifications are given in terms of EWRs.

**Table E3 The existing and new preliminary river Reserve sites for the study area and provisional RECs**

| 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 | Pombers River | D | C | H | DWA, 2010c |
| Berg7 | Bviii11 | D9 | G10D | Kromme River | D/E | D | 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.

**Table E4 The estuary nodes considered for EWRs in the study area and provisional RECs.**

| Node | IUA | Quat | Name | PES | REC | EIS |
|---|---|---|---|---|---|---|
| Bxi1 | A1 | G10M | Berg River Estuary | D | 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 | Wildvoelvlei 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 |

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. BAS = Best attainable state.
Note: Priority estuaries highlighted in red.

# Contents

# Appendices



# Electronic Data

The following electronic data is included in the attached CD.

- EWR Rule tables for Reserve sites
- EWR Summary tables for Reserve sites
- EWR Modified time series for Reserve sites

# Figures

# Tables

# 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 water resources. 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.

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) A class in accordance with the prescribed classification system; and

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

The Chief Directorate: Water Ecosystem has therefore commissioned a study to determine Water Resource Classes (WRCs) and associated Resource Quality Objectives (RQOs) for all significant water resources in the Berg catchment. This includes the area of the former Berg WMA (i.e. former WMA 19)

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 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).

## 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 final outcome from the study will be a recommended water resource class for each integrated unit of analysis and associated Resource Quality Objectives for the significant water resources of the catchment.

## 1.3 Purpose of this Report

This report presents the results of step three in the seven step process (DWAF, 2007) for determination of the water resources classes (Figure 1.1). Step 3, is associated with and provides the introductory tasks for step 4 and 5 of the Water Resource Classification System (WRCS) which involves the determination of classification and development scenarios to support the evaluation of the proposed classification systems in the Integrated Water Resources Management (IWRM) framework prescribed by DWS.

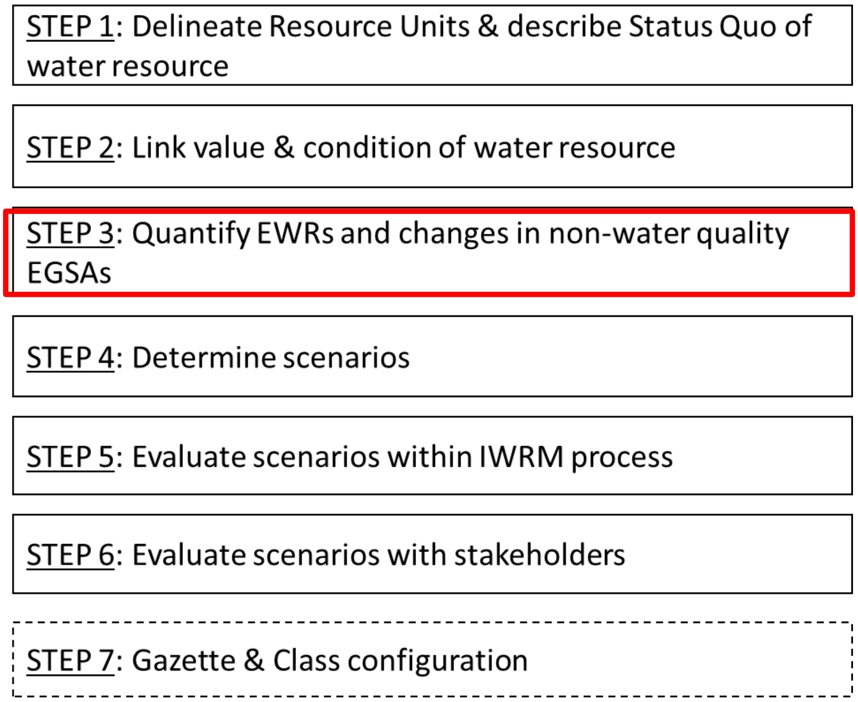


**Figure 1.1 Prescribed process for determining water resources classes showing the step relevant for this report in the red block. (Source: after DWA, 2012)**

The *objective* of Step 3 of the classification procedure is to *quantify the Ecological Water Requirements (EWRs)* and to *describe the changes in non-water quality Ecological Goods, Services and Attributes (EGSAs)*. While the quantification of EWRs is part of the Reserve determination process (see NWA, Chapter 3), the determination of the Reserve is part of the Classification Process.

In this study area there are already a number of existing sites for which river reserves have been determined. The purpose of this report is to review these existing reserve determinations and where possible to extrapolate the EWR requirements associated with these existing reserve sites to other nodes identified.

Where necessary additional studies are undertaken to either update the existing information at these sites or to determine new EWR requirements. In this case field visits were undertaken to update the Present Ecological Status (PES) at all the identified river node and additional EWRs were determined for three sites (Diep, Eerste and Lourens) for which no previous reserve determination information was available.

Reserve determination studies were also undertaken at 8 priority estuaries and used to determine EWRs.Groundwater information required prior to step 5 includes information on recharge, groundwater use, the current “stress”, and the relationship between changing use, availability, and “stress” (i.e. groundwater balance model). This information is included in this report, in addition to information on surface – groundwater interactions and groundwater’s link to EWR.

The objective in describing changes in the non-water quality EGSAs is to provide the information that will be used in later steps of the classification procedure (see DWAF, 2007) to assess the impacts of changes in catchment configuration scenarios on non-water quality EGSAs.

To incorporate these objectives, Step 3 consists of the following three sub-steps:

- **Step 3a:** Identify nodes to which existing Resource Directed Measures (RDM) data can be extrapolated and extrapolate;
- **Step 3b:** Develop rule curves, summary tables and modified time series for all nodes for all categories; and
- **Step 3c:** Quantify the changes in relevant ecosystem components, functions and attributes for each category for each node.

The details of the approach and outcome from these three sub-steps of Step 3 in the Classification Procedure are presented in this report and in the accompanying Appendices and electronic data files. These will then be used to inform the final recommendations for the water resource class for each IUA in the final Report.

# 2 SUMMARY AND BACKGROUND TO THE CATCHMENTS

The study area is made up of the Berg River Catchment (G1) and other smaller catchments (G2) of the former Berg WMA. Although these catchments were described in a large amount of detail within the *Status Quo* report (DWS, 2016c), a recap is provided to give context to the determination of EWRs for the nodes.

## 2.1 Berg River Catchments (G1)

The Berg River has its headwaters in the Drakenstein and Franschhoek Mountains, south of Franschhoek. The Table Mountain Group (TMG) outcrops in this area, with younger Cenzoic sediments infilling valleys. Rainfall and direct recharge is high in the mountainous areas, with the TMG being dominated by outcrop of Peninsula Formation, forming unconfined aquifer overlying basement. Alluvial sediments of the Sandveld Group are well developed around the Berg River as far as Paarl, and are likely to receive recharge from TMG when in connection and discharge to the Berg River. Water quality in the upper Berg River Catchment is good although some concerns have been expressed about water quality in the Franschhoek River.

The Berg River Improvement Plan (BRIP) (Western Cape Government, 2012) was developed in 2012 which included upgrading the Langrug and Klein Mooiwater informal settlements to reduce *Escherichia coli* and waste loads to receiving rivers. It seems that initial upgrades are having a positive impact on water quality in the Franschhoek River. Upstream of the Berg River dam the Berg River is in a natural condition, downstream and elsewhere on tributaries conditions are worse. The river reach between the dam and the supplement scheme has however been restored to its natural condition, and is maintained through the periodic releases of flood water and the diversion of summer releases via a pipeline to limit the impacts of seasonal flow reversals. The Franschhoek, Wemmershoek and Hugos Rivers are Fish Support Areas, with the Olifants and Dwars Rivers being targets for Phase2 Freshwater Ecosystem Priority Areas (FEPAs).

The middle Berg Catchment comprises sequences of basements rocks dominating outcrop in the undulating areas. The groundwater flow is focused in weathered zones and little regional flow can be expected. Several tributaries to the Berg River traverse the basement outcrops, and the groundwater will discharge to these. Water quality is affected by effluent discharges and there are a number of diffuse sources affecting water quality. Microbial water quality is a particular concern in this area, especially in the Drakenstein municipal area. Salinity also increases in the lower reaches partly due to the saline nature of geological formations as well as agricultural return flows. The Kromme River is the only FEPA in this section of the catchment.

The lower Berg Catchment is dominated by the TMG in the northern mountainous area, which is highly faulted causing Piekenierskloof and Peninsula Formations to be in contact in places. Irrigation return flows and naturally saline tributaries result in increased salinity. The Leeu River that drains from the Great Winterhoek Mountains has very good water quality and is one of the sources of high flow transfers into Voëlvlei Dam, which is a water source to the City of Cape Town and towns in the Swartland. There are six FEPAs on some high lying tributaries, and a number of Phase 2 FEPAs elsewhere. Two depression wetlands occur on a tributary of the Berg River, to the north of Darling, which host important biodiversity.

As the Berg Estuary is affected by seawater intrusion and tidal effects the water is unsuitable for irrigation and domestic and industrial use, reliance instead is on the Sandveld Group aquifers which are threatened by over extraction and salinity. The estuary has RAMSAR status but no formal protection and the river itself is associated with alluvial floodplain wetlands, characterised by wide river valleys. These wetlands are highly threatened by water abstraction, which threatens the seasonal inundation of the floodplain.

Langebaan is the only estuarine bay within the study area. The bay incorporates the largest estuarine channel area in South Africa, but it is largely a marine dominated system and is fed by groundwater rather than surface flows. The system is overall in good health and is protected within the West Coast National

Park. Seasonal Strandveld valley bottom wetlands are located in this area. These wetlands tend to be saline, although they are fed by hillslope seeps lying on higher ground and are not particularly groundwater dependent (Job et al., 2008). These wetlands are threatened by cultivation and urban expansion, with changes to the flow regime being of particular concern.

## 2.2 Coastal Catchments of the Study Area (G2)

There are a number of smaller catchments making up the rest of the study area including the West Coast Rivers, the Diep, Eerste, Kuils, Lourens and a number of rivers on the Cape Peninsula. These rivers tend to be small and relatively short flowing directly in to the sea. Many of these rivers occur in urban areas and the ecological process are generally dominated by the flow requirements for maintaining the estuaries.

Various smaller catchments occur along the West Coast in areas of subdued topography, where thick Sandveld Group deposits outcrop and overlie basement rock to form a significant aquifer. In the higher lying areas to the east, where the Sout River originates, basement outcrops and minor wetlands in coastal dunes are sustained by groundwater. The town of Atlantis abstracts groundwater via the Atlantis Water Supply Scheme. There are two FEPAs in this area; the Silverstroom River supporting an upstream conservation area and Yzerfontein salt pan, a saline depression wetland that is mined for gypsum but provides an important habitat for water birds and also ameliorates water quality.

The Diep River originates upstream of Malmesbury. Elevated salinity levels occur in the river at Malmesbury, as well as further downstream at Adderley. This is partly due to the saline nature of geological formations as well as agricultural return flows. High phosphate concentrations also occur, especially in the Diep River where effluent discharges are often the only flow during the dry season. Discharges from the Kraaifontein and Fisantekraal Wastewater Treatment Works (WWTWs) are delivered into the Mosselbank River, and the Malmesbury and Potsdam WWTW discharge effluent water into the Diep River, all of which contribute to the elevated nutrient concentrations (Day & Clark, 2012). The Maastricht Canal receives inflows of polluted water from agricultural return flows and leaks of sewage and runoff from poorly serviced informal settlements and backyard dwellings in formal settlements such as Fisantekraal (Day and Clark, 2012).

Water quality in the Diep River downstream of the Mosselbank confluence is affected by agricultural inputs, including runoff from numerous poultry and other areas of animal husbandry. Concerns have been expressed about elevated bacterial counts in the lower Diep River (downstream of the N7 Bridge). Monitoring of water quality between 2011 and 2013 indicated deterioration over time with 59% of samples in 2011 complying with the intermediate contact water quality guidelines, compared to only 36% in 2013 (Haskins, 2012; Haskins, 2015b). Improved operations at the Potsdam WWTW have resulted in improved nutrient concentrations downstream of the WWTW at the Milnerton Lagoon (Haskins, 2015b).

Despite the poor condition of the rivers there are a few Phase2 FEPAs, supported by upstream conservation areas and Fish Support Areas. The Rietvlei-Diep estuary includes Rietvlei Estuary and adjacent seasonal wetlands and pans within the estuary functional zone. Present day flows are influenced by treated waste water and runoff through areas with low cost housing and other informal settlements, often contaminated with untreated sewage. The lower portion of the estuary is in a poor ecological condition despite being within the Table Bay Nature Reserve. The deep water lake and seasonal pans of Rietvlei and Flamingovlei are in a better condition.

The Cape Peninsula is dominated by rugged areas of the TMG within the Table Mountain National Park. Recharge is mainly from rainfall, but may also occur from cloud moisture. Although recharge on the Peninsula is significantly higher than the surrounding areas its geological setting means that aquifer storage is low and recharge leads to discharge within a short time frame as the aquifer decants through rivers cascading off steep cliffs. Some of these are permanent seeps, other mountainous rivers and wetlands may result from localized groundwater flows. Cenzoic sands in the Fish Hoek Valley have high water tables supporting wetlands and streams around Fish Hoek and Noordhoek. Water quality in the Peninsula streams are good in the headwaters but the middle and lower reaches are highly impacted by urban stormwater runoff and runoff through dense settlements. There are two FEPAs, both in good condition and protected by being located in the conservation areas of the Table Mountain National Park.

The Hout Bay River is a Fish Support Area, with good condition in upper reaches. The lower reaches and estuary, however are highly impacted by runoff from agriculture areas and informal settlements.

Wildevoelvlei is a medium sized temporarily open estuary that is not fed by a river, but rather drains several seasonal wetlands and pans in the Fish Hoek-Noordhoek valley. Present day flows during summer months are almost entirely treated effluent from the WWTW that discharges into the upper Wildevoelvlei.

The Noordhoek Valley comprises many wetlands scattered between the various developments in the catchment and near the beach. Three permanent waterbodies occur in this area: Lake Michelle (developed from former salt pans) and the two Wildevoelvleis. These wetlands are of great conservation importance as they provide refuge to various rare plant and animal species.

Along the South Peninsula towards Cape Point there are numerous seasonal vleis, seeps and small rivers, which mostly dry up in summer (Brown and Magoba, 2009). The Silvermine River flows through the Silvermine Valley onto the Fish Hoek plain where it enters the sea through the Silvermine Estuary.

The Cape Flats is an area of subdued topography, where thick Sandveld Group deposits outcrop, overlying the basement of Malmesbury Shale and Cape Granite Suite. The Sandveld Group forms a significant primary aquifer, with links to surface water and various wetlands across the Cape Flats. The effects of urbanisation have significantly altered the Cape Flats aquifer, with runoff being concentrated into modified natural drainage lines and groundwater quality being affected by various sources. Domestic water supply is imported from elsewhere and registered groundwater use is focused on the Philippi agricultural area for irrigation use only. Water quality in the Cape Flats aquifer and rivers tends to be poor with elevated salinities and nutrient concentrations. Apart from the Fish Support Area of the Liesbeek River, there are very few FEPAs.

The estuaries in this area are the temporary open Sand (Zandvlei) and the permanently open Zeekoe estuaries. The Sand estuary is a moderately modified system that is intensively managed by the City of Cape Town and is protected in the Greater Zandvlei Estuary Nature Reserve. The Zeekoe estuary drains Zeekoevlei, although the estuary is now physically separated from the vlei by a weir and wastewater input from the Cape Flats WWTW dominates flows into the estuary. The Zeekoe estuary is in a degraded state.

Zeekoevlei is the largest of the Cape Flats wetlands. It is U-shaped with most of the present day surface inflows arriving from the northern catchment via the Big and Little Lotus “rivers” and the outflow being delivered in a southerly direction through the Zeekoe Canal (Brown and Magoba, 2009). 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 WWTW) form part of the False Bay Nature Reserve, which was proclaimed as South Africa’s 22$^{nd}$ Ramsar site in 2015. The importance of this area is attributed to the presence of endemic vegetation communities and important bird species. Most of the birds within this wetland system are concentrated at the Strandfontein WWTW due to the wide range of wetland habitats present and the proximity to the ocean (Wright, 2015). Key bird species are however in a state of decline, possibly in response to changes in water level and quality (Wright, 2015). Water hyacinth has also invaded some of the settling ponds, reducing habitat area available for birds and other fauna.

The Kuils River in its original state flowed through a flat sandy valley from source until the Cape Flats, where it meandered through a series of “kuils” (pools). In particular the Khayelitsha wetlands have been transformed as the informal settlement expanded around and over the natural wetlands as 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, assist with water purification and also help to recharge the Cape Flats Aquifer (Brown and Magoba, 2009).

The Eerste River originates from the mountainous area where the Peninsula Aquifer decants. Water quality in the upper reaches is good, but deteriorates in a downstream direction. There is a FEPA along the Jonkershoek River, supported by an upstream conservation area. The Lourens River also originates in the Peninsula formation, with water quality deteriorating in a downstream direction. There is a FEPA along the Steenbras River, and two Fish Support Areas, along the Lourens and Sir Lowry’s Pass Rivers. Paardevlei lies on the site of a natural and shallow seasonal vlei, which has been impacted by various changes in use over the years, particularly related to fishing.

The Steenbras River is also included in this study area (Catchment G40A). The catchment area is largely undeveloped consisting of rock and mountain vynbos. Previously there were large forestry plantations, but these have largely been removed. The upper and lower Steenbras Dams are located in this catchment and supply water to the City of Cape Town as well as for the Steenbras Pump-storage hydroelectric scheme.


**Figure 2.1 Map of the study area.**

# 3 SELECTION OF NODES

## 3.1 Integrated Units of Analysis and Biophysical Nodes

Integrated Units of Analysis (IUA) were determine for the study area based on a combination of hydrological, ecological and socio-economic factors. Twelve IUAs were identified and are shown in Figure 3.1. In addition 45 biophysical river nodes were defined according to the procedures described in DWAF (2007f). Nineteen estuary nodes were also identified and eight of these were considered to be priority estuary nodes for the purpose of the study. The details of the delineation IUAs and identified river and estuary nodes for the study are presented in the *Resource Units and Integrated Units of Analysis Delineation Report* (DWS, 2016b).

## 3.2 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 determination have been done and high confidence EWRs have been determined. These are listed in Table 3.1. These sites are all located in the Berg River Catchment (G1) and were considered sufficient for EWR information to be extrapolated to all other river nodes in the G1 catchment. It was, however, noted that there are no existing Reserve sites in the G2 catchments and it was requested that additional sites be identified in these catchment for which at least a Rapid Level III reserve determination study should be undertaken. This was despite the fact that these catchments are already highly impacted by development and they are relatively short which means that any ecological flow requirements are dominated by the requirements for the estuaries.

The Resource Unit (RU) prioritisation tool was used to identify the most significant resource units for which EWR site could be determined for catchments outside of the main Berg River Catchment. The results of this analysis identified the Steenbras River as the most significant resources unit, but there is already an established EWR site. The next most significant resource units were the Eerste River, the Diep River, the Lourens and the Disa River in Hout Bay. There is however no stream gauge on the Disa River.

A field trip and rapid Level III reserve determination study were undertaken on the Diep, Lourens and Eerste River. The results of this study and a summary of the previous reserve determination studies are presented in Section 4 and Appendices. 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.

Preliminary ecological flow requirements are determined for all nodes using the Desktop Reserve Model and where possible these sites are calibrated using the EWR data extrapolated from the identified Reserve sites.

During the scenario analysis the flow requirements at some of these river nodes may be updated based on the need to achieve EWRs at the priority river and estuary nodes when routed down the system.

The details of the delineated Reserve sites for the study area are shown in Table 3.1 and on Figure 3.1.

Table 3.1 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 | Pombers River | D | C | H | DWA, 2010c |
| Berg7 | Bviii11 | D9 | G10D | Kromme River | D/E | D | 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.

## 3.3 Estuary Nodes

There are twenty two estuary nodes identified in the study area. Eight of these are considered to be priority estuary nodes for which EWRs were determined (highlighted in bold in Table 3.2). Field visits and a specialist workshop were undertaken to determine the EWRs, PES and RECs for these priority estuary nodes. The results of these studies are given in Section 4.

Table 3.2 The estuary nodes considered for EWRs in the study area

| Node | IUA | Quat | Name | PES | REC | EIS |
|---|---|---|---|---|---|---|
| **Bxi1** | **A1** | **G10M** | **Berg River Estuary** | **D** | **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** | **Wildvoelvlei 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 |

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. BAS = Best attainable state.
Note: Priority estuaries highlighted in red.

## 3.4 Groundwater Contribution to Baseflow at River Nodes

Each river node was assessed for Groundwater Contribution to Baseflow (GWBF) and compared to the provisional EWRs as an indication of the relative importance of GWBF. Nodes with GWBF above 50% are considered to significant dependent on groundwater contribution and are highlighted in blue in Table 3.3.

## 3.5 Wetland links to River Nodes

Wetlands receive water inputs from either, or both, surface water and groundwater and as such may be related to the groundwater and surface water EWR assessments. The nodes associated with identified wetlands are also identified in Table 3.3. It is notable that nodes with a significant contribution to baseflow have Depression or Seep wetlands, which are indicative of the interaction between surface and groundwater.

## 3.6 Summary of All Nodes and Reserve Sites

A summary of all identified river and estuary nodes for the study area are given in Table 3.1. The following is displayed:

- The estuary nodes are highlighted in blue
- The nodes with a significant contribution from groundflow are highlighted in green.
- The nodes associated with Reserve sites are indicated in **red**
- The node type and considerations are indicated, as is whether the node is associated with wetlands or wetlands systems

**Table 3.3 List of nodes selected for the scenario analyses**

| IUA | NODE | QUAT | EIS | EC | Node type and considerations | Within conservation sites |
|---|---|---|---|---|---|---|
| A1 | **Bxi1** | **G10M** | **H** | **D** | **Berg River estuary EWR site, linked to river node Biv2; Floodplain, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.** | **Berg River Estuary IBA** |
| A2 | **Bxi3** | **G10M** | **VH** | **B** | **Langebaan estuary; Channelled Valley-bottom and Unchannelled Valley-bottom wetlands, significant groundwater contribution.** | **West Coast National Park IBA** |
| A3 | Bxi12 | G21A | M | C | Modder estuary | N/A |
| | Bviii3 | G21A | H | D | Inflow to Yzerfontein salt pan; Depression wetland (Yzerfontein Salt Pan) as well as Unchannelled Valley-bottom wetlands. | N/A |
| | Bviii10 | G21B | H | E | Sout River; Depression and Seep wetlands as well as Floodplain wetlands. | N/A |
| B4 | Biv3 | G10J | VH | D | Klein-Berg River, u/s of confluence with Berg; Channelled Valley-bottom wetlands. | N/A |
| | Biv1 | G10J | M | D | Berg River, u/s of confluence Klein-Berg, d/s Voëlvlei canal; Seep wetlands as well as Channelled Valley-bottom and Floodplain wetlands. | N/A |
| | Bvii16 | G10J | VH | A | Leeu River, gauge, 100% MAR. | N/A |
| | Bvii11 | G10F | H | D | Berg River, u/s of Voëlvlei canal; Depression and Hillslope seep wetlands. | N/A |
| | Biv4 | G10J | H | D | Vier-en-Twintig River, u/s of confluence with Berg; Depression wetlands as well as Channelled Valley-bottom, Unchannelled Valley-Bottom and Flat wetlands. | N/A |
| | Bvii17 | G10J | M | C | Sandspruit River, gauge; Depression wetlands as well as Floodplain and Flat wetlands. | N/A |
| | **Bvii6** | **G10J** | **H** | **D** | **Berg River, d/s of EWR 4, above Misverstand Dam; Depression wetlands as well as Floodplain wetlands.** | N/A |
| | Biii5 | G10J | M | D | Matjies River, gauge; significant groundwater contribution; Depression wetlands as well as Channelled Valley-bottom wetlands. | N/A |
| | Bvii8 | G10J | M | D | Berg River, u/s Misverstand reservoir, d/s Matjies River; Depression wetlands as well as Floodplain wetlands. | N/A |
| | Bvii18 | G10J | M | E | Morreesburg Spruit River, gauge; significant groundwater contribution; Depression wetlands as well as Flat and Channelled Valley-bottom wetlands. | N/A |
| | **Bvii12** | **G10K** | **H** | **D** | **Berg River, 3.5 km d/s Misverstand reservoir, at EWR 5; Depression wetlands and Floodplain wetlands.** | N/A |
| | Bii1 | G10L | M | D | Sout River, u/s of confluence with Berg; Depression wetlands as well as Floodplain, Flat, Channelled Valley-bottom and Unchannelled Valley-bottom. | N/A |

| IUA | NODE | QUAT | EIS | EC | Node type and considerations | Within conservation sites |
|---|---|---|---|---|---|---|
| | Biv2 | G10L | H | D | Berg River, u/s of confluence with Sout, head of estuary; Hillslope seep wetlands as well as Floodplain, Flat and Unchannelled Valley-bottom wetlands. | N/A |
| C5 | Biii4 | G10E | VH | C | Klein Berg River, gauge; Channelled Valley-bottom, Unchannelled Valley-bottom and Flat wetlands. | SWSA |
| | Bi1 | G10G | VH | A | Vier-en-Twintig River, gauge, pristine wilderness 100%. | NFEPA Fish1; Winterhoek MCA |
| D6 | **Biii6** | **G22F** | **H** | **C** | **Jonkershoek River, Eer1 EWR site** | **N/A** |
| | Biv8 | G22G | H | D | Klippies River | N/A |
| | Biv9 | G22H | H | E | Kuils River, u/s confluence Eerste; significant groundwater contribution; Depression and Seep wetlands as well as Floodplain wetlands and Valley-bottom wetlands. | N/A |
| | **Bxi3** | **G22H** | **M** | **E** | **Eerste estuary EWR site, linked to river nodes Biii6, Biv8 and Biv9; Floodplain wetlands.** | **N/A** |
| D7 | **Bvii21** | **G22J** | **H** | **C** | **Lourens River, Somerset West; Seep (Paardevlei) and Depression wetlands as well as Valley-bottom wetlands.** | NFEPA Fish1, SWSA; Lourens River |
| | **Bxi4** | **G22J** | **U** | **D** | **Lourens estuary, linked to river node Bvii21; Floodplain wetlands.** | **N/A** |
| | Bviii9 | G22K | H | C | Sir Lowry's Pass River; Depression and Seep wetlands as well as Valley-bottom wetlands. | NFEPA Fish1, SWSA |
| | **Bxi5** | **G22K** | **U** | **E** | **Sir Lowry's Pass estuary EWR site, linked to river node Bviii9** | **N/A** |
| | Bvii22 | G40A | VH | C | Steenbras River, at EWR 8, u/s of estuary mouth; significant groundwater contribution; Seep wetlands as well as Valley-bottom wetlands. | SWSA; Hottentots Holland MCA |
| | **Bxi6** | **G40A** | **U** | **B** | **Steenbras estuary EWR site, linked to river node Bvii22** | **Hottentots Holland MCA** |
| D8 | Bvii13 | G10A | VH | A | Berg River, gauge u/s Berg River dam, 100% MAR. | NFEPA Fish2; SWSA |
| | **Bviii1** | **G10A** | **H** | **C** | **Berg River, d/s of Berg River dam EWR 1** | SWSA |
| | Biv5 | G10A | H | D | Franschoek River, u/s of confluence with Berg. | N/A |
| | Biii2 | G10B | VH | D | Wemmershoek River, u/s of confluence with Berg; significant groundwater contribution; Depression and Hillslope seep wetlands as well as Channelled Valley-bottom wetlands. | NFEPA Fish1; SWSA |
| | Bvii14 | G10C | VH | C | Dwars River, gauge. | SWSA |
| | Bvii2 | G10C | H | D | Berg River, Berg Water Project pump station; Depression wetlands as well as Floodplain and Channelled Valley-bottom wetlands. | SWSA |
| | Biii3 | G10C | H | E | Berg River, gauge; Depression and Hillslope seep wetlands as well as Floodplain, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands. | SWSA |
| D9 | **Bviii11** | **G10C** | **H** | **D** | **Pombers River, EWR 7 u/s of confluence with Kromme; Flat, Channelled Valley-bottom, Unchannelled Valley-bottom and Floodplain wetlands** | **N/A** |
| | **Bvii3** | **G10D** | **H** | **D** | **Kromme River, North of Wellington, EWR 6; Hillslope seep wetlands as well as Flat, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.** | **NFEPA Fish2; SWSA** |
| | Bvii10 | G10D | H | D | Berg River, d/s of confluence Kromme, gauge; significant groundwater contribution; Hillslope seep and Depression wetlands as well as Floodplain, Channelled Valley-bottom, Unchannelled Valley-bottom and Flat wetlands. | NFEPA Fish2; SWSA |
| | Bvii15 | G10D | VH | D | Doring River, gauge; significant groundwater contribution; Depression wetlands as well as Unchannelled Valley-bottom (Klein Sand vlei and Sand River vlei) and Floodplain wetlands. | SWSA |
| | Bvii4 | G10D | H | D | Kompanjies River, gauge; Hillslope seep and Depression wetlands as well as Channelled Valley-bottom and Floodplain wetlands. | SWSA |
| | **Bvii5** | **G10D** | **H** | **D** | **Berg River, gauge and u/s of EWR 3; Depression (Blouvlei) and Seep wetlands.** | **SWSA** |

| IUA | NODE | QUAT | EIS | EC | Node type and considerations | Within conservation sites |
|---|---|---|---|---|---|---|
| D10 | **Bv1** | **G21D** | **H** | **D** | **Diep River; significant groundwater contribution; Depression and Seep wetlands as well as Flat wetlands.** | NFEPA Fish2 |
| | Bviii4 | G21D | H | D | Swart River, u/s of confluence with Diep; significant groundwater contribution; Depression wetlands as well as Unchannelled Valley-bottom wetlands. | NFEPA Fish2 |
| | Biv6 | G21D | H | D | Diep River; significant groundwater contribution ; Depression and Seep wetlands as well as Valley-bottom wetlands. | NFEPA Fish2 |
| | Biv7 | G21E | H | D | Mosselbank River; significant groundwater contribution; Depression and Seep wetlands as well as Floodplain and Valley-bottom wetlands. | N/A |
| | **Bxi7** | **G21F** | **H** | **D** | **Rietvlei/Diep estuary EWR site, linked to river nodes Bv1, Bviii4, Biv6, Biv7; Floodplain and Valley bottom wetlands (Rietvlei) as well as Depression wetlands.** | N/A |
| E12 | Bviii8 | G22C | M | F | Elsieskraal River, u/s of confluence Black; Depression as well as Valley-bottom wetlands. | N/A |
| | **Bvii7** | **G22D** | **H** | **D** | **Keysers River, at EWR site; Depression (Princessvlei) and Seep wetlands as well as Floodplain and Valley-bottom wetlands.** | **N/A** |
| | **Bxi9** | **G22D** | **H** | **D** | **Sand estuary EWR site, linked to river node Bvii7; Depression as well as Floodplain wetlands.** | **SWSA, False Bay Nature Reserve** |
| | **Bxi20** | **G22D** | **U** | **E** | **Zeekoe estuary; Depression (Zeekoevlei and Rondevlei) and Seep wetlands as well as Floodplain wetlands.** | **SWSA, False Bay Nature Reserve** |
| E11 | Bviii6 | G22B | H | D | Hout Bay River, at EWR site; Seep wetlands as well as Floodplain and Valley-bottom wetlands. | SWSA, NFEPA Fish1 |
| | **Bxi10** | **G22B** | **U** | **E** | **Hout Bay estuary EWR site, linked to river node Bviii6** | SWSA, Table Mountain National Park |
| | Bvii20 | G22A | U | C | Silvermine River, Fish Hoek, 100% MAR; Seep wetlands. | NFEPA Fish1 |
| | Bxi11 | G22A | U | D | Silvermine estuary EWR site, linked to river node Bvii20 | N/A |
| | Bxi13 | G22A | M | D | Goeiehoop estuary | N/A |
| | **Bxi14** | **G22A** | **M** | **D** | **Wildevoelvlei estuary; Depression wetlands (Noordhoek Salt Pan and Pick n Pay Reedbeds) as well as Valley-bottom wetlands.** | Table Mountain National Park |
| | Bxi15 | G22A | U | D | Bokramspruit estuary (micro-estuary); Depression wetlands as well as Valley-bottom wetlands. | N/A |
| | Bxi16 | G22A | U | A | Schuster estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands. | NFEPA Fish1, Table Mountain National Park |
| | Bxi17 | G22A | U | A | Krom estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands. | Table Mountain National Park |
| | Bxi18 | G22A | U | F | Buffels Wes estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands. | Table Mountain National Park |
| | Bxi19 | G22A | U | E | Elsies estuary (micro-estuary); Depression wetlands as well as Valley-bottom wetlands. | SWSA |

With IUA = Integrated Unit of Analysis; IBA = Important Bird Area; Quat = Quaternary catchment; EIS = Ecological Importance and Sensitivity; EC = Ecological Category; SWSA: Strategic Water Source Area, MCA = Mountain Catchment Area; N/A = Not applicable; NFEPA: National Freshwater Priority Area

Note: Reserve sites in red; blue highlights estuary nodes and green highlights river nodes with significant groundwater contribution

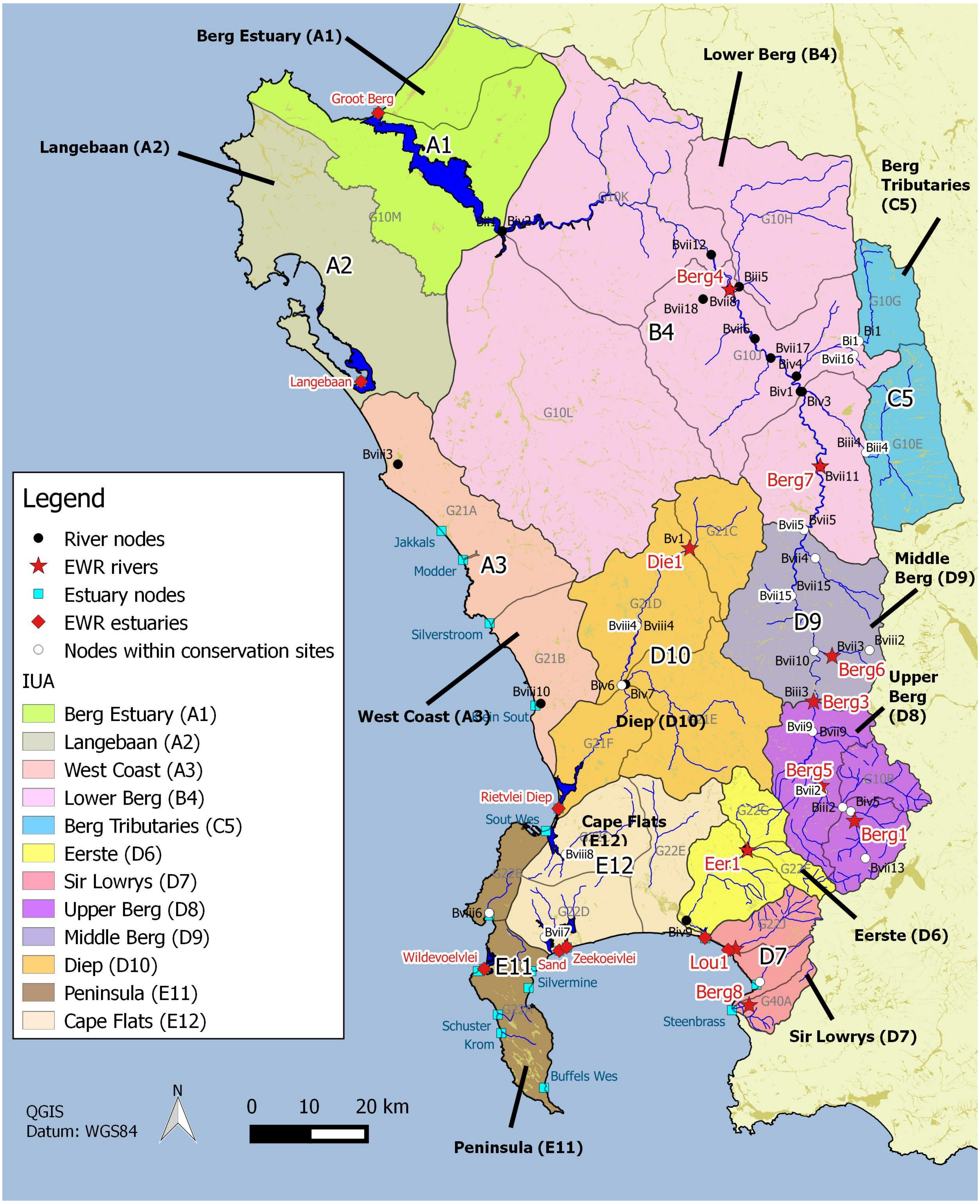


Figure 3.1 Integrated Units of Analysis (IUAs) and biophysical nodes for the Berg catchment.

# 4 QUANTIFICATION OF EWRs

## 4.1 Overview

Ecological Water Requirements (EWRs) were extrapolated from previous reserve studies at eight existing locations in the study area and determined for three additional preliminary Reserve sites located in the G2 catchments.

EWRs were also determined for all other river nodes using the Desktop Reserve Determination model. EWRs were also determined for the eight priority estuaries in Study Area.

Present Ecological Status (PES) and Recommended Ecological Category (REC) were also determined for all river nodes and for the eight priority estuary nodes. These EWRs, PES and RECs for all sites will be used to determine the changes in ecological goods, services and attributes (EGSA) necessary for the analysis of base line and alternative development scenarios as the next step in the classification process.

## 4.2 Ecological Water Requirements for River Nodes

The first step in determining environmental water requirements (EWRs) is to assess whether existing high-confidence Reserve data at established Reserve sites is available and can be extrapolated to any of the biophysical nodes established in Step 1d (Section 7.1.2. of DWAF, 2007). This should be followed by an extrapolation procedure based on the outcome of the assessment and where necessary additional studies.

In order to identify which nodes can be extrapolated to, a distinction needs to be made between:

- nodes that are suitable for extrapolation from high-confidence Reserve data; the EWR quantification for those nodes should be based on those data rather than a desktop model (e.g. Hughes and Hannart, 2003); and

- nodes that are not suitable for extrapolation from sites with high-confidence Reserve data; the EWR quantification for those nodes should be based on a desktop model (e.g. Hughes and Hannart, 2003).

Step 3a also has implications for Step 3c, in that changes in some biophysical EGSAs can only be provided:

- at nodes that are suitable for extrapolation from sites with high-confidence Reserve data; and

- for EGSAs that were considered during the Reserve determination process.

The objective of developing flows for different ecological conditions (rule curves, summary tables and modified time series) for the rivers nodes (Step 3b in the WRCS) is to provide hydrological inputs into the analysis of ecological and developmental scenarios, Steps 4 to 6 of the classification procedure (DWAF 2007). Step 3b requires generating the EWRs using the Desktop Model (Hughes and Hannart, 2003) both for nodes identified as not being suitable for extrapolation and those that may be calibrated using flows prescribed from preceding Reserve determination studies.

In the delineation, there were initially 47 rivers nodes identified, but these were subsequently reduced to 45 that are now taken through here and into the scenario analyses that follow in the next report due. For the pragmatic purpose of calculating EWRs and during the scenario analyses, this list of nodes may change based on their necessity and suitability for routing flows through the catchment in a downstream direction, their individual importance to capture flows required at estuaries and also their usefulness in being used to describe and represent the locations of the points of interest in the future development scenarios. During the scenario analyses, nodes may be added, their locations changed or deleted as required.

### 4.2.1 Conceptual Framework

In considering the ecological flow requirements at each river node it is useful to understand the linkages between flow and ecological condition, as flow in a river has a direct influence on riverine biota (Naiman *et al.* 2005). Key principles are summarised in the Natural Flow Regime paradigm (Poff *et al.* 1997), which included much of the environmental flow theory upon which methods for determining environmental flows (and Reserve assessments) have been based. The guiding principle of the Natural Flow Regime paradigm is that the integrity of flowing ecosystems depends largely upon their natural dynamic character (Poff *et al.* 1997). The natural flow regime varies over time-scales from hours and days, to seasons and years, and flow is considered the 'master variable' that dictates the abundance and distribution of riverine species (Resh *et al.* 1998). Components of the flow regime are described in terms of magnitude, frequency, duration, timing and rate of change of flow. These characterise the range of river flows from floods to low flows, each of which is critical for different species in some way (Poff *et al.* 1997).

Surface flow in rivers ultimately derives from precipitation but, at any given time, may comprise a combination of surface runoff, soil water and groundwater (Viddon and Hill 2004). Climate, geology, topography, soils and vegetation all play a role in water supply and the path that flow may take (Gurnell, 1997). Variability in intensity, timing and duration of precipitation combined with the effects of soil texture, topography and plant evapotranspiration contribute to locally- and regionally-variable flow patterns (Poff and Ward 1989). Generalisations about hydrological properties, between headwater streams and lowland rivers for example, should be made with caution, since natural flow characteristics are highly variable across river catchments in response to properties such as climate, geology and topography (Naiman *et al.* 2008).

Rivers are dynamic and the relative dominance of species changes from river source to river mouth. Areas of broadly similar physical habitat contain broadly similar communities, but the species composition and density at any one site is affected by changes in sediment moisture, nutrient status and topography (Van Coller, 1992); the frequency and intensity of droughts and floods, fire, plant disease and grazing, biogeographical distributions (Naiman *et al.* 2005); and species interactions (Francis, 2006).

Methods for assessing and monitoring river health and environmental flow requirements of rivers are based on assumptions about how changes to a natural flow regime affect the structure and functioning of an aquatic ecosystem. In many environmental flow studies the assessment of river health forms an integral component of the establishment of baseline conditions against which future states are monitored.

#### 4.2.1.1 Environmental Flow Requirements in South Africa

Environmental flows describe the pattern of flows (magnitude, timing, frequency, duration, variability and quality) of water required to sustain freshwater and estuarine ecosystems and the livelihoods of subsistence users that depend on these ecosystems (Hirji and Davis 2009). Identifying flow components; such as the range of low flows in the dry and wet seasons; the size, numbers and timing of small floods; the size and timing of large floods, and; the temporal characteristics of the flow regime; and understanding the consequences of their loss, to the ecosystem under investigation, is central to a flow assessment (King *et al.* 2003).

Work on environmental flows began in the 1940s in western United States with simple hydrological approaches to determine minimum flows, usually at an annual, seasonal or monthly basis, for some ecological feature of a river ecosystem (Gordon *et al.* 1992). Further developments in the 1970s focussed on quantifying the relationship between the quantity and quality of an aquatic resource, such as seasonal changes in the distribution of flow-related fish habitat required for passage and spawning, with discharge (Tharme, 2003). Since then, two approaches to flow assessments have developed (Brown and King, 2006):

1. *Prescriptive*, in which flows are described to achieve a narrow and specific objective; and
2. *Interactive*, which focus on changes in river flow and one or more aspects of the river to provide a range of options for river condition.

In South Africa, initial work in the 1990s led to the development of the Building Block Methodology (BBM) (King and Louw, 1998), a *prescriptive* approach that formed the basis of the determination of the Ecological Reserve in the South African National Water Act (NWA) (Act 36 of 1998) (King and Pienaar, 2008). The BBM method was abandoned as the outcome did not lend itself to negotiation between water users nor provide sufficient information about the implications of not meeting the recommended values. Since then, two other interactive and holistic methods (Arthington, 1998) are in use in South Africa, DRIFT (Downstream Response to Instream Flow Transformation, King *et al* 2003) and the Flow Stressor-Response method (Hughes and Louw, 2010). Both incorporate assessments of changes in a range of biophysical disciplines, such as hydrology, hydraulics, fluvial geomorphology, sedimentology, chemistry, botany and zoology; and socio-economic disciplines where there are subsistence users, such as sociology, anthropology, water supply, public health, livestock health and resource economics (King *et al.* 2003).

The consequences of flow changes to aquatic ecosystems are predicted by understanding how flow influences aquatic organisms and aquatic habitat, based on assumptions about responses, for example when thinking about riparian vegetation; extreme floods reset physical river and riparian habitat (Naiman *et al.* 2008); medium floods flush riparian vegetation from the channel and small floods recharge groundwater for shallow rooted species (Naiman *et al.* 2000); normal low flows maintain the wet bank community (Boucher 2002); and drought lows enable recruitment and purge invasive riparian and aquatic species (Naiman *et al.* 2000). Many of these assumptions remain hypotheses to be tested, which requires empirical data collected with this purpose in mind.

Environmental flows were recognised as the foundation of integrated water-resources management (King and Pienaar, 2011) during the writing of the NWA, which stipulated that water must be secured as a basic water supply to satisfy basic human needs and to protect aquatic ecosystems sustainably during water resource development (NWA ,1998). These two components were collectively called the Ecological Reserve and are stipulated in terms of quantity and quality of water required (King and Pienaar, 2011).

Determination of the Ecological Reserve for a water resource follows an eight step procedure (DWAF, 1999) the main outcomes of which are as follows:

- the study area is delineated in terms of significant biophysical features;
- the present condition is determined;
- the ecological water requirements are calculated, using either the DRIFT or Flow Stressor-Response methods, and;
- the consequences of different operational scenarios determined on the available water resources (King and Pienaar, 2011).

The results are presented to the Department of Water and Sanitation Directorate: Reserve Determination who make a decision on the condition of the water resources that are to be maintained and then sign off on these preliminary reserves, which are legally binding and represent water quality and quantity parameters that must be adhered to. The next step is to calculate the Resource Quality Objectives (RQOs) (DWA, 2011), which are the requirements for agreed water quantity, quality, and the associated habitat and biotic integrity to maintain the agreed conditions. RQOs are defined in terms of EcoSpecification (EcoSpec), descriptors of the ecosystem and Thresholds of Potential Concern (TPCs), points along a continuum of change for each EcoSpec, which may highlight the need for some action in response to a measured change in one of the indicators. EcoSpecs are recognised for major ecosystem components, including hydrology, geomorphology, water quality, riparian vegetation, macroinvertebrates and fish. The final step in this process is implementation of the reserve flows and any other mitigation measures as well as establishing a monitoring programme to monitor the EcoSpecs.

Most Reserves determined thus far are preliminary as they have been completed without consideration of catchment-wide water issues. This is because development and testing of the WRCS (Brown *et al.* 2007), designed to address this issue, has lagged behind that of the Reserve determination procedures. The WRCS addresses the economic, social and ecological implications of various permutations of managing the catchment-wide water resources in one of three classes; minimally, moderately and heavily used. The water resource class is set for separate river resource units throughout the catchment. In this way, the

WRCS establishes the boundaries of the volume, distribution and timing of the water needed for ecosystem maintenance for that river resource unit, and the amount of water potentially available for off-stream use.

### 4.2.2 Ecological Condition of Rivers

Kleynhans (1996) and his later research have been the primary sources for the assessment of aquatic ecosystem conditions for the last 20 years and this has been based largely on calculating a condition score, relative to a hypothetical reference condition (Table 4.1). In the table, percentage scores are decreased relative to natural for increasingly degraded river conditions, A to F. It is important to note that the condition assessments using this table include both flow- and non-flow-related impacts on the condition.

It follows that translating flow estimates using these ecological conditions scores, as is the norm, requires specifying whether the conditions predicted to change will do so as a result of changes in flow and/or in response to non-flow-related changes, or both.

**Table 4.1 Ecological categories, scores and descriptions (adapted from Kleynhans, 1996)**

| Ecological Category | PES % Score | Description of the habitat |
|---|---|---|
| A<br>A/B | 92-100%<br>87-92% | Still in a Reference Condition. |
| B<br>B/C | 82-87%<br>77-82% | Slightly modified from the Reference Condition. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged. |
| C<br>C/D | 62-77%<br>57-62% | Moderately modified from the Reference Condition. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged. |
| D<br>D/E | 42-57%<br>37-42% | Largely modified from the Reference Condition. A large loss of natural habitat, biota and basic ecosystem functions has occurred. |
| E<br>E/F | 22-37%<br>17-22 | Seriously modified from the Reference Condition. The loss of natural habitat, biota and basic ecosystem functions is extensive. |
| 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. |

In general there are few A and B category rivers in the Western Cape, these generally being restricted to the upper reaches of tributaries (mountain streams) that are usually not cultivated, due to being situated in narrow valleys with limited or with no floodplain development. Similarly, and for the same reasons, there are a dearth of foothill and lowland river reaches in good condition (A or B category) since the floodplains and wetlands situated here are usually targeted for agricultural or urban development.

For this reason, the condition of such foothill and lowland rivers tends to be at best C, but generally are in a D-F category, depending upon the extent to which water is abstracted (zero dry season flow in most cases), the riparian area is transformed (e.g. cleared of indigenous vegetation and cultivated) and the channel disturbed (e.g. bulldozed to facilitate transfer of flood flows downstream). The basis for the latter is much the same logic that is applied when designing canals, shown as the category F River in Figure 4.1.

Looking at the rivers here in Figure 4.1 we can make some generalisations about the composition of rivers at different ecological conditions. In the generic descriptions that follow, the general principle is that diversity (of flow, sediment texture, channel shape and sinuosity, the size, shape and number of different kinds of riparian plants present, and other aquatic biota) reflects better conditions, whereas homogeneity reflects poorer conditions. Also the descriptions below are for perennial rivers only; the situation for seasonal and non-perennial rivers is less well documented and less obviously (visually) descriptive.

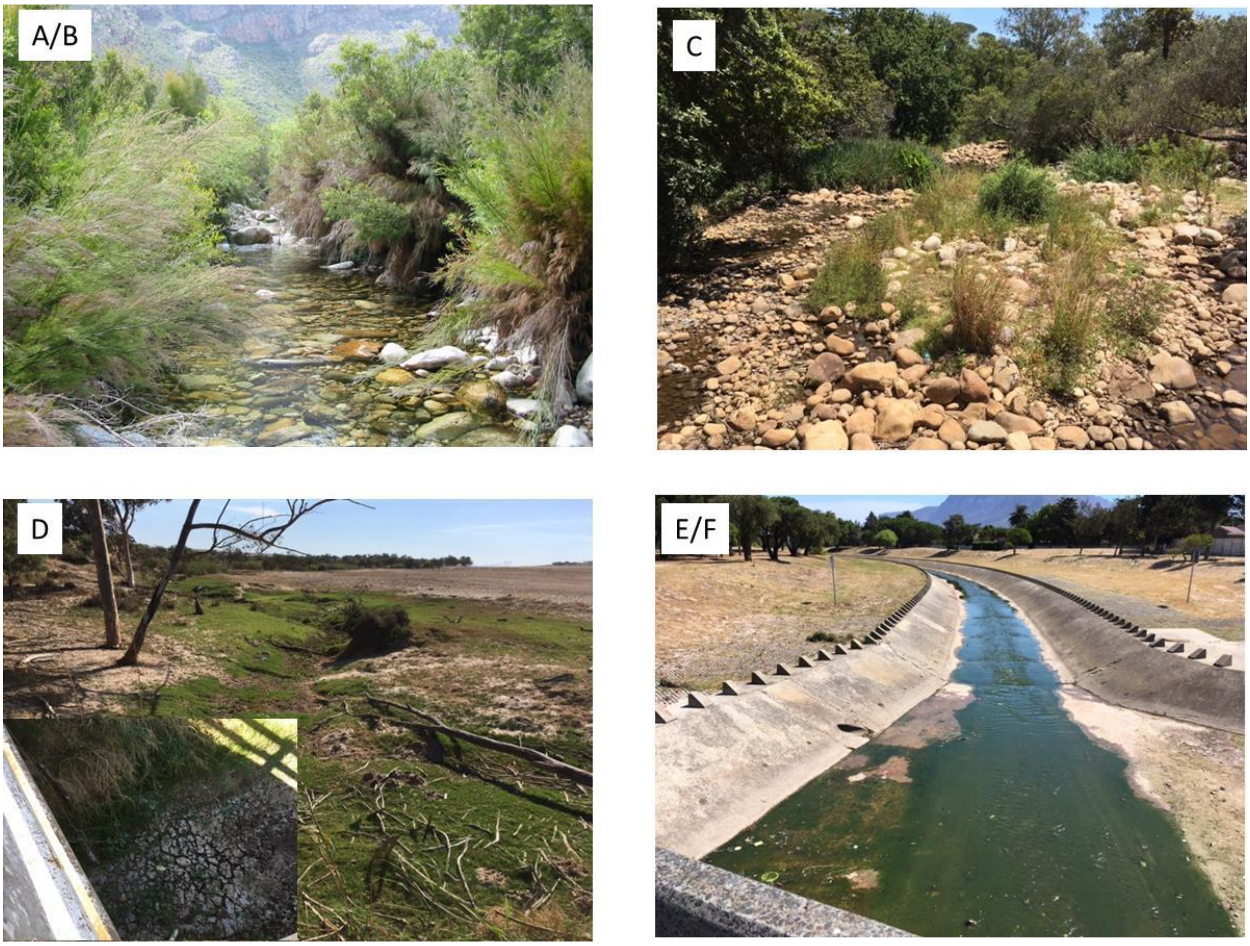


**Figure 4.1 Examples of rivers in different ecological conditions**

***Characteristics of rivers with different ecological categories:***

- **A or a B category rivers:**
    - Generally has flowing water that is clean and free of odour, indicating no water quality problems at the site.
    - Normally a range of substratum particles present (boulders, cobbles and gravels higher up; gravels, sands and muds lower down the system) that are distributed across and along the river channel in pockets with similarly-sized particles forming clumps.
    - Aquatic plants may or may not be present as these are more frequently present lower down in the river system, as they tend to be scoured out higher up where flows carry more energy.
    - The riparian area normally comprises a range of different flexible and evergreen growth forms (grasses, reeds, restios, sedges, algae, small pioneering trees) in the marginal area of the channel *viz.* adjacent to the low flow water's edge. This area is often called the wet bank and is where flow (water) is available to plants most of the year.
    - There normally is an obviously different plant layer higher up the bank, called the dry bank, where woodier and larger plants (normally shrubs and trees but also grasses, reeds and restios) may be found. These plants tend to be inundated by the larger floods that recur inter-annually.
    - Since there is a diversity of different aquatic habitats (represented by the range of sediment particles of different sizes and the presence of aquatic and marginal vegetation, as well as flow being present at different velocities) the abundance and diversity of aquatic organisms

should be high (macroinvertebrates, crustaceans, fish) but so also should be the presence of birds and other riparian or terrestrial fauna that visit the river and/or riparian area.

- **C category river:**
  - Normally has water present but this may not necessarily be flowing during the dry season; it may be that standing pools are present or that flow is barely perceptible.
  - The water present is normally NOT polluted, it may be clear or slightly opaque but would not have an obvious odour (and/or the presence of over-growing algae feeding off an oversupply of nutrients from agricultural runoff that normally carries fertilisers, or cow dung or sewage releases).
  - The diversity of different sediment particles is reduced, due to changes in flow that have taken place. Either low flows or intra-annual floods are reduced and thus the sorting of aquatic sediments is reduced, or there has been collection or mining of these sediments.
  - The channel shape may be less sinuous and/or the channel bank may be less diverse in slope and form, often due to the trapping of sediments and floods upstream in reservoirs.
  - There normally are riparian plants present, but the ratio of indigenous to exotic plants now may be lower, *viz.* there are more exotic plants present.
  - So too may be the variety of growth forms and sizes of plants present. There should however be some variety of plants present, exotic or indigenous, and there should still be an obvious separation of the wet from the dry bank - still normally represented by flexible green specimens lower down on the wet bank and dry woody specimens higher up on the dry bank. It could be that this situation is reversed, and woody plants dominate the wet bank while herbaceous plants dominate the dry bank.
  - Since the diversity of habitat is somewhat compromised, one would expect there to be a lesser abundance of aquatic biota for some or other reason. It could be that water quality is impaired, or flows are compromised, or exotic plants or fish are present. Whatever the case, C category rivers have one or other component either missing or in a degraded state that is countered by the others still in relatively good condition.
- **D category river:**
  - Normally one where the stratification or types, be that of flows, sediment textures, plants or biota, are normally at a reduced abundance but mostly that a diversity of types is no longer present.
  - There may be a handful of aquatic organisms present and there may only be exotic and no indigenous fish.
  - There may be no flow in the dry season and the only flows to pass are the intra-annual floods.
  - It could be that there is a strong odour of sewage/agricultural pollutants present, be there water or not, that indicates an unnatural oversupply of nutrients.
  - This monoculture of type, typical of rivers in a D category, offers little diversity of habitat to aquatic biota.
- **E/F category river:**
  - Monoculture type in the extreme.
  - A canal that represents a void of variety or shape. It could also be that a natural river is channelized, meaning that it is straightened, cleared of vegetation, and bulldozed into a geometric shape that offers little resistance to flow.
  - These types of channels tend to end up being comprised entirely of one sediment type, cobbles if higher up, and sand/mud if lower down.

- Also, rivers in this final and degraded condition tend to be kept up in this way for the purposes of flood conveyance. This means that they are cleared or cleaned out each autumn prior to the onset of floods, whch bring with them sediments, plant propagules and organisms that get washed downstream and would settle in eventually if given reprieve from the clean-out.

### 4.2.3 Calculating Ecological Water Requirements (EWRs) for Rivers

There have already been a number of reserve studies undertaken in the study area to determine the EWRs for key sites that have already been accepted by DWS and the key stakeholders. For this study the EWR requirements for different ecological categories were determined by extrapolating information from exiting Reserve sites in the catchment were possible and appropriate to the additional identified biophysical and abstraction river nodes. Initially the desktop Reserve model of Hughes and Münster (2000) was used to generate preliminary EWRs. The results of the desktop model were then calibrated using the results from past EWR and existing high confidence reserve studies. The assurance rules together with the time series of natural flows per node were used to construct representative time series of EWR requirements. These DRAFT EWRs are available electronically but remain under consideration as adjustments are likely to be required as flows are routed and scenarios analysed. The final EWRs will be written and made available in the templates when final considerations and adjustments are concluded.

A summary of the model is provided below (adapted from Hughes and Hannart (2003)):

- The Desktop Model is based on the assumption that total water requirements for a river decrease as the ecological category changes from A through to D.
- The model consists of three components;
  - estimation of the maintenance/drought and high/low flows,
  - estimation of the seasonal distribution of annual total flows based upon the natural flow regime separated into high/low flows, and
  - estimation of the rules that combine the maintenance/drought requirements into continuous assurance frequency curves.
- The final output is a table of flows for each month of the year for a range of percentage assurances. The flows are expressed as volumes ($m^3x10^6$) or as mean monthly discharge ($m^3/s$).
- The frequency component of the estimated flows is based upon the assumption that drier areas with more variable flows have substantially greater maintenance flows but with lower levels of assurance. The numerical rules in the model that describe this function are set such that the maximum low flow value is a scaling factor, which varies with ecological category, such that lower categories have higher maximum values. These standardised settings for this maximum low flow value that increases from ecological category B through D created some problems with the validity of estimated (extrapolated) monthly flows.
- At sites where there was no existing EWR data in close enough proximity to justify extrapolation of EWR data, a generic desktop run, with either Western Cape wet or Western Cape dry selected (depending on location) was performed. All the data generated in this way produced valid comparative monthly flows between different ecological categories using the standard assurance level settings in the desktop for classes B through D. The problem described above with the assurance levels resulted in the generation of invalid data at some of the nodes that made use of extrapolated EWR data, where flows in some months exceeded those occurring naturally. Therefore, these were adjusted downwards to resolve this anomaly.
- The EWR data for each node comprise the following data: a summary of the desktop estimate (*.tab), the assurance table (*.rul) and the finally the time series of monthly flows (*.mrv) for each determined ecological category. In most cases there are data for three ecological categories, B through D. There are some instances where other categories were determined, for example a BC or CD and other cases where only one or two classes were determined. This was especially the case for the Berg River Catchment since the river is so heavily regulated and the corresponding condition of the main stream and its tributaries generally poor, in a C or D ecological category. With water availability being limited in general, it is expected that there will be few opportunities to meet

the existing reserve requirements and fewer to improving ecological conditions by providing more flow beyond these.

- This will be determined during the analyses undertaken to produce the Ecological Sustainable Base Configuration Scenario (ESBC), which will be presented in the next report for the Study.

## 4.3 Previous Reserve Studies and Determined EWRs

A number of previous Reserve studies have been undertaken in the study area. Relevant information was used where possible to inform the determination of EWR requirements for this study. These are described in the *Water Resources Information and Gap Analysis Report* (DWS, 2016a) and are summarised below.

The main studies that provided EWR related data to calibrate river flows throughout the study area are the Comprehensive (1993 (report not available)), reviewed and updated DWAF, 1996), Intermediate (DWAF, 2002a and b) and Rapid III Reserve determination studies (DWA, 2012b) for the Berg River Basin, which resulted in EWR estimates for seven river sites in the G1 catchment and one river site in the G4 catchment.

The original Comprehensive Reserve study (DWAF, 1993, report not available) undertook to calculate Reserve flows at 3 sites on the Upper Berg. These were as follows:

- **EWR 1** and **EWR 3**, to deal with water requirements up to Zonkwasdrift, as downstream releases from Voëlvlei were always intended to meet those required at the estuary, and
- **EWR 2** downstream of the confluences of the Dwars and Franschoek Rivers with the Berg River.

There were concerns about the methodology used for the Reserve calculations during this study, particularly that floods were not determined in eco-hydraulic terms but rather were based on reducing changes in yield. This lack of a hydraulically-based approach was seen to be ecologically indefensible. A further problem at EWR 2 was that the calculated volumes ignored contributions from the Wemmershoek River and so underestimated natural base flows at EWR 2. For these reasons, the original work was refined and updated to deal with these discrepancies and issues in the Skuifraam Dam feasibility study (DWAF, 1996). EWR 2 was rejected for further analysis on the basis that its location precluded contribution from important tributaries and also due to the degraded nature of the river at that location. The new work therefore focussed on reviewing and correcting the EWRs for the upper two sites, EWR 1 (upstream of Franschoek River), and EWR 3 at Hermon, upstream of Zonquasdrift and the incoming flows from Voëlvlei.

The Voëlvlei Intermediate Reserve study (DWAF, 2002) calculated Reserves at two additional sites:

- **EWR 4** and **EWR 5**, situated upstream and downstream of Misverstand Dam respectively.

This was followed by a study to determine the operating rules for the Berg River Dam, with updated ecological conditions of the river in 2001, and Preliminary Reserves for G10A at EWR 1 and G10C at EWR 3, and followed by internal project documents that explained discrepancies in Reserve estimates calculated in 2003 and updated in 2008 (Southern Waters 2003, 2008).

The Western Cape Water Supply System (WCWSS) study synthesized the Reserve work undertaken thus far (explained above for Reserve sites 1, 3, 4 and 5) and included:

- an Intermediate Reserve determination for the Berg River Estuary (DWA 2010)
- extrapolated EWR data to 23 nodes throughout the Berg River Catchment (DWA 2012b) for different ecological conditions using all the available Reserve-related data described above (adjusted and refined as needed)
- Rapid III Reserve determinations for the Krom, Steenbras and Pombers rivers (DWA 2012c).

These determinations were considered suitable for the purposes of generating EWR estimates for the 23 nodes of the Berg River Basin, as part of the WCWSS study, and were written into preliminary Classification templates (DWA 2012a). These determinations remain applicable going forward, given that there have been no notable catchment developments that would have changed these hydrologically-modelled estimates over the last four years.

The ecological condition of the four Berg River Reserve sites was verified during site visits conducted in November 2016 using the Index of Habitat Integrity approach (Kleynhans 1999). These data are presented in Appendix J. The outcome of this was that the ecological condition of the four Berg River Reserve sites has not changed. No assessment was made of Berg River EWR site 2 as this has not been carried forward in any study since the original Reserve study and is not used for calculating ecological water requirements here.

## 4.4 Summary of Existing Reserve Sites

A summary description of the following existing Reserve sites in the study area is provided below.

- EWR1, EWR 3 (DWAF, 1996)
- EWR 4, EWR 5 (DWAF, 2000)
- EWR 6, EWR 7, EWR 8 on tributaries (DWA, 2010c)

All available EWR data for the existing Reserve sites were translated into standard Desktop Model output files that are all formatted and presented in the same way so that the results from the different studies may be compared. These data are presented in electronic format and are the standard that flow specialists use.

### 4.4.1 EWR Site 1: Upper Berg River

- The flows signed off for this site in the preliminary template for G10A (DWA 2012a) were for an ecological category C.
- The refined and updated Reserve flow estimates (DWAF, 1996) are provided in Appendix B.

**Table 4.2 Summary characteristics of EWR 1**

| Site information | Detail |
|---|---|
| **EWR site** | EWR 1 |
| **Name** | Upper Berg River (La Motte State Forest) |
| **Co-ordinates** | S 33º25’80 E 18º58’2 |
| **Locality** | Situated immediately downstream of the Berg River Dam and upstream of the Franschoek River junction. |
| **Habitat Integrity**: | Instream Class 4 (comparable to an ecological category D today), meaning that the channel was largely modified, and a loss of natural habitat biota and basic ecosystem functions had occurred. Riparian = Class 5 (an ecological category E/F today), meaning that the loss of habitat, biota and basic ecosystem functions was extensive. |
| **Nature Conservation Importance**: | Rated very highly. |
| **Geomorphology**: | The site consisted of a stable boulder/cobble bed and a broad, shallow channel. There was little sand and the water was clear and sediment free. Bank collapse associated with fallen trees (*Pinus* spp.) was noted. A fairly clear pool-riffle sequence characterised the reach. |
| **Riparian vegetation**: | The vegetation along this reach was highly modified, and the banks and floodplain at this site were densely infested with *Acacia longifolia*, *Pinus pinea*, *Eucalyptus cladocalyx* and *Acacia mearnsii*. |
| **Fish**: | *Barbus andrewi* (witvis) was considered to be the single most important fish species needing protection at the site. |
| **Macroinvertebrates**: | The macroinvertebrates recorded at the site were indicative of a borderline case between natural and deteriorated water quality. Stoneflies, some mayflies, cased-caddis and elmid beetles that would normally be expected to occur in this part of the river were absent. |
| **Water quality**: | Good. |

| Site information | Detail |
|---|---|
| **EWR site advantages**: | |
| • it was easily accessible by vehicle<br>• it provided reasonable habitat for fish, especially witvis<br>• it had marginal vegetation<br>• it had varied instream habitat - pool, riffle, run sequence<br>• it was situated in the identified river stretch<br>• it was a single (un-braided channel)<br>• the flow measurements of DWAF gauge G1H004 could be utilised for hydraulic calculations<br>• it was geomorphologically representative of this stretch of the river. | |
| **EWR site disadvantages:** | |
| • riparian vegetation comprised predominately exotic species<br>• releases from Theewaterskloof Dam affected the flow in this part of the river, particularly during the summer months<br>• the site was mildly polluted by an upstream trout farm<br>• considerable disturbance of the banks had occurred. | |

### 4.4.2 EWR Site 3: Lower Berg River (Hermon)

- The flows signed off for this site in the preliminary template for G10C (DWA 2012a) were for an ecological category D.
- The refined and updated Reserve flow estimates (DWAF, 1996) are provided in Appendix B.

**Table 4.3 Summary characteristics of EWR 3**

| Site information | Detail |
|---|---|
| **EWR site** | EWR 3 |
| **Name** | Lower Berg River (Hermon) |
| **Co-ordinates** | S 33º25'80 E 18º58'2 |
| **Locality** | Situated immediately downstream of the DWAF gauging weir G1H036, upstream of the Koopmans tributary and upstream of the proposed Lorelei Diversion Weir. |
| **Habitat Integrity**: | Instream = Class 2 (ecological category B today), meaning that the river channel was largely natural with few modifications. Riparian Class 4 (ecological category D today), meaning that the riparian belt was modified, and a loss of natural habitat, biota and basic ecosystem functions had occurred. |
| **Nature Conservation Importance**: | High. |
| **Geomorphology**: | The site consisted of a sand bed channel with a low width-depth ratio. The predominant morphological unit consisted of long deep pools, interrupted by the occasional "rapids" over bedrock 'dikes' which crossed the channel. |
| **Riparian vegetation**: | The reach of the river represented by this site was the first reach downstream of the Mountain Torrent Zone to contain extensive stands of reasonably natural vegetation |
| **Fish**: | Predominately alien. |
| **Macroinvertebrates**: | Indicative of a major deterioration in water quality. |
| **Water quality**: | Poor. |
| **EWR site advantages**: | |
| • it was easily accessible by vehicle<br>• specialists present evaluated the site as having a high diversity of riparian vegetation and habitat for fish important for angling | |

| Site information | Detail |
|---|---|
| • the site was geomorphologically representative of the reach<br>• marginal vegetation was present<br>• a secondary channel was present<br>• the flow measurements from the gauge G1H036 could be used for the hydraulic calculations<br>• the site was suitable for monitoring | |
| **EWR site disadvantages:** | |
| • no riffles were present and therefore the site lacked habitats for sensitive aquatic macroinvertebrate species and riffle-dependant fish species<br>• biotype diversity was limited<br>• exotic vegetation, such as blue gums and poplars, was present among the riparian vegetation. | |

### 4.4.3 EWR Site 4: Heuningberg (Upstream of Misverstand Dam)

- Notwithstanding the good to fair water quality (at the time) condition, the ecological condition of the flora and fauna, together with consideration of the trajectory of change for each, resulted in an overall ecological condition category D.
- Since the driving forces of this were not related to flow, the target (Recommended Ecological Condition) was also set as a D category.
- Flood requirements and flow estimates for the recommended category D and an alternate category C are given in Appendix B.

**Table 4.4 Characteristics and view of EWR 4**

| Site information | Detail |
|---|---|
| **EWR site** | EWR 4 |
| **Name** | Heuningberg, upstream of Misverstand Dam |
| **Co-ordinates** | S 33º08’30 E 18º05’30 |
| **Locality** | Situated immediately upstream of Misverstand Dam |
| **Ecological condition** | D |
| **Recommended Ecological Condition** | D |
| **Geomorphology**: | B/C (stable trajectory of change at the macro scale);<br>C/D (negative trajectory of change at the habitat scale due to increased sediment loading leading to blanketing of habitat) |
| **Riparian vegetation**: | D (negative trajectory of change due to increase in alien vegetation, decrease in bank stability) |
| **Fish**: | F (negative trajectory of change due to progressive deterioration in water quality resulting in dominance by coarse, hardy taxa) |
| **Macroinvertebrates**: | D (negative trajectory of change due to anticipated progressive decline in water quality, with superimposed impact of seasonal flow reversal and reduction in low flow conditions) |
| **Water quality**: | Salinity: B (Stable trajectory of change due to large areas of land still being available for development under irrigation).<br>Nutrients: C (Negative trajectory of change due to nutrients available from irrigated fields will bring about further deterioration in the nutrient-based trophic status of the river). |

### 4.4.4 EWR Site 5: Nuwedrift (Downstream of Misverstand Dam)

- The trajectory of change for EWR site 5 was stated as being the same as for EWR site 4, as was the ecological condition and recommended category; a D.
- Flood requirements and total flows for the recommended category along with flows for an alternate category C given in Appendix B.

**Table 4.5 Summary characteristics of EWR 5**

| Site information | Detail |
|---|---|
| **EWR site** | EWR 5 |
| **Name** | Nuwedrif, downstream of Misverstand Dam |
| **Co-ordinates** | S 33º05'00 E 18º45'00 |
| **Locality** | Situated immediately downstream of Misverstand Dam. |
| **Ecological condition:** | D |
| **Recommended Ecological Condition:** | D |
| **Geomorphology**: | B/C (stable trajectory of change at the macro scale);<br>C/D (negative trajectory of change at the habitat scale due to increased sediment loading leading to blanketing of habitat) |
| **Riparian vegetation**: | D (negative trajectory of change due to increase in alien vegetation, decrease in bank stability) |
| **Fish**: | F (negative trajectory of change due to progressive deterioration in water quality resulting in dominance by coarse, hardy taxa) |
| **Macroinvertebrates**: | D (negative trajectory of change due to anticipated progressive decline in water quality, with superimposed impact of seasonal flow reversal and reduction in low flow conditions) |
| **Water quality**: | Salinity: B (Stable trajectory of change due to large areas of land still being available for development under irrigation).<br>Nutrients: C (Negative trajectory of change due to nutrients available from irrigated fields will bring about further deterioration in the nutrient-based trophic status of the river). |

### 4.4.5 EWR Site 6: Pombers River

- Flow in the Pombers was considerably higher than natural due to transfer of water from the Witte River via Gawie-se-water (a canal).
- The ecological condition of the Pombers River was a D so flows for this and the recommended ecological condition C category are provided along with flood requirements in Appendix B.

**Table 4.6 Summary characteristics of EWR 6**

| Site information | Detail |
|---|---|
| **EWR site** | EWR 6 |
| **Name** | Pombers River |
| **Co-ordinates** | -33.62554; 19.08985 |
| **Ecological Condition (EC)** | D (negative trajectory of change) |
| **Environmental Importance and Sensitivity** | Moderate |
| **Recommended Ecological Condition** | C |
| **Hydrology** | E/F (stable trajectory of change) |
| **Geomorphology**: | B (negative trajectory of change) |

| Site information | Detail |
|---|---|
| **Riparian vegetation**: | E (negative trajectory of change) |
| **Macroinvertebrates**: | B (stable trajectory of change) |
| **Factors contributing to Ecological Condition:** | • Incision of the river channel (flow-related)<br>• Bank erosion<br>• Infilling to create agricultural lands<br>• Invasion by alien plants<br>• Largely natural macroinvertebrate community |

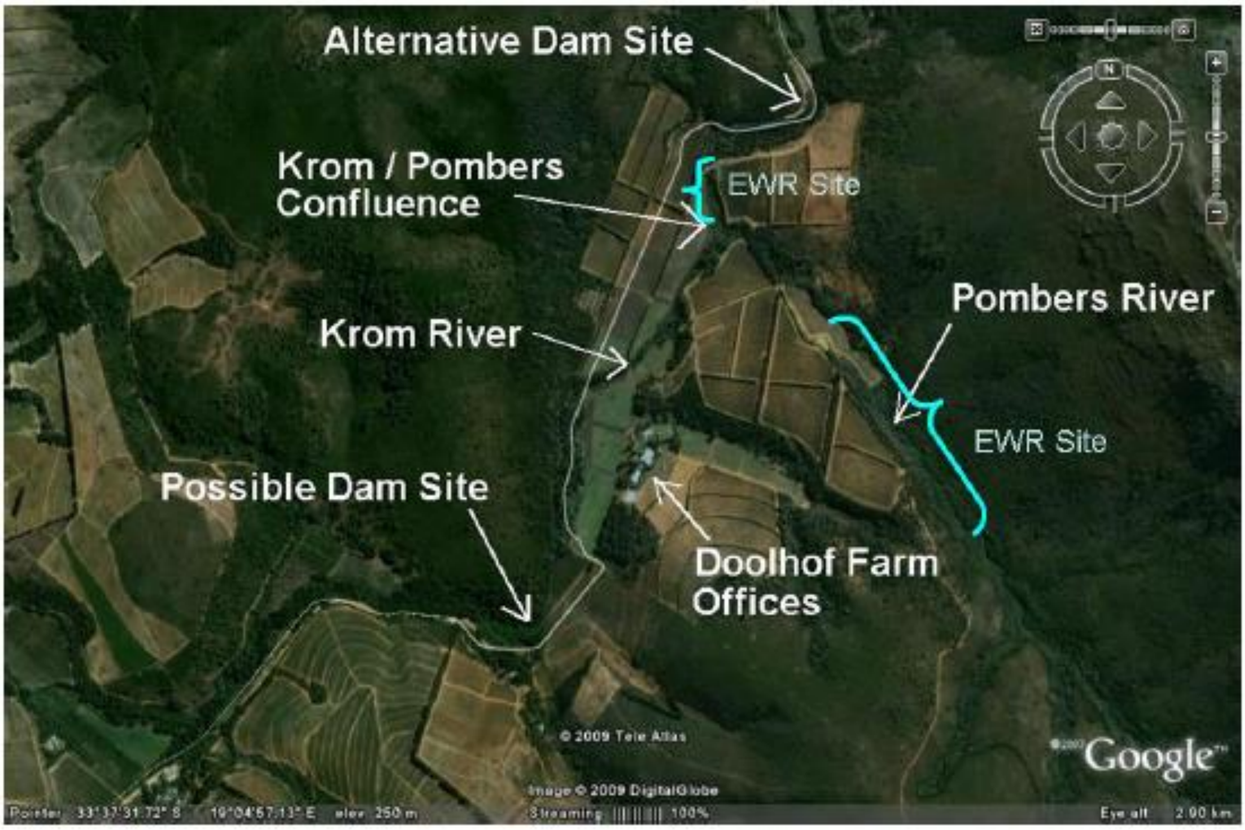


**Figure 4.2 Location of EWR Site 6 on the Pombers River and EWR Site 7 on the Kromme River**

### 4.4.6 EWR Site 7: Kromme River

- Flow in the Kromme River was higher than would be expected naturally due to transfer of water from the Witte River via Gawie-se-water (a canal).
- The ecological condition was determined to be a D/E category.
- Flows and flood requirements were provided for the recommended D category in Appendix B.
- Releases from the Wit River were predicted to prevent a higher EC being attainable.

**Table 4.7 Summary characteristics of EWR 7**

| Site information | Detail |
|---|---|
| **EWR site** | EWR 7 |
| **Name** | Kromme River |
| **Co-ordinates** | -33.62577; 19.08166 |
| **Ecological Condition:** | D/E (negative trajectory of change) |
| **Environmental Importance and Sensitivity** | Moderate |
| **Recommended Ecological Condition** | D |
| **Hydrology** | E/F (negative trajectory of change) |
| **Geomorphology**: | D/E (negative trajectory of change) |
| **Riparian vegetation**: | F (negative trajectory of change) |
| **Macroinvertebrates:** | B/C (negative trajectory of change) |
| **Factors contributing to Ecological Condition:** | • Incision of the river channel (flow-related)<br>• Bank erosion<br>• Infilling to create agricultural lands<br>• Invasion by alien plants<br>• Largely natural macroinvertebrate community |

### 4.4.7 EWR Site 8: Steenbras River

- The flow at the Steenbras River EWR site was considerable less than natural, due to the capture of flow by the Steenbras Dam upstream and no environmental flow releases.
- The ecological condition was determined to be a B/C.
- Flows and flood requirements were provided for this in Appendix B.
- The baseline condition was predicted to remain despite very low EWRs.

**Table 4.8 Summary characteristics of EWR Site 8**

| Site information | Detail |
|---|---|
| **EWR site** | EWR 8 |
| **Name** | Steenbras River |
| **Co-ordinates** | -34.19379; 18.82467 |
| **Ecological condition** | B/C (stable trajectory of change) |
| **Recommended Ecological Condition** | B/C |
| **Geomorphology**: | B (stable trajectory of change) |
| **Riparian vegetation**: | B/C (stable trajectory of change) |
| **Macroinvertebrates**: | A (stable trajectory of change) |
| **Factors contributing to Ecological Condition:** | • Low water levels associated with the presence of the Steenbras Dams<br>• Geomorphology that is highly resistant to flow changes<br>• Poor water quality immediately downstream of the dam<br>• Largely natural riparian and instream vegetation, which is reduced in extent<br>• Largely natural macroinvertebrate community |


**Figure 4.3 Location of EWR Site 8 on the Steenbras River**

## 4.5 New Reserve Sites in the Coastal Catchment (G2)

### 4.5.1 Selection of additional Preliminary Reserve sites

There were no previously identified reserve sites or EWR determinations in the coastal catchments (G2).

Rapid III level Reserve determinations were recommended for three rivers in order to provide input into basin-wide assessment of EWRs for the Rivers in secondary catchments G20, the Cape Flats.

The Resource Unit Prioritisation tool (DWAF 2011) was used to assess the relative importance of the rivers on which nodes had been delineated following the Classification procedures (Dollar et al. 2006) in the secondary basin G20. The top six rivers in order of priority were the Diep, the Disa, the Steenbras, the Eerste, the Lourens and the Sir Lowry's Pass Rivers. There were gauges with suitably long flow time series' for the purposes of calculating EWRs on the Diep, the Eerste and the Lourens Rivers. There are no gauges on the Disa and the Sir Lowry's Pass Rivers and there was already an EWR site on the Steenbras River so these rivers were not considered further. The Lourens, the Disa and the Sir Lowry's Pass Rivers were considered similar enough to one another that EWRs calculated for one could be extrapolated to the other.

There was one node on each of the Lourens and the Eerste Rivers and four on the Diep River. An EWR site was selected on the same river reach as the existing node on the Lourens and the Eerste Rivers, both also in close proximity to existing DWS monitoring sites. The EWR site on the Diep River was selected on the same river reach as the gauge G2H012 in Malmesbury and downstream of the existing node on the river. Summary information for the new preliminary Reserve sites in the G2 catchment are given in the following sections.

### 4.5.2 New Preliminary Reserve Site Die1: Diep River

EWR site Die1 is located at the position of the DWS monitoring site G2DIEP-MALM, d/s of node Bv1 and gauge G2H012, situated d/s of Malmesbury (Co-ordinates: -33 28 41.10, 18 41 52.69) (Figure 4.4)


**Figure 4.4 Location of EWR site Die1 on the Diep River**

The EWR site on the Diep River (Die1) was in an unacceptably low E category with an overall PES score of 24% (Table 4.9). The EIS was moderate but the specialists felt that this type of river was regionally important as a West coastal river type. Together, these were two reasons why an REC of a D category was selected for this river. It is unlikely that the aquatic biota can be improved since both are influenced primarily by water quality and flow impacts that will be difficult to ameliorate. Since the river flows primarily through agricultural land and since the next two lowest discipline scores for this river were geomorphology and riparian vegetation, which are intricately linked, more indigenous riparian plants in the channel and on the river banks would help to ameliorate the oversupply of sediments into the river. If a riparian buffer of indigenous plants could be established along this river it is possible that the river condition may improve close to the recommended D category through improving the riparian vegetation score and lifting the geomorphological score. There are sufficient indigenous plant species present for self-seeding and dispersal to facilitate this revegetation of the river channel IF this is combined with removal of the exotic woody species present and fencing off of the channel from animals that would graze in the riparian area.

**Table 4.9 PES, EIS, and REC for the EWR Site on the Diep River**

| EWR site | Discipline | Component score | Ecological condition |
|---|---|---|---|
| Die1 | Water quality | 70 | C |
| | Geomorphology | 40 | E |
| | Riparian vegetation | 10 | F |
| | Aquatic macroinvertebrates | 19 | F |
| | Fish | 24 | E |
| | Median PES | 24.00 | E |
| | EIS | 1.83 | MODERATE |
| | REC | | D |

The specialists felt that the EIS tool underscored the importance of the EWR site Die1 (Table 4.10) especially as it does not consider river type *per se* in its ranking of importance, rather being focussed at biota and conservation importance of plant and animal species.

**Table 4.10 EIS for EWR site Die1**

| Reserve site | Category | Component score | Confidence |
|---|---|---|---|
| Die1 | Biota (riparian and aquatic) | | |
| | Rare and endangered | 2.33 | 1.33 |
| | Unique (endemic) | 2.33 | 0.67 |
| | Intolerant (flow and water quality) | 2.33 | 1.33 |
| | Species richness | 1.00 | 0.33 |
| | Habitat (riparian and aquatic) | | |
| | Diversity of types | 1.67 | 2.67 |
| | Refugia | 2.00 | 3.00 |
| | Sensitivity to flow changes | 2.00 | 2.67 |
| | Sensitivity to flow related water quality changes | 2.33 | 3.33 |
| | Migration corridors | 2.00 | 1.00 |
| | Conservation importance | | 2.00 |
| | Median of scores | | 1.67 |
| | EISC | | MODERATE |

The likely causes and sources of present day conditions and future trends are given in Table 4.11.

**Table 4.11 Causes and sources of present day condition and projected trends for EWR Site Die1**

| EWR site | Discipline | Causes and sources | Trend |
|---|---|---|---|
| Die1 | Water quality | Contamination from urban runoff, industrial runoff, and WWTW discharges. Also agricultural runoff impacts in the upper Diep River. | There is an increasing trend in salinity over time along with increases in potassium, total alkalinity and pH. |
| | Geomorphology | Urban impacts, in particular wastewater treatment works. Significant morphological change. | Stable, little room for improvement as so severely transformed. |
| | Riparian vegetation | Animal husbandry of cattle and sheep farming. | Stable, little room for improvement as so severely transformed. |
| | Aquatic macroinvertebrates | Water quality deterioration due to both diffuse runoff from intensively cultivated catchment as well as point source inputs such as effluent from the Malmesbury WWTW and other industrial and commercial operations within the town itself. Some cause of present day deterioration can be attributed to loss of habitat, particularly cobble substrata that have been lost due to sedimentation and vegetation due to grazing and trampling of the natural marginal areas and the abundance of *Phragmites australis*. | Very few aquatic macroinvertebrate taxa remain and all are hardy and unlikely to deteriorate further. |
| | Fish | • Hydrological alteration (reduction in low flows, increase in zero flows)<br>• Loss of connectivity<br>• Introduction of alien invasive fish species | Stable/declining. No fish were recorded during the site visit but it is possible that two indigenous species are still present in this reach, albeit in low numbers. Unless conditions in |

| EWR site | Discipline | Causes and sources | Trend |
|---|---|---|---|
| | | • Poor water quality<br>• Sedimentation<br>• Channelisation of the river<br>• Habitat degradation (loss of cover)<br>• Pollution and litter | the river are improved it is likely that these too will be lost. |

### 4.5.3 New EWR Site Eer1: Eerste River

EWR site Eer1 is located on the Eerste river, up stream of node Biii6 and gauge G2H020 in Stellenbosch (Co-ordinates: -33 56 26.43, 18 53 22.80) (Figure 4.5).

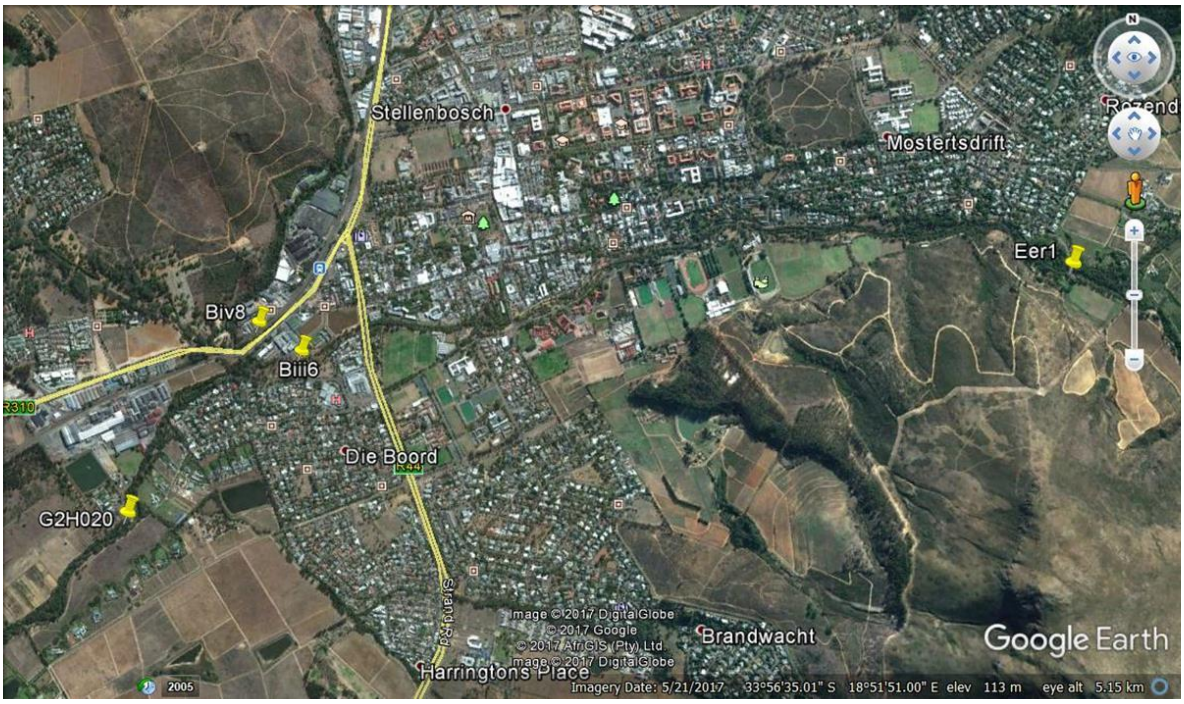


**Figure 4.5 Location of EWR site Eer1 on the Eerste River**

The EWR Site on the Eerste River (Eer1) was in a C category with a PES score of 67% (Table 4.12). The EIS was high and this would normally require management toward an improved ecological category, either a B/C or B but this was considered to be unrealistic. This urban river is channelized through the town of Stellenbosch and the location of the EWR site is situated downstream of the Jonkershoek dam and other abstraction weirs where summer low flows are abstracted by the Stellenbosch municipality. The lowest scoring metric was fish and this may only be improved by removal of these alien fish, which is unlikely with the presence of trout breeding stations in the Jonkershoek Dam. There could be some improvement made by continually removing the exotic woody plants present and this could lift the PES score but this will not improve river condition to a B category. Similarly, since the river is channelized there is little room to reclaim lateral aquatic habitat or floodplain. Since the river is in a good overall condition the most sensible course of action was to set the REC to maintain the current condition of the river at the ecological category C.

**Table 4.12 PES, EIS, and REC for the EWR Site on the Eerste River**

| EWR site | Discipline | Component score | Ecological condition |
|---|---|---|---|
| Eer1 | Water quality | 85 | B |
| | Geomorphology | 64 | C |
| | Riparian vegetation | 67.5 | C |
| | Aquatic macroinvertebrates | 67 | C |
| | Fish | 46 | D |
| | Median PES | 67.00 | C |
| | EIS | 2.25 | HIGH |
| | REC | | C |

The individual components of the ecological importance and sensitivity are given in Table 4.13.

**Table 4.13 EIS for EWR site Eer1**

| EWR site | Category | Component score | Confidence |
|---|---|---|---|
| Eer1 | Biota (riparian and aquatic) | | |
| | Rare and endangered | 2.33 | 1.67 |
| | Unique (endemic) | 2.33 | 1.00 |
| | Intolerant (flow and water quality) | 2.33 | 2.50 |
| | Species richness | 2.33 | 1.83 |
| | Habitat (riparian and aquatic) | | |
| | Diversity of types | 2.33 | 2.33 |
| | Refugia | 1.67 | 3.00 |
| | Sensitivity to flow changes | 2.00 | 2.33 |
| | Sensitivity to flow related water quality changes | 2.00 | 2.33 |
| | Migration corridors | 2.33 | 1.67 |
| | Conservation importance | | 1.67 |
| | Median of scores | | 2.08 |
| | EISC | | HIGH |

The likely causes and sources of present day conditions and future trends are given in Table 4.14.

**Table 4.14 Causes and sources of present day condition and projected trends for EWR Site Eer1**

| EWR site | Discipline | Causes and sources | Trend |
|---|---|---|---|
| Eer1 | Water quality | Urban runoff in built-up area, some agricultural impacts upstream of Stellenbosch, largely natural in headwaters. | Upstream of the Stellenbosch in the Jonkershoek valley there is a slight increase in salinity over time even though the quality is still in a very good state. |
| | Geomorphology | Upstream impacts include the Jonkershoek Dam, cultivation and agriculture. Local impacts include a weir and gabion structures on banks. | Stable, little room for improvement as river channelized. |
| | Riparian vegetation | Wine grape farming, residential and urban development. | Stable, provided exotics are cleared regularly. |

| EWR site | Discipline | Causes and sources | Trend |
|---|---|---|---|
| | Aquatic macroinvertebrates | The main cause of loss of taxa at this site is due to habitat loss, particularly those associated with moderate and fast flowing conditions due to the presence of the in channel dam upstream. Some impact can also be attributed to deterioration in water quality associated with diffuse runoff from vineyards in the catchment. | It is likely that this system will continue to deteriorate as flow related impacts will be exacerbated by drought conditions. |
| | Fish | • Hydrological alteration (reduction in low flows, increase in zero flows)<br>• Loss of connectivity<br>• Introduction of alien invasive fish species<br>• Habitat degradation (loss of cover)<br>• Pollution and litter | Stable. One indigenous, one translocated and one invasive alien fish species was recorded during the site visit. It is likely that one additional indigenous species is still present in this reach, albeit in low numbers. Water quality remains good although flows have been impacted severely. |

### 4.5.4 New EWR Site Lou1: Lourens River

EWR site Lou1 is located on the Lourens River downstream of the N2 crossing and upstream of node Nvii15 and gauge G2H044 (Co-ordinates: -34 05 41.18, 18 50 08.83) (Figure 4.6).


**Figure 4.6 EWR site Lou1, situated d/s of the N2 and u/s of node Nvii15 and gauge G2H044**

The new EWR site on the Lourens River (Lou1) was in a D category with a PES score of 42.5% (Table 4.15). The EIS was moderate and the REC was set to maintain the current condition of the river in a D category. The river is channelized through the town of Somerset West and there is little room to reclaim lateral aquatic habitat of floodplain. Some improvement in overall condition could be made by clearing exotic woody and non-woody plants from the riparian area but this is unlikely to increase the condition out of its current D category.

**Table 4.15 PES, EIS, and REC for the EWR Site on the Lourens River**

| EWR site | Discipline | Component score | Ecological condition |
|---|---|---|---|
| Lou1 | Water quality | 85 | B |
| | Geomorphology | 55 | D |
| | Riparian vegetation | 42.5 | D |
| | Aquatic macroinvertebrates | 42 | D |
| | Fish | 28 | E |
| | Median PES | 42.50 | D |
| | EIS | 2.25 | MODERATE |
| | REC | | D |

The individual components of the ecological importance and sensitivity are given in Table 4.16.

**Table 4.16 EIS for EWR site Lou1**

| EWR site | Category | Component score | Confidence |
|---|---|---|---|
| Lou1 | Biota (riparian and aquatic) | | |
| | Rare and endangered | 2.33 | 1.33 |
| | Unique (endemic) | 2.33 | 0.67 |
| | Intolerant (flow and water quality) | 2.33 | 2.00 |
| | Species richness | 2.33 | 1.00 |
| | Habitat (riparian and aquatic) | | |
| | Diversity of types | 2.33 | 2.17 |
| | Refugia | 1.67 | 2.67 |
| | Sensitivity to flow changes | 2.00 | 2.33 |
| | Sensitivity to flow related water quality changes | 2.00 | 2.67 |
| | Migration corridors | 2.33 | 2.00 |
| | Conservation importance | | 1.33 |
| | Median of scores | | 2.00 |
| | EISC | | MODERATE |

The likely causes and sources of present day conditions and future trends are given in Table 4.17.

**Table 4.17 Causes and sources of present day condition and projected trends for EWR Site Lou1**

| EWR site | Discipline | Causes and sources | Trend |
|---|---|---|---|
| Lou1 | Water quality | Agricultural return flows in headwaters, urban and light industrial runoff in middle and lower reaches. | The long term trend in salinity is mostly stable although a strong increasing trend is evident in recent years. |
| | Geomorphology | Steepening slope and urban impacts. Changes to channel morphology. | Stable, little room for improvement as river channelized. |
| | Riparian vegetation | Wine grape farming, residential and urban development. | Stable, provided exotics are cleared regularly. |
| | Aquatic macroinvertebrates | Channelisation and thus loss of habitat diversity at this site is the likely cause of deterioration in | These impacts are not flow related and thus, unless agricultural activities or |

| EWR site | Discipline | Causes and sources | Trend |
|---|---|---|---|
| | | the aquatic macroinvertebrate community. Also water quality impacts from upstream agricultural activities as well as inputs of poor quality storm water from the residential suburbs of Somerset West have impacted this community. | unmitigated urban development takes place within this catchment, the condition is unlikely to change from its current state. |
| | Fish | • Hydrological alteration (reduction in low flows, increase in zero flows)<br>• Loss of connectivity<br>• Introduction of alien invasive fish species<br>• Poor water quality<br>• Sedimentation<br>• Channelisation of the river<br>• Habitat degradation (loss of cover)\\<br>• Pollution and litter | Stable/declining. One alien invasive fish species was recorded during the site visit but it is possible that some indigenous species are still present in this reach, albeit in low numbers. Unless conditions in the river are improved it is likely that these too will be lost. |

## 4.6 Preliminary Ecological Water Requirements for River Nodes

Preliminary Ecological Water Requirements (EWRs) were developed for the 45 nodes identified in the study area as described above and are given in Table 4.18. The following information is provided:

- the natural mean annual runoff (nMAR) (million $m^3/a$) is provided per node
- flows required to maintain the Baseline 2014 Ecological Condition (EC) is provided per node, as a percentage of the nMAR and the annual total EWR (million $m^3/a$)
- where the EC is an E-category, flows are provided for the minimum allowed D-category
- nodes calibrated using the same EWR data are colour coded.

In the table below, reading from left to right, the IUA in which the node is located if listed first, followed by the node number and the sub-quaternary code that relates to the biophysical data gathered during the PES/EIS updates. Then the EWR column states what EWR site has been used to extrapolate the ecological water requirements, followed by a descriptive comment about the site and then the river name, The coordinates are given next and this is followed by the quaternary code, a code for the Ecoregion Level 1, Hydrological Index and Geozone, and then the Ecological Importance and Sensitivity.

This is followed finally by the Mean annual runoff, the Ecological category from the 1999 PES data and that of the updated data used as the baseline in this study, either that from the PES/EIS 2014 or updated during this study in 2017, and finally the % of the mean annual runoff assigned as the EWR and the mean annual runoff volume for this.

It is worth noting that there are a few differences between the PES in 1999 and in 2014 shown. It is not possible to do a direct comparison as the two studies, used slightly different methodologies for both the analysis of condition and also the way in which the data is reported. There are however a few examples of where there has been a significant change in status (i.e. more than one category change) and this is largely as a result of the removal of invasive alien plants in areas such as upstream of the Berg River dam which was done as part of the construction of the dam and has for example resulted in a significant improvement in the condition at node Bviii13 (Guage u/s Berg River dam) and similar for Bvii16 on the Leeu River.

**Table 4.18 Nodes at which DRAFT EWRs have been calculated in the Study Area**

| IUA | # | SQ Code | NODE | EWR | COMMENT | RIVER | LONG | LATI | QUAT | ER | HI | GZ | EIS | nMAR million m$^3$/a | EC 1999 | EC 2014/17 | EWR % | EWR MAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **G1 Catchment** | | | | | | | | | | | | | | | | | | |
| D8 | 1 | G10A-09199 | Bvii13 | No | Gauge u/s Berg river dam, 100% MAR | Berg | 19.0732 | -33.9552 | G10A | CFM | 1 | UF | VH | 84.5 | D | A | 100 | 84.5 |
| D8 | 2 | G10A-09172 | Bviii1 | Berg 1 | D/s of Berg River dam at EWR 1 – C | Berg | 19.0526 | -33.8965 | G10A | SCB | 1 | UF | H | 141.7 | D | C | 31.1 | 44.0 |
| D8 | 3 | G10A-09153 | Biv5 | WCWET | U/s of confluence with Berg | Franschhoek | 19.0455 | -33.8812 | G10A | SCB | 1 | UF | H | 34.9 | D | D | 15.2 | 5.3 |
| D8 | 4 | G10B-09136 | Biii2 | WCWET | U/s of confluence with Berg | Wemmershoek | 19.0303 | -33.8766 | G10B | SCB | 1 | UF | VH | 85.6 | D | D | 14.6 | 12.5 |
| D8 | 5 | G10C-09145 | Bvii14 | WCWET | Gauge | Dwars | 18.9919 | -33.8511 | G10C | SCB | 1 | UF | VH | 43.7 | D | C | 22.4 | 9.8 |
| D8 | 6 | G10C-09028 | Bvii2 | Ssupp | Berg Water Project (BWP) pump station area | Berg | 18.9882 | -33.8414 | G10C | SCB | 1 | LF | H | 356.0 | D | D | 13.5 | 4.7 |
| D8 | 7 | G10D-08957 | Biii3 | Berg 3 | At gauging weir G1H020 | Berg | 18.9743 | -33.7076 | G10C | SCB | 1 | LF | H | 418.1 | D | E | 22.1 | 92.2 |
| D9 | 8 | G10D-08928 | Bviii11 | Berg 7 | At EWR 7 u/s of confluence with Kromme - C | Pombers | 19.0862 | -33.6217 | G10C | SCB | 1 | UF | H | 1.51 | D | D | 21.8 | 0.33 |
| D9 | 9 | G10D-08928 | Bvii3 | Berg 6 | North of Wellington, G1H037, d/s EWR 6 - D | Kromme | 19.0097 | -33.6354 | G10D | SCB | 1 | UF | H | 18.2 | D | D | 14.2 | 2.6 |
| D9 | 10 | G10D-08893 | Bvii10 | Berg 3 | D/s of confluence Kromme, at gauging weir G1H015 | Berg | 18.9766 | -33.6271 | G10D | SCB | 1 | LF | H | 461.6 | D | D | 22.1 | 101.8 |
| D9 | 11 | G10D-08819 | Bvii15 | WCWET | Gauge | Doring | 18.9326 | -33.539 | G10D | SCB | 1 | LF | VH | 3.8 | D | D | 14.4 | 0.6 |
| D9 | 12 | G10D-08803 | Bvii4 | WCWET | At gauging weir G1H041 | Kompanjies | 18.9781 | -33.4792 | G10D | SCB | 1 | LF | H | 24.8 | D | D | 13.9 | 3.5 |
| D9 | 13 | G10F-08726 | Bvii5 | Berg 3 | At gauging weir G1H036 and u/s of EWR 3 - C/D | Berg | 18.9569 | -33.4350 | G10D | SCB | 1 | L | H | 534.3 | D | D | 33.2 | 177.4 |
| B4 | 14 | G10F-08669 | Bvii11 | VAugS | U/s of Voëlvlei canal | Berg | 18.9871 | -33.3340 | G10F | SCB | 1 | L | H | 557.0 | D | D | 20.7 | 115.1 |
| C5 | 15 | G10F-08505 | Biii4 | WCWET | At gauging weir G1H008 | Klein Berg | 19.0743 | -33.3115 | G10E | SCB | 1 | LF | VH | 84.2 | D | C | 22.2 | 18.7 |
| B4 | 16 | G10F-08505 | Biv3 | WCWET | U/s of confluence with Berg | Klein-Berg | 18.9562 | -33.2150 | G10J | SCB | 1 | LF | VH | 96.8 | D | D | 13.9 | 14.4 |
| B4 | 17 | G10J-08520 | Biv1 | Berg 4 | U/s of confluence Klein-Berg, d/s Voëlvlei canal | Berg | 18.9503 | -33.2147 | G10J | SCB | 1 | L | M | 679.0 | D | D | 20.7 | 140.3 |
| B4 | 18 | G10J-08464 | Bvii16 | No | Gauge, 100% MAR | Leeu | 19.0511 | -33.1561 | G10J | SCB | 1 | UF | VH | 21.5 | D | A | 100 | 21.5 |
| C5 | 19 | G10G-08382 | Bi1 | No | At gauging weir G1H028, pristine wilderness 100% | Vier-en-Twintig | 19.0608 | -33.1339 | G10G | SCB | 1 | T | VH | 125 | B | A | 100 | 125 |
| B4 | 20 | G10J-08433 | Biv4 | WCWET | U/s of confluence with Berg | Vier-en-twintig | 18.9418 | -33.1900 | G10J | SCB | 1 | LF | H | 165.5 | D | D | 14.6 | 24.1 |
| B4 | 21 | G10J-08487 | Bvii17 | WCWET | Gauge | Sandspruit | 18.8927 | -33.1611 | G10J | SCB | 1 | LF | M | 9.2 | D | C | 20.8 | 1.9 |
| B4 | 22 | G10J-08414 | Bvii6 | Berg 4 | D/s of EWR 4, above Misverstand Dam G1H013 - D | Berg | 18.8619 | -33.1328 | G10J | SCB | 1 | L | H | 860.7 | D | D | 20.7 | 177.9 |
| B4 | 23 | G10J-08366 | Biii5 | WCWET | At gauging weir G1H035 | Matjies | 18.8326 | -33.0473 | G10J | SCB | 1 | LF | M | 32.9 | D | D | 12.9 | 4.2 |
| B4 | 24 | G10J-08319 | Bvii8 | Berg 4 | U/s Misverstand reservoir, d/s confluence with Matjies | Berg | 18.8148 | -33.0522 | G10J | SCB | 1 | L | M | 896.4 | D | D | 20.7 | 185.2 |
| B4 | 25 | G10J-08322 | Bvii18 | WCWET | Gauge | Moreesburg Spruit | 18.7637 | -33.0670 | G10J | SCB | 1 | LF | M | 3.3 | D | E | 14.0 | 0.5 |
| B4 | 26 | G10K-08197 | Bvii12 | Berg 5 | 3.5 km d/s of Misverstand reservoir, at EWR 5 - D | Berg | 18.7792 | -32.9960 | G10K | SCB | 1 | L | H | 901.8 | C | D | 24.1 | 217.5 |
| B4 | 27 | G10L-08287 | Bii1 | WCDRY | U/s of confluence with Berg | Sout | 18.3805 | -32.9584 | G10L | SCB | 2 | L | M | 13.7 | D | D | 12.6 | 1.7 |
| B4 | 28 | G10K-08152 | Biv2 | Berg 5 | U/s of confluence with Sout, head of estuary | Berg | 18.3808 | -32.9580 | G10L | SCB | 1 | L | H | 924.5 | D | D | 24.1 | 223.0 |
| **G2 Catchment** | | | | | | | | | | | | | | | | | | |
| A3 | 30 | G21A-08690 | Bviii3 | WCDRY | Inflow to Yzerfontein salt pan | - | 18.1821 | -33.3303 | G21A | SCB | 2 | UF | H | 1.0 | C | D | 14.6 | 0.1 |
| A3 | 31 | G21B-08896 | Bviii10 | WCWET | Cumulative at outlet G21B | Sout | 18.4544 | -33.7104 | G21B | SCB | 2 | LF | H | 6.2 | D | E | 16.4 | 1.0 |
| D10 | 32 | G21D-08761 | Bv1 | Die1# | D/s of Malmesbury | Diep | 18.7383 | -33.4643 | G21D | SCB | 1 | LF | M | 13.7 | D | E | 13.9 | 1.91 |
| D10 | 33 | G21D-08825 | Bviii4 | Die1$ | U/s of confluence with Diep | Swart | 18.6372 | -33.5869 | G21D | SCB | 1 | LF | H | 2.3 | D | D | 25 | 0.6 |
| D10 | 34 | G21D-08906 | Biv6 | Die1$ | | Diep | 18.6085 | -33.6813 | G21D | SCB | 1 | LF | H | 9.3 | D | D | 25 | 2.4 |
| D10 | 35 | G21E-08962 | Biv7 | Die1$ | | Mosselbank | 18.6159 | -33.6799 | G21E | SCB | 1 | LF | H | 30.3 | D | D | 25 | 7.6 |
| E12 | 37 | G22C-09142 | Bviii8 | WCWET | U/s of confluence Black | Elsieskraal | 18.5018 | -33.9849 | G22C | SCB | 1 | L | M | 23.2 | E | F | 15.4 | 3.6 |

| IUA | # | SQ Code | NODE | EWR | COMMENT | RIVER | LONG | LATI | QUAT | ER | HI | GZ | EIS | nMAR million m³/a | EC 1999 | EC 2014/17 | EWR % | EWR MAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E12 | 38 | G22D-09294 | Bvii7 | Sand estuary$ | At EWR site | Keysers | 18.4621 | -34.0798 | G22D | CFM | 1 | LF | H | 4.5 | EF | D | 71 | 3.2 |
| E11 | 39 | G22B-09261 | Bviii6 | Hout Bay estuary$ | At EWR site | Hout Bay | 18.3561 | -34.0416 | G22B | CFM | 1 | LF | H | 17.2 | C | D | 50 | 8.6 |
| E11 | 40 | G22A-09324 | Bvii20 | No | Town, 100% MAR | Silvermine | 18.4245 | -34.1250 | G22A | CFM | 1 | UF | U | 3.5 | C | C | 100 | 3.5 |
| **D6** | **41** | **G22F-09205** | **Biii6** | **Eer1#** | **At Lanzerac draw bridge** | **Jonkershoek** | **18.8483** | **-33.9249** | **G22F** | **SCB** | **1** | **UF** | **H** | **36.6** | **C** | **C** | **22.6** | **8.2** |
| D6 | 42 | G22G-09120 | Biv8 | Eer1$ | | Klippies | 18.8461 | -33.9415 | G22G | SCB | 1 | LF | H | 30.3 | D | D | 61 | 18.5 |
| D6 | 43 | G22E-09207 | Biv9 | Eer1$ | U/s confluence Eerste | Kuils | 18.7319 | -34.0533 | G22H | SCB | 1 | LF | H | 1.0 | D | E | 61 | 0.61 |
| **D7** | **44** | **G22J-09266** | **Bvii21** | **Lou1#$** | **D/s of the N2** | **Lourens** | **18.8257** | **-34.0987** | **G22J** | **SCB** | **1** | **UF** | **M** | **70.0** | **D** | **D** | **14.7** | **8.5** |
| D7 | 45 | G22K-09315 | Bviii9 | Sir Lowry's Pass estuary$ | Cumulative at outlet G22K | Sir Lowrys Pass* | 18.8721 | -34.1504 | G22K | SCB | 1 | UF | H | 48.7 | D | C | 24.4 | 11.8 |
| **D7** | **46** | **G40A-09346** | **Bvii22** | **Berg 8** | **At EWR 8, u/s of estuary mouth - B/C** | **Steenbras** | **18.8516** | **-34.1876** | **G40A** | **CFM** | **1** | **MS** | **VH** | **34.8** | **C** | **C** | **13.5** | **4.7** |

*The condition scores of the Jonkershoek, Lourens and Sir Lowry's Pass Rivers assessed in February 2017 (see Appendix K) are higher than those previously determined (DWA 2014) and are all currently in ecological condition C.

$ The preliminary EWR requirements for these nodes will be superseded by the flow requirements for the associated estuary. These will therefore be updated after the scenario analysis phase by routing the required estuary flow requirements upstream to these river nodes.

# Established as an EWR site in this study and assessed in July 2017

With IUA = Integrated Unit of Analysis; SQ = Sub-quaternary catchment; EWR = Ecological Water Requirements; Long = Longitude; Lati =Latitude; Quat = Quaternary catchment; ER = Eco Region HI = Hydrological Indix ; GZ = Geo Zone; nMAR =; EC 1999 = Ecological Condition 1999; EC 2014/17: Ecological Condition 2014/17

Note: Reserve sites in red font

## 4.7 Recommend Ecological Categories (REC) for River Nodes

The ecological condition of rivers in the Berg River Catchment was collated and synthesized during the PES/EIS project (DWS 2014) along with empirical data collected at about 41 sites, dealing with river condition, riparian vegetation and aquatic macroinvertebrates. These data were only collected for rivers in primary drainage region G1, therefore the same approach was undertaken for this study in primary drainage region G2 and used to calculate the present-day ecological condition (February 2017) in order to cross-check earlier condition calculations for G2. These assessments are presented in Appendix B.

The PES/EIS project (DWS 2014) also calculated provisional RECs for all sub-quaternary rivers in primary drainage basins G1 and G2. These, along with the PES and REC calculated for each river Reserve study site are listed below in Table 4.19, as are those for the estuaries.

It can be seen that in most cases, the provisional RECs for the Berg River, its tributaries and the coastal rivers in primary drainage area G2 surpass the present ecological condition (EC) and in most cases will be unachievable due to limited additional water availability and mostly due to the ecological condition also being driven by non-flow related factors, such as poor water quality, the presence of exotic woody vegetation, alien fish and poor habitat conditions from physical disturbances related to agricultural and urban influences of various sorts. This is not a problem for the construction of the REC scenario as the scenario will be constructed to achieve the REC at each EWR site as a starting point, and this will then require adjusting the nodes up and downstream of these EWR site (nodes) in order to balance flows to achieve these. **This means, in practical terms, that these desktop RECs at all nodes, other than the Reserve sites, will be over-ridden by what is practically and realistically achievable, taking current day flows, water quality and non-flow related factors into account on a node by node basis.**

Reserve studies (existing and new) provided estimates of present ecological status (PES) for all of the significant estuaries in the study area along with estimates for 11 of the micro-estuaries in the study area (i.e. all the estuaries included in the 2012 National Biodiversity Assessment).

**Table 4.19 The EcoClassification results for quantification of EWRs**

| Associated Reserve Site or EWR | SQ code | Node | RIVER | QUAT | EC | REC |
|---|---|---|---|---|---|---|
| **G1 Catchment** | | | | | | |
| N/A | G10A-09199 | Bvii13 | Berg | G10A | A | A* |
| **Berg 1** | **G10A-09172** | **Bviii1** | **Berg** | **G10A** | **C** | **C** |
| WCWET | G10A-09153 | Biv5 | Franschhoek | G10A | D | B* |
| WCWET | G10B-09136 | Biii2 | Wemmershoek | G10B | D | A* |
| WCWET | G10C-09145 | Bvii14 | Dwars | G10C | C | A* |
| Ssupp | G10C-09028 | Bvii2 | Berg | G10C | D | D* |
| Berg 3 | G10D-08957 | Biii3 | Berg | G10C | E | B* |
| **Berg 7** | **G10D-08928** | **Bviii11** | **Pombers** | **G10C** | **D** | **D** |
| **Berg 6** | **G10D-08928** | **Bvii3** | **Kromme** | **G10D** | **D** | **C** |
| Berg 3 | G10D-08893 | Bvii10 | Berg | G10D | D | B* |
| WCWET | G10D-08819 | Bvii15 | Doring | G10D | D | A* |
| WCWET | G10D-08803 | Bvii4 | Kompanjies | G10D | D | B* |
| **Berg 3** | **G10F-08726** | **Bvii5** | **Berg** | **G10D** | **D** | **D** |
| VAugS | G10F-08669 | Bvii11 | Berg | G10F | D | D* |

| Associated Reserve Site or EWR | SQ code | Node | RIVER | QUAT | EC | REC |
|---|---|---|---|---|---|---|
| WCWET | G10F-08505 | Biii4 | Klein Berg | G10E | C | A* |
| WCWET | G10F-08505 | Biv3 | Klein-Berg | G10J | D | A* |
| Berg 4 | G10J-08520 | Biv1 | Berg | G10J | D | B* |
| N/A | G10J-08464 | Bvii16 | Leeu | G10J | A | A* |
| N/A | G10G-08382 | Bi1 | Vier-en-Twintig | G10G | A | A* |
| WCWET | G10J-08433 | Biv4 | Vier-en-Twintig | G10J | D | B* |
| WCWET | G10J-08487 | Bvii17 | Sandspruit | G10J | C | C* |
| **Berg 4** | **G10J-08414** | **Bvii6** | **Berg** | **G10J** | **D** | **D** |
| WCWET | G10J-08366 | Biii5 | Matjies | G10J | D | B* |
| Berg 4 | G10J-08319 | Bvii8 | Berg | G10J | D | C* |
| WCWET | G10J-08322 | Bvii18 | Morreesburg Spruit | G10J | E | C* |
| **Berg 5** | **G10K-08197** | **Bvii12** | **Berg** | **G10K** | **D** | **D** |
| WCDRY | G10L-08287 | Bii1 | Sout | G10L | D | C* |
| Berg 5 | G10K-08152 | Biv2 | Berg | G10L | D | B* |
| **N/A** | **G10M** | **Bxi1** | **Berg (Groot) Estuary** | **G10M** | **D** | **C** |
| **N/A** | **G10M** | **Bxi3** | **Langebaan Estuary** | **G10M** | **B** | **A** |
| **G2 Catchment** | | | | | | |
| WCDRY | G21A-08690 | Bviii3 | - | G21A | D | B* |
| N/A | N/A | Bxi12 | Modder Estuary | G21A | C | C* |
| WCWET | G21B-08896 | Bviii10 | Sout | G21B | E | B* |
| WCWET | G21D-08761 | Bv1 | Diep | G21D | D | B* |
| WCDRY | G21D-08825 | Bviii4 | Swart | G21D | D | B* |
| WCWET | G21D-08906 | Biv6 | Diep | G21D | D | B* |
| WCWET | G21E-08962 | Biv7 | Mosselbank | G21E | D | B* |
| **N/A** | **G21F** | **Bxi7** | **Rietvlei/Diep Estuary** | **G21F** | **D** | **C** |
| WCWET | G22C-09142 | Bviii8 | Elsieskraal | G22C | F | C* |
| WCWET | G22D-09294 | Bvii7 | Keysers | G22D | D | C* |
| **N/A** | **G22F** | **Bxi9** | **Zandvlei Estuary** | **G22D** | **D** | **C** |
| **N/A** | **G22D** | **Bxi20** | **Zeekoe Estuary** | **G22D** | **E** | **D** |
| WCWET | G22B-09261 | Bviii6 | Hout Bay | G22B | D | B* |
| N/A | G22B | Bxi10 | Hout Bay Estuary | G22B | E | D |
| No | G22A-09324 | Bvii20 | Silvermine | G22A | C | A* |
| N/A | G22A | Bxi11 | Silvermine Estuary | G22A | D | D |
| N/A | G22A | Bxi19 | Elsies Estuary | G22A | E | D |
| N/A | G22A | Bxi18 | Buffels Wes Estuary | G22A | F | D |

| Associated Reserve Site or EWR | SQ code | Node | RIVER | QUAT | EC | REC |
|---|---|---|---|---|---|---|
| N/A | G22A | Bxi17 | Krom Estuary | G22A | A | A |
| N/A | G22A | Bxi16 | Schuster Estuary | G22A | A | A |
| N/A | G22A | Bxi15 | Bokramspruit Estuary | G22A | C | C |
| **N/A** | **G22A** | **Bxi14** | **Wildevoëlvlei Estuary** | **G22A** | **C** | **C** |
| WCWET | G22F-09205 | Biii6 | Jonkershoek | G22F | C | B* |
| WCWET | G22G-09120 | Biv8 | Klippies | G22G | D | B* |
| WCWET | G22E-09207 | Biv9 | Kuils | G22H | E | B* |
| WCWET | G22J-09266 | Bvii21 | Lourens | G22J | C | B* |
| **No** | **G22J** | **Bxi4** | **Lourens Estuary** | **G22J** | **D** | **D** |
| WCWET | G22K-09315 | Bviii9 | Sir Lowrys Pass | G22K | C | B* |
| No | G22K | Bxi5 | Sir Lowrys Pass Estuary | G22K | E | D* |
| **Berg 8** | **G40A-09346** | **Bvii22** | **Steenbras** | **G40A** | **BC** | **BC** |
| N/A | G40A | Bxi6 | Steenbras Estuary | G40A | B | B* |

With EWR = Ecological Water Requirements; SQ = Sub-quaternary catchment; Quat = Quaternary catchment; EC = Ecological Category; REC = Recommended Ecological Category. * Source: DWS, 2014.
Note: Reserve sites in red; blue highlights estuary nodes

## 4.8 Ecological Water Requirements for Estuaries

### 4.8.1 Conceptual framework

Ecological water requirements for estuaries are described in terms of the quantity and quality of flows required to meet defined health thresholds. The way in which estuary health is determined is described below, followed by an explanation of what determines how sensitive estuaries are to freshwater inflows, and our conceptual understanding of the mathematical relationships we can expect between inflows and health.

#### 4.8.1.1 Ecological condition of estuaries

Various approaches have been used in the past to assess the health of estuaries in South Africa. The first broad scale assessment of estuary health in South Africa was attempted by Heydorn & Tinley who reviewed the condition of the estuaries of the former Cape Province (from the Orange to the Great Kei). This was followed by a national assessment of the condition of South African estuaries (Heydorn 1986). Various other attempts have been made since this including the work by Ramm (1988, 1990), Cooper *et al.* (1994), CERM (1996), Coetzee *et al.* (1997), Van Driel (1998), Whitfield (2000), and Harrison & Whitfield (2004). The above attempts all ultimately paved the way towards the formulation of a robust health index that is now routinely used in RDM processes for estuaries – the Estuary Health Index (EHI). The first version of the EHI was developed in 1999 after a series of workshops with members of the Consortium for Estuary Research and Management (Turpie 1999) as a component of the methodology for determining the freshwater Reserve for estuaries (DWAF 1999). Since then this method has been applied in RDM studies of a large number of estuaries in South Africa, during which time the various aspects of the methods have been fine-tuned. After a second round of workshops and review, a second version of the method was developed in 2004 (officially published in 2008), while a third round of review and workshops by the

Consortium for Estuary Research and Management led to the version of the method that is currently in use – the Estuary Health Index or EHI (Turpie *et al*. 2012).

Essentially, this assesses the Present Ecological Status (PES) of an estuary using a simple scale of A to F (Table 4.20). The index has three tiers, with the basic measures grouped, using weighted means or minima, into four abiotic and five biotic measures, the weighted averages of which form overall abiotic and biotic scores. These are then equally weighted to compute the overall Estuary Health Score (Figure 4.7). The computation of the scores is summarized in Table 4.21. In all cases the scoring is based on available data (including data that might have been collected specifically for the study) for describing present day, and historical data (if available), models or expert opinion to describe the estimated reference condition.

The Reference Condition of an estuary refers to the ecological status that it would have had:

- before any anthropogenic changes to freshwater inputs
- before any human development in the catchment or within the estuary, and
- before any mouth manipulation practices (e.g. artificial breaching)

Once the Reference Condition has been described for all the abiotic and biotic components, the Estuary Health Index (EHI) is applied, which entails estimating the degree to which features of the PES (e.g. inflows, fish species richness etc.) resemble those under the Reference Condition. To account for cyclical variability, the mean conditions during pristine conditions are compared with the mean conditions at present. All scores involve a min-mean scoring system in which the weighted mean of the scores is combined with the minimum score. Scores are done quantitatively as far as possible, and using a similarity index wherever appropriate, in order to maximise comparability and standardise the procedure as far as possible.

**Table 4.20 The six categories for indicating the Present Ecological Status of an estuary using the** Estuarine Health Index (EHI). Categories A to D are within the acceptable range, whereas E **and F are not (Kleynhans 1996, MacKay 1999).**

| EC | DESCRIPTION |
|---|---|
| **A** | **Unmodified, or approximates natural condition**; *the natural abiotic template should not be modified. The characteristics of the resource should be determined by modifying natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.* |
| **B** | **Largely natural with few modifications**. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. *Only a small risk of modifying the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.* |
| **C** | **Moderately modified**. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. *A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.* |
| **D** | **Largely modified**. A large loss of natural habitat, biota and basic ecosystem functions has occurred. *Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk to the well-being and survival of intolerant biota depending on (the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.* |
| **E** | **Seriously modified**. The loss of natural habitat, biota and basic ecosystem functions is extensive |
| **F** | **Critically modified**. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible |

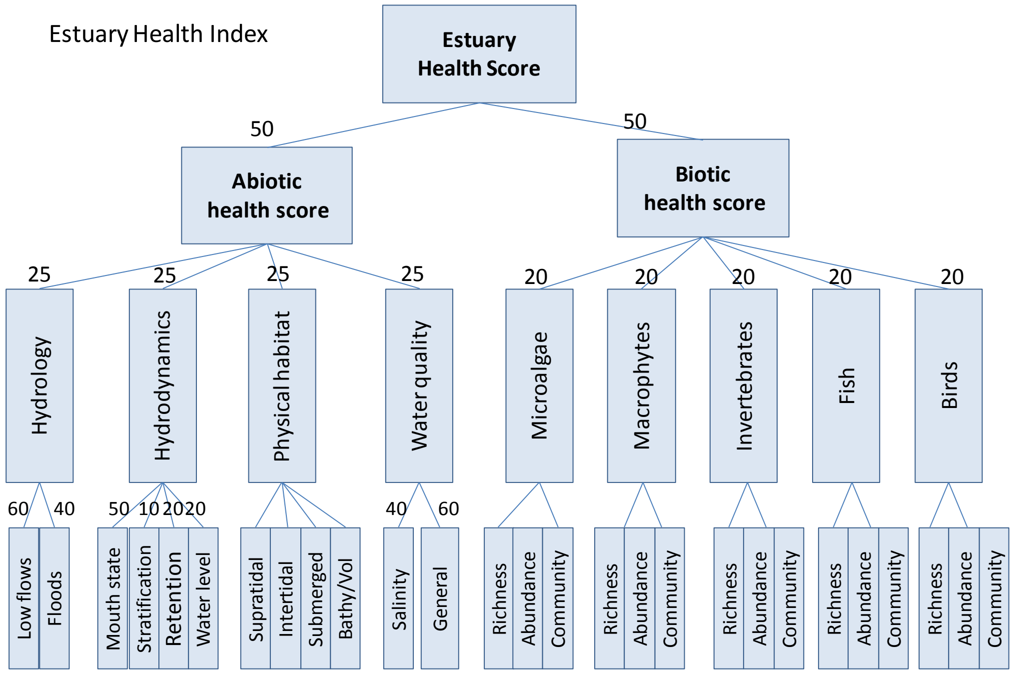


**Figure 4.7 Structure of the Estuary Health Index (Source: Turpie et al. 2012). Weightings are equal unless otherwise shown.**

**Table 4.21 Summary description of the measures used in scoring the 1st tier variables that make up the 2nd and 3rd tier scores.**

| 2nd Tier | 1st Tier | Measures used in scoring |
|---|---|---|
| Hydrology | Low flows | Similarity in the amount of flow during a defined low flow period or simply % natural MAR (data poor). |
| | Floods | Similarity in the magnitude and frequency of floods. Usually summarized as the average volume of the highest 2% of average monthly flows, based on the simulated monthly flows described above. |
| Hydrodynamics | Abiotic/mouth states | Similarity in terms of proportion of time the estuary is in different states. e.g closed, open freshwater dominated. |
| | Stratification | Similarity in the degree of mixing or stratification in the water column |
| | Retention | Similarity in the duration of water retention in different parts of the estuary |
| | Water level | Similarity in average water levels |
| Physical habitat | Supratidal area | Similarity in supratidal physical habitat |
| | Intertidal area | Similarity in intertidal extent and sediment characteristics |
| | Subtidal/ submerged area | Similarity in subtidal extent and sediment characteristics |
| | Bathymetry/volume | Similarity in channel morphology and estuary volume |
| Water quality | Salinity | Similarity in axial salinity gradient and vertical salinity stratification, based on the amount of time in which different zones of the estuary are within different salinity ranges, or at worst (data poor) considering just average salinity. |
| | General | Similarity among different variables (N & P, suspended solids, dissolved oxygen, toxins), based on a scoring guideline (Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously modified = 20; completely modified = 0). |
| Microalgae, macrophytes, invertebrates, fish and birds | Richness, abundance and community composition | Similarity in estimated average instantaneous species richness, total abundance (biomass or numbers), and community composition, with the latter being based on the estimated abundance of defined subgroups of the biotic component (e.g. waterfowl, waders etc). |

The prevalent or average level of confidence is also described for each of the abiotic and biotic components of the study, for the present and reference state. Confidence categories are usually translated to % certainty using values listed in Table 4.22.

Overall confidence is provided for each component of the Estuary Health Index, and weighted in the same way to obtain overall confidence. The overall confidence level is then converted back to a category (High, medium etc.).

**Table 4.22 Guidelines for describing levels of confidence**

| Degree of confidence | Explanation | Score (~ % certainty) | Range |
|---|---|---|---|
| Very Low | If no data were available for the estuary or similar estuaries (i.e. < 40% certain) | 30 | ≤40 |
| Low | Limited data were available, and estimates could be out by 60% (40%-60 certain of estimate) | 50 | 41 – 60 |
| Medium | If reasonable data were available for the estuary and estimates could be out by 20-60% (i.e. 60% – 80% certain of estimate) | 70 | 61 – 80 |
| High | If good data were available for the estuary and estimates are probably not more than 20% out (i.e. > 80% certain of estimate) | 90 | 81 - 100 |

#### 4.8.1.2 Sensitivity of estuaries to river inflows

All estuaries are sensitive to reductions and changes in river inflow. However, there are certain parameters (primarily physical parameters) that indicate whether an estuary is particularly sensitive to modifications in this regard. Based on current understanding of estuaries, the following are important indicators that could be used towards establishing the extent to which estuaries would be sensitive to modification in inflows:

***Frequency of mouth closure (mostly applicable to temporarily open/closed systems).*** The sensitivity of an estuary mouth to closure can roughly be correlated to the river inflow, particularly during low flow periods, required to keep the mouth open. For many estuaries, especially the smaller ones, the most important factor in keeping the mouth open is river flow, and particularly base flows. In addition to river flow there are also other factors and/or a combination of thereof, that may contribute to an estuary's sensitivity to mouth closure such as:

- ***Size of the estuary***. In general, larger estuaries are less sensitive to mouth closure than smaller estuaries, because of greater tidal flows through the mouth, e.g. Berg. At breaching, larger estuaries also tend to scour deeper mouths due to higher outflows, which generally take longer to close, e.g. Diep. However, when the mouth of a large estuary closes, a substantial amount of water is required to first fill up the estuary before breaching can occur and as a result more river flow is needed to ensure breaching in large estuaries compared to smaller estuaries. Small estuaries are very sensitive to flow reduction as this is the main force keeping the mouth open, once flow decrease below a certain volume the system will close, and remain closed, until such time as flow increase enough to cause a mouth breaching.
- ***Availability of sediment***. In general, the larger the amount of sediment available in the adjacent marine environment, the greater the sensitivity to mouth closure, e.g. Zandvlei. In estuaries where there is not a large amount of sediment available, for example on a rocky coastline or where longshore transport is further offshore, e.g. Steenbras, the system would be less sensitive to flow reductions.
- ***Wave action in the mouth***. Wave action is the most important contributing cause of mouth closure in estuaries. In general, the stronger the wave action in the mouth the greater the sensitivity to mouth closure. Wave conditions in the mouth are influenced by the degree of protection of the mouth, e.g. by a headland, and beach slope. A steep beach slope normally

means that high-energy wave action occurs on the beach at the mouth, resulting in higher suspended sediment load. This type of beach slope is characteristic of the KwaZulu-Natal coastline. The beach slope can also vary from winter to summer due to winter storms. Generally the steeper the slope of a beach, the higher the suspended sediment load in the mouth area, therefore the greater the sensitivity to mouth closure. A mild beach slope means that less energetic wave action occurs at the mouth and a mild beach slope therefore provides a special type of protection against wave action.

Taking the above into account, the degree of sensitivity of a temporarily open/closed estuaries mouth to reduction in flow can broadly be categorized as follows:

| Sensitivity | River inflows |
|---|---|
| High sensitivity to closure | < 2 -10 $m^3/s$ are likely to result in closure |
| Medium sensitivity to closure | 0.5 $m^3/s$ - 2.0 $m^3/s$ are likely to result in closure |
| Low sensitivity to closure | < 0.5 $m^3/s$ are likely to result in closure |

Although mouth closure is normally only factored in during the analyses of temporarily open/closed estuaries, it should be noted that even some permanently open estuaries can close relatively easily if the flows are reduced.

***Volume of mean annual runoff (MAR)***. As a first estimate, the volume of the natural MAR that an estuary receives is probably the most important parameter in judging overall sensitivity to reduced river inflows. It is, however, important to realize that it is not only the amount of river inflow that is important, but also the variability of flows. In general (although there are many exceptions), it can be assumed that the larger the natural MAR of an estuary, the less sensitive it might be to reduced river inflow. Care should be taken in applying this guideline as the local bathymetry of an estuary can cause exceptions.

Sensitivity to reduced river flows versus natural MAR volumes can roughly be categorized as follows:

| Sensitivity to reduced river flows | Natural mar |
|---|---|
| Low sensitivity | > 100 $Mm^3/a$ (large estuaries) |
| Medium sensitivity | 50 $Mm^3/a$ < MAR > 100 $Mm^3/a$ (medium - small estuaries) |
| Higher sensitivity | < 50 $Mm^3/a$ (smaller estuaries). |

***Extent of Saline intrusion (especially relevant to permanently open systems)***. If an estuary is permanently open to the sea, the most important effect of reduced seasonal base flows or extended duration of low flows is an increase in the upstream intrusion of saline water. The variation in salinity distribution gradients in estuaries and the sensitivity to estuaries in this regard, is very difficult to quantify. In general if an estuary is permanently open, its sensitivity to reduction in seasonal base flows during the low flow period is assumed to be very high and, therefore a reduction in river inflow during the low flow period should not be considered. Permanently open estuaries are often less sensitive to reductions in higher flows, e.g. >50 – 100$m^3/s$.

***NOTE:***

*It is important to note, that although the above-mentioned parameters are mainly influenced by seasonal base flows, floods play an important role in the long-term equilibrium of an estuary. Floods are therefore needed for the scouring of accumulated marine and catchment sediment from the system, deepening the mouth and the resetting of the salinity regime in estuaries.*

#### 4.8.1.3 Relationship between freshwater inflows and estuary health

The relationship between freshwater inflows as a percentage of natural Mean Annual Runoff (%MAR) and estuary health is expected to be a logarithmic function in which ecosystem health initially falls off fairly slowly in relation to falling %MAR, but then falls off more rapidly as %MAR tends towards zero (Figure 4.8). This has been borne out by empirical analysis of the health scores used in Reserve determination workshops. With flow = 100% of MAR, the EHI ($EHI_{100}$) is expected to be below 100, because EHI is also influenced by anthropogenic factors other than changes in flow volume, such as changes in nutrient inputs, habitat reclamation and fishing. Thus in most cases, restoring flows to 100% of natural would not be sufficient to restore estuary condition to natural.

In addition, it is expected that the slope of the curve will be steeper (i.e. health will deteriorate more rapidly in response to decreasing flows) for some kinds of estuaries than for others. Thus the slope of the curve reflects sensitivity to freshwater inflows.

In Figure 4.8, it is possible to read off the threshold %MAR above which a hypothetical estuary would be in a D, C, B or A category. In this example, the non-flow influences on estuary health are significant, and for all else equal, it would not be possible to achieve a B or A condition for the estuary by restoring the quantity of inflows alone.

Setting environmental flows requires consideration of both quantity and quality of flows. If anthropogenic impacts on water quality are reduced, then EHI goes up. Thus one can achieve an improvement in EHI through increase in flows, reduced pollution or a combination of both. Figure 4.9 extends the initial conceptual model to show the hypothetical relationship that could be derived if anthropogenic polluting inputs were removed. The EHI for each %MAR would be expected to be higher, but again, the graph would not achieve an EHI of 100 at 100% of flow unless there were no other anthropogenic pressures on the system. The difference between the health at EHI for natural water quality and 100 reflects the degree of non flow-related pressures on the system, and the sensitivity of the system to those pressures.

Comparison of the threshold values shows that the flow thresholds (%MAR) for each EC would vary depending on the degree to which catchment management measures are put in place to reduce pollution. It is important to note that higher ECs are also possible when water pollution issues are eliminated. In this example, the system that could not achieve higher than C category with quantity of flows alone, could reach an A category when both quantity and quality of flows are addressed.

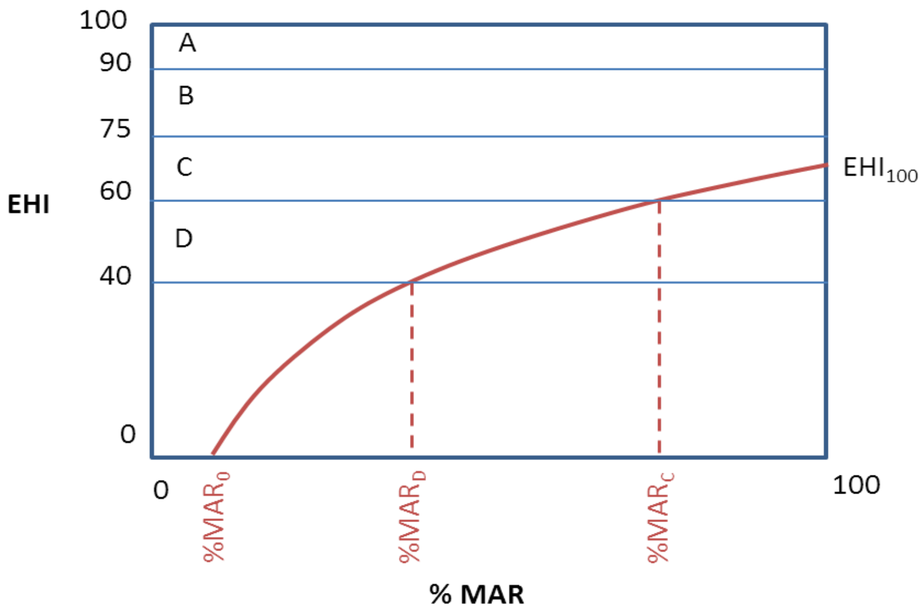


**Figure 4.8 Hypothetical relationships between %MAR and estuary health (EHI) for the (typical) situation where flows are reduced compared to natural (Turpie in prep)**

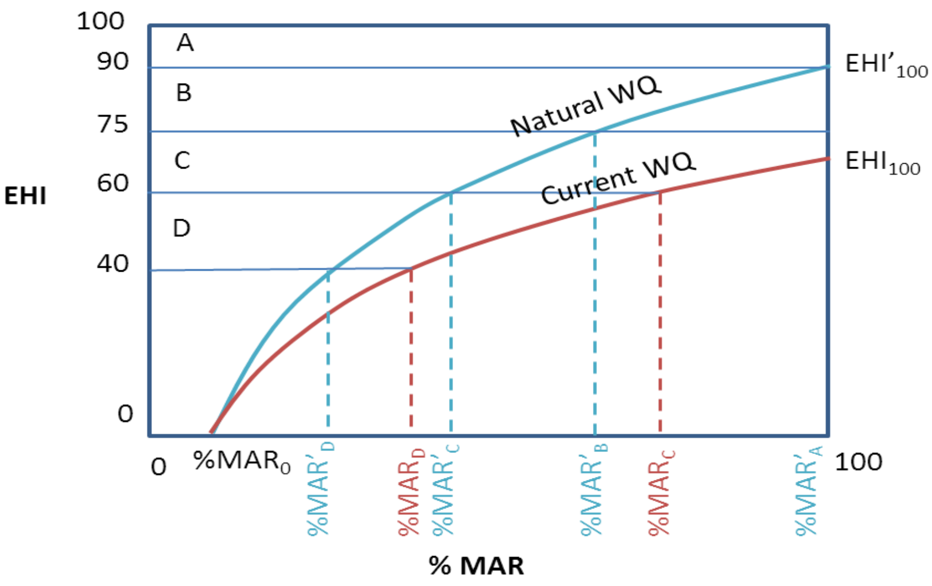


**Figure 4.9 Hypothetical relationships between %MAR and estuary health (EHI) for the (typical) situation where flows are reduced compared to natural, (a) under current non-flow pressures and (b) when anthropogenic impacts on water quality are removed (Turpie in prep)**

The means with which a class threshold should be achieved is essentially an economic problem, depending on the relative costs of fixing pollution problems and those of meeting water supply requirements from alternative sources.

Another dimension which is not depicted here is the temporal distribution of the flows. We recognise that the manner in which MAR is disaggregated into a seasonal flow pattern for a particular estuary can have a profound impact on the health of the system depending on how this is done (i.e. the extent to which dry season and wet season flows have been reduced relative to natural) and also on the type of estuary in question (the seasonal distribution of flow is generally less important for estuarine lake than a permanently open or temporally open-closed system). An examination of monthly flow data for the Present State for estuaries in the Berg WMA (and indeed nationally, Turpie *et al*. in prep.) shows very clearly that the percentage reduction in flows during the dry season is almost without exception greater than that in the wet season. This intuitively makes sense as it is generally during the dry season when additional water is required for irrigation which is one of the major uses for water in a catchment. (Note that this is not always the case for rivers, owing to the fact that river channels are often used as conduits to convey water from a major impoundment upstream to areas downstream where it is required for other purposes.) Again, while we recognise that the precise extent to which flow in each season for a particular system is impacted in any particular scenario should be assessed in an expert workshop for each estuary, we know that this is not practically possible given the number of estuaries and scenarios that need to be evaluated in this study.

### 4.8.2 Data and methods

EWRs of estuaries are determined using scenarios. In most estuary EWR studies, operational scenarios are provided by DWS, together with a description of the hydrology associated with each. These usually represent real planning options. Depending on the range of the operational scenarios provided by DWS, additional scenarios are then designed to expand the range of scenarios in order to fine-tune the understanding between flows and estuary health enough to identify thresholds between different categories of health (A, B, C, D and E). The additional scenarios, termed the Ecological Reserve Scenarios (or Ecological Water Requirement Scenarios), are hypothetical, and may or may not be feasible. They could take the form of a series of hypothetical runoff scenarios with a range of % natural MAR (e.g. 75%, 50% and 25% of natural MAR). However, the number of scenarios analysed is usually subject to a budget constraint, and since the results are unknown until the scenario is analysed, the outcomes often do not cover the full range of health categories.

There are two significant estuaries located in the Berg River Catchment – the Berg estuary and Langebaan Lagoon. A Reserve Determination study was completed for the Berg Estuary in 2010 (DWA 2010) and data from this study was used to determine flows corresponding to class thresholds for this system. No RDM study had been completed for Langebaan Lagoon before this study was commissioned, so this was undertaken as part of this study (Appendix D). Langebaan Lagoon is in itself a very interesting case, owing to the fact that this system receives virtually all its freshwater input from groundwater rather than surface water runoff. The volume of freshwater entering the system is extremely small relative to the size of the system and also relative to the size of the tidal prism which is larger than a "normal" estuary due to the size of its mouth and greater average depth. In this case, reduction in freshwater inflow does not cause the health of the system to drop below a C category, owing to the fact that only a small portion (albeit an important one) of the system (viz. the salt marshes at the head of the system) are dependent on freshwater inflow.

Reserve studies had not previously been completed for any of the estuaries in the G2 catchments. This was identified as a critical requirement for this study and so reserve (RDM) studies were carried out for all six significant estuaries in this area as part of this study. The estuaries for which RDM studies were undertaken include the Rietvlei/Diep, Wildevoëlvlei, Sand, Zeekoe, Eerste, and Lourens estuaries. Detailed reports for these individual studies are presented in Appendices C - I. Data included in these reports consists of estimates of % MAR and present ecological status (PES) for each system. Health assessments for each system entailed scoring the present day situation (PES) using the Estuary Health Index (EHI) as well as under a range of alternate scenarios in accordance with the methodology described in Section 4.8.2.

In most cases flow scenarios evaluated in EWR studies for the Berg River and G2 catchments did not cross all of the class thresholds from A/B to D/E. To get around this problem, a set of models was developed using scenario results of EWR studies, based on the conceptual model described above. This allowed us to interpolate and extrapolate the results of previous studies in order to identify EWRs at EC thresholds.

The results from all the RDM studies were analysed in order to develop a set of models from which to estimate the flows corresponding to estuary class thresholds. In nearly all cases, scenarios involved changes in flow, whereas very few included changes in water quality. The latter were too scarce to allow statistical analysis and were excluded from the analysis of flows.

The relationship between %MAR and both abiotic health score (AHS) and the overall estuary health score (EHI) was generally logarithmic as expected, but the shape of the function beyond the scenarios evaluated could not be reliably predicted from these functions alone. In order to extend the relationships to the full extent, we solved for $\%MAR_0$, the %MAR where AHS = 0 and for AHS where %MAR = 100 to maximize fit ($R^2$). The relationship between overall EHI and %MAR was then derived using the $\%MAR_0$ derived from AHS and solving for $EHI_{100}$ (EHI where %MAR = 100) to maximize fit. In nearly all cases, $EHI_{100}$ was lower than $AHS_{100}$. This is to be expected, since the biotic components are subject to a wider range of anthropogenic pressures than the abiotic components.

It should be noted that this effectively extends the analysis to a range beyond the data, with the extent of this varying between estuaries depending on the data. Thus the models are not entirely empirical. Nevertheless, the consistency with which the same approach fitted all the data sets suggests that the model is fairly reliable. The difference between this approach and the DRIFT method used to assess the ecological flow requirements for rivers is that in the latter, specialist scientists model responses to flows across the full range of possibilities. The scenario-based approach used in most estuary studies falls short in this regard. For this reason, it is necessary to extrapolate beyond existing estimates. The models developed here involved two experienced estuarine ecologists, rather than a full team of specialists, but they are anchored in the estimates of a full team. Given the way in which the estuary EWRs have been determined (a scenario based approach as opposed to DRIFT or similar modelling) the only alternative to identifying the minimum flow requirement (for a D) would be to have a workshop and create new scenarios for each estuary. This is not feasible where large numbers of estuaries are involved, necessitating a modelling approach. However, it should be recognised that there could be a significant error margin around the EWR estimates in cases where they extend well beyond the range of the data.

Following this, a new relationship was derived to simulate the potential thresholds in the absence of existing anthropogenic impacts on water quality. This was done by imputing a new EHI100 based on the difference between the AHS100 and EHI100, as $EHI'_{100} = EHI_{100}-(AHS_{100}-EHI_{100})$. This theoretically captures the difference due to pollution versus other anthropogenic impacts. However, following the precautionary principle, and especially in light of the error margins of the estimates as discussed above, the EWRs applied should only be those using data corresponding to the current water quality, irrespective of requirements for improving water quality.

Note that Reserve studies for the urban systems in the G2 for which flows are augmented by effluent from waste water treatment works often included scenarios which entailed improvements in the quality or reductions in the volume of the effluent discharged (e.g. Rietvlei/Diep, Wildevoëlvlei, Zeekoe, Eerste). For these systems only scenarios where 100% of the effluent was diverted were used in deriving relationships between runoff and abiotic and overall health. For these systems, effluent from the WWTWs often does not enter at the head of the estuary (as is the case for the Rietvlei/Diep and Zeekoevlei systems) and is generally of extremely poor quality and hence confounded relationships between runoff and health, as the additional water was not available to large parts of the system and/or did not serve to improve health in the manner that might otherwise be expected due to poor quality (increased discharge often caused a reduction rather than an improvement in health). Furthermore, for these systems the discrepancy between the amount of flow required to achieve a particular health category with and without the anthropogenic impacts of water quality was generally much larger than systems for which flows are not augmented by waste water.

Finally, in order to disaggregate the annual flows to their monthly distribution, we used a statistical analysis of monthly flows used in all the Reserve determination scenarios in order to model the distribution of flows at each threshold between ecological categories.

### 4.8.3 Ecological Water Requirements for Estuaries

These relationships described above were used to determine threshold flow requirements for each EC for each of the estuaries in the Berg River and G2 catchments, based on current WQ (the default minimum requirement) and based on a situation where pollution is entirely eliminated (Figure 4.10 and Figure 4.11, Table 4.23 and Table 4.24). The final threshold value will be determined in each case based on assessment of the feasible and likely degree to which pollution problems can be reduced relative to the present-day situation. This %MAR will then be translated into flow pattern for use in the water supply model using the patterns of the relevant RDM studies used the approach described in Section 4.8.2 above.

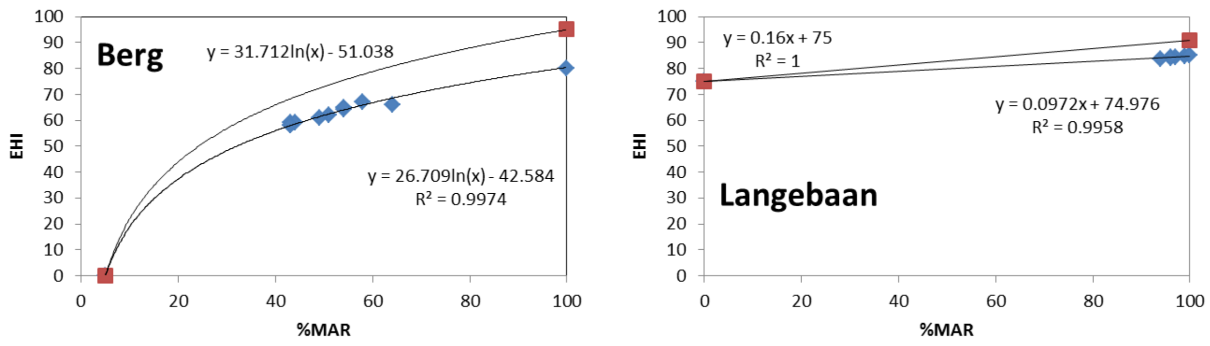


**Figure 4.10 Relationships between %MAR and estuary health (EHI) for the Berg estuary and Langebaan under (a) current non-flow pressures – lower line, and (b) when anthropogenic impacts on water quality are removed – upper line.**

It was not possible to complete RDM studies for all the micro-estuaries in the G2 catchment, thus it was necessary to extrapolated results from the most similar significant estuary in each case. In many cases, especially for the urban system which receive runoff from WWTW and/or much of the runoff comprises of highly contaminated stormwater and/or where the estuary channel has been highly modified (canalised or developed), it was not possible to improve estuary health above a “D” class through addition of water alone (indicated by the letters “n/a” in Table 4.24). For these systems, improving health beyond this point will require a combination of restoring flows, improving water quality, diverting waste water, restoring natural mouth functioning and/or restoring habitat lost to development.

**Table 4.23 Ranges of threshold flow requirements (%MAR) for each Ecological Category for each of the estuaries within Berg River Catchment (G1), based on current WQ (the default minimum requirement) and based on a situation where pollution is entirely eliminated.**

| %MAR thresholds | E/D threshold | | D/C threshold | | C/B threshold | | B/A threshold | |
|---|---|---|---|---|---|---|---|---|
| | Fixed WQ | Current WQ | Fixed WQ | Current WQ | Fixed WQ | Current WQ | Fixed WQ | Current WQ |
| Berg | 18 | 22 | 33 | 46 | 53 | 80 | 85 | n/a |
| Langebaan | n/a | n/a | n/a | n/a | 0 | 0 | 94 | 94 |

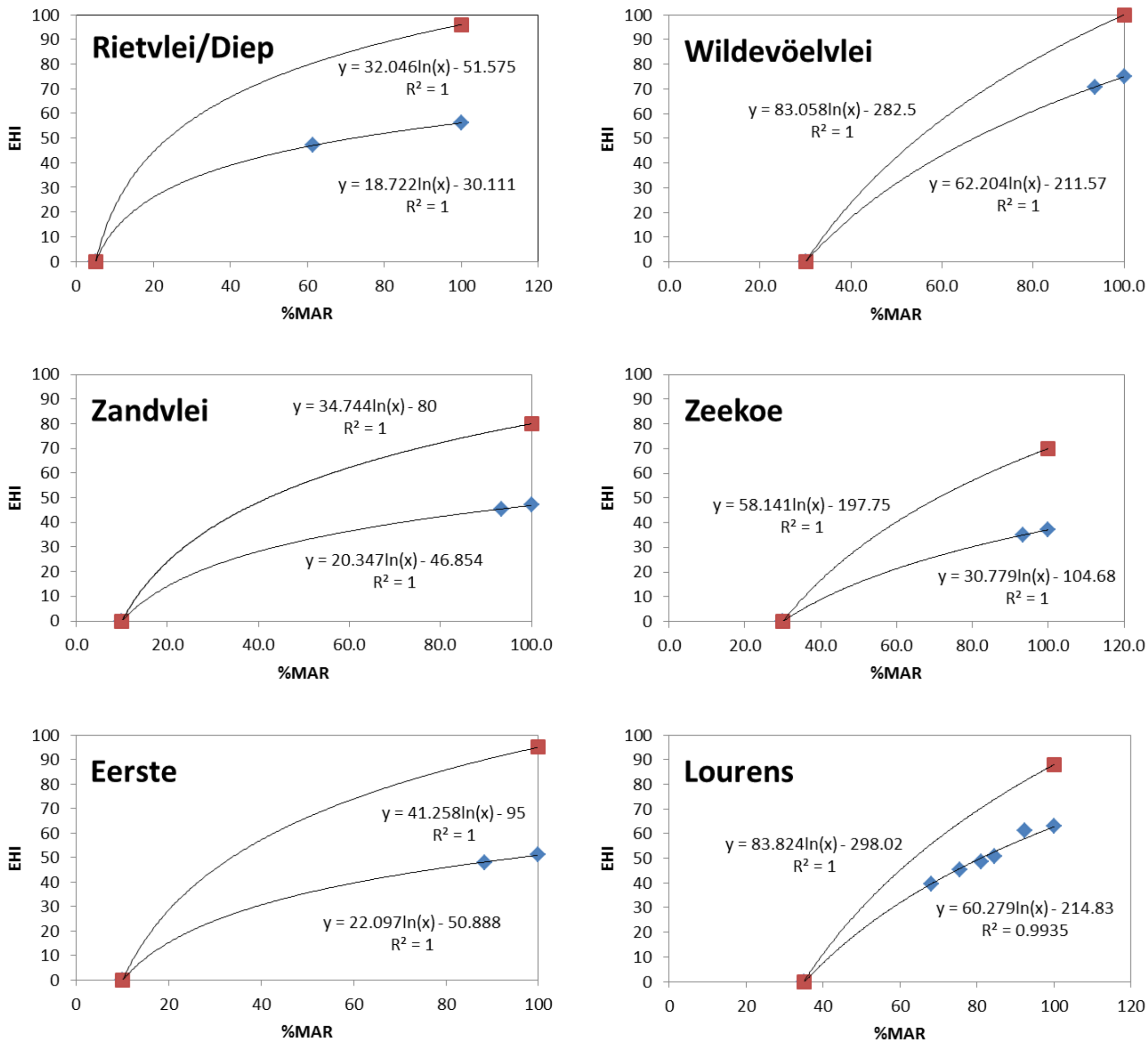


**Figure 4.11 Relationships between %MAR and estuary health (EHI) for six estuaries in the G2 catchment area under (a) current non-flow pressures – lower line, and (b) when anthropogenic impacts on water quality are removed – upper line.**

**Table 4.24 Ranges of threshold flow requirements (%MAR) for each Ecological Category for each of the estuaries within the G2 Secondary Catchment, based on current WQ (the default minimum requirement) and based on a situation where pollution is entirely eliminated, *imputed from similar systems.**

| %MAR thresholds | E/D threshold | | D/C threshold | | C/B threshold | | B/A threshold | |
|---|---|---|---|---|---|---|---|---|
| | Fixed WQ | Current WQ | Fixed WQ | Current WQ | Fixed WQ | Current WQ | Fixed WQ | Current WQ |
| Modder | 17 | 42 | 33 | n/a | 52 | n/a | 83 | n/a |
| Rietvlei/ Diep | 17 | 42 | 33 | n/a | 52 | n/a | 83 | n/a |
| Hout Bay | 26 | 35 | 42 | 65 | 59 | n/a | 85 | n/a |
| Goedehoop | 26 | 35 | 42 | 65 | 59 | n/a | 85 | n/a |
| Wildevoëlvlei | 49 | 57 | 62 | 79 | 74 | n/a | 89 | n/a |
| Bokramspruit | 26 | 35 | 42 | 65 | 59 | n/a | 85 | n/a |
| Schuster | 67 | 66 | 77 | 77 | 85 | 86 | 95 | 95 |
| Krom | 67 | 66 | 77 | 77 | 85 | 86 | 95 | 95 |
| Buffels Wes | 67 | 66 | 77 | 77 | 85 | 86 | 95 | 95 |
| Elsies | 26 | 35 | 42 | 65 | 59 | n/a | 85 | n/a |
| Silvermine | 26 | 35 | 42 | 65 | 59 | n/a | 85 | n/a |
| Zandvlei | 32 | 71 | 56 | n/a | 87 | n/a | n/a | n/a |
| Zeekoei | 60 | 110 | 84 | n/a | n/a | n/a | n/a | n/a |
| Eerste | 26 | 61 | 43 | n/a | 62 | n/a | 89 | n/a |
| Lourens | 56 | 69 | 72 | 96 | 86 | n/a | n/a | n/a |
| Sir Lowry's Pass | 26 | 35 | 42 | 65 | 59 | n/a | 85 | n/a |
| Steenbras | 7 | 12 | 17 | 39 | 35 | 97 | 72 | n/a |

Note: The letters "n/a" indicate that it is not possible to achieve the health category in question through restoration of flows alone (Current WQ) or even by restoring flows and fixing water quality (Fixed WQ). In these cases, restoration of estuarine habitat and/or mouth functionality is also required.

### 4.8.4 Recommended Ecological Water Requirements for Estuaries

There are twenty two estuary nodes identified in the study area. Field visits and a specialist workshop were undertaken to determine the EWRs, PES and RECs for these priority estuary nodes (Table 4.25).

It is important to note that the REC and associated EWRs area based purely on environmental considerations and does not include potential additional considerations such as recreational use or importance in terms of tourism and residential properties. Also does not include potential challenges in terms of achieving the desired status based on the current and future challenges. Final changes to the REC will need to be discussed with key stakeholders during the evaluation of scenarios phase in order to results in the final recommended classification and associated EWRs for each of these estuaries.

In some cases the desired REC can be achieved by addressing water quality and other habitat issues and not just flow. The last two columns in Table 4.25 9 show the flow volume (as a percentage of MAR) that would be required to achieve the change in REC (by adding information presented in Table 4.23 and Table 4.24 above). The first flow value applies if the current level of water quality is maintained (Current WQ). The second value assumes that the water quality is improved somehow (Fixed WQ). This demonstrates how a higher REC can be achieved if water quality is improved without increasing flow.

**Table 4.25 The estuary nodes considered for EWRs in the study area and provisional RECs**

| Node | IUA | Quat | Name | PES | REC | EIS | Minimum %MAR to achieve REC with Current WQ | Minimum %MAR to achieve REC with Fixed WQ |
|---|---|---|---|---|---|---|---|---|
| **Bxi1** | **A1** | **G10M** | **Berg River Estuary** | **D** | **C** | **H** | **46** | **33** |
| **Bxi3** | **A2** | **G10M** | **Langebaan Estuary** | **B** | **A** | **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 |

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. 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: Priority estuaries highlighted in red.

# 5 WETLAND LINKS TO RIVER AND ESTUARY NODES AND EWRS

## 5.1 Overview of wetland classification

The *Water Resources Classification and RQOs Status Quo* report (DWS, 2016c) defined the wetlands within the study area according to the spatial framework of Ecoregions to define wetland resource units (considered to be wetland "regions"). The associated hydrogeomorphic (HGM) unit characteristics for each wetland resource unit was also described. According to the "Classification system for wetlands" (Ollis et al., 2013), whilst the HGM unit is influenced by the source of water and how it moves into, through and out of an Inland System, the hydrological regime describes the behaviour of water within the system and in the underlying soil. This level of assessment is an important consideration for the development of scenarios as the hydrological regime relates to the ecological water requirements for surface flow.

In terms of hydrological regime, rivers may be described as either perennial (flows continually throughout the year) or non-perennial (does not flow continually throughout the year). Wetlands should be classified according to the period of inundation (Level 5A) and saturation (Level 5B), together with inundation depth class (Level 5C) for permanently inundated open water bodies. Although classification in this regard may be relatively straightforward for rivers, the classification of the hydrological regime for wetlands is more complicated due the non-uniformity of wetness across a wetland.

There is also lack of quantitative date for most wetlands according to hydrology. An additional constraint for this study is the lack of baseline data for wetlands in the study area in terms of hydroperiod. The NFEPA dataset classifies wetlands up to the HGM unit (Level 4) scale of classification, whilst the FSP dataset classifies wetlands up to the hydrological regime (Level 5), but does not extend over the entire study area.

Wetlands are transitional between aquatic and terrestrial systems, and are generally classified by saturated soils and hydrophytic vegetation. The Hydrogeomorphic (HGM) approach (using hydrological and geomorphological characteristics) to wetland classification may distinguish the primary wetland unit, but a finer scale assessment is required for quantification of ecological water requirements for wetland systems.

An overview of the classification of wetlands (Ollis et al., 2013) is provided to determine the level of information necessary for this report.

- **Level 1: Systems**

  *Wetlands include all aquatic ecosystems and can be divided at the broadest level into Marine, Estuarine and Inland systems. For the purpose of this study only inland systems were described. Inland systems may include all rivers plus any other inland areas that are permanently or periodically inundated or saturated.*

  - Inland systems are ecosystems that
    - Are permanently or periodically inundated or saturated
    - Have no existing connection to the ocean
    - Are characterised by absence of marine exchange or tidal influence
- **Level 2: Regional Setting**

  Identification of the regional setting allows for an understanding of the broad ecological context within which an aquatic ecosystem occurs. The DWA ecoregions were described in the Status Quo report, which indicated a coarse scale wetland regional setting. The NFEPA wetland dataset also provides a coarse scale regional setting for priority wetlands.

- **Level 3: Landscape Setting**

  The use of these units recognises that the hydrological and hydrodynamic processes acting within Inland Systems are likely to be strongly influenced by their topographical processes that have brought about and drive these topographical contexts. Four landscape units are defined according to landscape setting, these are as follows:

  - Valley floor, the base of a valley, situated between two distinct valley side-slopes, where alluvial or fluvial processes typically dominate.
  - Slope, an inclined stretch of ground typically located on the side of a mountain, hill or valley floor.
  - Plain, an extensive area of low relief.
  - Bench, a relatively discrete area of mostly level or nearly level high ground, including hilltops, saddles and shelves.

- **Level 4: Hydrogeomorphic Unit**

  Hydrogeomorphic Units (HGMs) are distinguished primarily on the basis of:

  - Landform, which defines the shape and localised setting of the aquatic ecosystem.
  - Hydrological characteristics, which describe the nature of water movement into, through and out of the aquatic ecosystem.
  - Hydrodynamics, which describe the direction and strength of flow through the aquatic ecosystem.

  There are six HGM types for wetland inland systems at Level 4A:

  - Valley-bottom wetlands (Channelled and Unchannelled), a mostly flat wetland area located along a valley floor, often connected to an upstream or adjoining river channel.
  - Floodplain wetland,
  - Depression, a wetland or aquatic ecosystem with closed (or near closed) elevation contours, which increases in depth from the perimeter to a central area of greatest depth and within which water typically accumulates.
  - Seep, a wetland area located on gently to steeply sloping land and dominated by colluvial, unidirectional movement of water and material downslope.
  - Wetland flat, a level or near level wetland area that is not fed by water from a river channel, and which is typically situated on a plain or a bench. Closed elevation contours are not evident around the edge of wetland.

- **Level 5: Hydrological regime**

  The hydrological regime describes the behaviour of water within the system and, for wetlands, in the underlying soil. For wetlands and inland water bodies the hydrological regime may be classified according to the period of inundation and saturation, as well as inundation depth class for permanently nundated waterbodies.

- **Level 6: Descriptors**

  Certain descriptors for the structural/chemical/biological characterisation of inland systems may be used depending on relevance.

It is clear that the HGM approach to wetland classification provides a starting point for assessment of the ecological water requirements for wetlands, but that further assessment of additional information related to the use of wetlands is required to determine the value and ecological condition of priority wetlands. This assessment will be provided for during the determination of Resource Quality Objectives for the study area.

## 5.2 Link to River and Estuary nodes

This study is associated with flow related non-consumptive use and has been assessed as such. Wetlands in the study area were identified according to Hydrogeomorphic unit, Hydroperiod, Present Ecological State (PES) and Environmental Importance and Sensitivity (EIS), where this information is available.

Wetlands are either driven by channel flow (i.e. river associated) or interflow (i.e. groundwater driven), therefore the assessment of wetlands can be associated with river nodes and groundwater resource units in terms of ecological water requirements.

The wetland units associated with river nodes are as follows:

- Valley bottom
- Floodplain
- Depression linked to a channel

The wetland units associated with groundwater resource units are as follows:

- Valley bottom
- Floodplain
- Isolated depression

There are a total of 45 identified river nodes and 12 estuary nodes identified in the study area. The link between surface water driven wetlands and groundwater driven wetlands for each identified river and estuary node are shown in Table 5.1 and Table 5.2 respectively. The estuary nodes are highlighted in blue and high groundwater yield areas in green. The source for the available information is also referenced.

Where these have been determined the PES and EIS for wetlands is also given. Note that for a number of these individual wetlands or wetlands systems, the PES and EIS remains undefined (indicated by a U). In addition to defining the EIS in terms of categories A, B, C, etc., the NFEPA data also includes Z1, Z2 and Z3 classifications. This is from the NFEPA assessment and is defined as follows: Z1 = wetland overlap with artificial inland water body, Z2 = majority wetland artificial, Z3 = percentage natural land cover <25%.

Each river node was assessed for Groundwater Contribution to Baseflow (GWBF), compared to EWR for ecological category, as an indication of the relative reliance of ecology on GWBF. Certain nodes have GWBF above 50%, this is considered to be a significant contribution from groundwater. The wetlands which are groundwater driven are related to the river and estuary nodes, with consideration of the significance of groundwater contribution to each node.

## 5.3 Provisional RECs for Wetlands

Provisional recommended ecological categories (RECs) have been determined for wetlands for which PES data is available (Table 5.3). The RECs are based primarily on maintaining the PES, except where the PES is an E or below. In these cases the REC is raised to a minimum of a D. These provisional RECs will be revised during the process for determining RQOs for wetlands and where necessary updated for the priority wetlands identified through the RQO process. The overall impact of the classification scenarios on wetlands will also be determined and described as part of the results of the Scenario Analysis Report.

**Table 5.1 The surface water driven wetlands associated with nodes**

| Node | Quat | Description | Associated wetlands | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| | | | | **Berg Catchment (G1)** | | | | |
| Biii2 | G10B | U/s of confluence with Berg | | Channelled Valley Bottom | Intermittently inundated | U | U | Drak |
| **Bvii2** | **G10C** | **Skuifraam pump station area** | | **Floodplain** | **Unknown** | U | U | **Drak** |
| | | | | **Channelled Valley Bottom** | **Unknown** | **Z1** | U | **EGI** |
| **Biii3** | **G10C** | **At gauging weir G1H020** | | **Channelled Valley Bottom** | **Never inundated** | U | U | **Drak** |
| | | | | **Floodplain** | **Intermittent inundation** | U | U | **Drak** |
| | | | | **Unchannelled Valley Bottom** | **Never inundated** | U | U | **Drak** |
| | | | | **Channelled Valley Bottom** | **Unknown** | **Z1** | U | **EGI** |
| **Bvii3** | **G10D** | **North of Wellington, G1H037, d/s EWR 6 - D** | | **Channelled Valley Bottom** | **Unknown** | U | U | **Drak** |
| | | | | **Channelled Valley Bottom** | **Unknown** | **Z1** | U | **EGI** |
| | | | | **Unchannelled Valley Bottom** | **Unknown** | **Z1** | U | **EGI** |
| | | | | **Flat** | **Unknown** | **Z1** | U | **EGI** |
| Bvii10 | G10D | D/s of confluence Kromme, at gauging weir G1H015 | | Channelled Valley Bottom | Unknown | U | U | Drak |
| | | | | Unchannelled Valley Bottom | Never inundated | U | U | Drak |
| | | | | Floodplain | Unknown | C | U | EGI |
| | | | | Channelled Valley Bottom | Unknown | Z1 | U | EGI |
| | | | | Unchannelled Valley Bottom | Unknown | Z1 | U | EGI |
| | | | | Flat | Unknown | Z1 | U | EGI |
| Bvii15 | G10D | Gauge | Klein-Sand River vlei* | Unchannelled Valley Bottom | Never inundated | U | U | Drak |
| | | | Sand River vlei* | Unchannelled Valley Bottom | Never inundated | U | U | Drak |
| | | | | Unchannelled Valley Bottom | Never inundated | U | U | Drak |
| | | | | Floodplain | Seasonally inundated | U | U | Drak |
| | | | | Floodplain | Unknown | C | U | EGI |

| Node | Quat | Description | Associated wetlands | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| Bvii4 | G10D | At gauging weir G1H041 | | Channelled Valley Bottom | Seasonally inundated | U | U | Drak |
| Bvii5 | G10D | At gauging weir G1H036 and u/s of EWR 3 - C/D | | Channelled Valley Bottom | Seasonally inundated | U | U | Drak |
| | | | | Floodplain | Unknown | C | U | EGI |
| **Bvii11** | **G10F** | **U/s of Voëlvlei canal** | | **Channelled Valley Bottom** | **Seasonally inundated** | U | U | **Drak** |
| | | | | **Channelled Valley Bottom** | **Intermittently inundated** | U | U | **Drak** |
| | | | | **Unchannelled Valley Bottom** | **Seasonally inundated** | U | U | **Drak** |
| | | | | **Unchannelled Valley Bottom** | **Intermittently inundated** | U | U | **Drak** |
| | | | | **Floodplain** | **Unknown** | U | U | **Drak** |
| | | | | **Flat** | **Seasonally inundated** | U | U | **Drak** |
| | | | | **Floodplain** | **Unknown** | **C** | U | **EGI** |
| Biii4 | G10E | At gauging weir G1H008 | | Channelled Valley Bottom | Unknown | C | U | EGI |
| | | | | Unchannelled Valley Bottom | Unknown | Z1 | U | EGI |
| | | | | Flat | Unknown | C | U | EGI |
| Biv3 | G10J | U/s of confluence with Berg | Bonne Esperance vlei* | Channelled Valley Bottom | Unknown | Z1 | U | EGI |
| | | | | Channelled Valley Bottom | Seasonally inundated | U | U | Drak |
| Biv1 | G10J | U/s of confluence Klein-Berg, d/s Voëlvlei canal | | Channelled Valley Bottom | Seasonally inundated | U | U | Drak |
| | | | Berg River | Floodplain | Unknown | C | U | EGI |
| Biv4 | G10J | U/s of confluence with Berg | | Unchannelled Valley Bottom | Seasonally inundated | U | U | Drak |
| | | | | Channelled Valley Bottom | Never inundated | U | U | Drak |
| | | | | Flat | Never inundated | U | U | Drak |
| Bvii17 | G10J | Gauge | Berg River | Floodplain | Unknown | C | U | EGI |
| | | | | Flat | Unknown | C | U | EGI |
| Bvii6 | G10J | D/s of EWR 4, above Misverstand Dam G1H013 - D | Berg River | Floodplain | Unknown | C | U | EGI |

| Node | Quat | Description | Associated wetlands | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| Biii5 | G10J | At gauging weir G1H035 | | Channelled Valley Bottom | Unknown | Z1 | U | EGI |
| **Bvii8** | **G10J** | **U/s Misverstand reservoir, d/s confluence with Matjies** | **Berg River** | **Floodplain** | **Unknown** | **C** | U | **EGI** |
| Bvii18 | G10J | Gauge | | Flat | Unknown | Z1 | U | EGI |
| | | | | Channelled Valley Bottom | Unknown | Z1 | U | EGI |
| Bvii12 | G10K | 3.5 km d/s of Misverstand reservoir, at EWR 5 - D | | Floodplain | Unknown | C | U | EGI |
| Bii1 | G10L | U/s of confluence with Berg | | Floodplain | Unknown | C | U | EGI |
| | | | | Flat | Unknown | C | U | EGI |
| | | | | Channelled Valley Bottom | Unknown | AB | U | EGI |
| | | | | Unchannelled Valley Bottom | Unknown | AB | U | EGI |
| Biv2 | G10L | U/s of confluence with Sout, head of estuary | | Floodplain | Unknown | C | U | EGI |
| | | | | Floodplain (within G10K) | Unknown | AB | U | EGI |
| | | | | Flat (within G10K) | Unknown | AB | U | EGI |
| | | | | Channelled Valley Bottom (within G10K) | Unknown | C | U | EGI |
| **Bxi1** | **G10M** | **Berg River Estuary** | **Berg River** | **Floodplain** | **Unknown** | U | U | **EGI** |
| | | | | **Channelled Valley Bottom** | **Unknown** | U | U | **EGI** |
| | | | **Bookram vlei*** | **Unchannelled Valley Bottom** | **Unknown** | U | U | **EGI** |
| | | | **Velddrift vlei*** | **Unchannelled Valley Bottom** | **Unknown** | U | U | **EGI** |
| **Bxi3** | **G10M** | **Langebaan estuary** | | **Channelled Valley Bottom** | **Unknown** | U | U | **EGI** |
| | | | | **Unchannelled Valley Bottom** | **Unknown** | U | U | **EGI** |
| **Other Catchments (G2)** | | | | | | | | |
| Bviii3 | G21A | Inflow to Yzerfontein salt pan | | Unchannelled Valley Bottom | Unknown | AB | U | EGI |
| Bviii10 | G21B | Cumulative at outlet G21B | | Floodplain | Unknown | U | U | EGI |

| Node | Quat | Description | Associated wetlands | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| **Bv1** | **G21D** | | | **Flat** | **Unknown** | **Z1** | U | **EGI** |
| Bviii4 | G21D | U/s of confluence with Diep | | Unchannelled Valley Bottom | Unknown | C | - | EGI |
| Biv6 | G21D | | | Valley bottom | Unknown | U | U | EGI |
| Biv7 | G21E | | | Floodplain | Unknown | U | U | EGI |
| | | | | Valley bottom | Unknown | U | U | EGI |
| **Bxi7** | **G21F** | **Rietvlei/Diep Estuary** | **Rietvlei#** | **Floodplain** | **Unknown** | **C** | **A** | **EGI; CCT** |
| | | | | **Valley bottom** | | U | U | **EGI** |
| Bviii8 | G22C | U/s of confluence Black | | Valley bottom | Unknown | U | U | EGI |
| Bvii7 | G22D | At EWR site | | Floodplain | Unknown | U | U | EGI |
| | | | | Valley bottom | Unknown | U | U | EGI |
| **Bxi9** | **G22D** | **Sand Estuary** | | **Floodplain** | **Unknown** | U | U | **EGI** |
| **Bxi20** | **G22D** | **Zeekoe Estuary** | **Zeekoevlei*** | **Floodplain** | **Unknown** | U | U | **EGI** |
| | | | **Rondevlei*** | **Floodplain** | **Unknown** | U | U | **EGI** |
| Bviii6 | G22B | At EWR site | | Floodplain | Unknown | U | U | EGI |
| | | | | Valley bottom | Unknown | U | U | EGI |
| Bvii20 | G22A | Town, 100% MAR | | Floodplain | Unknown | U | U | EGI |
| **Bxi14** | **G22A** | **Wildvoelvlei estuary** | | **Valley-bottom** | **Unknown** | U | U | **EGI** |
| Bxi15 | G22A | Bokramspruit estuary (micro) | | Valley-bottom | Unknown | U | U | EGI |
| Bxi16 | G22A | Schuster estuary (micro) | | Valley-bottom | Unknown | U | U | EGI |
| Bxi17 | G22A | Krom estuary (micro) | | Valley-bottom | Unknown | U | U | EGI |
| Bxi18 | G22A | Buffels Wes estuary (micro) | | Valley-bottom | Unknown | U | U | EGI |
| Bxi19 | G22A | Elsies estuary (micro) | | Valley-bottom | Unknown | U | U | EGI |
| Biv9 | G22H | U/s confluence Eerste | Cape Corps* | Floodplain | Unknown | U | U | EGI |
| | | | Khayelitsha pool* | Floodplain | Unknown | U | U | EGI |
| | | | Nooiensfontein# | Floodplain | Unknown | E | C | EGI; CCT |
| | | | | Valley bottom | Unknown | U | U | EGI |

| Node | Quat | Description | Associated wetlands | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| **Bxi3** | **G22H** | **Eerste Estuary EWR site** | **Zandvleit vlei*** | **Floodplain** | **Unknown** | U | U | **EGI** |
| | | | **Drift Sands vlei*** | **Floodplain** | **Unknown** | U | U | **EGI** |
| **Bvii21** | **G22J** | **Town** | | **Valley bottom** | **Unknown** | U | U | **EGI** |
| **Bxi4** | **G22J** | **Lourens Estuary** | | **Floodplain** | **Unknown** | U | U | **EGI** |
| Bviii9 | G22K | Cumulative at outlet G22K | | Valley bottom | Unknown | U | U | EGI |
| **Bvii22** | **G40A** | **At EWR 8, u/s of estuary mouth - B/C** | | **Valley bottom** | **Unknown** | U | U | **EGI** |

IIUA = Integrated Unit of Analysis, Quat = Quaternary; * Western Cape Wetlands Directory, # = Working for Wetlands wetland, EGI = Electrical Grid Infrastructure Data;
IBA = Important Bird Area, NFEPA = National Freshwater Ecosystem Priority Area, FSP = Fine Scale Planning, HGM = Hydrogeomorphic Unit, PES = Present Ecological Status. U = Undefined
NFEPA: Z1 = wetland overlap with artificial inland water body, Z2 = majority wetland artificial, Z3 = percentage natural land cover <25%.

Note: EWR sites in red; green highlights estuary nodes and blue highlights river nodes with significant groundwater contribution

### Table 5.2 The groundwater driven wetlands associated with river and estuary nodes

| Node | Quat | Description | Wetland name | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| **Berg Catchment (G1)** | | | | | | | | |
| Biii2 | G10B | U/s of confluence with Berg | Wemmershoek Dam* | Depression | Permanently inundated | U | U | Drak |
| | | | | Depression | Permanently inundated | U | U | Drak |
| | | | | Hillslope seep | Never inundated | U | U | Drak |
| **Bvii2** | **G10C** | **BWP pump station area** | | **Depression** | **Permanently inundated** | U | U | **Drak** |
| **Biii3** | **G10C** | **At gauging weir G1H020** | | **Hillslope seep** | **Never inundated** | U | U | **Drak** |
| | | | | **Depression** | **Permanently inundated** | U | U | **Drak** |
| Bviii11 | G10C | At EWR 7 u/s of confluence with Kromme - C | | | | U | U | |
| **Bvii3** | **G10D** | **North of Wellington, G1H037, d/s EWR 6 - D** | | **Hillslope seep** | **Never inundated** | U | U | **Drak** |
| Bvii10 | G10D | D/s of confluence Kromme, at gauging weir G1H015 | | Hillslope seep | Never inundated | U | U | Drak |
| | | | | Depression | Seasonally inundated | U | U | Drak |

| Node | Quat | Description | Wetland name | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| Bvii15 | G10D | Gauge | | Depression | Seasonally inundated | U | U | Drak |
| | | | | Depression | Permanently inundated | U | U | Drak |
| Bvii4 | G10D | At gauging weir G1H041 | | Hillslope seep | Never inundated | U | U | Drak |
| | | | | Depression | Seasonally inundated | U | U | Drak |
| | | | | Depression | Intermittently inundated | U | U | Drak |
| Bvii5 | G10D | At gauging weir G1H036 and u/s of EWR 3 - C/D | | Depression | Seasonally inundated | U | U | Drak |
| | | | | Hillslope seep | Never inundated | U | U | Drak |
| Bvii11 | G10F | U/s of Voëlvlei canal | Voelvlei Dam* | Depression | Permanently inundated | U | U | Drak |
| | | | | Depression | Seasonally inundated | U | U | Drak |
| | | | | Hillslope seep | Never inundated | U | U | Drak |
| Bviii10 | G21B | Cumulative at outlet G21B | | Depression | Unknown | U | U | EGI |
| | | | | Seep | Unknown | U | U | EGI |
| **Bv1** | **G21D** | | | **Seep** | **Unknown** | U | U | **EGI** |
| Bviii4 | G21D | U/s of confluence with Diep | | Depression | Unknown | U | U | EGI |
| Biv7 | G21E | | | Depression | Unknown | U | U | EGI |
| | | | | Seep | Unknown | U | U | EGI |
| Biv1 | G10J | U/s of confluence Klein-Berg, d/s Voëlvlei canal | | Seep | Unknown | C | U | EGI |
| Biv4 | G10J | U/s of confluence with Berg | | Depression | Unknown | Z1 | U | EGI |
| Bvii17 | G10J | Gauge | | Depression | Unknown | Z1 | U | EGI |
| Bvii20 | G22A | Town, 100% MAR | | Seep | Unknown | U | U | EGI |
| Bvii6 | G10J | D/s of EWR 4, above Misverstand Dam G1H013 - D | | Depression | Unknown | Z1 | U | EGI |
| Biii5 | G10J | At gauging weir G1H035 | | Depression | Unknown | Z1 | U | EGI |
| **Bvii8** | **G10J** | **U/s Misverstand reservoir, d/s confluence with Matjies** | | **Depression** | **Unknown** | **Z1** | U | **EGI** |
| Bvii18 | G10J | Gauge | Hollerivier vlei* | Depression | Unknown | Z1 | U | EGI |

| Node | Quat | Description | Wetland name | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| Bvii12 | G10K | 3.5 km d/s of Misverstand reservoir, at EWR 5 - D | | Depression | Unknown | Z1 | U | EGI |
| Bii1 | G10L | U/s of confluence with Berg | | Depression | Unknown | Z1 | U | EGI |
| Biv2 | G10L | U/s of confluence with Sout, head of estuary | | Hillslope seep | Unknown | C | U | EGI |
| **Other Catchments (G2)** | | | | | | | | |
| Bviii3 | G21A | Inflow to Yzerfontein salt pan | Yzerontein Salt Pan | Depression | Unknown | AB | U | EGI |
| Bviii10 | G21B | Cumulative at outlet G21B | | Depression | Unknown | U | U | EGI |
| | | | | Seep | Unknown | U | U | EGI |
| **Bv1** | **G21D** | | | **Depression** | **Unknown** | **Z1** | U | **EGI** |
| | | | | **Seep** | **Unknown** | **Z1** | U | **EGI** |
| Bviii4 | G21D | U/s of confluence with Diep | | Depression | Unknown | Z1 | U | EGI |
| Biv6 | G21D | | | Depression | Unknown | Z1 | U | EGI |
| | | | | Seep | Unknown | Z1 | U | EGI |
| Biv7 | G21E | | | Depression | Unknown | Z1 | U | EGI |
| | | | | Seep | Unknown | Z1 | U | EGI |
| | | | | Depression | Seasonally inundated | U | U | Drak |
| Bvii5 | | | Blouvlei# | Depression | Unknown | B | A | EGI; CCT |
| | | | | Seep | Unknown | U | U | EGI |
| **Bxi7** | **G21F** | **Rietvlei/Diep Estuary** | | **Depression** | **Unknown** | U | U | **EGI** |
| Bviii8 | G22C | U/s of confluence Black | | Depression | Unknown | U | U | EGI |
| Bvii7 | G22D | At EWR site | Princessvlei* | Depression | Unknown | C | C | EGI; CCT |
| | | | | Depression | Unknown | U | U | EGI |
| | | | | Seep | Unknown | U | U | EGI |
| **Bxi9** | **G22D** | **Sand Estuary** | | **Depression** | **Unknown** | U | U | **EGI** |
| **Bxi20** | **G22D** | **Zeekoe Estuary** | **Zeekoevlei*** | **Depression** | **Unknown** | **E** | U | **EGI; CCT** |
| | | | **Rondevlei*** | **Depression** | **Unknown** | **B** | **A** | **EGI; CCT** |

| Node | Quat | Description | Wetland name | HGM | Hydroperiod | PES | EIS | Source |
|---|---|---|---|---|---|---|---|---|
| | | | | **Seep** | **Unknown** | U | U | **EGI** |
| Bviii6 | G22B | At EWR site | | Seep | Unknown | U | U | EGI |
| Bvii20 | G22A | Town, 100% MAR | | Seep | Unknown | U | U | EGI |
| **Bxi14** | **G22A** | **Wildvoelvlei estuary** | **Noordhoek Salt Pan*** | **Depression** | **Unknown** | U | U | **EGI** |
| | | | **Pick n Pay Reedbeds#** | **Depression** | **Unknown** | **B** | **-** | **CCT** |
| Bxi15 | G22A | Bokramspruit estuary (micro) | | Depression | | U | U | EGI |
| Bxi16 | G22A | Schuster estuary (micro) | | Seep | Unknown | U | U | EGI |
| Bxi17 | G22A | Krom estuary (micro) | Sirkelvlei* | Seep | Unknown | U | U | EGI |
| | | | Booiskraal* | Seep | Unknown | U | U | EGI |
| | | | | Seep | Unknown | U | U | EGI |
| Bxi18 | G22A | Buffels Wes estuary (micro) | | Seep | Unknown | U | U | EGI |
| Bxi19 | G22A | Elsies estuary (micro) | | Depression | Unknown | U | U | EGI |
| Biv9 | G22H | U/s confluence Eerste | | Depression | Unknown | U | U | EGI |
| | | | | Seep | Unknown | U | U | EGI |
| **Bvii21** | **G22J** | **Town** | | **Seep** | **Unknown** | U | U | **EGI** |
| | | | | **Depression** | **Unknown** | U | U | **EGI** |
| **Bxi4** | **G22J** | **Lourens Estuary** | **Paardevlei*** | **Seep** | **Unknown** | U | U | **EGI** |
| | | | | **Seep** | **Unknown** | U | U | **EGI** |
| | | | | **Depression** | **Unknown** | U | U | **EGI** |
| Bviii9 | G22K | Cumulative at outet G22K | | Depression | Unknown | U | U | EGI |
| | | | | Seep | Unknown | U | U | EGI |
| **Bvii22** | **G40A** | **At EWR 8, u/s of estuary mouth - B/C** | | **Seep** | **Unknown** | U | U | **EGI** |

IIUA = Integrated Unit of Analysis, Quat = Quaternary; * Western Cape Wetlands Directory, # = Working for Wetlands wetland, EGI = Electrical Grid Infrastructure Data;
IBA = Important Bird Area, NFEPA = National Freshwater Ecosystem Priority Area, FSP = Fine Scale Planning, HGM = Hydrogeomorphic Unit, PES = Present Ecological Status. U = Undefined
NFEPA: Z1 = wetland overlap with artificial inland water body, Z2 = majority wetland artificial, Z3 = percentage natural land cover <25%.
Note: EWR sites in red; blue highlights estuary nodes and green highlights river nodes with significant groundwater contribution

### Table 5.3 Provisional RECs for identified wetlands with existing PES data (Source: EGI, Malan and CCT)

| Node | Quat | Description | Associated wetlands | HGM | Hydroperiod | PES | EIS | REC | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **Berg Catchment (G1)** | | | | | |
| Bvii10 | G10D | D/s of confluence Kromme, at gauging weir G1H015 | | Floodplain | Unknown | C | U | C | EGI |
| Bvii15 | G10D | Gauge | Klein-Sand River vlei* | Floodplain | Unknown | C | U | C | EGI |
| Bvii5 | G10D | At gauging weir G1H036 and u/s of EWR 3 - C/D | | Floodplain | Unknown | C | U | C | EGI |
| **Bvii11** | **G10F** | **U/s of Voëlvlei canal** | | **Floodplain** | **Unknown** | **C** | U | **C** | **EGI** |
| Biii4 | G10E | At gauging weir G1H008 | | Channelled Valley Bottom | Unknown | C | U | C | EGI |
| | | | | Flat | Unknown | C | U | C | EGI |
| Biv1 | G10J | U/s of confluence Klein-Berg, d/s Voëlvlei canal | Berg River | Floodplain | Unknown | C | U | C | EGI |
| | | | | Seep | Unknown | C | U | C | EGI |
| Bvii17 | G10J | Gauge | Berg River | Floodplain | Unknown | C | U | C | EGI |
| | | | | Flat | Unknown | C | U | C | EGI |
| Bvii6 | G10J | D/s of EWR 4, above Misverstand Dam G1H013 - D | Berg River | Floodplain | Unknown | C | U | C | EGI |
| **Bvii8** | **G10J** | **U/s Misverstand reservoir, d/s confluence with Matjies** | **Berg River** | **Floodplain** | **Unknown** | **C** | U | **C** | **EGI** |
| Bvii12 | G10K | 3.5 km d/s of Misverstand reservoir, at EWR 5 - D | | Floodplain | Unknown | C | U | C | EGI |
| Bii1 | G10L | U/s of confluence with Berg | | Floodplain | Unknown | C | U | C | EGI |
| | | | | Flat | Unknown | C | U | C | EGI |

| Node | Quat | Description | Associated wetlands | HGM | Hydroperiod | PES | EIS | REC | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Channelled Valley Bottom | Unknown | AB | U | AB | EGI |
| | | | | Unchannelled Valley Bottom | Unknown | AB | U | AB | EGI |
| Biv2 | G10L | U/s of confluence with Sout, head of estuary | | Floodplain | Unknown | C | U | C | EGI |
| | | | | Floodplain (within G10K) | Unknown | AB | U | AB | EGI |
| | | | | Flat (within G10K) | Unknown | AB | U | AB | EGI |
| | | | | Channelled Valley Bottom (within G10K) | Unknown | C | U | C | EGI |
| | | | | Hillslope seep | Unknown | C | U | C | EGI |
| **Other Catchments (G2)** | | | | | | | | | |
| Bviii3 | G21A | Inflow to Yzerfontein salt pan | | Unchannelled Valley Bottom | Unknown | AB | U | AB | EGI |
| Bviii4 | G21D | U/s of confluence with Diep | | Unchannelled Valley Bottom | Unknown | C | U | C | EGI |
| **Bxi7** | **G21F** | **Rietvlei/Diep Estuary** | **Rietvlei#** | **Floodplain** | **Unknown** | **C** | **A** | **C** | **EGI; CCT** |
| Biv9 | G22H | U/s confluence Eerste | Cape Corps* | Floodplain | Unknown | U | U | | EGI |
| | | | Khayelitsha pool* | Floodplain | Unknown | C/D | U | C/D | EGI, Malan |
| | | | Nooiensfontein# | Floodplain | Unknown | E | C | D | EGI; CCT |
| Bviii3 | G21A | Inflow to Yzerfontein salt pan | Yzerontein Salt Pan | Depression | Unknown | AB | U | AB | EGI |
| Bvii5 | | | Blouvlei# | Depression | Unknown | B | A | B | EGI; CCT |
| Bvii7 | G22D | At EWR site | Princessvlei* | Depression | Unknown | C | C | C | EGI; CCT |
| **Bxi20** | **G22D** | **Zeekoe Estuary** | **Zeekoevlei*** | **Depression** | **Unknown** | **E** | U | **D** | **EGI; CCT** |
| | | | **Rondevlei*** | **Depression** | **Unknown** | **B** | **A** | **B** | **EGI; CCT** |
| **Bxi14** | **G22A** | **Wildvoelvlei estuary** | **Noordhoek Salt Pan*** | **Depression** | **Unknown** | U | U | | **EGI** |
| | | | **Pick n Pay Reedbeds#** | **Depression** | **Unknown** | **B** | U | **B** | **CCT** |
| **Bxi4** | **G22J** | **Lourens Estuary** | **Paardevlei*** | **Seep** | **Unknown** | U | U | | **EGI** |

IIUA = Integrated Unit of Analysis, Quat = Quaternary; * Western Cape Wetlands Directory, # = Working for Wetlands wetland, EGI = Electrical Grid Infrastructure Data;
IBA = Important Bird Area, NFEPA = National Freshwater Ecosystem Priority Area, FSP = Fine Scale Planning, HGM = Hydrogeomorphic Unit, PES = Present Ecological Status. U = Undefined
Note: Reserve sites in red; blue highlights estuary nodes and green highlights river nodes with significant groundwater contribution

# 6 WATER QUALITY LINKS TO RIVER AND ESTUARY NODES

In preparation for the scenario analyses, water quality monitoring points and flow gauging stations associated with the IUAs and nodes were identified (Table 6.1). The will be used to examine the relationships between key water quality constituents and flow during the next phases of the study, namely Ecological Base Configuration Scenarios, and Evaluation of Classification Scenarios, to determine the water quality consequences of different flow and development scenarios. Some of the nodes did not have water quality sampling points associated with them, and some that were associated with water quality sampling points did not have flow gauges associated with those water quality points.

**Table 6.1 Water quality sampling points associated with nodes. WQ point is the registered number in WMS and n is the number of samples in the water quality data record.**

| IUA | Node | Quat | WQ point | Description | Type | n | Flow gauge |
|---|---|---|---|---|---|---|---|
| A1 | Bx1 | G10M | 190790 | - CMNT-Berg River-Berg G Vlaminke Vlei 54 - at R27 Road Bridge (Carinusbrug) on Groot-Bergrivie | Rivers | 14 | n/a |
| B4 | Biv3 | G10J | 100060 | Kleinberg River GW1-031 NR55/71 | unknown | 27 | n/a |
| B4 | Biv1 | G10J | 190309 | No 6 Schoenemakersfontein 486 Saron at Goedverwag Bridge on Berg River (nmmp) | Rivers | 587 | n/a |
| B4 | Bvii16 | G10J | 101934 | Leeu River at de Hoek Estates (NCWQ) | Rivers | 603 | G1H029 |
| B4 | Biv4 | G10J | 100135 | Vier en Twintig Riviere GW1-052 | unknown | 7 | n/a |
| B4 | Bvii17 | G10J | 101945 | At Vrisgewaagd on Sandspruit (NCWQ) | Rivers | 483 | G1H043 |
| B4 | Bvii6 | G10J | 101922 | At Drieheuvels on Berg River (ncwq NCMP nemp) | Rivers | 1541 | G1H013 |
| B4 | Biii5 | G10J | 101938 | At Matjiesfontein on Matjiesriver (NCWQ nemp) | Rivers | 842 | G1H035 |
| B4 | Bvii18 | G10J | 101937 | Moorreesburg Spruit at Holle River (NCWQ nemp) | Rivers | 1368 | G1H034 |
| B4 | Bvii12 | G10K | 101935 | At Misverstand Die Brug on Berg River (ncwq NCMP nemp) | Rivers | 1557 | G1H031 |
| C5 | Biii4 | G10E | 101917 | Nieuwkloof 198 - on Klein Berg River (ncwq NCMP nemp) | Rivers | 1287 | G1H008 |
| C5 | Bi1 | G10G | 101933 | Vier en Twintig River at Drie-Das-Bosch (NCWQ) | Rivers | 763 | G1H028 |
| D6 | Biii6 | G22F | 183043 | At Die Boord D/S of Eersterivier and Plankenbrug Confluence (nmmp) | Rivers | 827 | n/a |
| D6 | Biv8 | G22G | 183043 | At Die Boord D/S of Eersterivier and Plankenbrug Confluence (nmmp) | Rivers | 827 | n/a |
| D6 | Biv9 | G22H | 183040 | Zandvliet Bridge downstream of Zandvliet Sewage Works (nmmp) | Rivers | 849 | n/a |
| D7 | Bvii21 | G22J | 101983 | Lourens River at Strand | Rivers | 401 | G2H029 |
| D7 | Bx4 | G22J | 101983 | Lourens River at Strand | Rivers | 401 | G2H029 |
| D7 | Bviii9 | G22K | 2E+08 | CMNT-CCT-Sir Lowry S Pass River at Gordon S Bay | Rivers | 103 | n/a |
| D7 | Bvii22 | G40A | 102009 | Steenbras Catchment Area 306 - Steenbras Dam on Steenbras River: near Dam Wall (NCWQ) Q01 | Dam / Barrage | 301 | G4R001 |

| IUA | Node | Quat | WQ point | Description | Type | n | Flow gauge |
|---|---|---|---|---|---|---|---|
| D8 | Bvii13 | G10A | 101949 | Jonkershoek Tunnel West Portal at Franschhoek for (NCWQ) | Tunnel | 911 | G1H056 |
| D8 | Bviii1 | G10A | 187097 | Downstream of Skuifraam on Berg River | Rivers | 39 | G1H004 |
| D8 | Biv5 | G10A | 101914 | At le Mouillage la Motte on Franschhoekrivier (NCWQ) | Rivers | 852 | G1H003 |
| D8 | Biii2 | G10B | 101960 | Wemmershoek Dam on Wemmers River: near Dam Wall (NCWQ nemp) Q01 | Dam / Barrage | 395 | G1R002 |
| D8 | Bvii14 | G10C | 187153 | Between Railway and Road Bridges at R45 on Dwars River (nmmp) | Rivers | 51 | n/a |
| D8 | Biii3 | G10C | 101929 | At Dal Josafat Noorder Paarl on Berg River (ncwq NCMP) | Rivers | 1451 | G1H020 |
| D9 | Bvii3 | G10D | 101940 | Krom River at Wellington | Rivers | 633 | G1H037 |
| D9 | Bvii10 | G10D | 100067 | Berg River GW1-018 nr 55171 Hwk | unknown | 31 | n/a |
| D9 | Bvii15 | G10D | 101942 | At Grensplaas Diepe Gat on Doringrivier (NCWQ) | Rivers | 565 | G1H039 |
| D9 | Bvii4 | G10D | 101944 | Kompanjies River at de Eikeboomen (NCWQ) | Rivers | 1030 | G1H041 |
| D9 | Bvii5 | G10D | 101939 | At Vleesbank Hermon Bridge on Berg River (ncwq NCMP nemp GEMS) | Rivers | 1112 | G1H036 |
| D10 | Bv1 | G21D | 101972 | Diep River at Malmesbury (ncwq NCMP) | Rivers | 695 | G2H012 |
| D10 | Bviii4 | G21D | 187153 | Between Railway and Road Bridges at R45 on Dwars River (nmmp) | Rivers | 51 | n/a |
| D10 | Biv6 | G21D | 1E+09 | CMNT-Diep+mb-Dr G-Diep Above Mosselbank Confluence | Rivers | 55 | n/a |
| D10 | Biv7 | G21E | 1E+09 | CMNT-Diep+mb-MR720J-Mosselbank upstream of Diep Confluence | Rivers | 96 | n/a |
| D10 | Bviii5 | G21F | 187150 | Otto du Plessis Bridge at Milnerton on Diep (nmmp) | Rivers | 651 | n/a |
| D10 | Bx7 | G21F | 187150 | Otto du Plessis Bridge at Milnerton on Diep (nmmp) | Rivers | 651 | n/a |
| E12 | Bviii8 | G22C | | | | | |
| E12 | Bx8 | G22C | 2E+08 | CMNT-CCT-Above Confluence of Black and Liesbeek Rivers | Rivers | 120 | n/a |
| E12 | Bvii7 | G22D | 1E+09 | CMNT-CCT-Keysers River on Military Road Bridge | Rivers | 132 | n/a |
| E12 | Bx9 | G22D | 2E+08 | CMNT-CCT-Sandvlei at Yacht Club | Estuary/Lagoon | 86 | n/a |
| E11 | Bviii6 | G22B | 1E+09 | CMNT-CCT-Hout Bay River at Bridge on Princess Road | Rivers | 192 | n/a |
| E11 | Bx10 | G22B | 1E+09 | CMNT-CCT-Hout Bay River at Bridge on Princess Road | Rivers | 192 | n/a |
| E11 | Bvii20 | G22A | 2E+08 | CMNT-CCT-Silvermine River at Clovelly | Rivers | 123 | n/a |
| E11 | Bx11 | G22A | 2E+08 | CMNT-CCT-Silvermine River at Clovelly | Rivers | 123 | n/a |

With CMNT = Catchment; CCT = City of Cape Town, NCWQ = National Chemical Water Quality Network; NCMP = National Chemical Monitoring Programme; GEMS = Global Environment Monitoring System

# 7 GROUNDWATER BALANCE AND CONTRIBUTION TO EWRs

## 7.1 Groundwater's Role in Classification

Groundwater's role in classification studies, and in the associated Reserve and RQO studies, and the resulting methodology, has varied over time (Parsons, 1995; Parsons and Wentzel, 2007; Dennis et al., 2013) and varies between the studies that have been completed to date. The following points summarise the theory underlying the approach applied here to the classification system for groundwater:

- **There is no separate Water Resource Class for groundwater** (a departure from the early guidelines of Parsons (1995), applied by Conrad et al. (1999), and earlier studies such as Classification in the Olifants-Doorn, DWA (2012a) and DWA (2012b)). The primary emphasis of a Water Resource Class is protection of water resources. A Water Resource Class is established for an IUA (only), based on the percentage of biophysical nodes within that IUA that fall into a particular EC (Dollar et al, 2006). Groundwater has a role in supporting this Water Resource Class through its contribution to baseflow, and hence towards part of the EWRs, and hence the EC. As such, a ***separate*** Water Resource Class for groundwater ***is not gazetted*** from this study. This approach is in alignment with DWA (2013), in which it was deemed that gazetting a class would limit groundwater development, and with Riemann (2013).
- **The present status is established for groundwater** largely related to the alteration of the groundwater system from natural state. Various indicators can be used to inform the present status, but it is predominantly linked to the level of use (Dennis et al, 2013), which can be assumed to influence current groundwater contribution to baseflow, and hence to river flow at particular nodes, and hence to the PES.
- **A recommended category can be established for groundwater, however this is related to the recommended EC and hence Water Resource Class.** Via analysis of development driven scenarios, a groundwater yield required for abstraction may be specified. This in turn has implications for groundwater contribution to baseflow, and hence to the ability to meet various EWRs, and hence to the EC and resulting Water Resource Class.
- **An established Water Resource Class dictates the REC, and hence dictates the REC for Groundwater.** Via analysis of conservation driven scenarios, a Water Resource Class may be established based on a required EC, which has EWRs. This in turn dictates the amount of groundwater contribution to baseflow required to be maintained in the river, and hence the groundwater use that is permissible under the Water Resource Class.
- In areas where groundwater has no contribution to baseflow and may form a significant resource, the REC for groundwater will dominate the determination of the class for that particular IUA in order to protect groundwater resources through the WRC process.

Although the above theory may well be widely accepted, the simplifying assumptions required to implement the theory, and the associated scale, data availability and modelling challenges, mean that methods still vary greatly between studies. The method applied also varies between studies naturally based on the location of the study. In some cases, only a present status is calculated (based on use / recharge), and the link between the Water Resource Class and groundwater availability is not considered, hence groundwater availability not specifically calculated (DWA, 2015). This may be an acceptable simplification in areas where groundwater-surface water interaction is minimal, and as such the impact of groundwater's use (and changing abstraction rates) on ecology (and meeting the EWR) is minimal, greatly simplifying the connection between groundwater use and the resulting Water Resource Class.

In other cases, groundwater is recognised as playing an important role in maintaining low flows, and as such, it is assumed that the groundwater contribution to baseflow should be maintained (when setting the Reserve &/ RQOs), in order to ensure groundwater's role to meeting the EWR is met (DWA, 2013). This is also a simplification to some degree, as the low flow may be met in part by interflow (or even return flows from WWTW in altered systems), and EWR may be less than groundwater contribution to baseflow. As such, there may not be the need to maintain all of groundwater's contribution to baseflow (Riemann, 2013).

Also, the above theoretical connection aside, whether the recommended category for groundwater is determined in addition to the REC, per Water Resource Class, and whether the recommended category for groundwater is gazetted along with the Water Resource Class, is often questioned. DWA (2013) did not establish RECs for groundwater, based on the motivation that "there is no guideline and current recommendations are not aimed at maintaining the ecological requirements in the receiving surface water bodies" (DWA 2013, op cit. pg35/206). DWA (2013) therefore consider the primary role of the Water Resource Class to be protection of water resources, and groundwater's primary role in that is maintaining low flows. As such, RQOs are linked directly to maintaining groundwater contribution to baseflow, without specification of a related REC (the related groundwater availability or use / recharge).

The Berg catchment includes areas where groundwater contribution to baseflow makes up a significant portion of runoff (on average 14%, and up to 40% using GRAII data (DWAF 2006), and up to 90% using data the WR2000 Pitman model with Sami GW utility, (i.e. the hydrology model updated and used within this study). It also includes areas where further surface water availability is limited and groundwater development is proposed as a means to meet future demand, and as such any measures that inappropriately limit groundwater availability are to be avoided. Therefore, in this study, attempts were made to fully accommodate groundwater's potential role in classification, thus requiring that in addition to determination of the PS, the relationship between groundwater status (associated to groundwater use), and groundwater contribution to baseflow be established, in order that a Water Resource Class can be related to the RC for groundwater (and hence groundwater use and availability).

A groundwater balance model is developed in which the relationship between availability and groundwater contribution to baseflow is established (albeit highly simplified) and data from which is used to inform the present status. Where various limitations (scale, and associated data) have prevented fully accommodating groundwater's theoretical role in classification, at least the intended analysis is described, along with the necessary simplifications applied.

## 7.2 Groundwater Balance and the Capture Principle

In all (known) WRCS studies (Reserve Determinations, Classification, RQOs) the present status has generally been defined in terms of groundwater stress: the level of groundwater use (within a quaternary catchment, see section 7.3.6, compared to recharge within the same area (Dennis et al., 2013). The underlying assumptions in this calculation are:

i) that recharge is comparable to or an indicator of groundwater availability, and
ii) that the proportion of this recharge/ availability being used, is a direct indicator of the acceptability of groundwater use (at least at regional scale).

These underlying assumptions are in line with those of groundwater balance approaches, in which groundwater availability is set to some portion of recharge. The basis for the water balance approach (recently discussed in Seyler et al. (2016) and summarised here), is that an aquifer, as a contained unit, is in a natural balance over the long term or in steady state: recharge enters the aquifer, and water leaves the aquifer via discharge. Applying thinking consistent with the Law of Conservation of Matter, it is seemingly logical to think then that if an aquifer is pumped more than it is recharged, it will one day run out of water (Delvin and Sophocleous, 2005). Water budget (or balance) type approaches therefore generally compare groundwater use against recharge, and sometimes include the groundwater contribution to baseflow, or to the (ecological) Reserve (Dennis et al., 2013). There is an assumption in the approach that abstraction should not exceed the recharge rate if it is to be considered sustainable. Aquifers with high use compared to recharge are generally identified as “stressed” or “over-utilised”.

This abstraction/recharge approach to groundwater availability can be useful for broad scale resource planning. For potentially under-utilized aquifers it could provide a rapid indication of an aquifer with very low use compared to recharge, suggesting further groundwater development may be feasible. However Seyler et al. (2016) provide examples in which the results of this approach have limited groundwater development in cases where there is high groundwater use compared to recharge, and perhaps incorrectly so as various authors have shown a number of ways in which water balance type calculations are incorrect, inaccurate and are an inappropriate approach for groundwater management.

Application of the water balance approach implicitly means application of the assumption that the recharge rate does not change from the original or natural rate, due to pumping (Delvin and Sophocleous, 2005). This assumption is false as there are a number of mechanisms, each widely accepted and dictated by fundamental groundwater flow theory, by which pumping can affect recharge. Application of the water balance approach also implicitly means application of the assumption that the change in discharge from original or natural under a pumped regime is equal to the pumped yield (related to equation 1, and Delvin and Sophocleous, 2005).

Given that the recharge does not remain constant under pumping, the pumped yield cannot only be equated to the change in discharge. The water balance approach also implicitly assumes that the aquifer is a closed system or a fixed directional flow system in which water only enters through prescribed pathways and only leaves through different prescribed pathways. Aquifers may behave as fixed directional systems under some conditions, but they can change when those conditions change, and saline intrusion is an example of this. The water balance approach also considers only the long term or steady state of an aquifer and does not consider the dynamic nature of aquifer behaviour, and does not allow for the use or management of water stored in the aquifer. It is essentially equivalent to managing a surface water dam at a constant storage/water level only.

A theoretically accurate and appropriate to the assessment of groundwater availability is the Capture Principle Approach, recently discussed in Seyler et al (2016) and summarised here. Under natural conditions an aquifer is in a state of dynamic equilibrium: wet and dry years balance out, aquifer discharge equals recharge, and the groundwater levels (equivalent to the stored volume) are constant over the long-term. When an aquifer is pumped this equilibrium is disturbed, and “water withdrawn artificially from an aquifer is derived from a decrease in storage in the aquifer, a reduction in the previous discharge from the aquifer, an increase in the recharge, or a combination of these changes” (Theis,1940). On pumping, water levels will therefore decline, natural discharge may decline, and recharge may increase.

Over time (and with the same rate of pumping), a new dynamic equilibrium will be reached in response to the changed fluxes (i.e. new discharge mechanisms to abstraction, reduced discharge and or enhanced recharge). Once the new dynamic equilibrium is reached, there is no further loss from storage i.e. groundwater levels no longer decline in response to abstraction. The initial, and the final, reduction in discharge is therefore not directly proportional to the abstracted yield.

The time taken to reach this new dynamic equilibrium (the “response time”) can vary from relatively short to hundreds of years, depending on the aquifer parameters (hydraulic diffusivity) and the distance between abstraction and hydraulic boundaries (rivers, streams, faults) (Sophocleous 2000; Bredehoeft and Durbin, 2009). The magnitude of storage depletion (water level change before new equilibrium is met), is also dependent on the aquifer parameters and location of abstraction.

If the abstraction can be met by changes in the aquifer fluxes (reduced discharge, enhanced recharge) and a new equilibrium can be established (halting water level decline), then the abstraction can be considered maintainable (note, not sustainable) (Delvin and Sophocleous, 2005; Seyler et al., 2016). The maintainable yield therefore depends on the abstraction location within the aquifer, and one value for an aquifer is inappropriate: one value for a combination of wellfields in optimal locations best describes aquifer maintainable yield. Water balance approaches by comparison provide one value for the area assessed.

If "sustainable groundwater use" is defined as groundwater use that is socially, environmentally (ecologically), and economically acceptable, then abstraction of a maintainable yield is not necessarily sustainable. A critical step from quantification of a maintainable aquifer yield to quantification of sustainable groundwater use, is to determine the volume contribution from each source under the new dynamic equilibrium (projected reduced discharge, enhanced recharge, impact on storage / groundwater levels), and then take a socio-economic-environmental decision as to whether this is acceptable (Sophocleous, 2000; Alley and Leake, 2004; Seyler et al., 2016).

Not all abstraction can be maintained. Abstraction from groundwater without an active flow regime (fossil groundwater) simply harvests stored groundwater and groundwater levels continue to fall. "Runaway" drawdown, in which the rate of decline of groundwater level increases over time, is an indication that the abstraction rate cannot be met by changes in the aquifer fluxes (it is not maintainable).

The groundwater theory outlined above dictates that groundwater use/ abstraction will reduce discharge, at some time (dependent on distance and hydraulic diffusivity), but not necessarily by an amount directionally proportional to use. Groundwater use is hence connected to ecological integrity in surface waters (where aquifers discharge to surface water). As the groundwater present status or recommended category is generally defined based on groundwater use, it is related to groundwater contribution to baseflow, and as such, impacts the surface flow and hence relates to the ecological category and hence Water Resource Class. Projection of the impact of pumping on storage / water levels can be completed (for simple situations) with analytical models that derive a characteristic water level decline over time when pumped ("pump curves", Kruseman and de Ridder, 1991).

## 7.3 Groundwater Balance for the Berg Catchment

### 7.3.1 Groundwater Balance Equations

The approach to determining the groundwater balance is underpinned by the hypothesis that sustainable groundwater use is determined by the recharge rate and that if availability is reduced by an amount equivalent to groundwater contribution to baseflow (GWBF), that discharge will continue and surface water is not affected. This can be illustrated by the following equations which are typically applied in desktop scale groundwater availability assessments and Reserve determinations (specifically equation 3):

**Total Groundwater Availability = recharge** **(equation 1)**

**Groundwater availability** (whilst "maintaining" groundwater's contribution to the ecological integrity of surface water, and maintaining ecological integrity in its natural state)

**= recharge – natural GWBF** **(equation 2)**

**Remaining Groundwater availability** (whilst "maintaining" groundwater's contribution to the ecological integrity of surface water, and maintaining ecological integrity in its present state)

**= recharge – current use – current GWBF** **(equation 3)**

The following assumptions underlie these equations:

- The aquifer has reached dynamic equilibrium in response to abstraction, where groundwater recharge is equivalent to discharge. As such, contribution to groundwater availability from storage are not considered.
- Contribution from enhanced recharge is not accommodated (i.e. recharge is constant under abstraction).
- Abstraction is therefore met by reduced discharge (at some time). As discharge is equivalent to recharge (when at dynamic equilibrium), recharge can be used as a proxy for groundwater availability.
- The aquifer is a closed system or a fixed directional flow system.

- If the portion of discharge that is known to support surface water (GWBF) is removed from the availability equation, it is not impacted. I.e., if abstraction is at or set below recharge minus use minus GWBF, then the quantity of GWBF will not be affected.
- Abstraction occurs sufficiently distant from locations of groundwater discharge to surface water, such that abstraction can harness recharge minus use minus GWBF, before reducing GWBF. Said in other words, it is assumed that abstraction is sufficiently distant from surface water such that the portion of recharge discharging to surface waters, is unaffected by the abstraction.

*For the remainder of this section* ***Remaining Groundwater availability (whilst "maintaining" groundwater's contribution to the ecological integrity of surface water's)*** *is simplified to groundwater availability.* The assumption that abstraction occurs sufficiently distant from locations of groundwater discharge to surface water is a significant, and if not met, equation 3 would **overestimate** remaining groundwater availability. It is not possible to overcome this potential overestimate within a water balance approach, which provides one result for the area over which the equation is applied, independent of abstraction location. The results generated with this approach therefore come with the proviso that the resulting groundwater abstraction is a potential yield if abstraction is optimally located and far enough from the river (the exact distance is aquifer specific).

The assumption of dynamic equilibrium in response to pumping is also a significant assumption. If the aquifer response time (related to hydraulic diffusivity and distance to discharge point) is so great that reduction in discharge will not be recognised within a realistic planning timeframe (or 100s years), then "maintaining" GWBF may not be necessary. This is potentially the case in areas where diffusivity is low and surface water discharge points are more distant.  In this case, equation 3i **underestimates** groundwater availability, and groundwater availability could be set simply to recharge minus use. This is also appropriate in areas where the relative contribution from groundwater to flow is negligible such that maintaining GWBF has insignificant contribution to meeting EWR.

The dependence of surface water on groundwater contribution and degree to which the GWBF can meet EWR, was assessed through comparison of GWBF to EWR and MAR (Table 7.8). The analysis also shows that where GWBF is a low portion of EWR (<5%), GWBF/MAR is also very low (generally <1%), indicative of low surface water – groundwater interactions, low dependence of the surface water system, and hence surface water ecology, on GWBF. Hence where the criteria of GWBF/MAR ≤1% (in the final quaternary scale dataset) is met, the equation recharge minus use could theoretically be applied.

Where the response time is short, and groundwater abstraction does within planning horizon reduce discharge to surface water, then a decision is required as to how much (what %) of recharge (equivalent to natural discharge) is considered available. Equation 3 assumes that it is unacceptable to reduce groundwater contribution to baseflow at all. However, if GWBF encompasses all discharge to surface water in a defined area, then recharge minus use, minus GWBF (equation 3), simply equates to unquantified discharge. This discharge may include oceanic discharge, evapotranspiration where water tables are near surface, or lateral recharge to other aquifers beyond the area of assessment (where it may then support groundwater contribution to baseflow in other areas).

These other forms of discharge are not necessarily any more or less available to use than GWBF – depending on the acceptability of reducing the natural discharge.  Nevertheless, if groundwater's primary role in classification is to support / ensure its portion of EWR for a specified EC is maintained, then where EWR is less than GWBF, GWBF in equation 3 is better replaced by EWR to avoid underestimation of groundwater availability.

**Table 7.1 Various surface water – groundwater interaction conditions in the study area, and the corresponding applied groundwater balance equations**

| Conditions In order of hierarchy | Groundwater balance equation | Comments / motivation | Applicability |
|---|---|---|---|
| ***Quaternary catchments with GW-fed wetlands***<br><br>***Quaternary catchments with estuaries*** | *Balance = Recharge – use - GWBF* | *Maintain all of GWBF to protect areas where quantitative EWRs are not always established* | *Applied to all catchments in study area* |
| ***Where ERW > GWBF***<br><br>***(or GWBF/MAR>1%)*** | *Balance = Recharge – use - GWBF* | *Maintain GWBF to protect groundwater's role in meeting EWRs* | |
| ***Where EWR < GWBF*** | *Balance = Recharge – use – EWR* | *If EWR < GWBF do not necessarily need to maintain all of GWBF to protect groundwater's role in meeting a specific EC*<br><br>*Avoids inappropriately limiting groundwater availability* | *Not applied due to hierarchy* |
| ***Where GWBF/MAR<1%*** | *Balance = Recharge – use* | *Limited SW-GW interactions*<br><br>*Very long response time*<br><br>*GWBF plays insignificant role in meeting EWRs, do not necessarily have to maintain GWBF.* | *Not applied due to reduced natural MAR* |

Equation 3 would **underestimate** groundwater availability if:

- Only direct recharge is considered under "recharge", and direct recharge is not the only source of recharge (i.e. indirect natural recharge from surface water losses, or lateral recharge from a unit beyond the boundary considered in the water balance calculation)
- Recharge is enhanced under abstraction (enhanced recharge may increase groundwater availability, and whether the available groundwater yield is considered 'sustainable' depends on an assessment of the acceptability of the impact of abstraction, including the induced recharge, Seyler et al. 2016)

It is not possible to overcome the potential underestimate of neglecting enhanced recharge within a water balance approach, as the hydraulic response to abstraction, and hydraulic connection to surface water, is not considered. It is not possible to account for indirect recharge (losses from surface water) without significant effort to analyse gauge data and model surface water use and evaporation on a small scale in the area of interest. However, some attempts have been made to determine locations of significant lateral recharge and indirect recharge. Lateral recharge from a unit beyond the boundary considered in the water balance calculation is related to the spatial scale of the assessment.

### 7.3.2 Impacts of Spatial and Temporal Scale on data and approach

An assessment of groundwater availability or assessment of impact of groundwater use on discharge (and hence relationship to EWR), whether based on water balance equations or numerical modelling, is appropriately conducted over an area defined by aquifer boundaries. It is this area for which the equations outlined in section 7.3.1 apply, as recharge and discharge within these aquifer boundaries can be considered to balance (over the long-term, and if in dynamic equilibrium). The defined groundwater resource units (GRUs) attempt to follow hydraulic boundaries (aquifer boundaries, flow divides within an aquifer). However, DWS manages surface and groundwater resources based on surface water quaternary catchments, and there is a specific requirement for groundwater information for the study to be presented at quaternary catchment scale. A quaternary catchment often contains several aquifers, and the boundaries do not generally coincide with aquifer boundaries. An aquifer may therefore extend beyond the quaternary boundary the primary implication of which is that recharge within one quaternary flows laterally to another, and may discharge in yet another.

Previous studies have attempted to overcome this disconnect between groundwater boundaries and the need to work at quaternary scale by disaggregating groundwater data (recharge, GWBF, use, remaining groundwater availability) to major aquifers within quaternary catchments (a relatively simple exercise based on outcrop area, DWAF, 2008). The result however is also not ideal. At least shallow groundwater in the quaternary catchment will largely mimic topography and within one quaternary shallow groundwater is likely to be in hydraulic connection between aquifers. For example shallow groundwater in the basement aquifers (Malmesbury Shale and Cape Granite Suite) in higher lying areas of the catchment will be in connection with the lower lying alluvial aquifer (for example G22E, G10L). Reporting the two aquifer balance separately can be misleading when they are in connection and use of one aquifer is supported by lateral recharge in another aquifer within the same quaternary. This kind of hydraulic interaction is common across the Berg, and as such, disaggregation of information to per aquifer per quaternary is not seen as necessary.

In an attempt to meet the need to present data on a quaternary scale, yet address the key simplification of application of surface water boundaries (or at least minimise its impact on results), key major lateral flows across quaternary catchments were identified and taken into account in the establishment of groundwater resource unit (GRU) boundaries. As such, the groundwater balance information is presented per GRU and per quaternary catchment. Groundwater balance data is presented here per quaternary catchment and per GRU.

All relevant quaternary catchments are included in the groundwater balance data:

- Catchment G40A is included in this report, as it is part of the Berg (previous) WMA and hence study area. However, it has been incorporated into a GRU with other catchments in the Breede-Gouritz area and as such is also reported on in the concurrent Breede-Gouritz WRCS study (DWS, 2016c (with identical data / results). The GRU is reported on within the Breede-Gouritz WRCS study.
- Catchments G30A and G30D are not within the Berg WMA, however are part of the Piketberg GRU. They are reported on within this study.

In terms of temporal scale, data for current GWBF and current MAR (from WR2012) were used in the groundwater balance, assuming that aquifers are in dynamic equilibrium in response to current groundwater use, to provide estimates of current remaining availability. EWR is however established based on natural MAR, which may have been supported by higher GWBF, since reduced by groundwater use. Where maintaining EWR requires additional water, groundwater use may (theoretically) have to reduce, up to the difference between natural and current GWBF. The maximum that groundwater could support EWR is natural GWBF, and may be considered in scenario analysis.

### 7.3.3 Summary of approach

The EWR is lower than GWBF at 11% of nodes (5/44). In these cases GWBF can theoretically be replaced by EWR in the groundwater balance equation (Table 7.1). However, for various reasons, GWBF was maintained in all cases:

- All nodes in G21D have EWR<GWBF (disaggregated to nodes). However, groundwater driven wetlands are identified in this quaternary catchment (Table 5.2) and as such, GWBF was maintained in the groundwater balance equation for G21D.

- Node Biv9 in G22E has an EWR lower than the GWBF disaggregated to the node, however the EWR is related to a PEC of E, unlikely to be acceptable. As such, GWBF was maintained in the groundwater balance equation for G22E.
- One node in G10L has EWR<GWBF, however the other has EWR >>GWBF. As such, GWBF was maintained in the groundwater balance equation for G10L.

The analysis also shows that GWBF is a low portion of EWR (<5%) at 13 nodes, indicating a low dependence of the surface water system (and hence surface water ecology) on GWBF. In these areas GWBF / nMAR is also insignificant (<1%). However, because of the large difference between nMAR and current MAR in the Berg, the GWBF / current MAR increases substantially (generally to 10%, and up to 79% in one quaternary). For this reason, the equation recharge minus use was not applied (which is a theoretical possibility where there's low dependence of the surface water system on GWBF).

### 7.3.4 Data selection

Various data including recharge, groundwater use, and groundwater contribution to baseflow were presented in the Status Quo report (DWS, 2016b), per GRU. Due to the numerous sources of data available, which are often widely conflicting, measures were taken to analyse the datasets and select the most appropriate data for the groundwater balance calculations, as described below.

### 7.3.5 Recharge

National recharge data is available for South Africa from the GRAII database (DWAF, 2006), and is used in most regional scale studies. A review of the recharge dataset is provided by DWA (2009), which highlights uncertainties in the data. As part of the Berg Water Availability Assessment Study, various regional GIS-based recharge estimation methods were applied (DWAF, 2008), including a "map-centric" approach:

> "The map-centric simulation considers the different rainfall – run-off responses, the potential overland flow, as well as the actual evapotranspiration, which is dependent upon the effective rainfall and maximum temperature. Furthermore, the delineation of recharge and discharge zones and the seasonal pattern of winter rainfall are taken into account. However, the results for the TMG aquifers are considerably lower than with the other methods… probably due to the emphasis on the slope-dependent overland flow that is not available for infiltration and the delineation of discharge and recharge zones... The results are considered conservative and require verification with other methods like Chloride Mass Balance or Saturated Volume Fluctuation, using spatially distributed field data. On the other hand, the results for the 'intergranular-fractured' aquifer type are significantly higher than compared to the other methods. This would require verification on a local scale prior to allocating the water for use.
>
> …Based on the comparison of the different approaches the recharge estimations from the … map-centric simulation are used as a worst case… [as the total recharge is lower] in the … water balance yield analysis". (DWAF, 2008)

Comparing the map-centric data with GRAII recharge echoes this observation: high-lying catchments dominated by TMG (And high rainfall) have a higher recharge in GRAII, and low-lying catchments dominated by intergranular aquifers (with low rainfall), have lower recharge in GRAII. Nevertheless, the recharge sum over the study area is greater in GRAII (~640 million $m^3$/a compared to 533 million $m^3$/a in map-centric). Although DWAF (2008) point to the need to verify the derived recharge data with local scale data, this level of verification also has not been conducted for GRAII recharge. To be in line with the most recent and most detailed efforts for groundwater resources assessment, the map-centric recharge dataset is used for the groundwater balance presented here.

### 7.3.6 Estimated Groundwater Use

Registered groundwater use was acquired from the Water Authorisation Registration and Management System (WARMS) database, at project commencement (refer to Information and Data Gaps Report).

Significant manual effort was applied to correct erroneous coordinates in the WARMS dataset, through comparison of the registered address with cadastral data (referred to as WARMS 2016 in Table 7.2). A water use dataset was generated from a combination of WARMS and the (then) NGDB database for the Berg WAAS project (DWA, 2008). Furthermore, the GRAII datasets include groundwater use estimates, derived from a combination of methods (such as identification of irrigated fields away from surface water sources for agricultural groundwater use).

These datasets were compared per quaternary catchment, and a summary is shown in Table 7.2.

The sum of groundwater use per quaternary catchment is similar between the WARMS 2016 and WARMS+NGDB 2008, but doesn't perfectly correlate per quaternary ($R^2$ of 0.5 for DWAF 2008 & WARMS 2016), due to the subjective user-decisions involved in manually correcting the WARMS datasets. The correlation between the WARMS and GRAII data is worse with a correlation ($R^2$) of only around 0.1.

In line with the approach of other similar studies (DWAF 2008), preference was given to WARMS data (over GRAII) for groundwater use, and in that the WARMS 2016 dataset sourced at the start of the project (2016). Where registered groundwater use is greater than actual use, the groundwater balance results will be conservative. For all quaternary catchments where WARMS 2016 was different to other estimates of groundwater use by >0.5 million m$^3$/a, the WARMS records in the catchment were further verified and in some cases amended, and this dataset used in the final groundwater balance and analysis.

**Table 7.2 Comparison of water use estimates for Berg WMA**

| Data Source | Sum (million m$^3$/a) | Maximum registration per quaternary catchment (million m$^3$/a) | Number of catchments with sum of abstraction as zero |
|---|---|---|---|
| WARMS ($\Delta$H) (2016) | 78.02 | 8.23 | 2 |
| WARMS+NGBD (DWAF, 2008) | 74.98 | 8.21 | 1 |
| GRAII (DWAF, 2006) | 65.43 | 14.81 | 1 |

### 7.3.7 Groundwater Balance

The results of the groundwater balance are contained in

Table 7.5 per quaternary catchment, and in

Table 7.6 per GRU. The results show that:

- 12 catchments (39%) have a groundwater balance in excess of 10 million m$^3$/a, reaching 48 million m$^3$/a in G10M.
- 18 catchments (58%) have a groundwater balance of 3 – 10 million m$^3$/a.
- One catchment (G21B) has a groundwater balance of less than 1 million m$^3$/a.
- No catchments have a negative groundwater balance.

The sum of remaining groundwater availability is ~374 million m$^3$/a. None of the quaternary catchments have a negative balance. Nevertheless, instances of negative groundwater balance would not necessarily mean groundwater mining is occurring: but simply illustrate that *registered* use within the quaternary catchment, minus GWBF, is greater than recharge within the same catchment. However, there is great uncertainty in each parameter: registered use over-estimates actual use, the recharge data used includes potential direct recharge only, and significant lateral or indirect recharge may occur, and the GRAII GWBF estimates are known to be of low confidence (DWA, 2009). In the Berg WAAS study (DWAF, 2008), a negative balance was reported for only G21B, due to a higher water use estimate derived there than applied here (8.21 compared to 6.33 million m$^3$/a applied here). The difference highlights the uncertainty in deriving water use estimates from WARMS, and the necessity to update this assessment as soon as results of the current Validation and Verification study are available.

Where the datasets are at least regionally representative of the real situation, a negative groundwater balance still does not necessarily indicate unsustainable groundwater use, if sustainability is considered as groundwater use that is economically socially and environmentally acceptable. In these areas the groundwater use may not impact on meeting the EWR, especially if the GWBF is a very small portion of EWR, and if the surface water flow is sufficient to meet EWR (hence groundwater use can still be ecologically acceptable). However (acknowledging the assumptions and shortcomings of a water balance model), the negative balance may indicate groundwater mining (i.e. use of storage that will not be replenished). This also not necessarily a problem. The abstraction will not be maintainable in the very long term, but the response time may be so long that use of storage can occur for hundreds of years.

## 7.4 Present Status Assessment

The present status of groundwater is formally defined in relation to the alteration from pre-development condition. It is a function of groundwater use, and the impacts of that use (Dennis et al, 2013), as summarised in Table 7.3. However, current guidelines (Dennis et al, 2013) then link the present status directly and only to groundwater use as a portion of recharge, as per Table 7.4. Perhaps the reason for this is that use/recharge provides a readily applicable quantitative assessment, and the impacts of use listed in Table 7.3 are rarely quantifiable or represented in regional datasets.

To attribute changes in river flow to groundwater use would require long term monitoring (pre abstraction, and current) in >3 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, interflow) are well known such that the change in GWBF can be accurately determined. The stress categories in Table 7.4 can also be used as spatial compliance categories; i.e. of 20-65% of the quantified units (i.e. quaternary's) in an area (i.e. IUAs) are moderately used, then the groundwater present status for the IUA can be considered II moderately used (Dennis et al, 2013).

Limitations from definition of present status 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 doesn't 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 (section 7.2, section 7.3.2), there is no spatial consideration: an 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 Table 7.4) has negative impacts (those listed in Table 7.3), 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, access to storage, section 7.21).
- 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, 2012b, DWS, 2015) and current guidelines, (Dennis et al, 2013), the Use/Recharge (stress) is calculated per quaternary catchment, and the present status assigned accordingly.

**Table 7.3 Definition of present 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:<br>-spring flow<br>-river flow<br>-vegetation<br>-land subsidence<br>-sinkhole formation<br>-groundwater quality |
| Heavily used (III) | The water resource is significantly altered from its pre-development condition | Moderate to significant impacts to:<br>-spring flow<br>-river flow<br>-vegetation<br>-land subsidence<br>-sinkhole formation<br>-groundwater quality |

**Table 7.4 Recharge/Use as an Indicator for present 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% |

**The results of the present status assessment are contained in**

**Table 7.5 and**

Table 7.6. The results show:

- 25 catchments (81%) have a groundwater stress of <20%, and present status I
- 5 catchments (16%) have a groundwater stress of 20-65%, and present status II
- 1 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

Based on the limitations of a water balance approach, and the limitations of the Present Status definition, it is noted that high stress / present status of III does not necessarily equate to an area where abstraction is not maintainable, or has unacceptable impacts. For example G21B incorporates the Atlantis aquifer, used by the City of Cape Town for municipal supply (one of the registered users in the catchment). Abstraction is supported by artificial recharge, not incorporated in the stress index calculation. Various considerations will be taken into account in the prioritisation of GRUs for RQO determination, and it is suggested that (at least) G21B be assessed in greater detail in future stages of the project.

**Table 7.5 Groundwater Balance, Use/recharge (Stress), and Present Status per Quaternary catchment**

| Quaternary | Recharge ($Mm^3/a$) | Use ($Mm^3/a$) | GWBF ($Mm^3/a$) | Balance ($Mm^3/a$) | Use/Recharge (%) | Present Status |
|---|---|---|---|---|---|---|
| G10A | 21.09 | 3.90 | 7.25 | 9.93 | 19% | I |
| G10B | 12.27 | 0.36 | 5.34 | 6.57 | 3% | I |
| G10C | 22.88 | 2.64 | 2.26 | 17.98 | 12% | I |
| G10D | 31.03 | 3.87 | 5.00 | 22.15 | 12% | I |
| G10E | 16.05 | 4.65 | 2.25 | 9.14 | 29% | II |
| G10F | 15.05 | 0.98 | 4.33 | 9.74 | 7% | I |
| G10G | 8.84 | 0.00 | 2.73 | 6.11 | 0% | I |
| G10H | 17.18 | 1.62 | 3.28 | 12.28 | 9% | I |
| G10J | 23.74 | 0.38 | 2.36 | 21.00 | 2% | I |
| G10K | 39.34 | 7.50 | 1.18 | 30.66 | 19% | I |
| G10L | 44.35 | 4.17 | 1.99 | 38.19 | 9% | I |
| G10M | 55.50 | 1.97 | 5.70 | 47.83 | 4% | I |
| G21A | 14.77 | 0.77 | 0.29 | 13.71 | 5% | I |
| G21B | 7.50 | 6.33 | 0.53 | 0.64 | 84% | III |
| G21C | 8.84 | 0.57 | 1.95 | 6.32 | 6% | I |
| G21D | 14.25 | 6.97 | 3.27 | 4.02 | 49% | II |
| G21E | 21.85 | 3.97 | 4.21 | 13.67 | 18% | I |
| G21F | 5.07 | 0.13 | 1.71 | 3.23 | 3% | I |
| G22A | 6.81 | 0.06 | 3.24 | 3.51 | 1% | I |
| G22B | 4.22 | 0.04 | 0.65 | 3.52 | 1% | I |
| G22C | 13.07 | 3.54 | 2.56 | 6.97 | 27% | II |
| G22D | 13.08 | 7.31 | 2.40 | 3.37 | 56% | II |
| G22E | 12.27 | 0.92 | 2.63 | 8.71 | 8% | I |
| G22F | 8.54 | 0.50 | 2.41 | 5.63 | 6% | I |
| G22G | 6.57 | 0.82 | 1.10 | 4.66 | 12% | I |
| G22H | 14.03 | 1.25 | 2.08 | 10.70 | 9% | I |
| G22J | 11.28 | 0.51 | 1.58 | 9.20 | 4% | I |
| G22K | 4.78 | 0.24 | 1.06 | 3.48 | 5% | I |
| G30A | 27.88 | 3.81 | 1.19 | 22.88 | 14% | I |
| G30D | 15.61 | 8.23 | 0.62 | 6.76 | 53% | II |
| G40A | 15.26 | 0.00 | 3.17 | 12.09 | 0% | I |

**Table 7.6 Groundwater Balance, Use/recharge (Stress), and Present Status per GRU**

| GRU Name | Recharge ($Mm^3/a$) | Use ($Mm^3/a$) | GWBF ($Mm^3/a$) | Balance ($Mm^3/a$) | 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 |

## 7.5 Contribution to Baseflow and EWRs of River Nodes

Data for Groundwater contribution to base flow (GWBF) along with total baseflow is available per quaternary catchment from the GRAII database (DWAF 2006). Data for GWBF per quaternary catchment along with total baseflow and interflow is also a component of the WR2000 Pitman model with Sami GW utility used in this surface water analysis. A comparison of these two datasets (in terms of sum per quaternary catchment) reveals a lack of correlation (an $R^2$ of 0.003 for current GWBF, and 0.04 for natural GWBF).

In line with previous studies (DWAF 2008), a preference was placed on the GRAII dataset, for the following reasons:

- The WR2012 Pitman model data is considered unrealistically low. The median GWBF/Recharge is only 6%, with 25 out of 31 catchments having GWBF/Recharge <10%.
- Quaternary catchments with the largest difference between natural and current GWBF in the GRAII database do correlate with those where groundwater use is high (although not all quaternary catchments with high groundwater use are recorded to have a large decline). The same is not true for data in the WR2012 Pitman model: quaternary catchments with high reduction in GWBF do not correlate to high use.

However, in seven catchments the GRAII GWBF, and total baseflow, is zero, correlating with drier catchments in the lower Berg (West Coast GRU quaternary's), and the Cape Flats area (G22D). These catchments have limited MAR, and as such the GRAII model appears to have assumed baseflow is zero.

Whilst groundwater contribution to surface water may be limited, these catchments do have recharge, are composed of highly permeable intergranular aquifers, which will decant to the rivers and streams present.

Localised numerical models have also quantified GWBF in some areas of the catchment (i.e. Seyler et al, 2016) and these values were also consulted where required. GRAII data was derived in 2006, and the WR2012 model has been recalibrated for this study. In some circumstances, the GRAII GWBF was > current MAR (considered potentially unrealistic). The following steps were taken to derive the final dataset:

- GRAII data was used in catchments where values were non-zero.
- In catchments where GRAII GWBF is zero, yet based on the catchment setting (geology, recharge, total baseflow in GRAII and WR2012 Pitman) some GWBF was deemed likely, then GWBF was established by assigning the most reasonable out of:
    - the WR2012 Pitman GWBF data
    - calculating GWBF by the median portion of total baseflow from surrounding catchments
- In G10M the GRAII GWBF is zero, the WR2012 Pitman data shows GWBF of 1.87 million $m^3/a$. The Langebaan Lagoon in G10M (estuary node Bxi3) is known to be groundwater fed, and to meet the Recommended Ecological Category of A (EWR report), this discharge would need to be maintained. The groundwater discharge to the lagoon has most recently been quantified using a numerical model in Seyler et al (2016). The GWBF from this model was applied.
- Where GRAII GWBF was > current MAR, GWBF was set at midway between the GRAII estimate and the WR2012 estimate.

The sum of GWBF in the final dataset is therefore slightly higher than the GRAII data (Table 7.7), which represents a cautious approach to the groundwater balance.

**Table 7.7 Statistics comparing various estimates of Groundwater Contribution to Baseflow per quaternary catchment**

| Parameter | GWBF (million $m^3$/a) | | |
|---|---|---|---|
| | WR2012 Pitman + Sami | GRAII | Final used |
| Mean | 1.09 | 2.20 | 2.59 |
| Median | 1.18 | 2.25 | 2.36 |
| Max | 2.90 | 7.25 | 7.25 |
| Min | 0.00 | 0.00 | 0.29 |
| St dev | 0.74 | 1.82 | 1.62 |
| Count quaternary with zero | 2 | 7 | 0.00 |
| Sum (all quaternaries) | 33.66 | 68.34 | 80.32 |

Some portion of the flow required to maintain a particular EC for river, wetland or estuary is derived from surface water (runoff), and some from groundwater via groundwater contribution to baseflow (GWBF). Use of groundwater can potentially reduce the GWBF and hence impact the flow in the river necessary to maintain the recommended ecological category (REC). A groundwater balance model has been established to support scenario evaluation (Step 5). However prior to establishing the groundwater balance model, information is required on *the degree to which EWRs can be met by GWBF,* for two purposes:

1. The role of GWBF in meeting EWR shapes the approach to the groundwater balance model.
2. The information will assist in prioritisation of resource units and the development of RQOs, such that GWBF can be protected, supporting groundwater's role in maintaining ecological integrity.

In this study EWRs are defined at biophysical nodes. However, groundwater discharge to surface water can occur over large distributed areas which may extend beyond quaternary boundaries (i.e. a alluvial aquifer surrounding a river), along specific river reaches, or at points related to spring discharge, and is not homogenously distributed across the catchment or aquifer (Riemann, 2013).

Data for GWBF is available to the study per quaternary catchment from the GRAII database (DWAF 2006). GWBF is also a component of the WR2000 Pitman model with Sami GW utility, used in the surface water component of the study, and available per quaternary catchment. Using these two datasets, a final GWBF dataset was established for the project. In order to compare GWBF to EWR, the final GWBF dataset was disaggregated to biophysical nodes based on the proportion of the area of the quaternary catchment upstream of a particular node. The following procedures were applied in the establishment of a representative node (and associated EWR) per quaternary catchment:

The GWBF values are not considered cumulatively along a river course. The GWBF per catchment reflects the GWBF contribution to surface water across a particular quaternary catchment (or between two nodes when disaggregated): but flow in that catchment will be contributed to by GWBF from upstream catchments.

This approach has the potential to underestimate groundwater availability (by 'maintaining' all GWBF contributed per quaternary catchment in groundwater balance equations, section 7.1), given that some GWBF at a particular node may be contributed to the river farther upstream, not 'used' from the river, hence still available to provide for GWBFs role in meeting the EWR downstream. Nevertheless it can be seen as conservative. Also, the spatial disaggregation of GWBF alters an already low- confidence dataset away from the boundaries over which it was intended for use. These challenges arise due to the differing scale and physical processes that the two datasets represent (section 7.1).

It is therefore stressed that this activity was completed as an indicator, alongside GWBF/MAR, for groundwater's role in meeting EWRs, but that the results should only be taken as indicative of the ***relative*** importance of groundwater to support meeting EWRs, rather than quantitative values.

Groundwater is particularly important in terms of maintaining the EWRs during the low flow period. Hence the relative contribution from groundwater was also determined as a percentage of the maintenance low flow EWR for the reserve sites (i.e. river nodes for which EWRs were determined). This was not for all nodes and the results for those nodes are indicated in Table 7.8.

The GWBF/EWR proportion and GWBF/MAR are expressed as a percent in Table 7.8 and show that:

- The median GWBF/EWR for the study area is 16%;
- GWBF/EWR is low to moderate (<16%) at 22 nodes,
- GWBF/EWR is moderate to high (17-75%) at 12 nodes,
- GWBF/EWR is high (>75%) at 8 nodes.
- The nodes for which GWBF/EWR where considered low, moderate and high were also the same nodes for which the GWBF/EWR-MLF were also low, moderate and high.

## 7.6 Sensitive Areas at Risk from Groundwater Abstraction

A potential impact of abstraction is the reduction of natural discharge (to the ocean, rivers, wetlands and estuaries), or enhanced recharge from surface water, both of which in turn have a potential ecological impact. These impacts, however are rarely monitored which makes it very difficult to identify risk areas.

In the Berg catchment, for example there are no known cases where groundwater abstraction has caused an unacceptable ecological impact, although there are areas where there is the potential for significant impact, particularly given current and future demands for groundwater.

Based on the limitations of a water balance approach, and the limitations of the Present Status definition, it is noted that high stress / present status of III does not necessarily equate to an area where abstraction is not maintainable, or has unacceptable impacts, particularly with regards to sensitive ecological areas.

**For example G21B incorporates the Atlantis aquifer, used by the City of Cape Town for municipal supply, and and has a present status of III (**

Table 7.5). Abstraction is supported in part by artificial recharge, which is not incorporated in the stress index calculation. The natural (pre abstraction) discharge is largely to the coast. Reducing this discharge is likely to have minimal ecological impact. The same is true for abstraction in the Philippi area of the Cape Flats aquifer. Natural discharge to the ocean and to the largely canalised streams crossing the Cape Flats aquifer will be reduced by current and potential future abstraction.

Groundwater availability in the Langebaan Road Aquifer (Langebaan Road area, G10M) and the Elandsfontein Aquifer System (G10M and G10L) is high. The Langebaan Lagoon has been shown to be dependent on groundwater inflow. Groundwater abstraction in the area (for mining or other potential future developments) has the potential to reduce discharge to the Langebaan Lagoon, and given the lack of other freshwater sources to the lagoon, this has the potential to impact the ecological functioning of the lagoon and in particular the sensitive wetland areas in the West Coast National Park. The degree of impact on these wetlands and the lagoon would however depend on the location and rate of abstraction, and on whether abstraction is from an upper of lower aquifer present in the area (Seyler et al, 2016).

**Table 7.8 Groundwater Contribution to Baseflow (GWBF) per node, compared to EWR and nMAR.**

| Node | Quaternary | EWR (Mm³/a) | EWR-MLF (Mm³/a) | nMAR (Mm³/a) | GWBF (Mm³/a) | GWBF/ EWR | GWBF /EWR-MLF | GWBF/ nMAR |
|---|---|---|---|---|---|---|---|---|
| Bvii13 | G10A | 84.5 | | 84.5 | 3.4 | 4% | | 4% |
| Bviii1 | G10A | 44.0 | 27.4 | 141.7 | 2.4 | 5% | 9% | 2% |
| Biv5 | G10A | 5.3 | 2.9 | 34.9 | 1.5 | 27% | 51% | 4% |
| Biii2 | G10B | 12.5 | 6.0 | 85.6 | 5.3 | 43% | 89% | 6% |
| Biii3 | G10C | 92.2 | 65.0 | 418.1 | 1.8 | 2% | 3% | 0% |
| Bvii14 | G10C | 9.8 | 5.9 | 43.7 | 0.5 | 5% | 9% | 1% |
| Bvii10 | G10D | 101.8 | 71.8 | 461.6 | 0.9 | 1% | 1% | 0% |
| Bvii5 | G10D | 177.4 | 83.1 | 534.3 | 2.8 | 2% | 3% | 1% |
| Bvii3 | G10D | 2.6 | 1.1 | 18.2 | 0.4 | 14% | 36% | 2% |
| Bvii4 | G10D | 3.5 | 1.4 | 24.8 | 0.5 | 16% | 37% | 2% |
| Bvii15 | G10D | 0.6 | 0.3 | 3.8 | 0.3 | 57% | 120% | 9% |
| Biii4 | G10E | 18.7 | | 84.2 | 2.3 | 12% | | 3% |
| Bvii11 | G10F | 115.1 | 74.0 | 557.0 | 1.8 | 2% | 2% | 0% |
| Bi1 | G10G | 125.0 | | 125.0 | 2.7 | 2% | | 2% |
| Bvii8 | G10J | 185.2 | 119.1 | 896.4 | 0.3 | 0% | 0% | 0% |
| Bvii6 | G10J | 177.9 | 114.3 | 860.7 | 0.4 | 0% | 0% | 0% |
| Bvii16 | G10J | 21.5 | | 21.5 | 0.1 | 0% | | 0% |
| Biv1 | G10J | 140.3 | | 679.0 | 1.8 | 1% | | 0% |
| Biv4 | G10J | 24.1 | 11.5 | 165.5 | 0.5 | 2% | 4% | 0% |
| Biv3 | G10J | 14.4 | 6.3 | 96.8 | 0.8 | 5% | 13% | 1% |
| Bvii17 | G10J | 1.9 | 1.0 | 9.2 | 0.4 | 23% | 41% | 5% |
| Bvii18 | G10J | 0.5 | | 3.3 | 0.4 | 78% | | 12% |
| Biii5 | G10J | 4.2 | 1.2 | 32.9 | 3.3 | 78% | 274% | 10% |
| Bvii12 | G10K | 217.5 | 151.9 | 901.8 | 0.3 | 0% | 0% | 0% |
| Biv2 | G10L | 223.0 | 155.8 | 924.5 | 1.1 | 1% | 1% | 0% |
| Bii1 | G10L | 1.7 | | 13.7 | 2.0 | 117% | | 15% |
| Bviii3 | G21A | 0.1 | 0.1 | 1.0 | 0.0 | 23% | 0% | 2% |
| Bviii10 | G21B | 1.0 | | 6.2 | 0.5 | 48% | | 8% |
| Bv1 | G21D | 1.9 | 0.8 | 13.7 | 1.9 | 103% | 250% | 14% |
| Biv6 | G21D | 1.3 | 0.6 | 9.3 | 2.6 | 201% | 450% | 28% |
| Bviii4 | G21D | 0.3 | 0.1 | 2.3 | 0.7 | 218% | 483% | 28% |
| Biv7 | G21E | 4.3 | 1.8 | 30.3 | 4.2 | 98% | 239% | 14% |
| Bviii5 | G21F | 8.6 | | 60.8 | 1.7 | 20% | | 3% |
| Bvii20 | G22A | 3.5 | | 3.5 | 0.3 | 8% | | 8% |
| Bviii6 | G22B | 2.6 | 1.2 | 17.2 | 0.7 | 25% | 56% | 4% |
| Bviii8 | G22C | 3.6 | | 23.2 | 1.0 | 28% | | 4% |
| Bvii7 | G22D | 0.7 | 0.3 | 4.5 | 0.2 | 28% | 57% | 4% |
| Biv9 | G22E | 0.6 | | 20.3 | 2.4 | 389% | | 12% |
| Biii6 | G22F | 8.3 | 5.1 | 36.6 | 2.4 | 29% | 47% | 7% |
| Biv8 | G22G | 4.3 | 1.4 | 30.3 | 1.1 | 26% | 81% | 4% |
| Bvii21 | G22J | 15.8 | 7.9 | 70.0 | 1.6 | 10% | 20% | 2% |
| Bviii9 | G22K | 11.8 | 8.1 | 48.7 | 1.1 | 9% | 14% | 2% |
| Bvii22 | G40A | 4.7 | 3.9 | 34.8 | 3.2 | 68% | 83% | 9% |

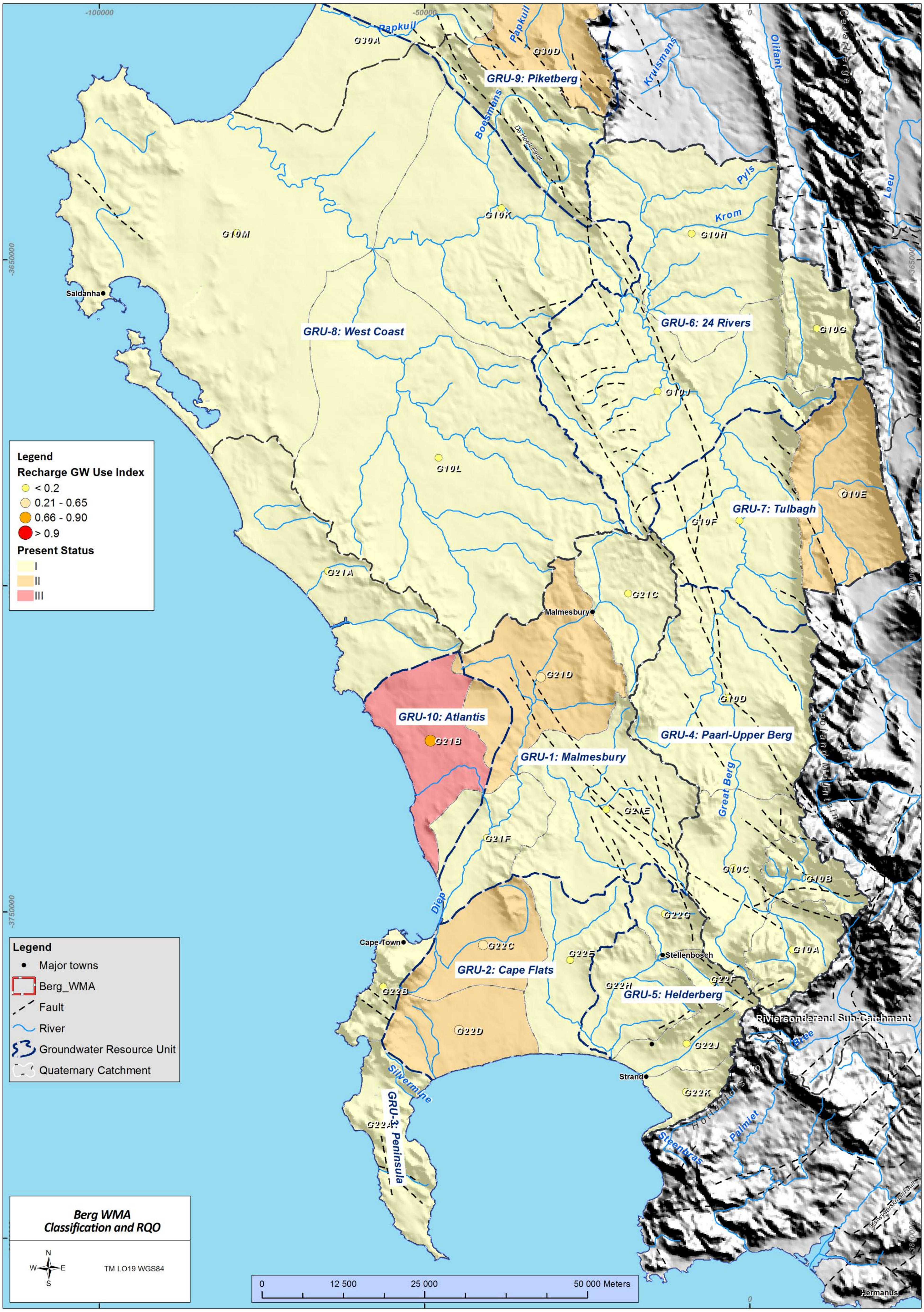


**Figure 7.1** Map showing Use/Recharge and resulting present status per quaternary catchment

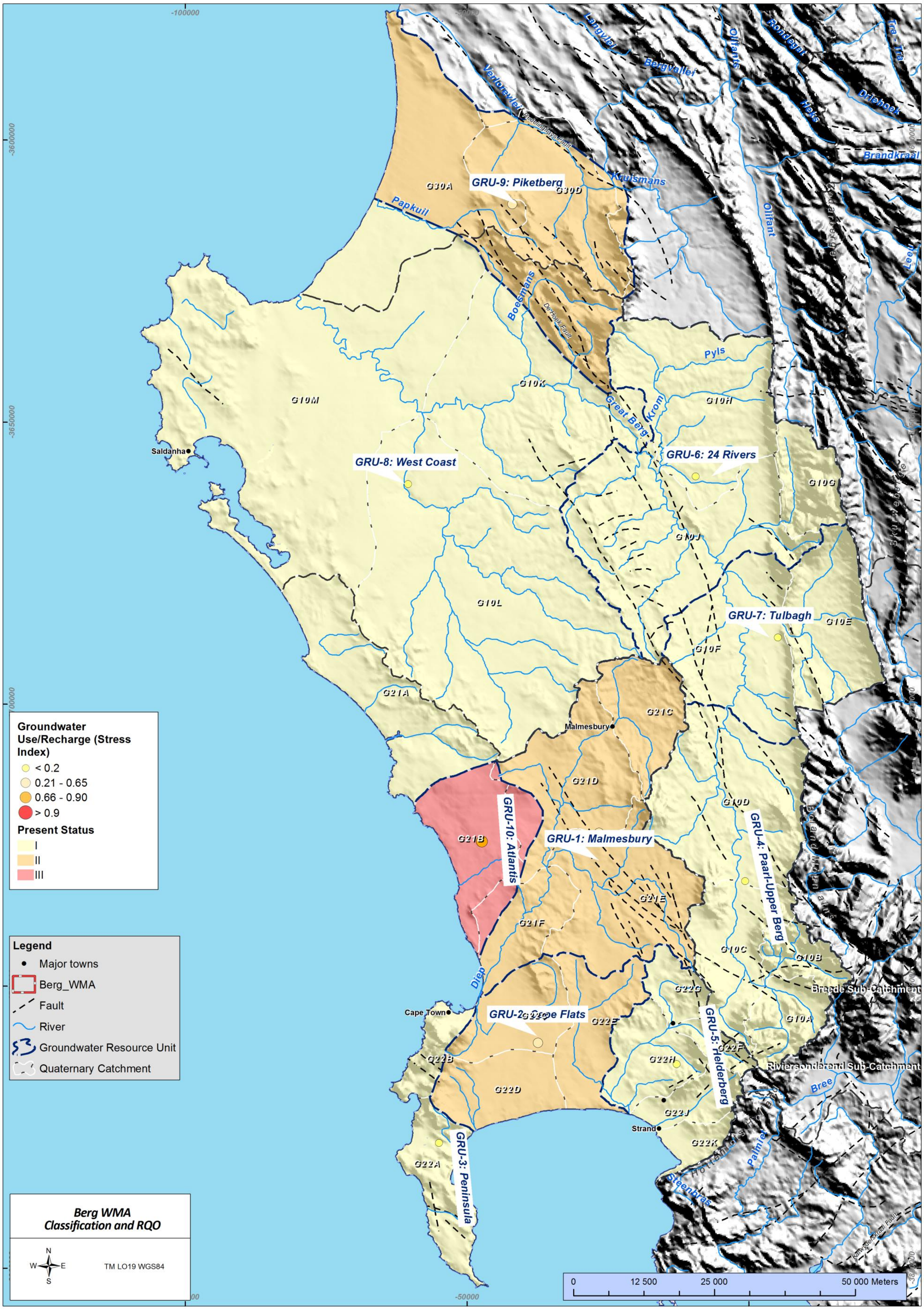


**Figure 7.2 Map showing Use/Recharge and resulting present status per GRU**

# 8 CHANGES IN ECOLOGICAL GOODS, SERVICES AND ATTRIBUTES (EGSA)

## 8.1 Overview

The objective of Step 3c is to *quantify the changes in relevant ecosystem components, functions and attributes for each category for each node* to help evaluate the socio-economic and ecological implications of different catchment configuration scenarios in later steps of the classification procedure (DWAF, 2007).

The ecosystem changes at different ecological categories allow for the consideration of ecological and socioeconomic information at different scales and enables the evaluation of various ecological catchment configurations. Thus, in terms of the socio-economic evaluation of scenarios, it is important to understand what the Ecosystem Goods Services and Attributes (EGSAs) are, the nodes at which the changes can be provided, and the changes that occur based on different characteristics within the water resource.

As per the WRCS guidelines the required information on changes in ecosystem components can be related to hydrological characteristics, biological components and processes, physical components and processes, structure and organisation of aquatic ecosystems and water quality characteristics.

This section details the EGSAs information required for socio-economic evaluation and the ecosystem changes that relate to these EGSAs considered for the study area. The EGSAs aspects considered were assessed based on a change in ecological category. The significance of the change is described in terms of the socio-economic assessment. In many instances the ecosystem changes will be quantified in the assessment of the scenarios (catchment configurations).

## 8.2 Ecosystem Goods, Services and Attributes for the Study Area

The sectors dependent on aquatic ecosystem services could either shrink or expand as a result of changing to a lower or higher ecological class, respectively. The availability and quality of water in rivers, wetlands and estuaries and the overall condition of these natural systems influence their capacity to deliver aquatic ecosystem services. These, in turn, will influence the value of final goods and services generated by activities that depend on them.

In this study, the main sectoral impacts considered are tourism, property and inshore fisheries. These sectors and their linkages to the aquatic ecosystem services in the study area are explained in more detail in the *Status Quo Report* (DWS, 2016c). Estuaries are the main freshwater-dependent ecosystems that impact on all three of these sectors, but rivers and wetlands can also influence tourism values.

In addition, we also consider the impact of changes in ecosystem condition on human wellbeing. This requires estimating the relationships between ecosystem condition and the capacity to supply natural resources, as well as amenity values such as recreation and spiritual fulfilment.

## 8.3 Relationship between EGSAs

The value of ecosystem services resides in the contributions that they make to human well-being. Of particular relevance is determining how changes in the supply of ecosystem services affect human well-being.To understand this, it is necessary to understand the underlying links between ecosystem structure and function and the supply of ecosystem services as well as their demand.

The condition of the aquatic ecosystems in the study area will vary under each of the Classification Scenarios. This will be expected to have an impact on their attributes that are valued by society as well as their capacity to deliver goods and services.

The main types of ecosystem services considered are summarised below, 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).

**Table 8.1 Main ecosystem services provided by estuaries of the study area, and the main flow-related variables that can be derived from RDM studies to estimate changes in the capacity to deliver these services**

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

The above relationships were used as a guide for the assumptions in this study. The relevant relationships and assumptions are described in more detail below.

### 8.3.1 Sustainable yield of stocks used by subsistence fishers

Rivers, wetlands and estuaries provide numerous resources which can be harvested, including raw materials such as reeds, fish, invertebrates, and food and medicinal plants. The delivery of these ecosystem goods is a function of the productivity of the system. The value of this service depends on the extent to which it is demanded, which can be influenced by regulation, as in the case of protected areas.

**Table 8.2 Factors to estimate changes in sustainable yield relative to present-day**

| | | Assigned Ecological Category | | | |
|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** |
| **PES** | **A** | 1.0 | 0.9 | 0.7 | 0.5 |
| | **B** | 1.2 | 1.0 | 0.8 | 0.6 |
| | **C** | 1.4 | 1.2 | 1.0 | 0.7 |
| | **D** | 2.0 | 1.7 | 1.4 | 1.0 |
| | **E** | 3.7 | 3.2 | 2.6 | 1.8 |
| | **F** | 23.0 | 19.8 | 15.9 | 11.3 |

### 8.3.2 Nursery function

Numerous species use estuaries as nursery areas and many of these are important in marine line fisheries. Most estuary-dependent fish species enter the estuary as larvae or post larvae and once the estuary dependent phase is complete, they leave the estuary for the marine environment where they become available to marine fisheries, and upon maturity contribute to the spawning stock.

The contribution of estuaries in terms of their outputs of these fish depends on their suitability as a nursery area, which, in turn is determined by the size and quality of the habitat and the amount of connection to the marine environment. These factors are taken into consideration when estimating changes in the populations of estuary-depending fish for the evaluation of estuary health. Estuary dependent fish form a significant component of estuary fish populations, and for this reason, it is acceptable to use the overall fish health score to estimate changes in estuary capacity to perform this service.

Currently it is estimated that the degradation of estuaries in the Western Cape (largely due to freshwater starvation, but also due to illegal fishing) has already led to the reduction of the nursery function to approximately 27% of the original capacity, which amounts to losses to the value of some R675 million (Turpie *et al*. 2014). This is because some of the most important nursery areas that account for much of the overall capacity have been severely degraded.

A similar approach was used in this study, in which capacity for nursery function was related to fish abundance score. However, this is simplified to a class level analysis, using the same multipliers as in Table 8.4.

### 8.3.3 Aesthetic/recreational appeal

Rivers, wetlands and estuaries may contribute to the tourism appeal of areas, and thus it can be expected that a change in their condition may affect tourism demand and values. In particular, estuaries are a dominant feature of many coastal resort areas in the study area, and have been investigated in some detail for this analysis. The approach derived here will be used for all aquatic systems.

These attractions, combined with other attractions, provide the amenity values that drive people to visit or even invest in property to remain in these areas. The tourism and property values of all the estuaries in the study area have been estimated in the *Status Quo Report* However, the Classification Process also requires an understanding of how these values might change as a result of changes in the characteristics of the systems. Very little research has been carried out on this, and previous classification studies have avoided this issue altogether.

Turpie and Clark (2007), in their assessment of how values would change with or without conservation measures, assumed that the relationship between amenity values and estuary health was logarithmic in form, with people being largely insensitive to decreasing health until a relatively low state of health is reached, after which value would drop off rapidly.

***Tourism value***

The tourism value estimated for each of the estuaries in this study was analysed in relation to nine different variables, using an ordinary least squares (OLS) regression (using *R Project for Statistical Computing (ver. 3.2.0*) (Table 8.3).

A total of 49 estuaries from both the Berg study area and the Breede-Gouritz Water Management Area (WMA) were included in the analysis to determine a tourism value associated with the estuary. A semi-log model was specified as follows:

$$Ln\, TV_e = \beta_0 + \beta_1 S_e + \beta_2 E_e + \beta_3 P_e + \varepsilon_e$$

where the dependent variable ($Ln\, TV_e$) is the natural logarithm of the tourism value for each estuary. $S_e$ represents the size of the estuary, $E_e$ the measure of environmental and health characteristics and $P_e$ represents the physical and social variables of interest. Similarly $\beta_0, \beta_1, \beta_2, \beta_3$ represent the corresponding parameters to be estimated, whereas $\varepsilon_{pt}$ captures the stochastic error term. The model was improved by disregarding collinear variables and non-significant variables through a stepwise approach.

The water quality score, fish score and overall health score were all correlated and a result, through a stepwise approach, only the variable contributing the most to the overall fit of the model was retained. The distance to Cape Town variable was removed early on in the analysis as it was insignificant and did not contribute to the overall model fit.

**Table 8.3 Definitions of variables used in the tourism value model**

| Independent variables | Unit | Description |
|---|---|---|
| **Size** | Ha | Size of the estuary in hectares |
| **Overall Health** | Score | Overall health score of estuary based on abiotic and biotic components |
| **Scenic beauty** | Score | Score out of 10 given to each estuary by a panel (Turpie and Clark, 2007) |
| **Water quality** | Score | Water quality health score given to each estuary |
| **Fish** | Score | Fish health score given to each estuary |
| **Distance to CT** | Km | Distance along national roads from each estuary to Cape Town |
| **Non-estuary tourism drawcards** | Score | Score out of 10 based on the availability of shops, restaurants and bars, recreational activities, golf courses and access to coastline and a swimming beach. The scores for these were weighted (40% beach and coast, 30% hospitality, 20% terrestrial activities, 10% golf) and summed to generate a score out of ten. |
| **Population size** | Categorical | The size of the surrounding population was given as low, medium or high |

The final model included estuary size, overall health score, non-estuary tourism drawcards, population and scenic beauty (Table 8.4). However, only two of these variables were significant and contributed to the overall model fit. Through a stepwise approach overall health score, population and scenic beauty were dropped from the model. Estuary size and non-estuary tourism drawcards were found to be the two most important variables influencing the tourism value associated with estuaries.

The adjusted $R^2$ (0.46) indicates only a reasonable model fit of the data into the specified model and the two variables retained in the model were statistically significant at the 1% level.

Table 8.4 Results of the regression estimates from the tourism value model

| Variable | Co-efficient | Standard error | t-value | Pr (>F) | |
|---|---|---|---|---|---|
| (Intercept) | 13.9500 | 0.5124 | 27.24 | < 2.2e-16 | *** |
| Estuary size | 0.0005 | 0.0002 | 2.29 | 0.000168 | *** |
| Non-estuary drawcard score | 0.8703 | 0.1854 | 4.69 | 0.000025 | *** |
| Sample size | | | | 49 | |
| R-squared | | | | 0.46 | |

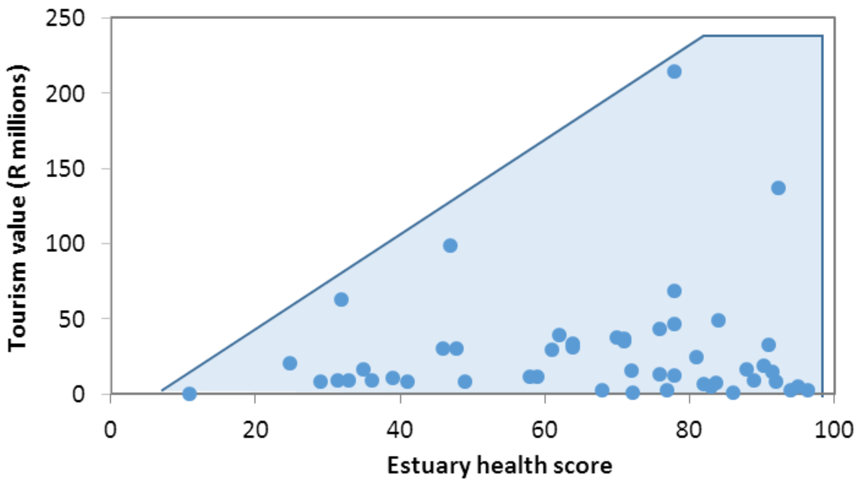


Figure 8.1 The relationship between tourism value and estuary health score

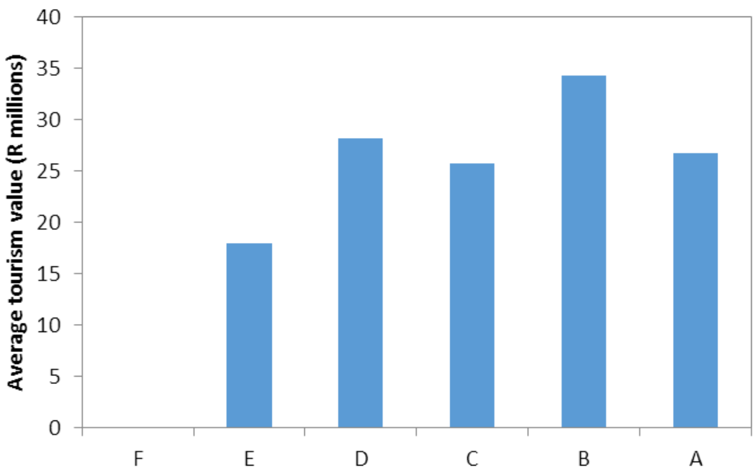


Figure 8.2 The relationship between average tourism value and estuary ecological health category

Based on the above relationship, a rule curve was derived with which to estimate the potential changes in tourism value as a result of changes in estuary health. This was used to develop a set of factors with which to adjust tourism value for changes from PES to alternative Ecological Categories in the scenario analysis (Table 8.5).

Table 8.5 Factors to estimate changes in property value attributed to estuaries, relative to present-day

| | | Assigned Ecological Category | | | |
|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** |
| **PES** | **A** | 1.0 | 1.0 | 0.9 | 0.8 |
| | **B** | 1.1 | 1.0 | 0.9 | 0.8 |
| | **C** | 1.1 | 1.1 | 1.0 | 0.9 |
| | **D** | 1.3 | 1.2 | 1.1 | 1.0 |
| | **E** | 2.0 | 1.9 | 1.8 | 1.6 |

***Property value***

An analysis of our property value estimates yielded similar results to those for tourism value. The estimated property value associated with estuaries was weakly related to EHI. However, the pattern suggests that potential for high property values is highest for estuaries of moderate to good health, and decreases with decreasing and increasing health. This makes sense, because estuaries of low health are not attractive for recreational use, and estuaries that are of very high health are usually protected and/or relatively inaccessible. In fact, high levels of property development around an estuary would seldom allow an estuary to retain a very high level of health.

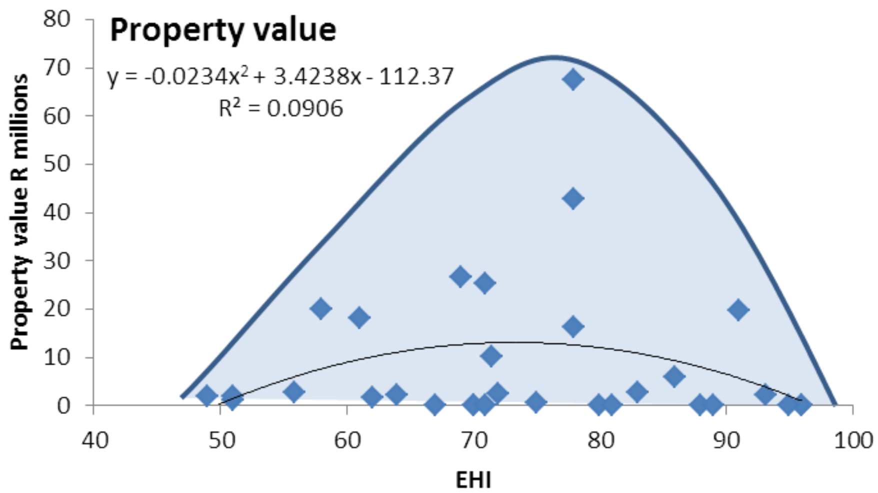


**Figure 8.3 The relationship between property value and estuary health score**

However, for all else being equal, if an estuary increases in health, property values would be expected to be unchanged or to increase, whereas a decrease in health would be expected to lead to a loss of property value. The factors to estimate changes in property value as a result of changed estuary health were estimated based on the average property value per estuary in each Ecological Category, but with the assumption that increases in condition from a B to an A class, for all else being equal, would lead to a slight increase in property value (Table 8.6).

**Table 8.6 Factors to estimate changes in property value attributed to estuaries, relative to present-day**

| | | Assigned Ecological Category | | | |
|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** |
| **PES** | **A** | 1.0 | 1.0 | 1.0 | 0.7 |
| | **B** | 1.0 | 1.0 | 1.0 | 0.7 |
| | **C** | 1.1 | 1.0 | 1.0 | 0.7 |
| | **D** | 1.5 | 1.5 | 1.4 | 1.0 |
| | **E** | 2.8 | 2.7 | 2.6 | 1.8 |

# 9 THE WAY FORWARD

The data on EWRs and changes in the non-water quality EGSAs will be used to determine the flow requirements at individual nodes based on the recommended ecological class as well as to determine the impact of alternative development scenario on the ecological condition of individual nodes. The associated impact in terms of changes in EGSAs will then be used to evaluate the impacts of alternative scenarios.

The general approach to the scenario analysis has been described in the *Linking the Value and Condition of the Water Resource* Report (DWS, 2017) and will be further developed as part of the *Ecological Base Configuration Scenarios* Report (DWS, in prep). The development of current and future development scenarios and the analysis of the potential impact of these scenarios is the next step.

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# Appendices

Appendix A: Additional Reserve Determination Studies (Quantity) for Diep, Lourens, and Eerste Rivers (Rapid Level III)

Appendix B: EWR Summary Tables (G1 and G2)

Appendix C: Additional Habitat Assessments

Appendix D: PES/EIS Factsheets for River Nodes (DWS, 2014)

Appendix E: Reserve Study for Langebaan Estuary

Appendix F: Reserve Study for Rietvlei/Diep

Appendix G: Reserve Study for Wildevoelvlei

Appendix H: Reserve Study for Zandvlei

Appendix I: Reserve Study for Zeekoevlei

Appendix J: Reserve Study for Eerste River Estuary

Appendix K: Reserve Study for Lourens River Estuary