REPORT NO.: **RDM/WE/00/CON/ORDM/0716**

DEVELOPMENT OF PROCEDURES TO OPERATIONALISE RESOURCE DIRECTED MEASURES

PROJECT NO: WP 10951

ESTUARIES AND MARINE TOOL ANALYSIS AND STANDARDISATION REPORT

OCTOBER 2016

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

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Title:	**ESTUARY AND MARINE TOOL ANALYSIS AND STANDARDISATION REPORT**
Authors:	***Van Niekerk L, Adams, JB, Lamberth, SJ, Taljaard, S, & Van Rooyen P.***

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Professional Service Providers: Rivers for Africa eFlows Consulting (Pty) Ltd.

Approved for the Professional Service Providers by:

……..	……
Delana Louw	*Date*
Project Manager	

DEPARTMENT OF WATER AND SANITATION (DWS)

Directorate: Water Resource Classification

Approved for DWS by:

……..	……
Ms Ndileka Mohapi	*Date*
Chief Director: Water Ecosystems	

REPORT AND DELIVERABLE INDEX

Index Number	DWS Report Number	Report Title and Deliverables
1	RDM/WE/00/CON/ORDM/0116	Lessons Learnt Report
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4		Integrated framework Workshop
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6		Reserve, Classification, RQO Frameworks Workshop
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8		River tool analysis and standardisation Workshop
9		Wetland tool analysis and standardisation Workshop
10		Estuaries and Marine tool analysis and standardisation Workshop (outcomes report)
11		Water quality tool analysis and standardisation Workshop
12		Groundwater, Hydrology, Hydraulics tool analysis and standardisation Workshop
13		Socio-economics and Ecosystem services tool analysis and standardisation Workshop
14	RDM/WE/00/CON/ORDM/0516	River tool analysis and standardisation Report
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16	**RDM/WE/00/CON/ORDM/0716**	**Estuaries and Marine tool analysis and standardisation Report**
17	RDM/WE/00/CON/ORDM/0816	Water quality tool analysis and standardisation Report
18	RDM/WE/00/CON/ORDM/0916	Groundwater, Hydrology, Hydraulics tool analysis and standardisation Report
19	RDM/WE/00/CON/ORDM/1016	Socio-economics and Ecosystem services tool analysis and standardisation Report
20	RDM/WE/00/CON/ORDM/1116	Stakeholder involvement and communication tool analysis and standardisation Report
21	RDM/WE/00/CON/ORDM/1216	RDM Communications Framework Report
22	RDM/WE/00/CON/ORDM/0117	Main Report
23	RDM/WE/00/CON/ORDM/0217	Capacity Building Report
24	RDM/WE/00/CON/ORDM/0317	Project Close-Up Report

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The following persons authored the report:

Authors	Company
Van Niekerk, Lara	Council for Scientific and Industrial Research
Adams, Janine	Nelson Mandela Metropolitan University
Lamberth, Stephen	Department of Agriculture, Forestry and Fisheries
Taljaard, Susan	Council for Scientific and Industrial Research

The following DWS representatives participated at the specialist meeting held 18 to 19 February and therefore contributed to the information in the report.

Name	Company
Cilliers, Gerhard	D: Resource Quality Information Services
Weston, Barbara	D: Resource Directed Measures
Gladys Makhado	D: Resource Directed Measures
Happy Khumalo	D: Resource Directed Measures
Sejamoholo, Biotumelo	Water Resource Classification

REPORT SCHEDULE

Version	Date	COMMENTS
First draft	October 2016	No comments received
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ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
BHNR	Basic Human Needs Reserve
CD: WE	Chief Directorate: Water Ecosystems
CWAC	Coordinated Waterbird Counts
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitation
DWA	Department Water Affairs
DWAF	Department Water Affairs and Forestry
DO	Dissolved Oxygen
DRIFT	Downstream Response to Imposed Flow Transformation
EC	Ecological Category
EWR	Ecological Water Requirements
EFZ	Estuary Functional Zone
EMP	Estuary Management Plan
HPLC	High Performance Liquid Chromatography
ICM	Integrated Coastal Management
IUA	Integrated Units of Analysis
IWRM	Integrated Water Resource Management
MLRA	Marine Living Resources Act (Act 18 of 1998)
MAR	Mean Annual Runoff
NBA	National Biodiversity Assessment
NWRCS	National Water Resource Classification System
PAR	Photosynthetically Active Radiation
PES	Present Ecological State
PESEIS	Present Ecological State and Ecological Importance-Ecological Sensitivity
PSP	Professional Service Provider
REC	Recommended Ecological Category
RDM	Resource Directed Measures
RQO	Resource Quality Objective
RU	Resource Unit
SANBI	South African National Biodiversity Institute
TEC	Target Ecological Category
ToR	Terms of Reference
TPC	Threshold of Potential Concern
UNEP	United Nations Environment Programme
WWTW	Waste Water Treatment Works
WReMP	Water Resources Modelling Platform

1 INTRODUCTION

1.1 BACKGROUND

The Chief Directorate: Water Ecosystems (CD: WE) of the Department of Water and Sanitation (DWS) initiated a study for the Development of Procedures to Operationalise Resource Directed Measures (RDM). Rivers for Africa eFlows Consulting (Pty) Ltd., in association with supporting specialists, was appointed as the Professional Service Provider (PSP) to assist the Department in undertaking this study.

1.2 STUDY OBJECTIVES

The study objectives as defined by the Terms of Reference (ToR) are as follows:

- Develop a framework for Reserve determination.
- Standardise methodologies for Reserve determination.
- Develop a framework for Water Resource Classification.
- Develop a framework for Resource Quality Objectives (RQOs).
- Develop a RDM Communications Framework.

In the ToR, the CD: WE also identified the need for the development of an Integrated RDM framework. The term operationalise was not defined clearly as part of the TOR, apart from the objectives stated above. However, a definition was presented by DWS and agreed by all as follows:

Provide the frameworks and methods to allow CD: WE to give effect to the Reserve, Classification and RQOs (i.e. give effect to RDM). It therefore includes the frameworks, steps, processes, methods and implementation and monitoring information. The operationalisation of RDM starts at planning and ends at corrective actions (though the continuum of the plan, do, check, act cycle) which will include implementation and monitoring guidelines and the provision of information for various line functions.

NB: Care should be taken to distinguish between the term "operationalise" as it is defined above and "operating" rules for dams etc. OR with operational scenarios.

1.3 PURPOSE OF THIS TASK

The aims and objectives for this task as addressed at the specialist workshops to consolidate and standardise RDM methods are provided below:

Aim: Standardise methodologies for Reserve determination. Note, methodologies required for Classification and RQO determinations which are not covered through the Reserve methodologies will also be included.

Objectives:

- Identify and standardise input and output for every sub-step (if relevant) of the Integrated Framework.
- Identify the range of tools and methods used in DWS and DWS related studies for each sub-step (if relevant).
- Evaluate the tools and methods according to a range of agreed criteria.

Approach:

These objectives were addressed during a workshop for estuarine specialists during July 2016. Standardisation of methods focussed on standardising the inputs and outputs of the tools used in the sub-steps to define the information and data that is required to ensure continuity between the processes and steps. This will ensure that during all phases of the frameworks, the methods comply with the standardised inputs and outputs and that the linkages through the whole process are seamless.

1.4 PURPOSE OF THIS REPORT

During a range of specialist meetings (July 2016), available tools and methods for each of the sub-steps will be identified, evaluated and documented in a range of reports (RDM/WE/00/CON/ ORDM/0516 to RDM/WE/00/CON/ORDM/01116). This report serves to document the outcomes of the Estuaries and Marine tool analysis and standardisation workshop specialist meeting (19 to 20 July 2016) (RDM/WE/00/CON/ ORDM/0517).

2 APPROACH

2.1 BACKGROUND

Currently Resource Directed Measures (RDM) consists of three major processes.

- Water Resource Classification System (DWAF, 2006).
- Determination of the Reserve (Louw and Hughes, 2002).
- Determination of RQOs (DWA, 2011).

Each of these processes consist of steps which were designed in 2002 (Reserve, Louw and Hughes, 2002), 2006 (Classification, DWAF, 2006) and 2011 (RQOs, DWA, 2011). These steps were gazetted (Gazette No. 19182, Notice No. 1091) on 17 September 2010. This gazette provides procedures (in the format of steps) for each of the RDM processes, which are largely similar to the initially designed steps for the Reserve and Classification. It must be noted however that the RQO steps and guideline appeared during 2011, i.e. after the gazette and differs significantly from the gazetted steps. During this project, the gazetted steps and the RQO guideline steps will be addressed.

Therefore, each of the RDM processes consists of gazetted steps, guidelines, methodologies and approaches and various methods and tools supporting the methodologies. There are inherent links, overlaps and complexities within all of the above. This situation is further complicated by having to deal with large study areas with many nodes (points of interest) requiring answers that may be either at a desktop level and/or more detailed level. Issues regarding confidence, uncertainty and decision-making on various aspects such as where the areas of focus should be in study areas, add to the complexities.

2.2 INTEGRATED FRAMEWORK

During a February 2016 specialist meeting, an Integrated Framework was designed and subsequently finalised (DWS, 2016). The Integrated Framework consists of eight steps. Each step is sub-divided into sub-steps described through a list of actions grouped together under various labels. The design and numbering of the flow diagrams are provided below:

Each individual step within the Integrated Framework is sub-divided according to sub-steps which represent the different components that need to be investigated during the process. Sub-steps are labelled and required actions are listed below each sub-step. The format is described below:

- Actions are listed in clear (not coloured) blocks which are labelled. The first numbering of the label will refer to the Step number and the second a sequential number. For example, a block numbered and labelled ‘1.4 Rivers’ will mean that the block represents the river component under Step 1. The four implies that this is the fourth block in the flow diagram. Essentially each block represents a sub-step which consists of a label and a list of actions. Reference is made to Step 1.4 as this is a secondary tier number, it represents a sub-step.
- These blocks are sometimes grouped together within a grey block which may have its own heading. The individual clear blocks are then labelled according to a next tier in the numbering, e.g. 1.4.1. This would mean that this block is part of Step 1, grouped within a grey block numbered 1.4 and would form the first block in the grey block, i.e. 1.4.1.
- The descriptions for these blocks are sub-steps. The reference in the report refers to these as Steps; however the numbering if a second tier (e.g. 1.1) will indicate that it is a sub-step. The numbering corresponds to the relevant flow diagram representing the relevant Integrated step.
- The actions that must be undertaken in each block are numbered from ‘1’ on.

- The descriptions of the actions in the report use a set of bullets as well as the numbers that can be cross-referenced to the flow diagram.
- Blocks with no numbers and shaded a light blue refer to KEY outputs (not all the outputs) of the step. These key outputs are those that are essential for use in the next step. This reflects the sequential manner of the Integrated Framework steps.

The integrated steps are provided in Figure 2.1.

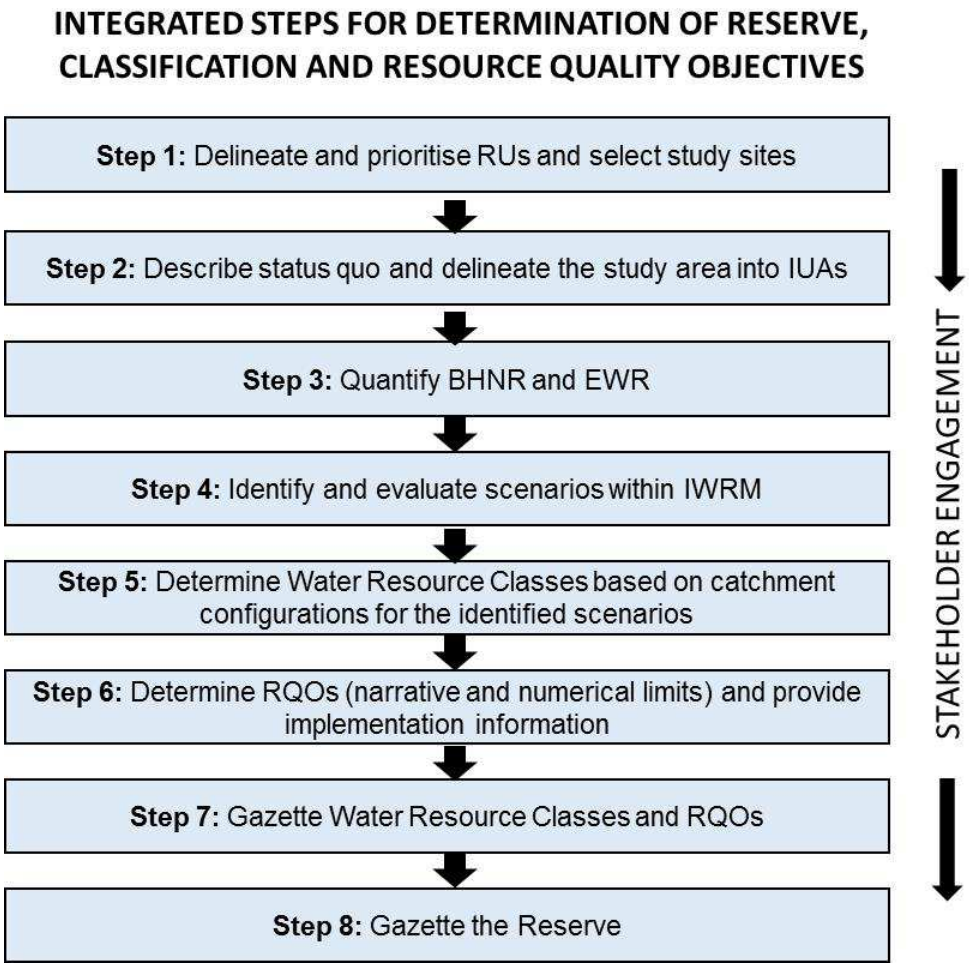

Figure 2.1 Integrated steps for the determination of the Reserve, Classification and Resource Quality Objectives

All numbering in this report will refer to the numbering in the flow diagram of each step illustrating the sub-steps as blocks and actions as a numbered list in the block.

2.3 STANDARDISATION OF TOOLS, METHODOLOGIES, METHODS AND APPROACHES

Since 1987, Instream Flow Requirements (now known as the Ecological Water Requirement) were considered by DWS in most water resource evaluations and investigations. Methods for determining environmental flow requirements were world-wide in its infancy. South Africa undertook research projects to evaluate existing methods and also developed one of the first holistic methods (King and Louw, 1998), the Building Block Methodology which catered for South African circumstances and DWS's requirements for Integrated Water Resource Management (IWRM). Since then, many methods and new methodologies have been developed to what has, since 1999, become known as the Ecological Water Requirement (EWR) which is used to determine the Ecological Reserve. This method development largely focussed on rivers and estuaries.

During the last five years, application of Classification studies has resulted in further expansion of the Ecological Reserve methods as well as developing additional methods through application to cater for the demand set by the complexities of Classification and then Resource Quality Objectives.

The myriad of methods and tools being applied have presented challenges, mostly as the output of methods did not necessarily comply with standard requirements and could not be seamlessly used between different phases of related studies. It must be noted Reserve, Classification and RQO studies are undertaken under the auspices of IWRM and results from these studies must be compatible with the prevailing IWRM practices. This of course also implies that the input used in methods, especially around the driver components (hydrology, geohydrology, water quality etc.), require standardisation.

As many methods in some cases are available for application within these studies, the focus of this work would not be to select specific methods that may be used in RDM work, but to indicate whether these methods comply with a range of requirements and whether the input and output comply with the required standard. Tools that will be evaluated are those methods that have been in use in environmental flow requirement studies in South Africa with the specific emphasis of those used for RDM. International methods that have not been used in South Africa will not be evaluated.

2.4 CONSIDERATIONS FOR STANDARDISATION

The focus of this evaluation is on the standardisation of the inputs and outputs of each sub-step's actions rather than the method themselves. The key requirements for standardisation are:

- Aim to achieve coherent application throughout the RDM steps and processes.
- Application of RDM processes is part of IWRM - the prevailing water resource management activities need to define the focus.

Examples of inputs and outputs are:

- Inputs: Hydrology time series datasets, or databases such as Present Ecological State and Ecological Importance-Ecological Sensitivity (PESEIS) etc.
- Outputs: EWR time series and rule definitions; Ecological Categories A to F.

The approach to the standardisation of methods will focus on standardising the inputs and outputs of the methods used in the sub-steps to define the information and data that will flow between the processes and steps. This will ensure that during all phases of the activities in the frameworks, the methods comply with the standardised inputs and outputs and that the linkages through the whole process are seamless. It must be noted that the Excel spreadsheet has been designed to include all sub-steps and all actions. However, this may not be relevant, necessary, or practical to provide the input and output at this level for a particular action.

Note: Not all sub-steps may require standardised inputs although most would require standardised outputs.

2.5 TOOL IDENTIFICATION

Studies carried out for DWS (directly or indirectly) were considered and methods were identified that have been applied for the sub-steps and actions. Tools refer to any models, methods or systematic approaches and any of these will be referred to in this document as **METHODS.** The

models could be detailed hydrological models, spreadsheet formulas, methodical procedures and techniques.
If a sub-step did not require a method, it was noted that it is not applicable. If methods are not available, this was identified as a gap.

Note:
- **Not all sub-steps or actions required a method.**
- **Actions were grouped in the sub-step if methods were applicable to these groups rather than per action.**
- **Note that if there are methods that have been used extensively in the past but which are now obsolete, these methods will not be evaluated, but will be provided in this report including the reasons why they are obsolete (e.g. TEACHA and BBM).**
- **Standard computer packages such as Google Earth, Microsoft Office suite of programmes, Statistica etc. are not RDM methods within the context of this study. Methods or models can be written using Excel as per example, but the method would be the method, not the computer package which is used.**

A generic set of criteria to rate the methods were identified and described (Section 2.7). The methods were rated using an Excel spreadsheet. **Note that not all criteria will be applicable to a method.**

TERMINOLOGY: TOOLS vs METHOD
The use of the word 'tools' created confusion as most people associated tools with computer models. Further in this report, the word '**method**' will rather be used to accommodate the confusion with regards to the tool terminology.

Tools refer to any models, methods or systematic approaches. The models could be detailed hydrological models, spreadsheet formulas, methodical procedures and techniques.

2.6 SPECIALIST WORKSHOP APPROACH

During the workshop, a step by step approach was followed to provide the necessary information for each step of the Integrated Framework which was presented as a series of Excel spreadsheets. The approach followed is given below:
- Determine whether there is standardised input that is relevant for the sub-step.
- Decide whether the standardised input is for the sub-step as a whole or if it is linked to the listed actions.
- Define the standardised input.
- Define the standardised output.
- Identify all tools (referring to models, approaches, methods) that are used for the sub-step.
- Some sub-steps may not have any specific tools as the output could be a qualitative description.
- Some actions within the sub-steps will often not have any action-specific tools and the specific actions can then be ignored.
- Evaluate the identified tools according to the given criteria. Note, that depending on the nature of the tool, all the criteria may not be valid and in these cases, the spreadsheet will not be populated.
- Transfer the information and all the added explanations in a MS Word report template.

2.7 EVALUATION CRITERIA

The criteria for the tool evaluation, the evaluation manner and an explanatory comment is provided in Table 2.1 below.

Table 2.1 Criteria and evaluation

Criteria	Evaluation	Explanatory comment
Frequency of application of use	1 - Very Low 2 - Low 3 - Medium 4 - High 5 - Very High	Supply supporting information. Provide year since it has been in use and approximate number of studies.
Can the method be applied at a catchment level?	Yes/No	Some methods can only be applied at a site and have to be repeated for every site, i.e. the method was not designed to deal with e.g. 200 nodes. Provide explanation using the following: 1. Node or site 2 River reach 3 Catchment 4 Water Management Area
Is the method described?	Yes/No	If Yes, provide type of method description (user manuals, method description, and spreadsheet).
Indicate the status of publication of the method.	1 N/A 2 None 3 Internal 4 National 5 International	Describe the type of publication.
Are there existing training course?	Yes/No	If Yes, provide a description.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes/No	Note: Level refers to Desktop or Detailed and more specifically to the Reserve Levels of Desktop, Rapid, Intermediate, Comprehensive. Provide a description of the assessment level to which the method is applicable.
Time efficient (link to assessment level)	Provide evaluation in terms of a description in weeks and provide seasonality requirements if necessary	Provide explanatory comment and explain time limitations.
Is the data available to apply the method?	Always; Usually; Seldom; Never	Describe the reliance of method on monitored and/or measured data and pre-processing.
Compatibility	Yes/No	Can the method use the standardised input and does the method provide the results (output) according to the standardised requirements? In short, is the method compatible with the standardised input and output requirements? Please provide explanations.
Must software be purchased?	Yes/No	If Yes, indicate the approximate costs and any associated conditions.
License requirements	None; Simple; Complex, Duration limiting	Risk of use and administrative requirements.
Enhancement flexibility or adaptability of algorithms	1 Open script; 2 Open source; [Intellectual Property:] 3 DWS; 4 WRC;	Purpose of criteria is to indicate the risk of keeping method relevant.

Criteria	Evaluation	Explanatory comment
	5 Commercial	
Is the method validated and verified?	Yes/No	Is the tool/method's results validated and can it be verified against the conditions on the ground? Provide an explanatory comment for the reasoning.
Description of mathematical algorithms and model structure	Algorithm based; Detail explanation; Conceptual description; None	Provide an explanatory comment for the reasoning.
Is the model robust?	Yes/No	Will different numerical tools provide similar answers e.g.?
Does the method include an objective assessment of uncertainty such as may influence confidence?	Yes/No	If Yes, describe the process to quantify the uncertainty. If no, and there is a qualitative assessment of confidence (such as a rating by expert opinion): please describe.

3 STEP 1: DELINEATE AND PRIORITISE RUs AND SELECT STUDY SITES

Objective: The objective of this step is to identify high priority areas (previously referred to as hotspots[1]) as these would be the areas where more detailed work for the rest of the Integrated steps would focus on. These high priority areas are selected based on ecological, socio-cultural and water resource use importance and are often areas of high ecological importance where water resources are stressed or may be stressed in future. This is a key step as the Resource Units (RUs) information is gazetted with measured information and potentially higher confidence output. The prioritisation therefore acts as a filter to allow one to focus on specific areas in the various ecosystems. Integrated Step 1 (Figure 3.1) therefore involves the delineation and prioritisation of RUs. Study sites where more detailed field work is undertaken are selected within High priority RUs, i.e. sites can only be selected after the prioritisation process.

Integrated Step 1 contains six sub-steps. Estuaries fall within sub-step 1.3 – Aquatic Ecosystems and is discussed in this Chapter.

[1] A biodiversity/ecological hotspot is a biogeographic region which is a significant reservoir of biodiversity which is threatened with destruction (http://en.wikipedia.org/wiki/Biodiversity_hotspot). In the context used in the Desktop EcoClassification, the hotspot represents a quaternary catchment with a high Integrated Importance which could be under threat due to its importance for water resource use. These hotspots indicate areas where Reserve assessments should ideally result in high confidence recommendations and requires appropriate methods.

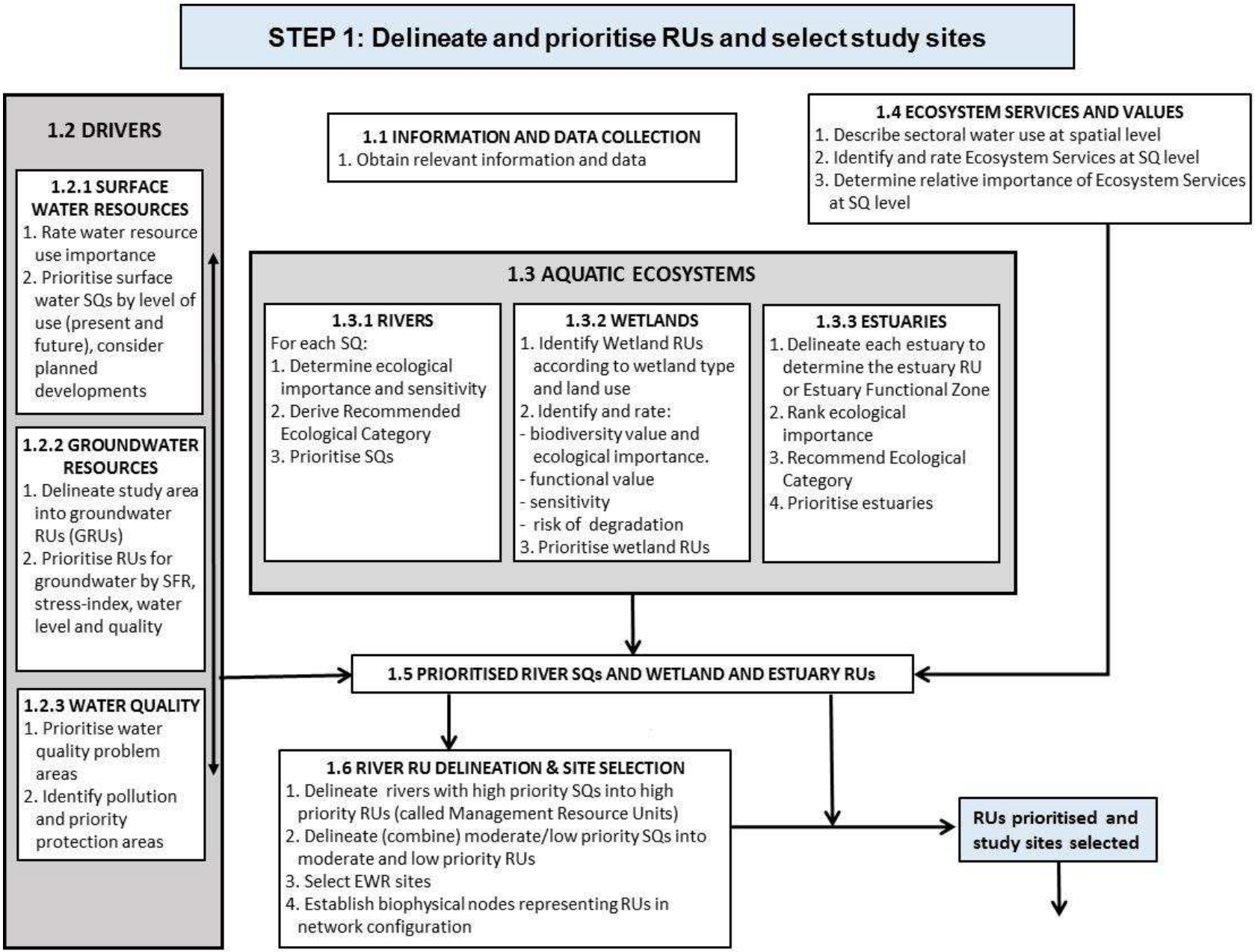

Figure 3.1 Illustration of the sub-steps for Integrated Step 1: Delineate and prioritise RUs and select study sites

3.1 STEP 1.3.3 ESTUARIES: ACTIONS

The bullets below describe the actions required.

- **1. Delineate each estuary to determine the estuary RU or EFZ**

Each estuary represents an individual RU as defined by the Estuary Functional Zone (EFZ).

- **2. Rank ecological importance**

Rank each estuary's importance considering estuarine importance, nursery function, conservation importance sensitivity/vulnerability to flow and pollution etc.

- **3. Recommend Ecological Category**

Provide each estuary's provisional Recommended Ecological Category (REC). The provisional REC represents the overall level of protection assigned to an individual estuary based on its importance and conservation status (i.e. protection level).

- **4. Prioritise estuaries**

Prioritisation for estuaries is assessed based on criteria such as the ecological and conservation importance, future pressures or important ecosystem services.

3.2 STEP 1.3.3 ESTUARIES: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 3.1.

Table 3.1 Step 1.3.3: Standardised input and output per action

Action	Input	Output	Methods/Tools	Comments
1. Delineate each estuary to determine the estuary RU or EFZ	EFZ layer (SANBI BGIS)	Map delineating the EFZ per estuary	Van Niekerk and Turpie (2012)	
	1:100 yr flood line	Expanded EFZ		If 1:100 yr flood line is available, takes less than a week to revisit and refine if need be
2. Rank ecological importance	Turpie *et al*. (2002)	Identified estuaries of high importance (biodiversity, conservation, ecosystem services)	DWAF (2008a) (or future updates)	
3. Provisional REC	National Estuaries Biodiversity Plan 2011 (or any updates thereof) (van Niekerk and Turpie, 2012)	Provisional REC for each estuary	Guidelines for setting REC as per DWAF (2008a) (or future updates)	
4. Prioritise estuaries	Present Ecological State (PES) Importance Biodiversity, Ecosystem services Conservation Priorities REC Current and future Pressures	List of priority estuaries for detailed/higher level confidence studies and future monitoring	Proposed Rule-base method described in (DWA, 2013)	

3.3 STEP 1.3.3 ESTUARIES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

3.3.1 Action 1: Delineate each estuary to determine the estuary RU or EFZ

Table 3.2 Step 1.3.3: Method evaluation of Delineation of the Estuary Functional Zone (Van Niekerk and Turpie, 2012)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	In use since 2009 in every EWR study.
Can the tool be applied at a catchment level?	Yes	Estuary specific. All estuaries have been delineated (EFZ) based on the assumptions that sedimentary and ecological processes is limited to under the 5 m contour.
Is the method described?	Yes	Method for delineation of EFZ described in Van Niekerk and Turpie (2012) with further refinements described in Veldkornet *et al.* (2015).
Indicate the status of publication of the method	National	As above.
Are there existing training courses?	No	Not required because delineation of estuaries is done for the entire country as part of National Biodiversity Assessment (NBA) process according to published method (e.g. Van Niekerk and Turpie, 2012). To be updated as part of NBA 2018.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Delineation of estuaries is done for the entire country as part of NBA process according to published method (e.g. Van Niekerk and Turpie, 2012).
Time efficient (link to assessment level)	<1 week	Takes less than a week to revisit and refine if need be.
Is the data available to apply the method?	Always	Available from South African National Biodiversity Institute (SANBI) BGIS website http://bgis.sanbi.org/ or CSIR.
Compatibility?	Yes	Yes, it is compatible with standardised input and outputs. Results can be used in other steps such as grouping of estuaries.
Must software be purchased?	No	Can be accessed using Google Earth or GIS software.
Licencing requirements?	None	Compatible with open source software.
Enhancement flexibility or adaptability of algorithms?		
Is the method validated and verified?	Yes	Validated and refined in Veldkornet *et al.* (2015).
Descriptions available of mathematical algorithms and model structure?	Very High	In use since 2009 in every EWR study.
Is the model robust?	Yes	Estuary specific. All estuaries have been delineated (EFZ) based on the assumptions that sedimentary and ecological processes is limited to under the 5 m contour.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Yes	Method for delineation of EFZ described in Van Niekerk and Turpie (2012) with further refinements described in Veldkornet *et al.* (2015).

3.3.2 Action 2: Rank ecological importance

Table 3.3 Step 1.3.3: Method evaluation of the ranking the ecological importance of estuaries (Turpie *et al*., 2002)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Every Estuary EWR study since 1999.
Can the tool be applied at a catchment level?	Yes	Estuary specific, but data available for all estuaries.
Is the method described?	Yes	Described in Turpie *et al*. (2002).
Indicate the status of publication of the method	National	Published in open source journal WaterSA (Turpie *et al*., 2002).
Are there existing training courses?	No	Not required because rating is done for the entire country according to published method (e.g. Turpie *et al*., 2002). Updates included in DWAF (2008a).
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Standard method applied to all estuaries.
Time efficient (link to assessment level)	Yes	Once-off done for entire country. Some smaller systems were excluded from the last national assessment, but assume that these small systems are of low to average importance due to their small size.
Is the data available to apply the method?	Yes	Once-off done for entire country, but some small systems were not evaluated.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs listed above.

3.3.3 Action 3: Provisional Recommend Ecological Category

Table 3.4 Step 1.3.3: Method Evaluation of the determination of the Ecological Water Requirements for Estuaries (DWAF, 2008a)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Every Estuary EWR study since 1999.
Can the tool be applied at a catchment level?	Yes	Estuary specific, but data available for all estuaries.
Is the method described?	Yes	Guidelines for allocation of REC described in in DWAF (2008a).
Indicate the status of publication of the method	National guideline document	Published as formal DWS guideline document.
Are there existing training courses?	No	Yes, but not being provided at this stage.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Method applicable to all levels of EWR/Classification studies.
Time efficient (link to assessment level)	<1 week	Yes, information available.
Is the data available to apply the method?	Always	At a minimum the data is available from the NBA 2011 (or any updates thereof off) (Van Niekerk and Turpie, 2012).
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

3.3.4 Action 4: Prioritise estuaries

Table 3.5 Step 1.3.3: Method evaluation of prioritisation of estuaries (DWA, 2013)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Low	Method was only applied in the Mvoti to Umzimkulu WMA Classification study as this was the first large estuary classification study.
Can the tool be applied at a catchment level?	Yes	Developed as a catchment level tool.
Is the method described?	Yes	Method is described in Van Niekerk and Turpie (2012).
Indicate the status of publication of the method	Published as a DWS reports	Available on DWS website.
Are there existing training courses?	No	
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Method developed to apply to all levels of study.
Time efficient (link to assessment level)	1 - 2 weeks	Yes, information available as part of the study.
Is the data available to apply the method?	Always	Yes, information generated as part of the study.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

3.4 SUMMARY OF METHOD DESCRIPTIONS AND ASSOCIATED PUBLICATIONS

All methods identified and used during Integrated Step 1 are listed below. The associated publications (e.g. source of a manual and/or description of the methods) are referenced in this section and not in Chapter 11.

- **Action 1: Delineation of the Estuary Functional Zone**

Van Niekerk, L. and Turpie, J.K. (eds). 2012. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report No. CSIR/NRE/ECOS/ER/2011/0045/B. CSIR, Stellenbosch.

- **Action 2: Ranking the ecological importance of estuaries**

Turpie, J.K., Adams, J.B., Joubert, A., Harrison, .TD., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. and van Niekerk, L. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA. 28, 2: 191–206. http://dx.doi.org/10.4314/wsa.v28i2.4885.

- **Action 3: Determination of the Ecological Water Requirements for Estuaries**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

- **Action 4: Prioritisation of estuaries**

Department of Water Affairs (DWA), South Africa. 2013. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu WMA: Desktop Estuary EcoClassification and Ecological Water Requirement. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWA Report Number: RDM/WMA11/00/CON/CLA/0313. June 2013.

4 STEP 2: DESCRIBE STATUS QUO AND DELINEATE THE STUDY AREA INTO IUAs

Objective: The objective of this step is to define Integrated Units of Analysis (IUAs) and provide a status quo description of each IUA. An IUA is a homogenous catchment or linear section of river based on the similarity of ecological state, system operation, land use, etc. The status quo description therefore provides the information at a broad scale to inform the delineation of the IUAs. Basically, this step provides the baseline for the, National Water Resource Classification System (NWRCS) in the sense that it defines and describes the study area and its components. This step therefore includes the identification of the water resource operation in the study area, the identification of users and socio-economics issues, describing the status quo which represents the current condition of the various components (as illustrated in Figure 4.1), and then, through a process of comparing similar areas, delineate IUAs. The status quo information for the study area is then used to describe the status quo for each IUA.

Integrated Step 2 contains eight sub-steps. Estuaries fall within sub-step 2.1 and 2.5 and is discussed in this Chapter.

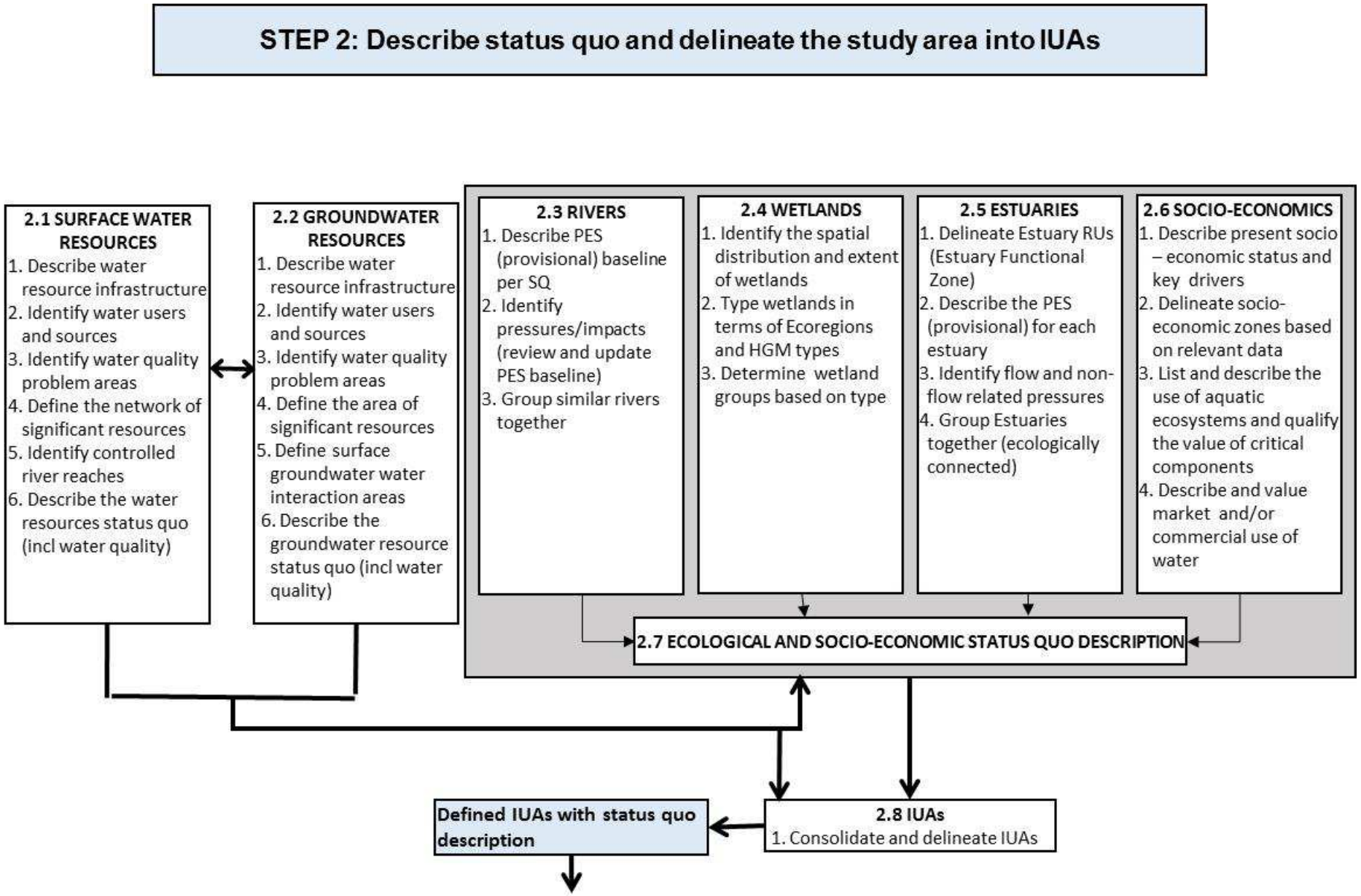

Figure 4.1 Illustration of the sub-steps for Integrated Step 2: Describe status quo and delineate the study area into IUAs

4.1 STEP 2.1 ESTUARIES: ACTIONS

Objective: Collate all readily available information and data on the estuaries in the study area.

The bullets below describe the actions required.

- **1. Compile an inventory on data and information availability**

The National Biodiversity Assessment Management and Monitoring register for South Africa's estuaries provide an overview of all management responses (e.g. historical EWR studies, Estuary Management Plans) and monitoring activities (e.g. DWS monitoring sites) per estuary. It is therefore critical that this register be consulted for readily available information. Additional information should also be sourced from scientific publications and research reports.

4.2 STEP 2.1 ESTUARIES: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 4.1.

Table 4.1 Step 2.1: Standardised input and output per action

Action	Input	Output
1.1 Compile an inventory on data and information availability	NBA Management and Monitoring register	Overview of available measured and published data

4.3 STEP 2.5 ESTUARIES: ACTIONS

Objective: Broadly determine the PES for all the estuaries in the study area in terms of the Ecological Categories (ECs) (A to F) which informs the delineation of IUAs. This information is used in the grouping of estuaries and the delineation of the IUAs.

The bullets below describe the actions required.

- **1. Delineate the individual Estuary RUs based on the Estuary Functional Zone (EFZ)**

An official GIS layer representing the EFZ is available from SANBI BGIS website (if considered necessary the EFZ boundaries can be extended but it must be motivated and accompanied by relevant information sources). The estuary mouth is taken as the downstream boundary or, when the mouth is closed, the middle of the sand berm between the open water and the sea is used. The upstream boundary is determined as the limits of tidal variation, salinity penetration or back-flooding, whichever penetrates furthest upstream. All developed areas must also be included to reflect change in the surrounding environs.

- **2. Provide the estuary Provisional PES**

Available information on the Provisional PES is available form a number of key sources. Where the above information is dated, the Provisional PES may need refinement based on new information. Note, if the PES have to be refined through a Desktop evaluation Reference and Present flow time series dataset needs to be generated (including current discharges volumes and concentrations).

- **3. Identify and rate key flow and non-flow pressures on the individual estuaries**

Pressures and/or impacts that are evaluated include flow and water quality changes, development and land-use changes in the EFZ, artificial breaching of estuary mouths, exploitation of living resources with a focus on fishing effort and harvesting of mangroves and reeds/sedges and mining (e.g. sand, diamonds). The pressures and/or impacts are identified from the baseline information / databases and refined where required. This information is also used to refine the PES where required.

- **4. Group estuaries coast-long based on ecological condition and function, pressures (current and future) and management boundaries (local authorities and water management)**

From an ecological perspective, all estuaries coastwise fall within three major biogeographical zones. However, for practical considerations the biogeographical zones need to be subdivided into smaller management units. Pragmatic consideration for this grouping may include:

- Similar condition or functioning systems to allow for a tight typing of the Water Resources Class.
- Estuaries under the same type of pressures (e.g. waste water discharges or high levels of coastal development), requiring the similar interventions; and
- local authority boundaries which will align management interventions through Estuary Management Plans (EMPs).

4.4 STEP 2.5 ESTUARIES: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 4.2.

Table 4.2 Step 2.5: Standardised input and output per action

Action	Input	Output	Methods/Tools	Comments
1 Delineate Estuary RUs (EFZ)	EFZ layer (SANBI BGIS)	Map delineating the EFZ per estuary	Van Niekerk and Turpie (2012)	
	1:100 yr flood line	Expanded EFZ		If 1:100 yr flood line is available, takes less than a week to revisit and refine if need be.
2. Describe the PES (provisional) for each estuary	NBA 2011 (or any updates their off)	Desktop EWR PES of individual estuaries	Desktop EWR Method (Van Niekerk *et al*., 2015)	
3. Identify flow and non-flow related pressures	Estuary Management Plans (Under Integrated Coastal Management (ICM) Act) Historical Estuary EWR studies (DWS)	List of flow and non-flow pressures	Estuary Pressure listing as per DWAF (2008a) (or any updated there off)	
4. Group Estuaries together (ecologically connected)				RECOMMENDATION: Proposed method has been developed for the grouping of estuaries, but this approach needs to be confirmed by relevant specialists (e.g. workshop) and consolidate to set formal guidelines for inclusion in official DWS methodology documentation. Connectivity should explicitly be addressed.

4.5 STEP 2.5 ESTUARIES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

4.5.1 Action 1: Delineate Estuary RUs (EFZ)

Table 4.3 Step 2.5: Method evaluation of Delineation of the Estuary Functional Zone (Van Niekerk and Turpie, 2012)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	In use since 2009 in every Ecological Water Requirement (EWR) study.
Can the tool be applied at a catchment level?	Yes	Estuary specific. All estuaries have been delineated (EFZ) based on the assumptions that sedimentary and ecological processes is limited to under the 5 m contour.
Is the method described?	Yes	Method for delineation of EFZ described in Van Niekerk and Turpie (2012) with further refinements described in Veldkornet *et al.* (2015).
Indicate the status of publication of the method	National	As above.
Are there existing training courses?	No	Not required because delineation of estuaries is done for the entire country as part of NBA process according to published method (e.g. Van Niekerk and Turpie, 2012). To be updated as part of NBA 2018.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Delineation of estuaries is done for the entire country as part of NBA process according to published method (e.g. Van Niekerk and Turpie, 2012).
Time efficient (link to assessment level)	<1 week	Takes less than a week to revisit and refine if need be.
Is the data available to apply the method?	Always	Available from SANBI BGIS website http://bgis.sanbi.org/ or CSIR.
Compatibility?	Yes	Yes, it is compatible with standardised input and outputs. Results can be used in other steps such as grouping of estuaries.
Must software be purchased?	No	Can be accessed using Google Earth or GIS software.
Licencing requirements?	None	Compatible with open source software.
Enhancement flexibility or adaptability of algorithms?		
Is the method validated and verified?	Yes	Validated and refined in Veldkornet *et al.* (2015).
Descriptions available of mathematical algorithms and model structure?	Very High	In use since 2009 in every EWR study.
Is the model robust?	Yes	Estuary specific. All estuaries have been delineated (EFZ) based on the assumptions that sedimentary and ecological processes is limited to under the 5 m contour.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Yes	Method for delineation of EFZ described in Van Niekerk and Turpie (2012) with further refinements described in Veldkornet *et al.* (2015).

4.5.2 Action 2: Describe the PES (provisional) for each estuary

Table 4.4 Step 2.5: Method evaluation of Estuary Desktop Assessment (Van Niekerk *et al.*, 2015)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Medium	Method has been applied in both Mvoti-Umzimkulu WMA Classification and in the Grouritz WMA Reserve studies.
Can the tool be applied at a catchment level?	Yes	Method was developed for evaluation of estuaries at the regional scale.
Is the method described?	Yes	The method is described in: Desktop Provisional EcoClassification of the Temperate Estuaries of South Africa.

Criteria	Evaluation	Explanatory comment
		WRC Report No K5/2187 (Van Niekerk *et al.*, 2015)
Indicate the status of publication of the method	WRC report	Published on WRC information hub (http://www.wrc.org.za/).
Are there existing training courses?	No	
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	No	Desktop level assessment only.
Time efficient (link to assessment level)	< 1 week	Yes, method can be applied in workshop forum (i.e. less than a day per estuary).
Is the data available to apply the method?	No	Method was developed for application in data poor environments.
Compatibility?	Yes	Yes, it is compatible with standardised input and outputs.

4.5.3 Action 3: Identify flow and non-flow related pressures

Table 4.5 Step 2.5: Method evaluation of determining pressures on estuaries as described in Methodology for the Determination of the Ecological Water Requirements for Estuaries (Version 2) (DWAF, 2008a)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Part of all Estuary EWR studies since 1999.
Can the tool be applied at a catchment level?	Yes	Estuary specific, but data available for all estuaries.
Is the method described?	Yes	Pressure listing described in DWAF (2008a).
Indicate the status of publication of the method	National	Published (DWAF, 2008a).
Are there existing training courses?	Yes	Yes, but not being provided at this stage.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Approach used in all studies, but level of information differs.
Time efficient (link to assessment level)	< 1 week	Yes, information available.
Is the data available to apply the method?	Always	
Compatibility?	Yes	Yes, it is compatible with standardised inputs and outputs.

4.6 SUMMARY OF METHOD DESCRIPTIONS AND ASSOCIATED PUBLICATIONS

All methods identified and used during Integrated Step 2 are listed below. The associated publications (e.g. source of a manual and/or description of the methods) are referenced in this section and not in Chapter 11.

- **Action 1: Delineate Estuary RUs (EFZ)**

Van Niekerk, L. and Turpie, J.K. (eds). 2012. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report No. CSIR/NRE/ECOS/ER/2011/0045/B. CSIR, Stellenbosch.

- **Action 2: Describe the PES (provisional) for each estuary**

Van Niekerk, L., Taljaard, S., Adams, J.B., Fundisi, D., Huizinga, .P, Lamberth, S.J., Mallory, S., Snow, G.C., Turpie, J.K., Whitfield, A.K. and Wooldridge, T.H. 2015. Desktop Provisional Ecoclassification of the Temperate Estuaries of South Africa WRC Report No K5/2187.

- **Action 3: Identify flow and non-flow related pressures**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

5 STEP 3: QUANTIFY BHNR AND EWR

Objective: The objective of this step is to quantify the EWRs for different ecological states and set the Basic Human Needs Reserve (BHNR). These EWRs (ECs and associated flow regime) are essential input into all the next steps and especially for the scenario evaluation. **Once a recommendation is made regarding the Target Ecological Category (TEC), the EWR determined during this step, which supports the TEC and the Class, will become the flow or hydrology RQO.**

During Integrated Step 3 (Figure 5.1), the BHNR and the EWR components that describe the Reserve, once the IUAs have been classified, are determined. EWRs are set at desktop level for the desktop biophysical nodes and at detailed level for the study sites (EWR sites) that are selected during Integrated Step 1. EWRs can be set for a range of ECs.

Note: Reference is made here to the EWR and not to the Ecological Reserve. The reason for this is that the Reserve can only be set once there is a decision on the TEC which happens in later steps in the process.

Integrated Step 3 contains four sub-steps. Estuaries fall within sub-step 3.3 – Ecological Water Requirements and is discussed in this Chapter.

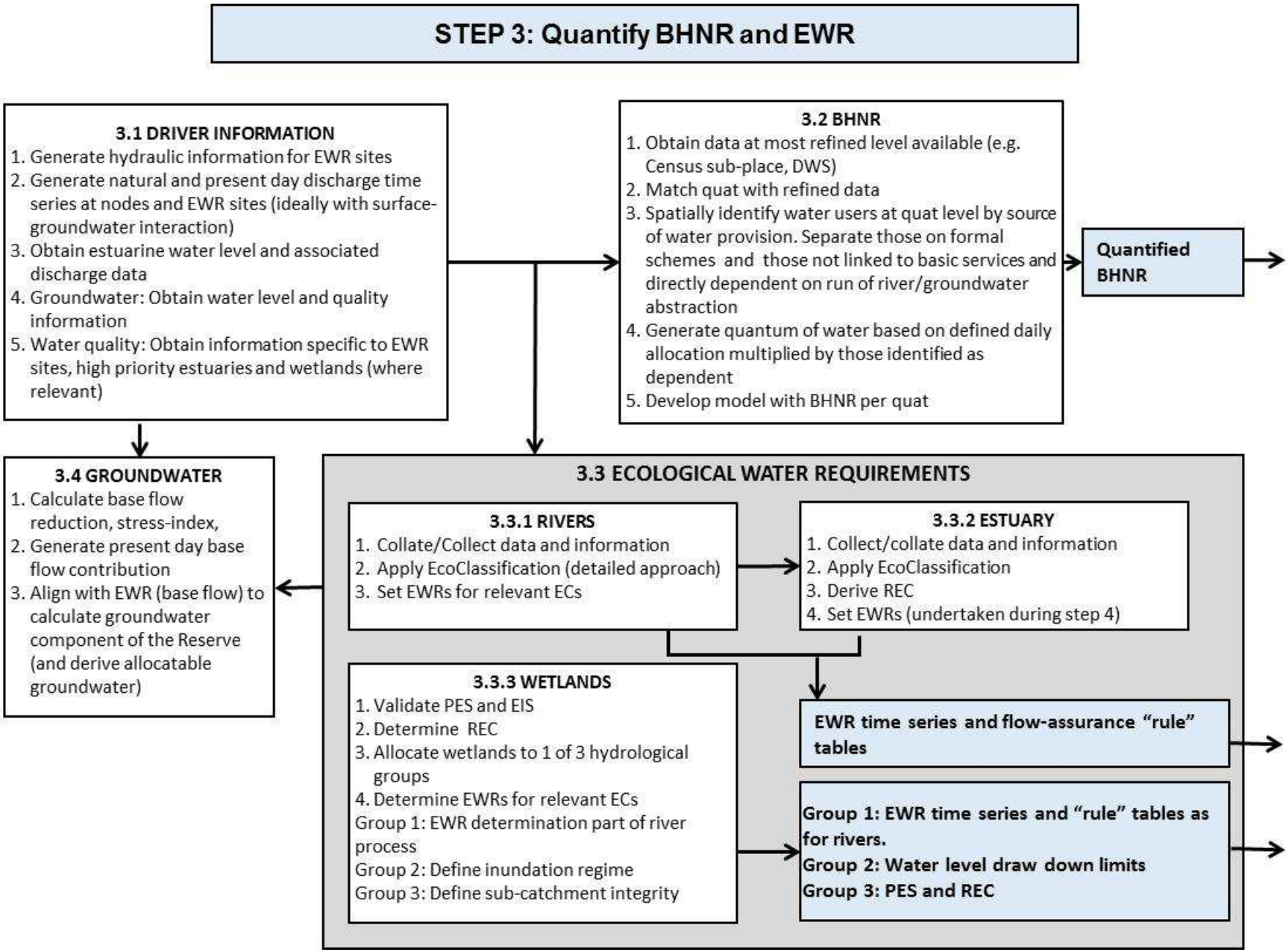

Figure 5.1 Illustration of the sub-steps for Integrated Step 3: Quantify BHNR and EWR

5.1 STEP 3.3.2 ESTUARIES: ACTIONS

Objective: To quantify the EWRs for relevant ECs. EWRs per se are not determined during this step for estuaries as the process of estuarine EWR determination follows a top down approach based on scenario evaluation. Scenarios are generated during Integrated Step 4 and the assessment of these scenarios lead to the estuary EWR being determined.

The bullets below describe the actions required.

- **1. Collect/collate data and information (including formation for development on operational scenarios for Reference, Present and Future uses generated in sub-step 4.1)**

This is applicable to individual systems identified for detailed EWR assessments. Depending on available information, field visits may be required (between one and four surveys) at various level of intensity to inform the more detailed evaluation.

Note (see Hydrology method/tool report for more detail):

- **Operational scenarios (generated during Integrated Step 4) need to be developed for estuaries that reflect all future development options including information on future discharges and effluent quality.**
- **Ideally, the operational scenarios need to encapsulate a range of development option, from run-of-river abstraction to large-scale dam development. Additional sensitivity testing flow scenarios may need to be developed to ensure a range of flow modifications resulting in a spread of associated Estuarine ECs.**
- **Operational scenarios may also include a range of effluent treatment options.**

- **2. Apply EcoClassification**
  - Refine provisional PES: Determine the estuary PES based on data collected during field surveys.
  - Determine Estuary Importance, Conservation status, Functional importance: Refine the ecological importance, current or desired protection (conservation) status, and functional importance (e.g. nursery function, export to the marine environment). The ecological importance of an estuary is an expression of its importance to the maintenance of biological diversity and ecological functioning on a regional, national or global scale.
  - Derive REC: Define the individual estuary RECs based on their PES, importance, (desired) protection status and reversibility of the impacts. The REC represents the recommended level of protection assigned to an estuary where the PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the estuary's ecological importance and its level of protection or desired protection. Where impacts are deemed irreversible a Best Attainable State (BAS) is recommended.
- **3. Set EWRs (undertaken during sub-step 4.1)**

For estuaries applying EcoClassification and determining the EWR is one process, with the estuary EWR determination undertaken during sub-step 4.1.

The process to determine the EWRs for estuaries require that operational scenarios (including future discharge volumes and associated quality) are identified (Integrated Step 4). During Integrated Step 4 the operational scenarios are evaluated to determine the resulting EC. The

results are in turn then compared to present to determine the REC (Integrated Step 3) and the associated EWR (Integrated Step 4) in an iterative process.

5.2 STEP 3.3.2 ESTUARY: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 5.1.

Table 5.1 Step 3.3.2: Standardised input and output per action

Action	Input	Output	Method/Tools	Comments
1.1 Collect/collate data and information on Hydrology	Measured daily flows	Identify typical flow ranges that occur in the system on decadal scales	Statistical analyses of flow frequencies	
	Hydrological parameters	Simulated monthly time series (reference, present and futures)	Standardised Hydrological Model (Model attributes: simulated data, monthly time step, min 80 years that includes 1930 drought, stationary. Account for base flow reduction of ground water, can simulate the impact of dam development on estuaries) (e.g. WRSM2012, WRYM, WRPM, WReMP) see hydrology report for review of models	
	Simulated monthly time series (reference, present and futures)	Monthly data in m^3/s (in tabulated form and column format). Standard summaries required: Mean Annual Runoff (MAR) Average monthly flow (Oct to Sep) Monthly flow (Oct to Sep) 50%ile monthly flow (Median flows) (Oct-Sep) 75% monthly flow (Base flows) (Oct - Sep) 10%ile Monthly Flows (Drought Flows) (Oct - Sep) Monthly Standard deviation The month in which the maximum flows occurs The month in which the minimum flow occurs Flood variance for both natural and present day flow, defined as the 95^{th} percentile over the 25^{th} percentile Base flow variance for both natural and present day flow, defined as the 75^{t}h percentile over the 25^{th} percentile for Oct to Sep The duration of low flow, which is defined as the number of months from when the mean monthly flow drops below 6% of the MAR to the minimum flow month The month in which high flows commence is defined as the first month after the minimum flow month in which the monthly flow exceeds the mean monthly flow Coefficient of variability, defined as average	Spreadsheet tool (DWS, 2015)	

Action	Input	Output	Method/Tools	Comments
		monthly flow minus median monthly flow divided by the median monthly flow An assessment of whether the flow is bimodal or not, that is, two wet periods and two dry periods List 25 highest flow months as identified in Reference time series		
	Simulated groundwater inflow time series into the estuaries /coast	Defined as a water level and a volume of input	Modflow (see hydrology report for review of models)	
1.2 Collect/collate data and information on Bathymetry	Estuary cross sections and topographical surveys	Topographical and Bathymetric map	DWAF (2008a)	More detail in Taljaard *et al*. (2003)
	LiDAR data			
1.3 Collect/collate data and information on Mouth State	DWS continuous water level recorders	Relationship between flow/groundwater and mouth state	Standard Statistical methods	
	Mouth state observations			
1.4 Collect/collate data and information on Sediment Dynamics	Bathymetry (Action 1.2) Sediment grain size as per DWS Daily flow (measured and modelled) Hourly flood hydrographs	Define the sensitivity of the estuary physical processes to change in floods and high flow regimes	DWAF (2008a) (or future updates thereof) EWR methods in terms of data collection as well as guidelines on selecting the abiotic states	
			Numerical modelling of sedimentary processes (using a physical model such as Mike 21)	
			Simulated daily flows (ACRU Model) (see assessment in hydrological report)	
			Monthly flows disaggregated as daily flows (e.g. Water Resources Modelling Platform (WReMP) (see assessment in hydrological report)	
			Flood hydrographs	
1.5 Collect/collate data and information on hydrodynamics (abiotic states)	Measured daily flow data (Action 1.1) Simulated monthly time series data Bathymetry (Action 1.2) Mouth State (Action 1.3) Salinity data	River inflow coupled to abiotic states (e.g. mouth state, water levels, salinity regime, retention)	DWAF (2008a) (or future updates thereof) EWR methods in term of data collection as well as guidelines on selecting the abiotic states	
			Statistical analysis	
			Selection of hydrodynamic models (Mike 11, Mike 21, Delt 3D) as described in Van Ballegooyen *et al*. (2004)	
1.6 Collect/collate data and information on	Salinity (Action 1.5) Temperature, pH, Turbidity/Suspended Solids,	Characteristic water quality associated with each abiotic state and reference water quality	Methods for data collection and assessment as described in DWAF (2008a) (or any updates thereof)	

Action	Input	Output	Method/Tools	Comments
Water Quality	Dissolved Oxygen (DO), nutrients, toxic substance			
1.7 Collect/collate data and information on Microalgae	Salinity, Temperature, pH, Turbidity/Suspended Solids, DO and nutrient data collected during field surveys Hydrology (Action 1.1) and Hydrodynamics (Action 1.2) Phytoplankton: To estimate phytoplankton biomass, collect duplicate samples for chlorophyll a at the surface and 0.5 m depth intervals Use a spectrophotometer for sample analysis before and after acidification Do cell counts (at 400 x magnification) on dominant phytoplankton species to establish species distribution and composition, i.e. green algae, flagellates, dinoflagellates, diatoms and blue-green algae Benthic microalgae: Collect intertidal and subtidal benthic samples for chlorophyll a (biomass) analysis Collect 5 samples at each station Analyse samples using a recognised technique, e.g. High Performance Liquid Chromatography (HPLC) Record the relative abundance of dominant algal groups, i.e. green algae, dinoflagellates, diatoms and blue-green algae and identify the dominant species At each station also measure: Water salinity and inorganic nutrients Sediment particle size distribution and organic content Light penetration -	Understand the relationship between key abiotic drivers and species richness, community composition, abundance to define responses to the abiotic states	DWAF (2008a) (or any updates thereof)	For more detail on method for microalgae collection and analyses see Snow (2016)

Action	Input	Output	Method/Tools	Comments
	Photosythetically Active Radiation (PAR) or Secchi depth			
1.8 Collect/collate data and information on Macrophytes	Salinity, Temperature, pH, Turbidity/Suspended Solids, DO, and nutrients collected during field surveys	Understand the relationship between key abiotic drivers and species richness, community composition, abundance to define responses to the abiotic states	DWAF (2008a) (or any updates thereof)	Additional information on the quantify changes in vegetation described in Fernandes and Adams (2016) Guidance on macrophyte characteristics, see Adams *et al.* (2016)
	Hydrology (Action 1.1) and Hydrodynamics (Action 1.2)			
	The following information needs to be captured from recent and any available historical aerial photographs and ortho-photographs covering the entire estuary as defined by the geographical boundaries: Number of different habitats (plant community types) Area covered by each plant habitat Historical change in area covered by plant habitat Extent of anthropogenic impacts (agriculture, flood plain development)			
	National Estuarine Botanical data base (Adams *et al.* (2016)			
1.9 Collect/collate data and information on Inverts	Salinity, Temperature, pH, Turbidity/Suspended Solids, DO, and nutrients collected during field surveys	Understand the relationship between key abiotic drivers and species richness, community composition, abundance to define responses to the abiotic states	DWAF (2008a) (or any updates thereof)	
	Observations on mouth state and velocities on day of sampling			
	Zooplankton: Record species and abundance Benthic invertebrates: Identify fauna to lowest taxon Record animal density and species abundance (animals per m^2) Macrocrustaceans: Identify fauna to lowest taxon, Record number of species and			

Action	Input	Output	Method/Tools	Comments
	determine densities			
1.10 Collect/collate data and information on Fish	Salinity, Temperature, pH, Turbidity/Suspended Solids, DO, and nutrients collected during field surveys	Understand the relationship between key abiotic drivers and species richness, community composition, abundance to define responses to the abiotic states	DWAF (2008a) (or any updates thereof)	For more detail on linking fish responses to abiotic state see Lamberth, *et al*. (2008)
	Observations on mouth state and velocities on day of sampling			
	Recorded species list, number of each species, size frequency distributions in total length			
1.11 Collect/collate data and information on Birds	Observations on mouth state and velocities on day of sampling	Understand the relationship between key abiotic drivers and species richness, community composition, abundance to define responses to the abiotic states	DWAF (2008a) (or any updates thereof)	More detail available in Turpie *et al*. (2012)
	Record species list, number of birds of each species, state of the habitat, levels of human disturbance Identify key areas for feeding, roosting and breeding on the estuary and adjacent floodplain Identify and count high tide aggregations of feeding or roosting birds Identify breeding areas and count breeding aggregations			
	Coordinated Waterbird Counts (CWAC) data			
2. Apply EcoClassification	Simulated monthly time series (reference and present)	Abiotic state distribution for reference and present as per DWAF (2008a)	DWAF (2008a) (or any updates thereof)	
	Output of Integrated Step 1	Templates for abiotic and biotic component as per DWAF (2008a)	Guidance on template structure see DWAF (2008a) (or any updates thereof)	
		Health scores for abiotic and biotic components combined into overall PES score for each estuary (indicate if achieving EMP objectives, Nursery targets, Recreational targets)	Estuarine Health Index - see DWAF (2008a) (or any updates thereof)	More detail available in Turpie *et al*. (2012)
	Ecological Rating Importance	Ecological Importance rating of each estuary	Estuarine Importance Index (DWAF, 2008a)	
	Conservation priorities		Turpie *et al*. (2012)	
			Downstream Response to Imposed Flow Transformation (DRIFT) (Brown *et al*., 2013; 2006; King *et al*., 2003)	Only been applied in St Lucia, does not deal well with water

Action	Input	Output	Method/Tools	Comments
				quality changes. Cannot reflect this aspect well in estuaries
3. Derive REC	Output of Integrated Step 2. Requirements as specified in EMPs (ICM Act) Requirements related to protection of nursery areas (DAFF layers)	REC for each estuary (indicating whether EMP objectives and nursery targets, recreational targets will be achieved)	See guideline for setting REC in DWAF (2008a) (or any updates thereof)	Recommendation: At present there is no explicit guideline how to incorporate the requirements of the EMPs (under ICM Act) and DAFF/Department of Environmental Affairs (DEA) targets such as maintaining/ensuring condition of nursery areas (Marine Living Resources Act - MRLA)
4. Set EWRs (undertaken during Integrated Step 4)	Input is results from sub-step 3.3 and sub-step 4.1	Determined the EWR	Method for setting EWRs described in DWAF (2008a) (or any updates thereof)	

5.3 STEP 3.3.2 ESTUARY: IDENTIFIED TOOLS AND EVALUATION PER ACTION

5.3.1 Action 1 to 4: Collect/collate data and information, EcoClassification, deriving the REC, and setting the EWR

Table 5.2 Step 3.3.2: Method evaluation of the methods for collection/collation of data and information, EcoClassification, deriving the REC, and setting the EWR for estuaries described in DWAF (2008a)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Applied in all Estuary EWR studies since 1999.
Can the tool be applied at a catchment level?	Yes	Methods primarily developed for application on individual systems, but can be scaled to the catchment level.
Is the method described?	Yes	The method is described in DWAF (2008a) (or future updates thereof).
Indicate the status of publication of the method	National	Official Estuary EWR methods (DWAF 2008a) (or future updates thereof).
Are there existing training courses?	Yes	Training courses have been developed under DWS, WRC and FETWater (although these have not been presented in recent years).
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Applied in all Estuary EWR studies.
Time efficient (link to assessment level)	1 – 4 weeks	This step may require field surveys that can take between 1 day to 2 weeks per field trip depending on level of sampling and size of estuary it also requires time for analysis and assessment (which can be months e.g. for invertebrates).
Is the data available to apply the method?	No	Where systems have been studied previously, data may be available but mostly additional field surveys are required to provide sufficient confidence.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

5.3.2 Action 1: Collect/collate data and information (on estuary hydrodynamics)

Table 5.3 Step 3.3.2: Method evaluation of hydrodynamic model selection (Mike 11, Mike 21, Delt 3D) (Van Ballegooyen *et al*., 2004).

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Low	Numerical modelling only applied in Intermediate and Comprehensive studies, mostly directed at permanently open estuaries.
Can the tool be applied at a catchment level?	No	Estuary specific.
Is the method described?	Yes	Approach is described in a journal publication (see below).
Indicate the status of publication of the method	International publication	Van Ballegooyen *et al.* (2004).
Are there existing training courses?	Yes	Training provided as part of Civil engineering degree at most universities.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	No	Modelling only required in Intermediate and Comprehensive studies.
Time efficient (link to assessment level)	6 – 12 weeks	Requires significant effort in model setup, calibration and output runs (6 to 12 weeks).
Is the data available to apply the method?	Seldom	Need bathymetry/topographical data of estuary, mouth dimensions, water levels (3 to 6 position along estuary for neap and spring tide), longitudinal salinity data (neap spring for low and high tide), predicted tidal data, river inflow data.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

5.3.3 Action 2: EcoClassification

Table 5.4 Step 3.3.2: Method evaluation of DRIFT (Brown *et al*. (2013), King *et al*. (2006), King *et al*. (2003))

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Low	Only been applied in St Lucia GEF study.
Can the tool be applied at a catchment level?	No	Developed for individual river / wetland assessments.
Is the method described?	Yes	WRC manual.
Indicate the status of publication of the method	International	
Are there existing training courses?	Yes	Training courses held in South Africa and Internationally.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Not developed for estuaries. Intermediate and Comprehensive River and Wetland DRIFT applied in RSA. Desktop/Rapid DRIFT applied outside of RSA.
Time efficient (link to assessment level)	> 1 month	Time intensive.
Is the data available to apply the method?	Seldom	Data intensive.
Compatibility?	Yes	Method is not compatible with standardised outputs.

5.4 SUMMARY OF METHOD DESCRIPTIONS AND ASSOCIATED PUBLICATIONS

All methods identified and used during Integrated Step 3 are listed below. The associated publications (e.g. source of a manual and/or description of the methods) are referenced in this section and not in Chapter 11.

- **Action 1.1: Collect/collate data and information on Hydrology**

Department of Water and Sanitation (DWS), South Africa. 2015. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Volume 7b: Recommended Water Resource Classes for the T4, T5, U2, U3, U5, U6, U7 and U8 secondary catchments. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Pieter van Rooyen, Delana Louw, William Mullins, Greg Huggins, Lara van Niekerk. DWS Report: RDM/WMA11/00/CON/CLA/0215. September 2015.

- **Action 1.2: Collect/collate data and information on Bathymetry**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

Taljaard S., Van Niekerk L., Huizinga P. and Joubert W. 2003. Resource Monitoring Procedures for Estuaries for application in the Ecological Reserve Determination and Implementation Process. WRC Report No. 1308/1/03. Water Research Commission, Pretoria.

- **1.4 Collect/collate data and information on Sediment Dynamics**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

- **Action 1.5: Collect/collate data and information on Hydrodynamics (abiotic states)**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

Van Ballegooyen, R., Taljaard, S., Van Niekerk, L. and Huizinga, P. 2004. Using 3D-Modelling to predict physico-chemical responses to variation in river inflow in smaller, stratified estuaries typical of South Africa. Journal of Hydraulic Research 42: 563-577.

- **Action 1.6: Collect/collate data and information on Water Quality**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

- **Action 1.7: Collect/collate data and information on Microalgae**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

Snow, G.C. 2016. Determining the health of river-dominated estuaries using microalgal biomass and community composition. South African Journal of Botany (in press).

- **Action 1.8: Collect/collate data and information on Macrophytes**

Adams J.B., Veldkornet, D. and Tabot. P. 2016. Distribution of macrophyte species and habitats in South African estuaries. South African Journal of Botany (in press).

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

Fernandes, M. and Adams, J.B. 2016. Quantifying the loss and changes in estuary habitats in the Umkomazi and Mvoti estuaries, South Africa. South African Journal of Botany (in press).

- **Action 1.9: Collect/collate data and information on Inverts**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

- **Action 1.10: Collect/collate data and information on Fish**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

Lamberth, S.J., Drapeau, L. and Branch, G.M. 2009. The effects of altered freshwater inflows on catch rates of non-estuarine-dependent fish in a multispecies nearshore line-fishery. Estuarine, Coastal and Shelf Science 84: 527–538.

- **Action 1.11: Collect/collate data and information on Birds**

Turpie, J.K., Wilson, G. and Van Niekerk, L. 2012. National Biodiversity Assessment 2011: National Estuary Biodiversity Plan for South Africa. Anchor Environmental Consultants Report No. AEC2012/01. Anchor Environmental, Cape Town.

- **Action 2: Apply EcoClassification**

Brown, C., Pemberton, C., Birkhead, A., Bok, A., Boucher, C., Dollar, E., Harding, W., Kamish, W., King, J., Paxton, B. and Ractliffe, S. 2006. In Support of Water-resources planning – highlighting key management issues using DRIFT: A Case study. Water SA Vol. 32 No. 2. Pg 181-191.

Brown, C.A., Joubert, A.R., Beuster, J., Greyling, A. and King, J.M. 2013. DRIFT: DSS software development for Integrated Flow Assessments. Water Research Commission. 2013. No.: K5/1873. 176 pp.

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

King, J., Brown, C. and Sabet, H. 2003. A scenario-based holistic approach to environmental flow assessments for rivers. River Research and Applications 19:619-639.

Turpie, J.K., Wilson, G. and Van Niekerk, L. 2012. National Biodiversity Assessment 2011: National Estuary Biodiversity Plan for South Africa. Anchor Environmental Consultants Report No. AEC2012/01. Anchor Environmental, Cape Town.

- **Action 3: Derive REC**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

- **Action 4: Set EWRs (undertaken during Integrated Step 4)**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

6 STEP 4: IDENTIFY AND EVALUATE SCENARIOS WITHIN IWRM

Objective: Integrated Step 4 consists of the preliminary identification and description of operational scenarios within IWRM. The objective of this step is to identify scenarios (operational) which are then modelled to provide the output of a model in the formats required to evaluate the scenarios. Note that these scenarios could consist of any changes to the water resource in terms of quantity and quality. As such, it can include groundwater scenarios as well as water quality scenarios (those associated with waste water transfer works) amongst others. These scenarios are then tested with stakeholders and an agreed list of scenarios are finalised for further analyses. The scenarios are modelled (yield and system models) and the outputs are evaluated to determine a range of consequences which is then compared in order to rank the scenarios.

Integrated Step 4 contains seven sub-steps. Estuaries fall within sub-step 4.2 and is discussed in this Chapter.

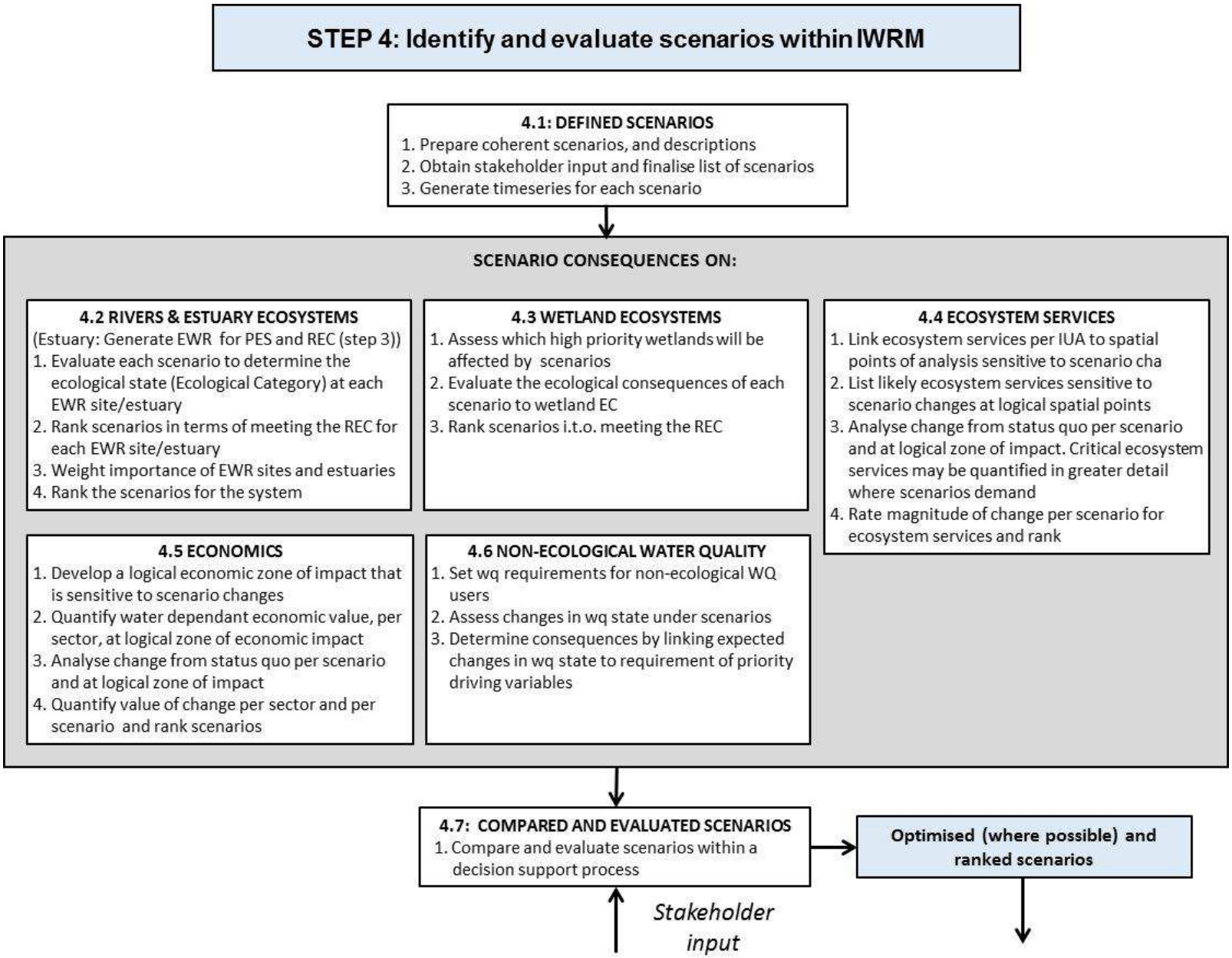

Figure 6.1 Illustration of the sub-steps for Integrated Step 4: Identify and evaluate scenarios within IWRM

6.1 STEP 4.2 ESTUARIES: ACTIONS

Objective: To determine the ecological consequences of the scenarios and provide a site and system ranking of scenarios.

This part of Integrated Step 3 is included here to link to the process of estuary EWR determination (Section 6.3.2). The process to determine EWRs for estuaries require that operational scenarios are identified and evaluated to determine the resulting EC during Integrated Step 4. The results are then compared to the present to determine the REC (Integrated Step 3) and the EWR (Integrated Step 4) in an iterative process. The step is therefore provided in brackets in the flow diagram. The detail is spelt out in Step 3.3.2 (Section 5.1 – 5.3), but included here as a reminder that, for estuaries, this is one process.

The bullets below describe the actions required for rivers.

- **1. Evaluate each scenario to determine the ecological state (Ecological Category) at each estuary**

Scenarios are evaluated to determine the predicted EC resulting from each scenario.

- **2. Rank scenarios in terms of meeting the REC for each estuary**

The predicted EC is compared with the PES and REC to provide a ranking of the scenarios in terms of how successful the scenarios meet the present and desired ecological objectives, i.e. the PES and REC.

- **3. Weight importance of EWR sites and estuaries**

The ranking provided above is applicable for each EWR site and estuary. As the ranking order may differ between sites, one has to determine the importance of the EWR sites and estuaries relative to each other which provides an EWR site/estuary weight.

- **4. Rank the scenarios for the system**

The weighting is then applied in the evaluation model which results in a ranking of scenarios on a system basis.

6.2 STEP 4.2 ESTUARIES: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 6.1.

Table 6.1 Step 4.2: Standardised input and output per action

Action	Input	Output	Method/Tools	Comments
1. Evaluate each scenario to determine the ecological state (EC) at each EWR site/estuary	a) Simulated monthly time series - Operational scenarios	Abiotic state distribution for reference and present as per DWAF (2008a)	DWAF (2008a) (or any updates thereof)	
	b) Input from Step 3	Health scores for abiotic and biotic components combined into overall Operational Scenario scores for each estuary	Estuarine Health Index (DWAF, 2008a, or any updates thereof)	Indicate if scenario achieving EMP objectives (ICM Act), conservation, and nursery targets (MLRA Act)
	Repeat step a) and b) to refine EWR if need be in a workshop setting		DWAF (2008a) (or any updates thereof)	
2. Rank scenarios in terms of	Individual Operational	Relative rating per scenario	Method for ranking scenarios	Derive relative ranking score of each

Action	Input	Output	Method/Tools	Comments
meeting the REC for each EWR site/estuary	Scenarios scores (sub-step 4.1)		in terms of meeting the REC for each estuary is described in DWS (2015)	scenarios by dividing scenario EC score (calculated with Estuary Health Index) by REC score
3. Weight importance of EWR sites and estuaries	1) Estuary size 2) Biodiversity Importance 3) Ecosystem services (nursery function) 4) Connectivity (distance to nearest system/distance to next similar type system/temporal aspect mouth state)	Relative importance weight.	Method for weighting estuarine scenarios is described in DWS (2015)	Weigh estuarine EWR results by estuarine area. Additional weight may be incorporated to reflect Biodiversity Importance, Nursery function, contribution to Marine environment (i.e. transitional waters)
4. Rank the scenarios for the system	Input Action 2 and 3	Relative ranking	Method for ranking estuarine scenarios is described in DWS (2015)	RECOMMENDATION: Proposed method has been developed for the ranking, weighting and rating of scenarios. The approach needs to be confirmed by relevant specialists (e.g. workshop) and consolidated to set formal guidelines for inclusion in official DWS methodology documentation. Connectivity (i.e. timing and duration of mouth closure in region) should explicitly be addressed

6.3 STEP 4.2 ESTUARIES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

6.3.1 Action 1: Evaluate each scenario to determine the ecological state (EC) at each EWR site/estuary

Table 6.2 Step 4.2: Method evaluation of determining EC of scenarios for estuaries (DWAF, 2008a)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Applied in all Estuary EWR studies since 1999.
Can the tool be applied at a catchment level?	Yes	Methods primarily developed for application on individual systems, but can be scaled to the catchment level.
Is the method described?	Yes	The method is described in DWAF (2008a) (or future updates thereof).
Indicate the status of publication of the method	National	Official Estuary EWR methods (DWAF 2008a) (or future updates thereof).
Are there existing training courses?	Yes	Training courses have been developed under DWS, WRC and FETWater (although these have not been presented in recent years).
Is the method applicable to all	Yes	Applied in all Estuary EWR studies.

Criteria	Evaluation	Explanatory comment
levels of assessment (Desktop to Comprehensive)?		
Time efficient (link to assessment level)	<1 week	The method is applied in a workshop environment.
Is the data available to apply the method?	No	Where systems have been studied previously, data may be available but mostly additional field surveys are required to provide sufficient confidence.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

6.3.2 Action 2 to 4: Rank scenarios in terms of meeting the REC for each estuary; Weight importance of EWR sites and estuaries; Rank the scenarios for the overall system

Table 6.3 Step 4.2: Method evaluation for ranking the scenarios in estuaries (DWS, 2015)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very Low	Method developed (DWS, 2015) was applied in Mvoti-Mzimkulu was the first WMA in which multiple estuaries were ranked and rated.
Can the tool be applied at a catchment level?	Yes	Designed to account over a catchment.
Is the method described?	Yes	Method documented in DWS (2015).
Indicate the status of publication of the method	Study report	Available from DWS web site.
Are there existing training courses?	No	
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Is designed to deal with all level of assessments.
Time efficient (link to assessment level)		
Is the data available to apply the method?		
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

6.4 SUMMARY OF METHOD DESCRIPTIONS AND ASSOCIATED PUBLICATIONS

All methods identified and used during Integrated Step 4 are listed below. The associated publications (e.g. source of a manual and/or description of the methods) are referenced in this section and not in Chapter 11.

- **Action 1: Evaluate each scenario to determine the ecological state (EC) at each EWR site/estuary**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

Department of Water and Sanitation (DWS), South Africa. 2015. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Volume 7b: Recommended Water Resource Classes for the T4, T5, U2, U3, U5, U6, U7 and U8 secondary catchments. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Pieter van Rooyen, Delana Louw, William Mullins, Greg Huggins, Lara van Niekerk. DWS Report: RDM/WMA11/00/CON/CLA/0215. September 2015.

- **Action 2: Rank scenarios in terms of meeting the REC for each EWR site/estuary**

Department of Water and Sanitation (DWS), South Africa. 2015. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Volume 7b: Recommended Water Resource Classes for the T4, T5, U2, U3, U5, U6, U7 and U8 secondary catchments. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Pieter van Rooyen, Delana Louw, William Mullins, Greg Huggins, Lara van Niekerk. DWS Report: RDM/WMA11/00/CON/CLA/0215. September 2015.

- **Action 3: Weight importance of EWR sites and estuaries**

Department of Water and Sanitation (DWS), South Africa. 2015. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Volume 7b: Recommended Water Resource Classes for the T4, T5, U2, U3, U5, U6, U7 and U8 secondary catchments. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Pieter van Rooyen, Delana Louw, William Mullins, Greg Huggins, Lara van Niekerk. DWS Report: RDM/WMA11/00/CON/CLA/0215. September 2015.

- **Action 4: Rank the scenarios for the system**

Department of Water and Sanitation (DWS), South Africa. 2015. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Volume 7b: Recommended Water Resource Classes for the T4, T5, U2, U3, U5, U6, U7 and U8 secondary catchments. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by Pieter van Rooyen, Delana Louw, William Mullins, Greg Huggins, Lara van Niekerk. DWS Report: RDM/WMA11/00/CON/CLA/0215. September 2015.

7 STEP 5: DETERMINE WATER RESOURCE CLASSES BASED ON CATCHMENT CONFIGURATIONS FOR THE IDENTIFIED SCENARIO

The flow diagram illustrating the steps, sub-steps and actions for Integrated Step 5 is provided in Figure 7.1. Note that abbreviations used are described in the acronyms and abbreviation list at the beginning of the document.

Objective: The objective of this step is to:

- Integrate the consequences to provide the resulting classes of each scenario, as well as Classes for the PES, REC and TEC for stakeholder evaluation during the next step; and
- with stakeholder input, arrive at Classes and the catchment configuration that will be available for the preparation of the legal notice.

Note that the PES, REC, TEC and operational scenarios all form part of the suite of identified scenarios that are evaluated. The most important part of Integrated Step 5 is the determination of the Classes for each IUA under different operational scenarios as well for different ecological states at various biophysical nodes. An analysis is undertaken to determine the best balanced option between protection and use for each IUA and the biophysical nodes in the IUA (referred to as the Catchment Configuration). The implications of not meeting the ecological objectives represented by the REC are identified and the best balanced option, the TEC is selected with appropriate motivations.

After input from both internal and external stakeholders, as well as liaison with relevant government institutions that play a role in IWRM or who are affected, recommendations for the legal notice are made.

TEC definition:

Information Block:
Target Ecological Category (TEC)

The TEC is the resulting Ecological Category based on the Class. One will always strive to meet the REC, however once the balance between use and protection is considered, the TEC may be the PES, the REC or any other category.

Integrated Step 5 contains four sub-steps. Estuaries fall within sub-step 5.2 and is discussed in this Chapter.

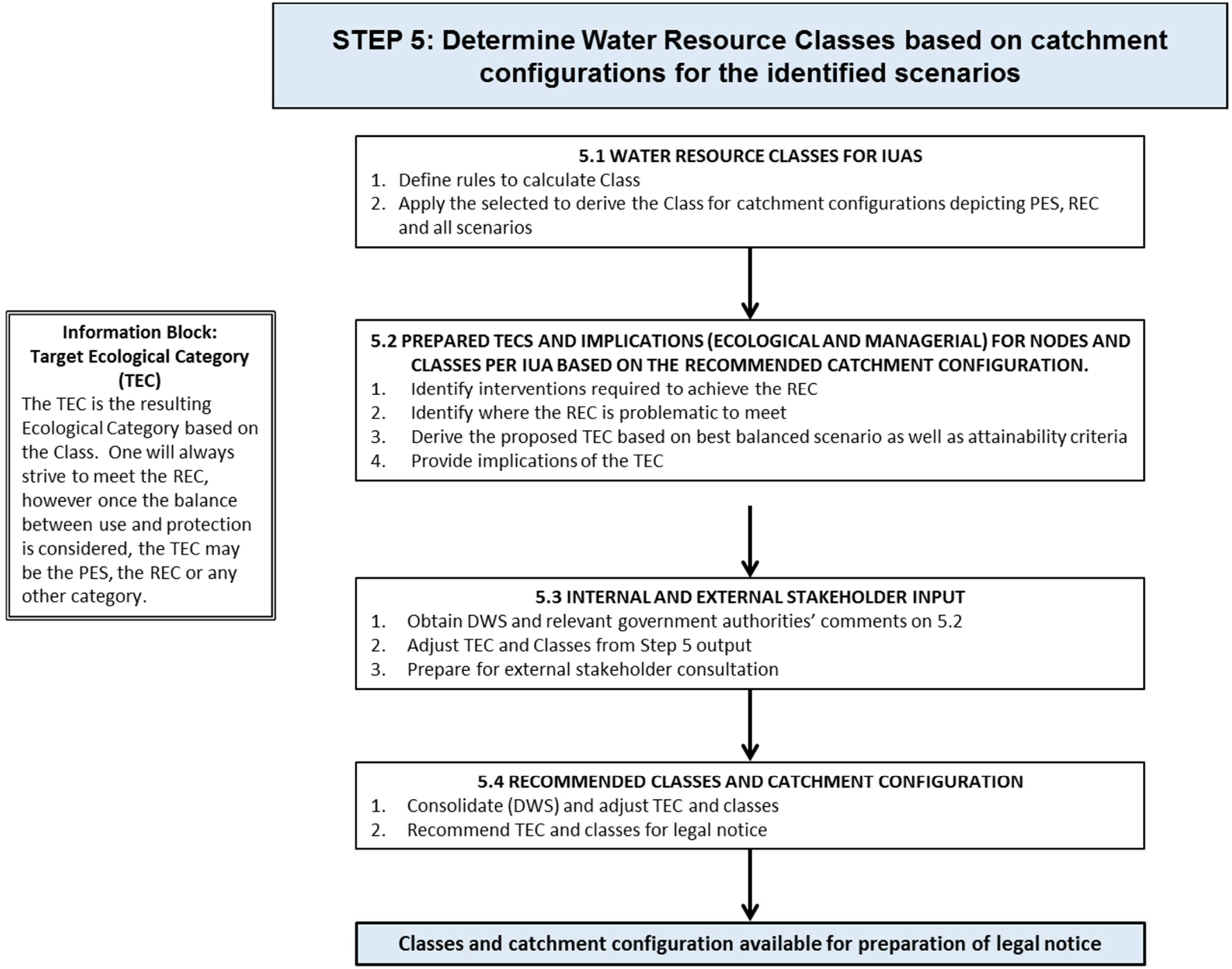

Figure 7.1 Illustration of the sub-steps for Integrated Step 5: Determine Water Resource Classes based on catchment configurations for the identified scenarios

7.1 STEP 5.2 ESTUARIES: ACTIONS

The bullets below describe the actions required.

- **1. Identify interventions required to achieve the REC**

During Integrated Step 3, the REC has been identified for all biophysical nodes. Interventions to achieve this have been identified, but further explored during Integrated Step 4 where scenarios which include the REC have also been evaluated. This information is consolidated at this point.

- **2. Identify where the REC is problematic to meet**

Based on the requirements to meet the REC as well as the socio-economic implications, the biophysical nodes where the REC will be problematic to meet are identified. An alternative EC that provides the balance between protection and use will then be selected (next bullet).

- **3. Derive the proposed TEC based on best balanced scenario as well as attainability criteria**

This EC could be any EC other than the REC and is called the TEC. Therefore, one will always strive to meet the REC, however once the balance between use and protection is considered, the TEC may be the PES, the REC or any other category.

- **4. Provide implications of the TEC**

The implications of providing the TEC and not meeting the REC (where relevant) will be provided.

7.2 STEP 5.2 ESTUARIES: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 7.1.

Table 7.1 Step 5.2: Standardised input and output per action

Action	Input	Output	Methods/Tools	Comments
1. Identify interventions required to achieve the REC	Results from Integrated Step 2 and 3. List of pressures on the system that is driving change in condition	List of interventions required to achieve individual component REC scores	Estuarine Health Index (DWAF, 2008a). Evaluate individual component scores in workshop setting to determine what management interventions can achieve the REC	Qualitative assessment
2. Identify where the REC is problematic to meet	List of interventions required to achieve individual component REC scores	List of confounding factors preventing the implementation of identified interventions required to meet REC		Qualitative assessment
3. Derive the proposed TEC based on best balanced scenario as well as attainability criteria	DAFF critical nursery layer for exploited species	Set the Estuary TECs	Multi-criteria decision analysis tool (including reporting on the achieving of overall conservation targets, EMP requirements (if available), DAFF/DEA nursery function, recreational targets)	
	EMPs ecological objectives (if available.			
	Transitional waters		Inter-governmental	

Action	Input	Output	Methods/Tools	Comments
	Requirements		meetings to resolve mandate conflicts Broad Stakeholder workshop	
4. Provide implications of the TEC	Output from sub-step 5.1 and sub-step 3.1	Summary of implication in not achieving the REC targets including a summary of were TEC do not meet: - Conservation targets, EMP requirements (ICM Act) and nursery protection requirements (MLR Act)		Qualitative assessment

7.3 STEP 5.2 ESTUARIES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

The evaluation of the method to determine flow RQOs for estuaries under Action 1 (Provide the flow RQO (EWR) as generated in Integrated Step 3 for the TEC of High priority RUs) are provided below.

Table 7.2 Step 5.2: Method evaluation of determining flow RQOs for estuaries (DWAF, 2008a)

Criteria	Evaluation	Comment
Frequency of use of the application?	Very High	Applied in most intermediate and comprehensive level studies since 1999.
Can the tool be applied at a catchment level?	Yes	This method was applied at the catchment level for the Mvoti-Umzimkulu WMA Classification and in the Gouritz WMA EWR study.
Is the method described?	Yes	Described in (DWAF 2008a).
Indicate the status of publication of the method	National	Part of official Estuary EWR methods (DWAF 2008a).
Are there existing training courses?	No	Specialist is trained by example (i.e. using template historical studies). Not technically challenging if data is available.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Until recently (2014) RQO and Thesholds of Potential Concern (TPCs) were not generated for Desktop and Rapid level EWR assessment as there is low confidence in RQO.
Time efficient (link to assessment level)	<1 week	Done in workshop environment with Estuarine abiotic and biotic specialists
Is the data available to apply the method?	Seldom	Data is generally only available for intermediate and comprehensive level studies.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

7.4 SUMMARY OF METHOD DESCRIPTIONS AND ASSOCIATED PUBLICATIONS

All methods identified and used during Integrated Step 5 are listed below. The associated publications (e.g. source of a manual and/or description of the methods) are referenced in this section and not in Chapter 11.

- **Action 1: Identify interventions required to achieve the REC**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for

protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

8 STEP 6: DETERMINE RQOs (NARRATIVE AND NUMERICAL LIMITS) AND PROVIDE IMPLEMENTATION INFORMATION

Objective: ROQs (narrative and numerical) are specified for the Classes and catchment configuration per RU. Different RQO levels, according to the RU priority (as determined during Integrated Step 1), are determined. The output provides appropriate level of RQOs for all RUs. RQOs of High Priority RUs are available for gazetting. It must be noted that the RQO report must include as much numerical information as possible for all priorities as this serves as the numerical limits document used for monitoring. Moderate and low priority RUs and broad RQOs are used e.g. for licensing of small developments and in the gazetting of the Reserve (Integrated Step 8).

This information informs the monitoring phase as well as the implementation of the Class configuration and the Reserve. According to the priorities of the RUs (determined during Integrated Step 1) different levels of detail is provided. High priority RUs will require detailed RQOs for a variety of components which will be gazetted while low and moderate priority RUs will require broad and mostly narrative RQOs. This information is then tested with stakeholders in preparation of gazetting the RQOs.

Integrated Step 6 contains five sub-steps. Estuaries fall within sub-step 6.3 and is discussed in this Chapter.

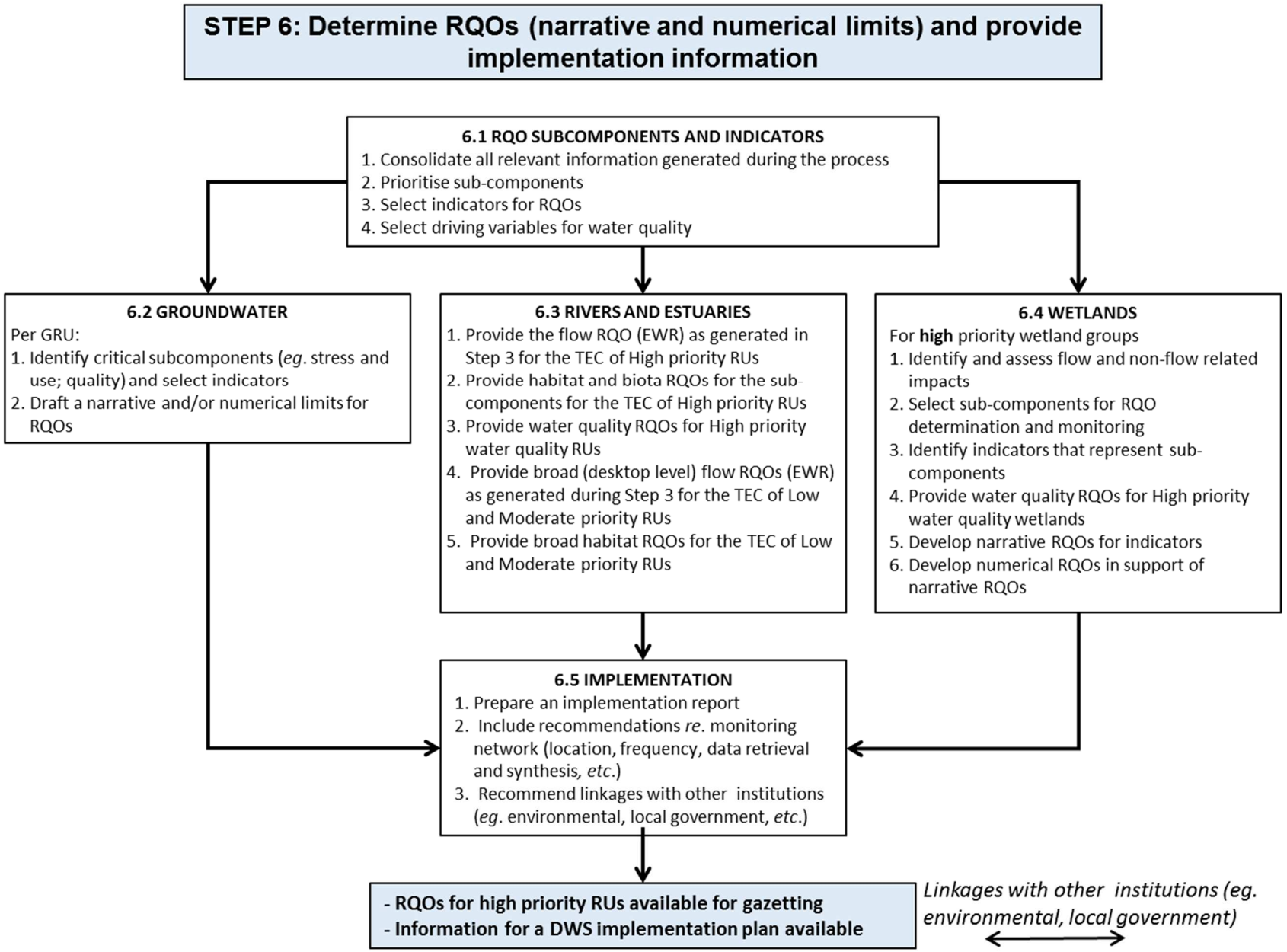

Figure 8.1 Illustration of the sub-steps for Integrated Step 6: Determine RQOs (narrative and numerical limits) and provide implementation information

8.1 STEP 6.3 ESTUARIES: ACTIONS

Objective: The objective of this step is to provide the RQOs for all RUs at the appropriate level. This information is then available to feed into the implementation report and the gazette. It must be noted that water quality is included in this step and addresses both the ecological aspects (in terms of habitat) as well as those for the non-ecological user.

The bullets below describe the actions required.

- **1. Provide the flow RQO (EWR) as generated in Integrated Step 3 for the TEC of High priority RUs**

EWRs are determined for different ECs during Integrated Step 3. During this step the recommendation regarding the TEC is available and the associated EWR can be selected. This EWR then becomes the Reserve and includes the flow RQO.

- **2. Estuaries: Provide habitat and biota RQOs for the subcomponents for the TEC of High priority RUs**

The subcomponents which are addressed for rivers are habitat (water quality, habitat integrity) and biota (fish, invertebrates, riparian vegetation). The subcomponents which are addressed for estuaries are habitat (water quality river inflow, water quality for the estuary, hydrodynamics and sediment) and biota (microalgae, macrophytes, invertebrates, fish and birds). Note that in the estuarine approach, the habitat subcomponents are referred to as the abiotic components.

- **3. Provide water quality RQOs for High priority water quality RUs**

This step encompasses the preparation of narrative and numerical RQOs for water quality, which would be represented by the driver variable(s) identified for the resource under investigation. Although ecological water quality is dealt with as a habitat RQO for rivers, provision has to be made for including non-ecological water quality, e.g. industry or recreational use, should these be the identified user. Driving variables for which RQOs need to be set must be identified. Cognisance must be taken as to whether RQOs are based on a database of monitored data (and RQOs may then be immediately applicable), or whether RQOs are preliminary, i.e. requiring data collection, and testing of monitored data against preliminary RQOs before the RQO becomes applicable. The following actions are required for determining RQOs for the water quality of rivers.

  - Use prioritisation (users and driving variables) from sub-step 4.6.
  - Use TECs from Integrated Step 5 for high priority RUs and moderate RUs where water quality is a driving variable.
  - Set RQOs (numerical in support of narrative, where available) based on the most stringent requirements, for the driving variables.

Standard DWS guidelines/databases are used as input. These include (but are not limited to the following: (1) benchmark values for ECs as in DWAF (2008b); (2) water quality ranges from water quality guidelines for users and the aquatic ecosystem (DWAF, 1996); and, (3) risk levels used by the DWS's National Microbial Monitoring Programme may be used for faecal coliforms and *Escherichia coli*. Estuarine information for users use guidelines such as: (1) water quality ranges from water quality guidelines (DWAF, 1995); and (2) recreational guidelines of DEA (2012).

- **4. Provide broad (desktop level) flow RQOs (EWR) as generated during Step 3 for the TEC of Low and Moderate priority RUs**

During Integrated Step 3, EWRs (rivers) were estimated for the PES and REC for the moderate and low priority RUs. The EWRs for rivers can therefore be provided for the TEC.

- **5. Provide broad habitat RQOs for the TEC of Low and Moderate priority RUs**

As part of habitat RQOs for rivers, water quality RQOs are provided for the driving variables linked to the driving users of the system (these may be non-ecological (e.g. industry or recreational users)). Broad estuary and habitat RQOs are also provided.

8.2 STEP 6.3 ESTUARIES: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 8.1.

Table 8.1 Step 6.3: Standardised input and output per action

Action	Input	Output	Methods/Tools	Comments
1. Provide the flow RQO (EWR) as generated in Integrated Step 3 for the TEC of High priority RUs	Time series data (PES, Operational scenarios)	Defined EWR	WRYM and WRPM tools (see hydrology report for assessment of tools)	
2. Provide habitat (including instream estuary water quality) and biota RQOs for the sub-components for the TEC of High priority RUs	Results from Integrated Step 3 (data collation and PES, REC) Estuary Management Plans Stakeholder workshop interaction	Numerical or narrative description of what the individual component REC entails	For guidance on RQOs see DWAF (2008a)	RQO Toolkit (not applied in estuaries see river and wetland evaluation)
3. Provide water quality RQOs for other uses and high priority water quality RUs including the river upstream of the estuary	Results from STEP 3 (data collation and PES, REC) and River RQOs	Numerical or narrative description of what the individual component REC entails	For guidance on RQOs see DWA (2008a), coastal marine water quality guidelines (DEA, 2012; DWAF, 1995; UNEPS and CSIR, 2009) for recreational use and setting targets for toxic substances for ecosystem protection	RQO Toolkit (not applied in estuaries see river and wetland evaluation)
4. Provide broad (desktop level) flow RQOs (EWR) as generated during Step 3 for the TEC of Low and Moderate priority RUs	Same as Action 1.			
5. Provide broad habitat (Including instream estuary water quality) and biota RQOs (including water quality in estuary) for the TEC of Low and Moderate priority RUs	Same as Action 2 and 3.			

8.3 STEP 6.3 ESTUARIES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

8.3.1 Action 1: Provide the flow RQO (EWR) as generated in Integrated Step 3 for the TEC of High priority RUs

Table 8.2 Step 6.3: Method evaluation of determining flow RQO (EWR) (DWAF, 2008a)

Criteria	Evaluation	Comment
Frequency of use of the application?	Very High	Applied in most intermediate and comprehensive level studies since 2002.
Can the tool be applied at a catchment level?	Yes	This method was applied at the catchment level for the Mvoti-Umzimkulu WMA Classification and in the Gouritz WMA EWR study.
Is the method described?	Yes	Yes described in official Estuary EWR methods (DWAF, 2008a).
Indicate the status of publication of the method	National	Part of official Estuary EWR methods (DWAF, 2008a).
Are there existing training courses?	No	Specialist is trained by example (i.e. using template historical studies). Not technically challenging if data is available.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Until recently (2014) RQO and TPCs were not generated for Desktop and Rapid level EWR assessment as there is low confidence in RQO.
Time efficient (link to assessment level)	<1 week	Done in workshop environment with Estuarine abiotic and biotic specialists.
Is the data available to apply the method?	Seldom	Data is generally only available for intermediate and comprehensive level studies.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

8.3.2 Action 2: Provide habitat and biota RQOs for the sub-components for the TEC of High priority RUs,

Table 8.3 Step 6.3: Method evaluation of determining habitat and biota RQOs (DWAF 2008a)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Applied in most intermediate and comprehensive level studies since 1999.
Can the tool be applied at a catchment level?	Yes	This method was applied at the catchment level for the Mvoti-Umzimkulu WMA Classification and in the Gouritz WMA EWR study.
Is the method described?	Yes	Yes described in official Estuary EWR methods (DWAF. 2008a).
Indicate the status of publication of the method	National	Part of official Estuary EWR methods (DWAF. 2008a).
Are there existing training courses?	No	Specialist is trained by example (i.e. using template historical studies). Not technically challenging if data is available.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Until recently (2014) RQO and TPCs were not generated for Desktop and Rapid level EWR assessment as there is low confidence in RQO.
Time efficient (link to assessment level)	<1 week	Done in workshop environment with Estuarine abiotic and biotic specialists.
Is the data available to apply the method?	Seldom	Data is generally only available for intermediate and comprehensive level studies.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

8.3.3 Action 3: Provide water quality RQOs for High priority water quality RUs

Table 8.4 Step 6.3: Method evaluation of the Determination of the Ecological Water Requirements for Estuaries Version 2 (DWAF, 2008a)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Applied in most intermediate and comprehensive level studies since 2002.
Can the tool be applied at a catchment level?	Yes	This method was applied at the catchment level for the Mvoti-Umzimkulu WMA Classification and in the Gouritz WMA EWR study.
Is the method described?	Yes	Yes described in official Estuary EWR methods (DWAF, 2008a).
Indicate the status of publication of the method	National	Part of official Estuary EWR methods (DWAF, 2008a).
Are there existing training courses?	No	Specialist is trained by example (i.e. using template historical studies). Not technically challenging if data is available.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Until recently (2014) RQO and TPCs were not generated for Desktop and Rapid level EWR assessment as there is low confidence in RQO.
Time efficient (link to assessment level)	<1 week	Done in workshop environment with Estuarine abiotic and biotic specialists.
Is the data available to apply the method?	Seldom	Data is generally only available for intermediate and comprehensive level studies.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

Table 8.5 Step 6.3: Method evaluation of determining RQO for recreational use (Coastal marine water quality guidelines: DEA, 2012)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Guidelines used widely in SA.
Can the tool be applied at a catchment level?	Yes	This is a national guideline document, applicable at any level.
Is the method described?	Yes	Published guidelines.
Indicate the status of publication of the method	National	This is a national/regional guideline documents guideline document.
Are there existing training courses?	N/A	N/A
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	
Time efficient (link to assessment level)	1?	Apply guideline.
Is the data available to apply the method?	Yes	Guidelines used widely in SA.
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

8.4 STEP 6.5 ESTUARIES: ACTIONS

Objectives: The rollout actions needed to implement the Water Resource Class and RQOs should be defined and describes in this step. This should include a schedule of measurement and monitoring requirements that are needed to periodically evaluate if the targeted ecological objectives are achieved. Cognisance should be taken if several of such implementation actions are already undertaken or is closely linked to functions what other DWS directorates, Local Authorities or Water Service Providers are performing. A generic activity of this plan would involve soliciting support from relevant directorates to adjust or incorporate appropriate actions into their business plans for the benefit of implementing Water Resource Class and RQOs.

The bullet below describes the actions required for each estuary.

- **2. Include recommendations regarding monitoring network (location, frequency, data retrieval and synthesis, etc.)**

Provide a schedule of existing and additional proposed measuring requirements along with a description of all the organisations conducting monitoring in the catchments of water resource system.

- **3. Recommend linkages with other institutions (e.g. environmental, local government)**

Identify and describe all the institutions, government or other, that are involved in related environmental compliance and monitoring activities linked to the water resource protection.

As an example for estuaries there are typically many cross-sectoral management interventions that require linkages with other institutions tasked with addressing interventions outside the DWS mandate. Estuarine resource protection and management is not only the mandate of DWS, other key government department include DEA (e.g. ICM Act) and DAFF (e.g. MLR Act). While DWS cannot be prescriptive to other Departments, it is critical that such cross-sectoral interventions are provided and the implementation thereof is addressed in consultation with responsible authorities in the implementation phase.

8.5 STEP 6.5 ESTUARIES: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 8.6.

Table 8.6 Step 6.5: Standardised input and output per action

Action	Input	Output	Methods/Tools
2. Include recommendations regarding monitoring network (location, frequency, data retrieval and synthesis, etc.)	RQOs, DWAF (2008a)	Estuary Monitoring Programme that aligns the requirements of the various mandates of DWS, DAFF and DEA	DWAF (2008a)
3. Recommend linkages with other institutions (e.g. environmental, local government, etc.)	TEC, Identified interventions, RQOs and monitoring plans	List of actions for inclusion in the Estuarine Management Planning and implementation process under the ICM Act (Implemented by Provincial/Local Coastal Committees)	DEA (2014) (EMP guidelines)
		Working Group 8 to facilitate inter-departmental collaboration (e.g. WWTW[1])	
		Liaise with DEA (pollution), municipalities/industry on waste water discharge permits under the ICM Act	
		Engage with DAFF regarding Fisheries Management Protocols	
		Liaise with SANBI regarding conservation targets	

1 Waste Water Treatment Works

8.6 STEP 6.5 ESTUARIES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

8.6.1 Action 2: Recommendations regarding monitoring network (location, frequency, data retrieval and synthesis, etc.)

Table 8.7 Step 6.5: Method evaluation of determining estuary monitoring requirements (DWAF, 2008a)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Applied in most intermediate and comprehensive level studies since 1999.
Can the tool be applied at a catchment level?	Yes	This method was applied at the catchment level for the Mvoti-Umzimkulu WMA Classification and in the Gouritz WMA EWR study.
Is the method described?	Yes	Yes described as part of the official Estuary EWR methods (DWAF, 2008a).
Indicate the status of publication of the method	Official DWS guideline	Part of official Estuary EWR methods (DWAF, 2008a).
Are there existing training courses?	No	Specialist is trained by example (i.e. using template historical studies). Not technically challenging if data is available.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Until recently (2014) Monitoring plan was not generated for Desktop and Rapid level EWR assessment, but have generic monitoring plan for all estuaries.
Time efficient (link to assessment level)	<1 week	Done in workshop environment with Estuarine abiotic and biotic specialists.
Is the data available to apply the method?		
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

8.6.2 Action 3: Recommend linkages with other institutions (e.g. environmental, local government, etc.)

Table 8.8 Step 6.5: Method evaluation related to institutional linkages (DEA, 2014)

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	Guidelines apply to all Estuary Management Plans.
Can the tool be applied at a catchment level?	No	The guideline describes the process by which identified interventions are linked to the Estuary Management Planning Process.
Is the method described?	Yes	Described in DEA (2014).
Indicate the status of publication of the method	Official DEA guideline document	Official DEA guideline.
Are there existing training courses?	Yes	Training courses have been developed and funded by WRC and DEA, presented and accredited by NMMU.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?		
Time efficient (link to assessment level)		
Is the data available to apply the method?		
Compatibility?	Yes	Method compatible with both standardised inputs and outputs.

8.7 SUMMARY OF METHOD DESCRIPTIONS AND ASSOCIATED PUBLICATIONS

All methods identified and used during Integrated Step 6 are listed below. The associated publications (e.g. source of a manual and/or description of the methods) are referenced in this section and not in Chapter 11.

8.7.1 Step 6.3

- **Action 2: Provide habitat (including instream estuary water quality) and biota RQOs for the sub-components for the TEC of High priority RUs**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

- **Action 3: Provide water quality RQOs for other uses and high priority water quality RUs including the river upstream of the estuary**

Department of Environmental Affairs (DEA), South Africa. 2012. South African water quality guidelines for coastal and marine waters. Volume 2: Guidelines for Recreational Use.

Department of Water Affairs and Forestry (DWAF), South Africa. 1995. South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment. Pretoria.

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

8.7.2 Step 6.5

- **Action 2: Include recommendations regarding monitoring network (location, frequency, data retrieval and synthesis, etc.)**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008a. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries Version 2. Department of Water Affairs and Forestry, Pretoria.

- **Action 3: Recommend linkages with other institutions (e.g. environmental, local government, etc.)**

Department of Environmental Affairs (DEA), South Africa. 2014. Guidelines for the Development and Implementation of Estuarine Management Plans in terms of the National Estuarine Management Protocol.

9 FRESHWATER REQUIREMENT OF THE TRANSITIONAL WATERS OF SOUTH AFRICA

9.1 BACKGROUND

Freshwater flow reduction has severe consequences for transitional waters (i.e. estuarine, coastal and nearshore marine) biodiversity and resources through impacts on physical habitat, reduced nutrient inputs and alterations to important ecological processes (Van Niekerk and Turpie 2012, Gillanders and Kingford 2002, Lamberth and Turpie 2003, van Ballegooyen *et al*., 2007, Lamberth *et al*., 2009, Porter, 2009). In South Africa, reduced river inputs have a significant impact on coastal and marine ecosystems around the entire South African coastline although impacts are expected to be more severe in the more nutrient poor marine environment of the east coast (van Ballegooyen *et al*., 2007). The impacts of altered fresh water flow reduction extend offshore with correlations between flow reduction and patterns in catches of commercial linefish documented more than 40 km offshore on the Thukela Banks (Lamberth *et al*., 2009).

Based on reductions in the 20 largest catchments in South Africa (those that contribute approximately 1% or more of total MAR in the region), the total freshwater flow to the marine environment has been reduced by about 40% (more than 11 000 million m^3/year) (see Table 9.1). The greatest reduction is on the west coast (approximately 7 000 million m^3/year) but there are significant reductions along both the south and east coasts. The larger river systems have experienced the greatest flow reduction and are therefore expected to have driven the most change in marine ecosystems. These include the Orange River on the west coast, the Thukela and Umzimvubu rivers in KwaZulu-Natal and the Breede River in the Agulhas Bioregion. The reduction of river flow leads to a reduced sediment supply to the coast with implications for beach and subtidal habitats. Reduced sediment input can change beach morphodynamic state, altering the beach biodiversity, accelerating beach erosion and can even lead to the loss of beach habitat (Harris *et al*., 2010). In the subtidal environment, riverine inputs provide important sediment inputs for the maintenance of unconsolidated sediment habitats. Reduced river inputs reduce the spatial extent of such habitats (van Ballegooyen *et al*., 2007).

Table 9.1 Summary of the 20 major catchments that play an important role in the development and productivity of South Africa's Transitional waters (Source: Van Niekerk and Turpie, 2012)

Catchment	MAR (Mill m^3/a)	% Change	% of SA Runoff
Orange	10 833.0	56	28.6
Thukela	3 753.6	27	9.9
Mzimvubu	2 893.8	10	7.7
Breëde	1 785.0	42	4.7
Umzimkulu	1 478.2	25	3.9
Olifants	1 070.1	34	2.8
Great Kei	1 064.1	15	2.8
Mkomazi	1034	15	2.7
Groot Berg	916.0	46	2.4
uMfolozi	885.0	19	2.3
Mbashe	836.0	10	2.2
Mgeni	682.9	61	1.8
Mhlathuze	645.0	20	1.7
Gouritz*	539.1	40	1.4

Catchment	MAR (Mill m^3/a)	% Change	% of SA Runoff
Great Fish	525.4	30	1.4
Gamtoos	500.6	35	1.3
Mvoti	482.0	25	1.3
St Lucia	417.9	30	1.1
Mtata	377.8	54	1.0
Mtamvuna	303.8	15	0.8

Many of these habitats are also important for ecological processes. For example the endemic and imperiled white steenbras *Lithognathus lithognathus* spawns on submarine fluvial fans, a localised habitat of limited extent, associated with mixed mud and sand banks deposited by rivers in the southeast Cape coast (Bennett, 1993). Changes in salinity and water temperature linked to flow alteration also impact thermohaline fronts which affects plankton feeding communities and the fish, birds and mammals that feed on the concentrated food associated with these habitats (van Ballegooyen *et al*., 2007).

Important processes that can be compromised through altered fresh water flow include nursery functions, environmental cues, productivity and food web processes. Increased frequency of estuary mouth closures and associated conditions due to reduced freshwater flow can also disrupt lifecycles and connectivity, and deprive fish and invertebrates of the important nursery function of estuaries (Whitfield, 1998). Sediment input leads to turbidity providing an important refuge for fish which is a key component of estuarine, coastal and offshore nursery areas (Whitfield, 1998; Lamberth *et al*., 2009). Reduced turbidity can alter predation pressure and the catchability of fisheries resources (van Ballegooyen *et al*., 2007). Altered freshwater flow leads to changes in important environmental cues such as those relevant for spawning, recruitment and migration (Lamberth *et al*., 2009). Changes in spawning intensity have been correlated with altered fresh water flow (QuiÑores and Montes 2001; Demetriades *et al*., 2000).

Catchment derived nutrients are an important component of coastal and marine foodwebs stimulating phytoplankton production. The impacts of reduced nutrient supplies will travel through coastal and marine ecosystems via foodwebs (van Ballegooyen *et al*., 2007). Reduced detritus may also impact on coastal and marine foodwebs as river-associated detritus and associated epiphytes are believed to be an important food source for microorganisms, filter feeders, detritivorous fish and invertebrates (Berry *et al*., 1979; Schleyer 1981; Berry and Schleyer 1983; Whitfield 1998; Porter, 2009). In KwaZulu-Natal, an isotope study showed that suspended riverine particulate organic matter (terrestrial, aquatic plant material and plankton) plays an important role in supporting inshore filter-feeder communities, i.e. intertidal and subtidal assemblages dominated by the sea-squirt known as red bait *Pyura stolonifera*, mussels *Perna perna*, and oysters *Striostrea margaritacea* and *Saccostrea cucullata* (Porter, 2009). Porter (2009) found that between 8 and 33% of filter-feeder diets consisted of material introduced to the sea by rivers and concluded that rivers play an important trophic role in promoting filter-feeder biomass in the Natal Bioregion. He also demonstrated the links between river, inshore and pelagic ecosystems, highlighting the need for adequate freshwater supplies for the maintenance of the integrity of coastal and marine ecosystems.

Changes in freshwater flow and associated variations in turbidity, nutrients and sediment supply can impact fisheries resources, alter catch composition and reduce the economic returns of fisheries (Lamberth and Turpie, 2003; Lamberth *et al*., 2009). Fisheries resources in South Africa that have, or may have been compromised by reduced fresh water input include linefish (Lamberth

et al., 2009), prawns (Demetriades *et al*., 2000), and filter feeding invertebrates in the intertidal and shallow subtidal (Porter, 2009).

Lamberth *et al*., (2009) identified significant relationships between flow and the catches of 14 linefish species (more than 90% of the total catch) on the Thukela Banks in KwaZulu-Natal. Most fish responded negatively, with reduced catches correlating with reduced flow (after a lag phase), slinger *Chrysoblephus puniceus* and squaretail kob *Argyrosomus thorpei*, the most important species in the fishery, showing the most marked response.

The ecological needs of South Africa's the Transitional waters (i.e. freshwater dependant coastal and marine environment) must be considered in the allocation of fresh water resources to ensure healthy functioning marine ecosystems that support productive and sustainable fisheries.

9.2 RECOMMENDATIONS FOR INCLUDING THE FRESHWATER REQUIREMENTS OF THE TRANSITIONAL WATERS AND COASTAL ENVIRONMENT

Van Ballegooyen *et al*. (2007) developed a comprehensive assessment framework for the marine ecosystems that takes cognisance of their freshwater requirements. This study proposes to use a modified the version of the propose framework to evaluate a range of freshwater flow scenarios to the by means of the steps listed in Table 9.2.

- **STEP 1**

1.1 Define legislative obligations (in terms of **biodiversity protection, sustainable fisheries, coastal protection -beach development):** Review the policies and legislation of relevance to the assessment and management of the freshwater requirements of the marine environment, including particular obligations under various treaties and international agreements.

1.2 Define the ecosystem extent (biogeographic domain): The boundaries of ecosystem extent of relevance to the assessment need to be defined based on the extent of the marine ecosystem potentially impacted by change of freshwater inflow (i.e. an appropriate definition of the ecological "footprint").

1.3 Identify key ecosystem functions and services: Provide adequate description of key ecosystem function and services (i.e. key components) to ensure an appropriate ecosystem management approach and the appropriate maintenance of biodiversity.

1.4 Identify of resource utilization in ecosystem: The resource utilization needs to be identified in order that, as a minimum, appropriate keystone/indicator species can be selected for the assessment of the freshwater requirements of the marine environment.

- **STEP 2**

2.1 Identify biodiversity and resource use targets (e.g. fish nurseries, fisheries production, Marine Protected Areas, sediment requirement of beaches): Based on the identified policy and legislative requirements, resource utilisation and characteristics of the ecosystem under consideration, specific management and environmental quality objectives need to be developed.

- **STEP 3**

3.1 Determine ecosystem sensitivity to flow through:

3.1.1 **Identification relevant abiotic components (habitat) and assess the response to flow modification:** The critical abiotic drivers (e.g. salinity, nutrients, sediments, etc.) influencing the quality of the required habitats during the various life-cycle stages of the key biotic species need to be identified. For some species it may be required that other biotic drivers need to be selected as well. However, to limit the

complexity of the assessment, this should be avoided if at all possible. This also includes an analysis of the temporal and spatial scales required to adequately characterise the drivers and their role in the biotic response of the species chosen. The various abiotic (and biotic) drivers need to be integrated and/or aggregated, such that they are relevant to determining the biotic response. Where the abiotic (and biotic) driver cannot be measured on the temporal and spatial scales required to adequately characterise the driver, an attempt should be made to characterise the driver based on a functional relationship based on a time series that has indeed been measured on the spatial and temporal scales required. Describe the changes in the past and present flow regime of the catchment to provide context to the assessment.

3.1.2 **Describe the implications of present flow regime on selected biological components (i.e. keystone/indicator species life-cycle and habitat requirements in terms of flow). Selection of keystone or indicator species:** Based on the management objectives, the defined ecosystem boundary and resource utilization, keystone and/or indicator species need to be identified that will minimise the complexity of the assessment, allow for the setting of clear and measurable environmental objectives and ensure practical and effective management advice. **Determination of life-cycle and habitat requirements:** An analysis of the various life-cycle stages of the identified keystone or indicator species is required to identify the habitat requirements for the various life-cycle stages and consequently the abiotic (and biotic) drivers of relevance.

- **STEP 4**

4.1 Assess hydrological operational scenario:

a) Describe the changes in the flow regime of the catchment to provide context to the assessment. Predicted the possible responses, if any, to predicted change in abiotic drivers.

b) Describe the implications of flow alteration on selected biological components (i.e. keystone/indicator species life-cycle and habitat requirements in terms of flow)

4.2 Evaluation of socio-economic importance of marine aquatic ecosystems and resource uses: The outcomes of the assessment of the potential impacts associated with changes in freshwater inflow into marine ecosystems need to be linked to the socio-economic implications of these changes as this is the primary basis upon which water resource allocations are likely to be made. Based on the outcome of this step, there may be modification of the recommended freshwater requirements for the marine ecosystems under consideration.

4.3 Recommendation of Freshwater Requirements: The adequacy of the scientific assessment will be determined by whether or not there is sufficient understanding and/or measurements to translate management and environmental quality objectives into specific freshwater requirements or target values, based on recognised usage of the marine environment as an existing or potential future resource. Typically this is only possible for a specific coastal and offshore region once existing and potential future resource utilisation in the region of interest has been mapped and there is a reasonable understanding of the functioning of the ecosystems of relevance.

- **STEP 5**

5.1 Include Transitional Waters EWR in the setting of the TEC for estuaries as part of a source protection measure: While the Water Act does not recognise South Africa's Transitional waters as a receiving environment, the Act does provide for "Source Protection". This, in turn, allows for the setting of EWR and RQOs for significant water resources or other ecosystem services. Therefore the requirements of the nearshore environment needs to be

incorporated in the setting of the TEC for estuaries as it may well mean that an estuary must maintain or improve its current condition to meet the requirements of its Transitional Waters.

- **STEP 6**

6.1. Set RQOs (e.g. freshwater flow and river water quality): At a minimum set the RQOs for freshwater flow and river water quality to the transitional waters. RQOs for special habitats, e.g. sediment loads may also be defined if information is available.

Table 9.2 Actions required for including the flow requirement of the transitional waters of South Africa into the Classification processes

Classification Step	Comment
Step 1	1.1 Define legislative obligations (in terms of biodiversity protection, sustainable fisheries, coastal protection -beach development). 1.2 Identify ecosystem extent (delineation). 1.3 Identify key ecosystem functions and services. 1.4 Identify ecosystem resource use.
Step 2	2.1 Identify biodiversity and resource use targets (e.g. fish nurseries, fisheries production, Marine Protected Areas, sediment requirement of beaches).
Step 3	3.1 Determine ecosystem sensitivity to flow. Identify relevant abiotic components (e.g. habitat) and assess responses to flow modification. Describe the implications of present flow regime on selected biological components (i.e. keystone/indicator species life-cycle and habitat requirements in terms of flow).
Step 4	4.1 Assess hydrological operational scenario. Predicted the responses, if any, to predicted change in abiotic drivers. Describe the implications of flow alteration on selected biological components. 4.2 Evaluation of socio-economic importance of marine aquatic ecosystems and resource uses. 4.3 Recommend EWR.
Step 5	5.1 Include in the setting of the TEC for estuaries as part of a source protection measure.
Step 6	6.1 Set RQOs (e.g. Flow and river Water Quality).

Table 9.3 include recommendations for including the coastal groundwater dependant systems in the Classification process.

Table 9.3 Actions required for including the flow requirement of the estuarine and coastal waters of South Africa into Step 3 of the Classification processes

Action	Input	Output	Methods/Tools
1.3.5 Define surface groundwater interaction areas (including estuaries and nearshore coastal environments)	Aquafer parameters Climatic parameters Recharge and rainfall	Flows to estuary, water levels Seepage to sea (steady state or time series)	See Groundwater tool report for detail

10 CONCLUSIONS

In general, the estuary methods and tools are well developed and most have been used extensively.

- **Step 1 Delineate and Prioritise RUs:** A method have been developed for the delineation of the EFZ for all estuaries in South Africa. This delineation is refined as part of the National Biodiversity Assessment to ensure coherence with other planning approaches. Most critical information is readily available for the ranking of estuaries based on their biodiversity importance, nursery function, conservation importance, and sensitivity/vulnerability to flow and pollution etc. Similarly, a provisional REC have been allocated to all estuaries in South Africa. An approach has been developed for the prioritisation of estuaries but it needs to be formalised.

- **Step 2 Describe status quo and delineate the study area into IUAs:** The National Biodiversity Assessment Management and Monitoring register for South Africa's estuaries provide an overview of all management responses (e.g. historical EWR studies, Estuary Management Plans) and monitoring activities (e.g. DWS monitoring sites) per estuary. It is therefore critical that this register be consulted for readily available information. Additional information should also be sourced from scientific publications and research reports. Similar to above, all critical information is readily available to describe the status quo and group the estuaries into logical units.

- **Step 3 Quantify the EWR:** This step forms the basis of the quantification of the Ecological Reserve. The Ecological Reserve Methodologies have been in place since 1999 and have been well applied over the past decade. A Desktop method have been developed as part of a WRC project and applied in a number of regional-scale studies since then. The DRIFT model has only been applied at St Lucia and needs further verification. At present there is no explicit guideline how to incorporate the requirements of the EMPs (ICM Act) and DAFF /DEA targets such as maintaining/ensuring condition of nursery areas (MRLA) formally into the EWR process. The flow requirements of the marine environment is not addressed in any of the EWR/Classification studies and is a significant oversite as freshwater is critical for the maintenance of a number of coastal processes.

- **Step 4 Evaluation of operational scenarios:** The tools to evaluate the operational scenarios are built into the DWS Estuary EWR methods. However current methods for the overall weighing and ranking of scenarios still needs to be formally incorporate.

- **Step 6 Determine RQOs:** The determination of EcoSpecs and setting of monitoring programmes form part of the DWS Estuary EWR methods. However, approaches and detail component specific methods are still lacking. As part of the RQO process it is important to link the REC, mitigation measures required to meet the REC, and the role the other key lead agents (e.g. DEA, DAFF) play in estuaries.

The following recommendations are made in this report:

- A proposed method has been developed for the grouping of estuaries in sub-step 1.6.4, but this approach needs to be confirmed by relevant specialists (e.g. workshop setting) and consolidate to set formal guidelines for inclusion in official DWS methodology documentation.

- Similarly, a proposed method has also been developed for the ranking, weighting and rating of scenarios. The approach needs to be confirmed by relevant specialists (e.g. workshop) and consolidated to set formal guidelines for inclusion in official DWS methodology documentation. Connectivity (i.e. timing and duration of mouth closure in region) should explicitly be addressed.
- There is reservation regarding the ability of the DRIFT method to deal with estuarine complexity, especially in the case of transformed systems were flow is not the dominant driver. It is therefore recommended that the DRIFT method be evaluated by a team of estuarine specialists comprising all the relevant estuarine disciplines (e.g. hydrodynamics, water quality, physical habitat, microalgae, macrophytes, invertebrates, fish and birds) before it becomes accepted as part of the formal methods for estuaries.
- At present there is no explicit guideline how to incorporate the requirements of the Estuary Management Plans (under ICM Act) and DAFF/DEA targets such as maintaining/ensuring condition of nursery areas (Marine Living Resources Act) and water quality modification in the Classification process.
- The fresh water requirements of South Africa's transitional water need to be incorporated in the Classification process. The loss of production and ecosystem services in the nearshore environment (fans and plume off large river systems) as a result of flow reduction need to be quantified and acknowledge in the Classification process. This includes aspects such as freshwater dependant coastal environments were groundwater feed the nearshore production.

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