REPORT NO.: RDM/WE/00/CON/ORDM/0516

DEVELOPMENT OF PROCEDURES TO OPERATIONALISE RESOURCE DIRECTED MEASURES

PROJECT NO: WP 10951

RIVER TOOL ANALYSIS AND STANDARDISATION REPORT

AUGUST 2016

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REPUBLIC OF SOUTH AFRICA

DEVELOPMENT OF PROCEDURES TO OPERATIONALISE RESOURCE DIRECTED MEASURES

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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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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
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24	RDM/WE/00/CON/ORDM/0317	Project Close-Up Report

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REPORT SCHEDULE

Version	Date
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Final	October 2016

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ACRONYMS AND ABBREVIATIONS

BHNR	Basic Human Needs Reserve
BBM	Building Block Methodology
CD: WE	Chief Directorate: Water Ecosystems
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitation
DWA	Department Water Affairs
DWAF	Department Water Affairs and Forestry
DRIFT	Downstream Response to Imposed Flow Transformation
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
FRAI	Fish Response Assessment Index
FROC	Frequency of Occurrence
GAI	Geomorphological Driver Assessment Index
HFSR	Habitat Flow Stressor Response
IHI	Index of Habitat Integrity
IUA	Integrated Unit of Analysis
IWRM	Integrated Water Resource Management
MIRAI	Macro Invertebrate Response Assessment Index
MRU	Management Resource Unit
NWRCS	National Water Resource Classification System
PBMT	Potential Bed Material Transport
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
REMP	River EcoStatus Monitoring Programme
SCI	Socio-Cultural Importance
SQ	Sub Quaternary
TEC	Target Ecological Category
ToR	Terms of Reference
VEGRAI	Vegetation Response Assessment Index
WRUI	Water Resource Use Importance

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 river 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 methods 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 River method analysis and standardisation workshop specialist meeting (20 to 21 July 2016) (RDM/WE/00/CON/ ORDM/0516).

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.

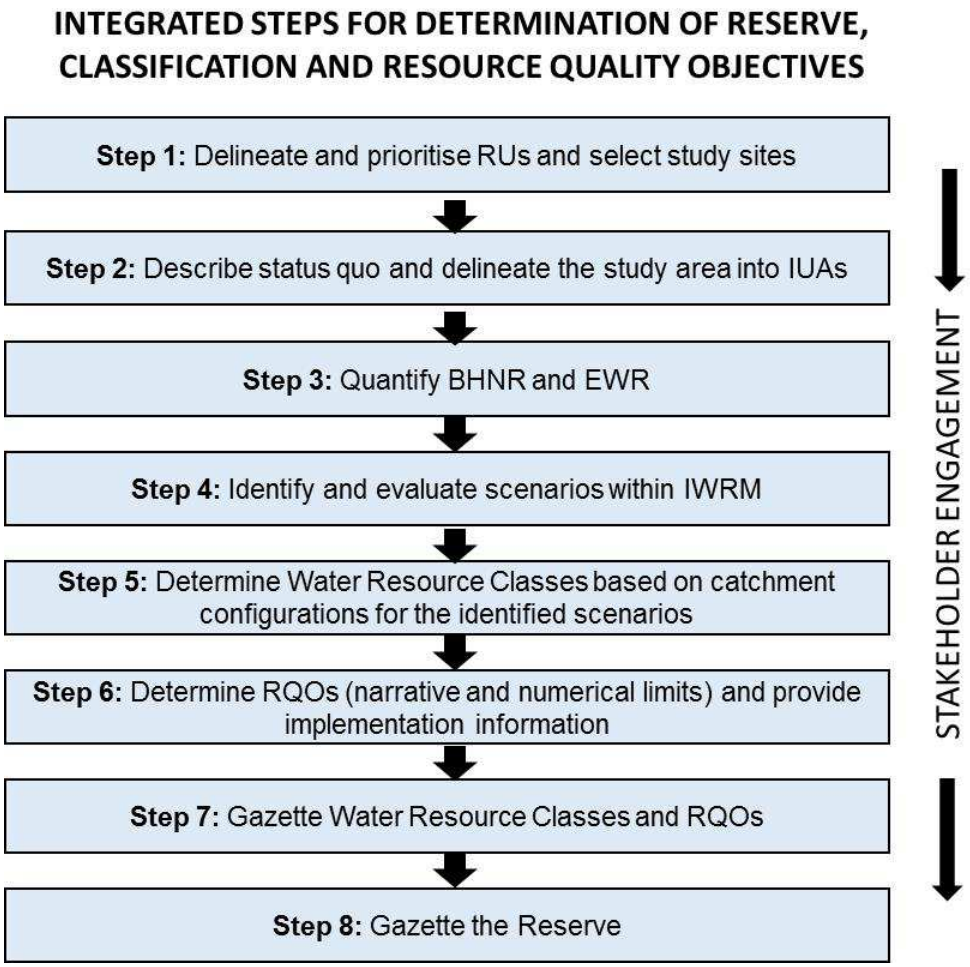

Figure 2.1 Integrated steps for the determination of the Reserve, Classification and Resource Quality Objectives

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 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 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 method evaluation, the evaluation manner and an explanatory comment are 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; 5 Commercial	Purpose of criteria is to indicate the risk of keeping method relevant.
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.

Criteria	Evaluation	Explanatory comment
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 five sub-steps which are discussed below. Second and third tier numbering e.g. Step 1.1 and Step 1.1.1 represent sub-steps within Integrated Step 1.

All methods identified and used during Integrated Step 1 are listed in Section 3.10.

[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.

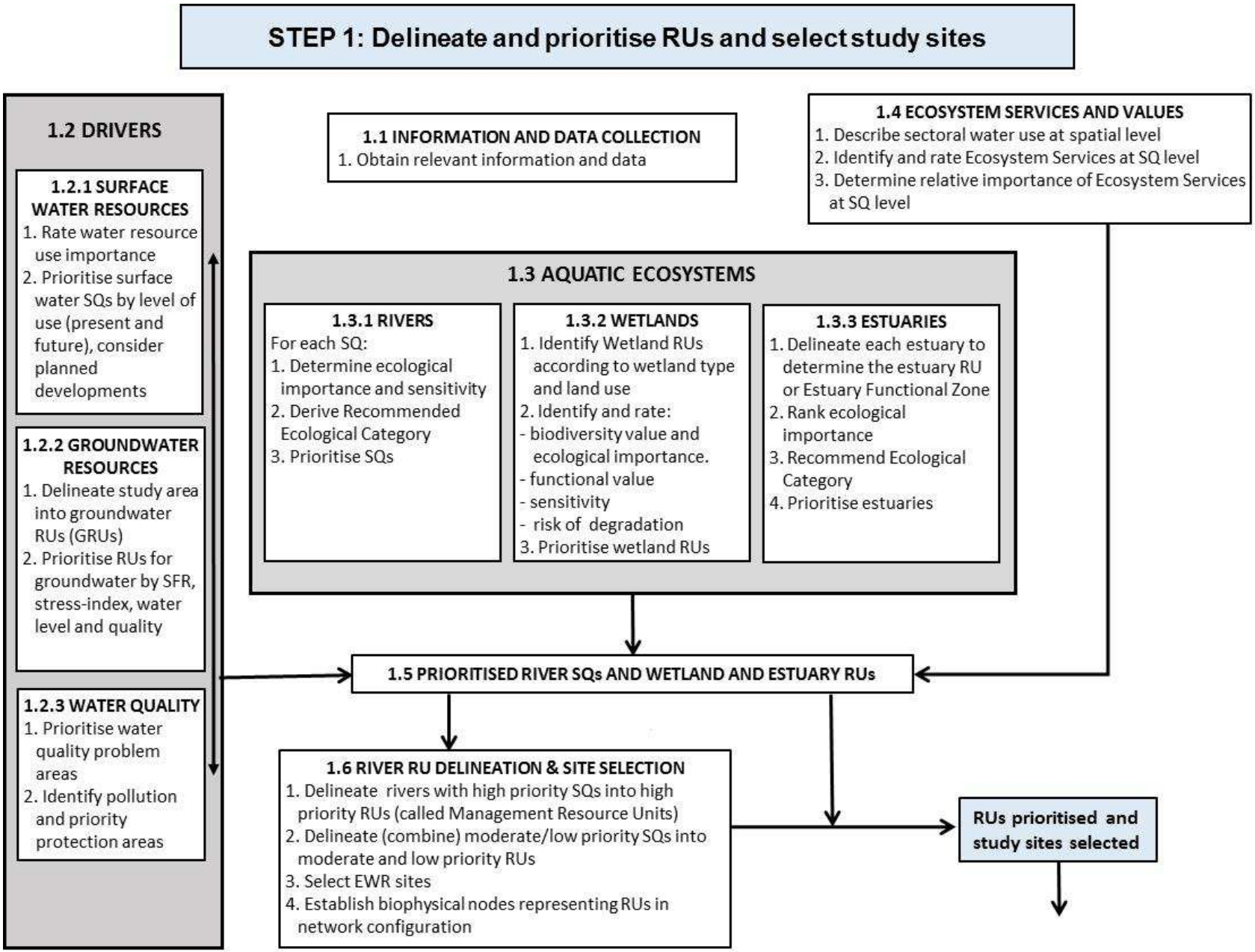

Figure 3.1 Illustration of the sub-steps for Integrated Step 1: Delineate and prioritise RUs and select study sites

3.1 STEP 1.3.1 RIVERS: ACTIONS

Objective: The objective is to delineate SQs for rivers and to prioritise these on the basis of Ecological Importance and Sensitivity (EIS). An additional output of this step is to determine the desired EC (based on a set of DWS rules) (DWS, 2014b) termed the **Recommended Ecological Category (REC) and also indicate what (broadly) would be required to achieve these ecological objectives where the REC represents an improvement of the PES**.

The bullets below describe the actions required.

- **1. Determine the ecological importance and sensitivity per SQ**

The existing PESEIS database (DWS, 2014a) is used to provide an EIS evaluation per SQ. This information then feeds into the assessment of determining high priority RUs.

- **2. Derive the REC**

As stated above, the REC is derived based on a set of rules. Where the REC requires improvement, the required actions are identified. This information is required during Integrated Step 3 (see Chapter 6).

- **3. Prioritise SQs**

These are prioritised using criteria such as the Ecological Importance (EI), Ecological Sensitivity (ES) and PES.

3.2 STEP 1.3.1 RIVERS: STANDARDISED INPUT AND OUTPUT

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

Table 3.1 Standardised input and output per action

Action	Input	Output	Comment	Methods
1. Determine the ecological importance and sensitivity per SQ	PESEIS database	EIS rating (number and description) per SQ		n/a
2. Derive REC	PESEIS database DWS rules	REC per SQ including identification of actions required to achieve REC (desktop level)	REC approach within the PESEIS database is included in the PESEIS database	Catchment Reserve RU priority spreadsheet (DWA, 2013)
3. Prioritise SQs		Ranked SQs in terms of priority	Embedded in the Catchment Reserve RU priority spreadsheet (previously known as the Hotspot method)	Catchment Reserve RU priority spreadsheet (DWA, 2013)

3.3 STEP 1.3.1 RIVERS: IDENTIFIED METHODS AND EVALUATION PER ACTION

Table 3.2 Evaluation of the Catchment Reserve RU priority spreadsheet

Evaluation criteria		Catchment Reserve RU priority spreadsheet
Frequency of application use	Evaluation	5 - Very High
	Explanatory Comment	In use since 2004 (Maputo Basin study) and applied in most Reserve studies and four large Classification studies.
Can the method be applied at a catchment level?	Evaluation	Yes
	Explanatory Comment	Designed for catchment level.
Is the method described?	Evaluation	Yes
	Explanatory Comment	Method is described in documents used since 2004.

Evaluation criteria		Catchment Reserve RU priority spreadsheet
Indicate the status of publication of the method.	Evaluation	3 - Internal
	Explanatory Comment	Site-specific reports.
Are there existing training course?	Evaluation	No
	Explanatory Comment	Explanation of methods in documents is sufficient and the method does not require training.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Evaluation	Yes
	Explanatory Comment	Catchment methods used for prioritisation irrespective of level of determination.
Time efficient (link to assessment level)	Evaluation	1
	Explanatory Comment	As existing databases and refinement is required and as this is desktop based - the process uses a spreadsheet that is built up with data in all previous actions and automatically calculates the output.
Is the data available to apply the method?	Evaluation	Always
	Explanatory Comment	Data is reliant on PESEIS database and reasonable Google Earth coverage.
Compatibility	Evaluation	Yes
	Explanatory Comment	Complies with input and output.
Is the model robust?	Evaluation	Yes
	Explanatory Comment	Based on broad estimates and set rules that ensure consistent answers.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Evaluation	No
	Explanatory Comment	Includes a rated confidence assessment scored from 0 – 5.

3.4 STEP 1.5 PRIORITISED RIVER SQs

Objective: All relevant information focussing on the various components' importance is fed into an assessment procedure which rates the priority areas (a rule-based scoring system is usually used). At this point rivers under current and future pressures in need of intervention or protection have been identified. These systems should be targeted for higher confidence Ecological Water Requirements (EWR) assessments, the level of which depends on data availability. One would have therefore have mapped all the high priority systems and can now plan for the next sub-steps. Note that rivers are prioritised at SQ level as this information is required to undertake the delineation (Integrated Step 1.6).

3.5 STEP 1.5 PRIORITISED RIVER SQs: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 3.3.

Table 3.3 Standardised input and output per action

Input	Output	Methods
Importance evaluation for water resource use and socio economic aspects	Priority scoring at SQ level	Catchment Reserve RU priority spreadsheet (DWA, 2013a)
		RU Prioritisation tool (Original guideline version; DWA, 2011)
		RU Prioritisation tool (Case study version)

3.6 STEP 1.5 RIVERS: IDENTIFIED METHODS AND EVALUATION

Table 3.4 Evaluation of various methods to prioritise RUs

Evaluation criteria		Catchment Reserve RU priority spreadsheet	Resource Unit Prioritisation tool (DWS and Southern Waters evaluation; DWA 2011)	Resource Unit Prioritisation Tool (Guideline version; DWA, 2011)	Resource Unit Prioritisation Tool (DWS 2011 modified for specific case studies)[2]
Frequency of application use	Evaluation	5 - Very High	2 - Low	3 - Medium	3 - Medium
	Explanatory Comment	In use since 2004 (Maputo Basin study) and applied since then in most Reserve studies and 4 large Classification studies.	Used in two classification studies.	Applied in RQO determination process for Olifants-Doorn and in limited training case studies across RSA.	Applied in the Olifants, Upper, Middle and Lower Vaal WMA RQO studies.
Can the method be applied at a catchment level?	Evaluation	Yes	Yes	Yes	Yes
	Explanatory Comment	Designed for catchment level.	Tested on one river system. WMA scale not considered during design. According to developers it may be difficult to apply at SQ level.	Applied on WMA level on basin scale.	Applied on WMA level on basin scale.
Is the method described?	Evaluation	Yes	Yes	Yes	Yes
	Explanatory Comment	Method is described in documents used since 2004.	Standard approach described in the RQO guidelines (DWA, 2011).	Standard approach described in the RQO guidelines (DWA, 2011).	Revised approach applied in the Upper, middle and lower Vaal and Olifant RQO case studies (see DWS, 2014).
Indicate the status of publication of the method.	Evaluation	3 Internal	3 Internal	4 National	3 Internal
	Explanatory Comment	Site-specific reports.		See DWA (2011).	See methodologies from case studies for updates.
Are there existing training course?	Evaluation	n/a	No	No	No
	Explanatory Comment	Simple spreadsheet based approach that does not require training.	Will be necessary.	Capacity building has been available from RQO case studies.	Capacity building has been available from RQO case studies.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Evaluation	Yes	Yes	Yes	Yes
	Explanatory Comment	Catchment tools used for prioritisation irrespective of level of determination.	Catchment tools used for prioritisation irrespective of level of determination.	The approach makes use of all available information including expert opinion from stakeholders. Any/all available data is used to prepare tool which is refined during a workshop.	The approach makes use of all available information including expert opinion from stakeholders. Any/all available data is used to prepare tool which is refined during a workshop.
Time efficient (link to assessment level)	Evaluation	1 one week	No	No (based on current requirement of working at all RU levels for a WMA scale).	No (based on current requirement of working at all RU levels for a WMA scale).
	Explanatory Comment	As existing databases and refinement is required and as this is desktop based - the process uses a spreadsheet that is built up with data in all previous actions and automatically calculates the output.	Over-elaborate, time-consuming, contradictory and confusing.	If applied on comprehensive scale approach may take up to one day per site. Based on Mvoti-Umzimkulu this would have approximately taken 150 days.	If applied on comprehensive scale revised approach may take approximately 1hr per site. Based on Mvoti-Umzimkulu this would have approximately taken 19 days.
Is the data available to apply the method?	Evaluation	Always	Usually	Usually	Always
	Explanatory	Data is reliant on PESEIS database		Makes use of available information	Makes use of available information and

[2] Both evaluations (2011 and 2014) undertaken by Gordon O'Brien, part of the development and application team.

Evaluation criteria		Catchment Reserve RU priority spreadsheet	Resource Unit Prioritisation tool (DWS and Southern Waters evaluation; DWA 2011)	Resource Unit Prioritisation Tool (Guideline version; DWA, 2011)	Resource Unit Prioritisation Tool (DWS 2011 modified for specific case studies)[2]
	Comment	(DWS, 2014a) and reasonable Google Earth coverage.		and expert opinion.	expert opinion.
Compatibility	Evaluation	Yes	Yes	Yes	Yes
	Explanatory Comment	Complies with input and output.		Flexible, transparent approach.	Flexible, transparent approach.
Is the model robust?	Evaluation	Yes		Yes	Yes
	Explanatory Comment	Based on broad estimates and set rules that ensure consistent answers.		Transparent weighted excel based tool.	Transparent weighted excel based tool.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Evaluation	No		No	No
	Explanatory Comment	Includes a rated confidence assessment scored from 0 - 5 for the individual components of the model (PES, Socio-Cultural Importance (SCI), Water Resource Use Importance (WRUI).		NA	NA

The RU prioritisation tool was developed based on the premises that Classification and Reserve Determination were not undertaken prior to the setting of RQOs (*pers. Comm.* Gordon O'Brien and Kate Pringle). However, application of Classification-Reserve-RQO studies showed that the determination of RQOs must follow after setting the Water Resource Class and should serve as a translation (specification) of the Reserve requirements once completed. The implication of the need for this sequential dependency is that the RU prioritisation and importance rating methods that is part of Reserve determination and Classification process has to be compatible to ensure consistency or prioritisation across the RDM processes.

It is therefore required to prioritise RUs for RQO determination along with the Classification and Reserve importance rating and prioritisation methods. The RU prioritisation processes for RQOs cannot be carried out independently and therefore the prioritisation methods need to be aligned.

The RU prioritisation tool's methods as it is currently structured need to be adjusted to encompass Reserve and Classification importance rating methods which will have the benefit that those methods already account for Socio-Cultural and Water Use Importance evaluations.

A further application problem with the RU prioritisation tool was the substantial intensity of effort that would have been required to cover the intended detail in the typical large areas being classified. This tool was designed to only deal with RQOs for high priority RUs that will be gazetted (*pers. Comm.* Gordon O'Brien). This potential overburden of work would be overcome and avoided by aligning RU prioritisation with the Reserve and Classification importance rating and prioritisation methods.

3.7 STEP 1.6 RIVER RU DELINEATION AND SITE SELECTION: ACTIONS

At this point, the assessment for rivers has been based on SQ scale. RUs have not yet been selected as, due to the number of SQs, a filtering process is required whereby detailed and desktop assessments of RU determination are undertaken. For this filtering process, the high priority RUs (previously referred to as hotspots) need to be identified first (Integrated Step 1.5).

Objective: The objective is to identify the main rivers with high priority areas and select EWR sites. EWR sites are the river study sites where surveys, measurements and observations are undertaken and are likely to be identified in high priority areas.

The bullets below describe the actions required.

- **1. Delineate rivers with high priority SQs into high priority RUs (called Management Resource Units)**

The high priority SQs serve to identify the rivers which require a more detailed delineation into RUs termed Management Resource Units (MRUs). This delineation is required as it in turn leads focus to the area where EWR sites should be selected. Furthermore, the EWRs in terms of flow can then be extrapolated from the EWR site to anywhere within the MRU. RQOs are usually set at a higher level of detail for these RUs and are generally gazetted.

- **2. Delineate (combine) moderate/low priority SQs into moderate and low priority RUs**

Moderate and low priority SQs are then assessed to determine whether the SQs can be combined into RUs. The reason why this is done is because the SQs are numerous and some could be short in length and RQOs set at a later stage for a very short reach is unwarranted. SQs can be grouped if they are linearly connected, have a similar ecological state and similar pressures and impacts. This also then leads to Integrated Step 3, as desktop EWRs are undertaken for these RUs during this step (more details in Chapter 5).

- **3. Select EWR sites**

The river study sites, EWR sites, are selected following a set procedure and site selection criteria. This is the main output of the river component leading to Integrated Step 3 as the EWR determination is undertaken at the EWR sites. EWR sites can only be selected at this stage as it is dependent on the prioritisation of SQs and RUs to determine the preferred areas for site selection.

- **4. Establish biophysical nodes representing RUs in network configuration**

EWR sites will represent the key biophysical nodes for each MRU. Desktop biophysical nodes must be established to address all the other RUs. A node is therefore established at the end of the RUs and included in the network configuration of the selected simulation model. Appropriate catchment delineation is applied to determine the hydrological information (time series) which is the basis for deriving the EWRs.

3.8 STEP 1.6 RIVERS: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 3.5.

Table 3.5 Standardised input and output per action

Action	Input	Output	Method
1. Delineate rivers with high priority SQs into high priority RUs (called MRUs)	EcoRegion Level II, Geomorphic zones[3]	Delineated RUs	MRU method (DWS) (DWAF, 2008)
2. Delineate (combine) moderate/low priority SQs into moderate and low priority RUs	n/a	Delineated RUs	
3. Select EWR sites	MRUs	Described and groundtruthed EWR sites	EWR site selection process (DWA, 2013c)
4. Establish biophysical nodes representing RUs in network configuration	MRUs and RUs	Nodes mapped at downstream end of RUs	

3.9 STEP 1.6 RIVERS: IDENTIFIED METHOD AND EVALUATION PER ACTION

Table 3.6 Evaluation of MRU and EWR site selection method

Methods		MRU method (DWS)	EWR site selection process
Frequency of application use	Evaluation	5 - Very High	5 - Very High
	Explanatory Comment	Formalised in 2008 (CJ Kleynhans and Louw). Used in all Reserve studies since then.	Process formalised 1997 and used for all EWR site selection.
Can the method be applied at a catchment level?	Evaluation	No	No
	Explanatory Comment	Method is designed for a single river, i.e. from source to sea if applicable.	Method is designed to select single sites.
Is the method described?	Evaluation	Yes	Yes
	Explanatory Comment	Method description (acting as manual) written and available as standalone document. (DWAF, 2008).	Method description (Louw and Kemper) taken up in the DWAF Reserve methods 1999 manuals and various study specific documents.
Indicate the status of publication of the method.	Evaluation	3 Internal	5 International
	Explanatory Comment	See method description.	Reference to procedure in Building Block Methodology (BBM) publication (Louw and Kemper, 2000).
Is the method applicable	Evaluation	No	No

[3] Information available for the whole country.

Methods		MRU method (DWS)	EWR site selection process
to all levels of assessment (Desktop to Comprehensive)?	Explanatory Comment	This method is designed to be a detailed method as SQs are surrogate RUs at desktop level. Method therefore applicable for any level of assessment that includes the selection of EWR sites.	Designed for selection of specific sites
Time efficient (link to assessment level)	Evaluation	1 day per river	n/a
	Explanatory Comment	Uses desktop information.	Site selection takes place during a single site visit. However, it must be noted that it is seasonality dependant (has to happen during low flows).
Is the data available to apply the method?	Evaluation	Always	Always
	Explanatory Comment		Previously the selection was often dependant on video footage. However, with reasonable resolution Google Earth available, that is not an issue anymore.
Compatibility	Evaluation	Yes	Yes
	Explanatory Comment	Complies with input and output.	Complies with input and output.

3.10 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 8.

- **Catchment Reserve RU priority spreadsheet:**

Chapter 5, Section 5.2 (Socio Cultural Importance)
Chapter 7, Section 7.2.3 (River PES information)
Chapter 10 (Determination of priority areas – hotspots)
IN
Department of Water Affairs (DWA), South Africa, 2013a. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Status quo assessment, IUA delineation and biophysical node identification. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWA Report: RDM/WMA11/00/CON/CLA/0113. July 2013.

- **RU Prioritisation Tool (Original guideline version)**

Annexure 1: Application of the Resource Unit Prioritisation Tool
IN
Department of Water Affairs (DWA), South Africa. 2011. Procedures to Develop and Implement Resource Quality Objectives. Department of Water Affairs, Pretoria, South Africa.

- **Resource Unit Prioritisation Tool (Case study version)**

- **MRU method (DWS)**

Appendix A: River reach demarcation, delineation and site suitability - CJ Kleynhans and MD Louw, September 2007
IN
Department of Water Affairs and Forestry (DWAF), South Africa. 2008. Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the

Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: Resource Unit Delineation: Prepared by Water for Africa, authored by Louw, MD. Report no. 26/8/3/10/12/006.

- **EWR site selection process**

Chapter 2, Section 2.5
IN
Department of Water Affairs (DWA), South Africa. 2013c. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Resource Units and EWR sites. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWA Report: RDM/WMA11/00/CON/CLA/0213. July 2013.

The above reference is a shortened and updated list of criteria, i.e. modified from Louw *et al*. (1999):
Louw, M.D., Kemper, N. and Birkhead, A.L. 1999. Procedure for selecting sites in intermediate and comprehensive determination of the Ecological Reserve (water quantity component). Appendix 18 in Resource Directed Measures for Protection of Water Resources: River Ecosystems. Published by Department of Water Affairs, South Africa.

Also:
Chapter 7: Selection of Study Sites - Louw M.D. and Kemper, N. 2000.
IN
King, J.M., Tharme, R.E. and De Villiers, M.S. (Editors). 2000. Environmental flow assessment for rivers: Manual for the Building Block Methodology. Water Research Commission report. WRC Report No. TT 131/00.

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 nine sub-steps which are discussed below. Second tier numbering e.g. Step 2.1 represents a sub-step within Integrated Step 2.

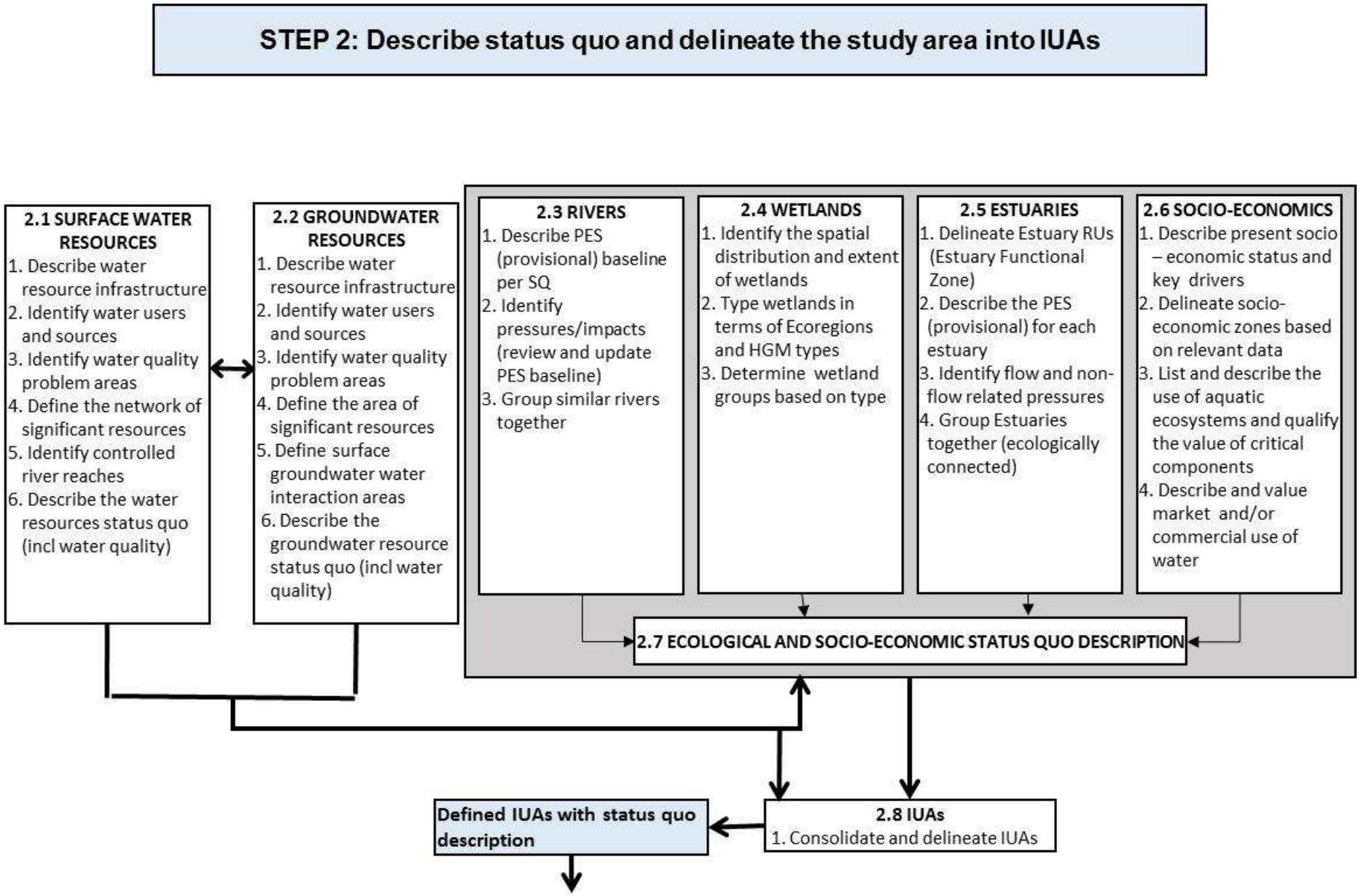

Figure 4.1 Illustration of the sub-steps for Integrated Step 2: Describe status quo and delineate the study area into IUAs

4.1 STEP 2.3 RIVERS: ACTIONS

Objective: Broadly determine the Present Ecological State (PES) for the study area in terms of the Ecological Categories (ECs: A to F) which informs the delineation of IUAs. A country wide database of the PES is used to allocate an EC to each of the Sub Quaternary (SQ) reaches (delineation forming the basis of the Present Ecological State and Ecological Importance-Ecological Sensitivity (PESEIS) database (DWS, 2014a) and based on the 1:500 000 map scale). During this step, all assessments are made at SQ scale.

The bullets below describe the actions required.

- **1. Describe PES (desktop) baseline per SQ**

The existing PESEIS database (DWS, 2014a) is used and an EC is provided per SQ. This is a desktop PES determination which will be updated with more detailed information in high priority areas (see Integrated Step 1.6).

- **2. Identify pressures/impacts (review and update PES baseline)**

The pressures and or impacts are identified from the PESEIS database (DWS, 2014a) and refined where required. This information is also used to refine the PES where required and an updated PES baseline will be available.

- **3. Group similar rivers together**

As per the overall objective of Step 2, homogenous areas must be identified in order to delineate IUAs. One of the criteria for this evaluation is areas with a similar PES. A grouping is therefore undertaken based on similar PES ECs.

4.2 STEP 2.3 RIVERS: STANDARDISED INPUT AND OUTPUT

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

Table 4.1 Standardised input and output per action

Action	Input	Comment	Output
1. Describe PES (provisional) baseline per SQ	PESEIS database (PES component)	The PES component of the database includes a summarised description of the impacts for each SQ which should be sufficient for a broad overview of the study area	Described and updated pressures /impacts based on land use and resulting ecological state
2. Identify pressures /impacts (review and update PES baseline)			

4.3 STEP 2.3 RIVERS: IDENTIFIED METHODS AND EVALUATION PER ACTION

No methods are relevant for this action, as the information is provided as an existing database in a spreadsheet format.

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 Target Ecological Category which happens in later steps in the process. The BHNR component of this step is addressed in Report RDM/WE/00/CON/ORDM/1016. This chapter focusses on the EWR for rivers only.

Integrated Step 3 contains four sub-steps which are discussed below. Second and third tier numbering e.g. Step 3.1 and Step 3.3.1 represent sub-steps within Integrated Step 3.

All methods identified and used during Integrated Step 3 are listed in Section 5.5.

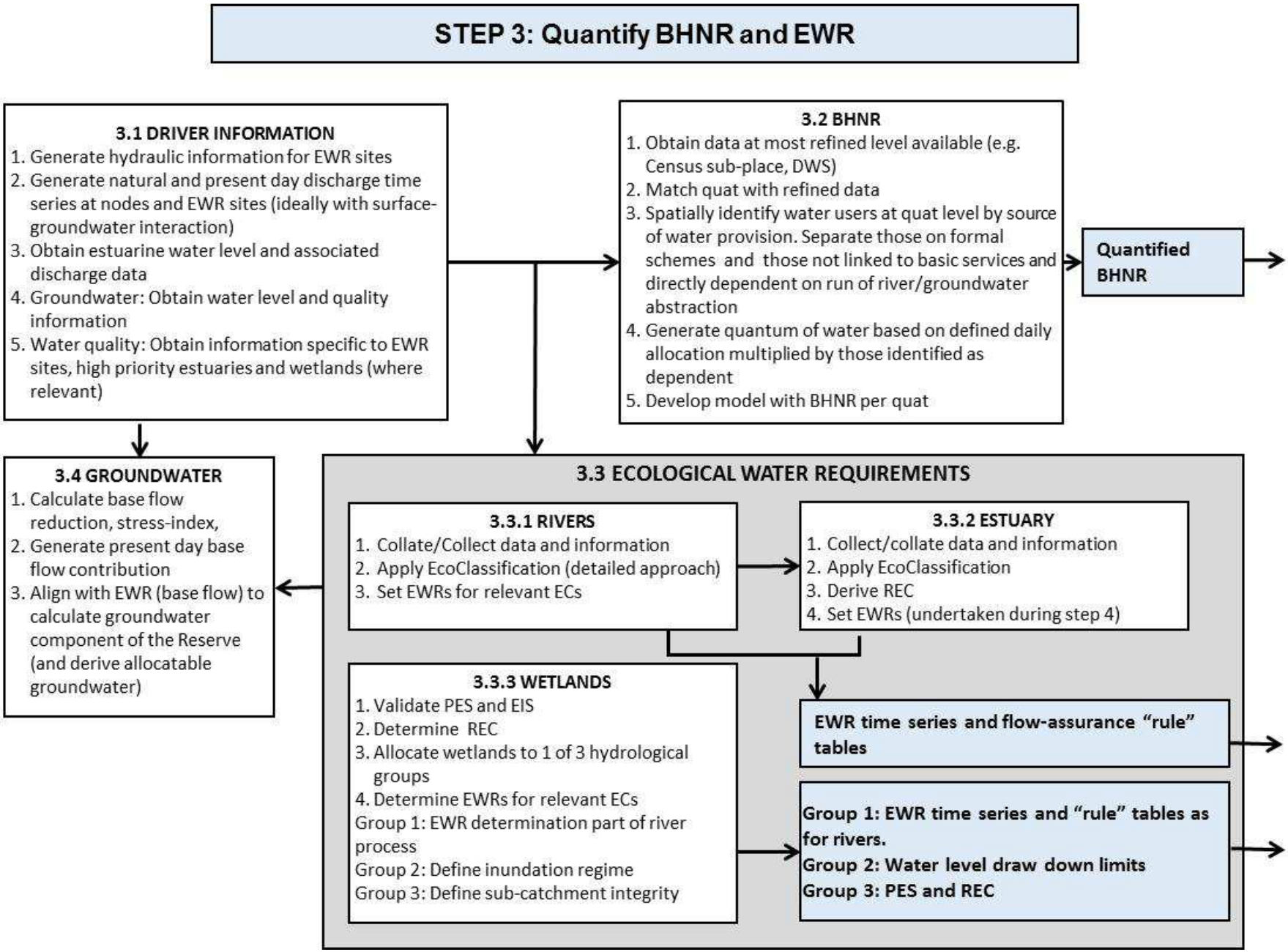

Figure 5.1 Illustration of the sub-steps for Integrated Step 3: Quantify BHNR and EWR

5.1 STEP 3.3.1 RIVERS

Objective: 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. Collate/Collect data and information**

EWRs are determined both at desktop and detailed level. The detailed level of assessment requires field assessments undertaken during specific seasons.

- **2. Apply EcoClassification methods (detailed approach)**

The essential steps that forms part of the EcoClassification process is the determination of the PES (i.e. the update of the preliminary PES used during previous steps), the EIS and deriving the REC. As will be noted, these appear to be a repeat of the steps already undertaken during Integrated Step 1 and Step 2. To put this into context, the assessments undertaken during previous Integrated steps are at a broad (desktop) level and at the desktop RU scale. This is an acceptable level given the size of the study area (at Water Management Area scale) and the fact that the information is used at desktop level during those steps – on par with the other components. The Level IV (more detailed) EcoClassification (Kleynhans and Louw, 2007) now has to be applied at the EWR sites which represent the MRU. This application uses the results of biophysical surveys, resulting in a higher confidence assessment. Conduct the water quality component of EcoClassification through Step 3 of the Reserve process.

- **3. Set EWRs for relevant ECs**

EWRs are calculated for the relevant ECs and the results provided as EWR time series and flow-assurance rule tables.

Key Outputs – EWR time series and flow assurance "rule" tables: Provide the EWRs in the standard output of EWR time series and flow assurance rule tables that feed into the next steps as input to the operational scenarios.

5.2 STEP 3.3.1 RIVERS: STANDARDISED INPUT AND OUTPUT

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

Table 5.1 Standardised input and output per action

Action	Input	Output	Method
2. Apply EcoClassification (detailed approach)	Fish reference condition from River EcoStatus Monitoring Programme (REMP) Fish present: Frequency of Occurrence (FROC) from Fish Response Assessment Index (FRAI) generator	Fish PES (categories per EWR site)	FRAI Ver 2.0 (Level IV EcoClassification) (Kleynhans, 2007)
	Reference list in Macro Invertebrate Response Assessment Index (MIRAI) version 2. Present day list from PESEIS (DWS, 2014a) and from Rivers database	Aquatic Invertebrate PES (categories per EWR site)	MIRAI Ver 2.2 (Thirion, 2007, Thirion 2016)
		Geomorphology (categories per EWR site)	Geomorphological Driver Assessment Index (GAI) IV

Action	Input	Output	Method
			(2006 version - Rowntree and du Preez)
			GAI III (2006 version - Rowntree and du Preez)
			GAI (Rowntree *et al* 2013)
		Vegetation (categories per EWR site)	Vegetation Response Assessment Index (VEGRAI) (IV) (Kleynhans *et al*., 2007)
			VEGRAI (III) (Kleynhans *et al*., 2007)
		Riparian and Instream habitat categories per EWR site	Index of Habitat Integrity (IHI) (Kleynhans *et al*., 2009)
			IHI (Kleynhans, 1996, ver2)
		EcoStatus per EWR site (EC)	EcoStatus model (Kleynhans and Louw, 2007)
		EIS per EWR site (score and evaluation in terms of Low to Very High)	EIS (2009, site based)
			EIS (1999)
			EIS (2014 - PESEIS) (DWS, 2014a)
	REC rules	REC per EWR site	
3. Set EWRs for relevant ECs	Modelled monthly and daily hydrological time series (see 1.1 and 3.1), natural and present day. Hydraulic rating curve tables and velocity depth classes.	Time series and EWR rules for relevant ecological status at EWR sites.	Habitat Flow Stressor Response (HFSR)
			Downstream Response to Imposed Flow Transformation (DRIFT)
			FIFHA (part of HFSR)
			FFHA (part of HFSR)
			HABFLO (Hydraulic model as input in EWR determination)
			BBM

5.3 STEP 3.3.1 RIVERS: IDENTIFIED METHODS AND EVALUATION PER ACTION

5.3.1 Action 2: Apply EcoClassification (detailed approach)

See Table 5.2 split into two sections.

5.3.2 Action 3: Set EWRs for relevant ECs

See Table 5.3.

Table 5.2 Evaluation of EcoClassification methods

Methods		FRAI Ver 2.0 (Level IV EcoCl)	MIRAI[4]	GAI IV (2006)	GAI III (2006)	GAI IV (2013)	Potential Bed Material Transport (PBMT)	VEGRAI (IV)	VEGRAI (III)
Frequency of application use	Evaluation	5 - Very High	5 - Very High	4 - High	2 - Low	1 – Very low	5 - Very High	4 - High	4 - High
	Explanatory Comment	Since 2004 in all Reserve studies.	Since 2004 in all Reserve studies.	Used in Elands, Crocodile, Inkomati, Letaba, Gouritz, Mvoti, Mhlatuze, Schoonspruit, Upper Vaal, middle Vaal, Lower Vaal, Orange EWR studies.	Has been used in PES assessment of Eastern Cape River Health Sites.	No known studies have been identified where this method has been applied.	Used in Elands, Crocodile, Inkomati, Letaba, Gouritz, Mvoti, Mhlatuze, Schoonspruit, Upper Vaal, middle Vaal, lower Vaal, Orange EWR studies.	Supported since 2007.	Supported since 2007.
Can the method be applied at a catchment level?	Evaluation	No	No	No	No	No	No	No	No
	Explanatory Comment	Site specific method.	Site specific method.	Site assessment PES method.	Site assessment PES method.	Site assessment PES method.	Method for the reach/site scale to identify flows for habitat maintenance.	Site specific method.	Site specific method.
Is the method described?	Evaluation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Explanatory Comment	Manual.	Manual. Unpublished PhD thesis (Thirion)	Draft WRC report and excel models available.	Draft WRC report and excel models available.	WRC report.	WRC report.	WRC report and manual.	WRC report and manual.
Indicate the status of publication of the method.	Evaluation	4 National	4 National	3 Internal	3 Internal	4 National	4 National	4 National	4 National
	Explanatory Comment	WRC document.	WRC document.					WRC report.	WRC report.
Are there existing training course?	Evaluation	Yes	Yes	Yes	Yes	No	No	No	No
	Explanatory Comment	Has been provided in the past.	Currently being offered.	Occasional EcoStatus courses run by the DWS or outside organisations (e.g. Free State University).	Occasional EcoStatus courses run by the DWS or outside organisations (e.g. Free State University) have used this in the training.		n/a - The manual is comprehensive.	Add hoc training has been done, but is not readily available.	As for VEGRAI IV.

[4] Various versions for MIRAI is available. The evaluation is relevant for all versions. The latest version should be use in all situations.

Methods		FRAI Ver 2.0 (Level IV EcoCl)	MIRAI[4]	GAI IV (2006)	GAI III (2006)	GAI IV (2013)	Potential Bed Material Transport (PBMT)	VEGRAI (IV)	VEGRAI (III)
Is the method applicable to all levels of assessment (Desktop to Comprehen-sive)?	Evaluation	Yes	Yes	No	No	No		No	No
	Explanatory Comment	Rapid to Comprehensive.	Rapid to Comprehensive.	Only applicable for Intermediate and Comprehensive EWRs; as these levels of study incorporate geomorphology.	Lower level confidence PES assessment method (for non-geomorphologists; and/or as part of monitoring).	Only applicable for Intermediate and Comprehensive EWRs; as these levels of study incorporate geomorphology.	Only applicable for Intermediate and Comprehensive EWRs; as these levels of study incorporate geomorphology.	Rapid to Comprehensive.	Rapid to Comprehensive.
Time efficient (link to assessment level)	Evaluation[5]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Explanatory Comment	.5 days.	.5 days.	2 to 3 hours per site.	2 to 3 hours per site.	2 to 3 hours per site.	Relatively fast - approx 0.5 days per site, assuming data availability.	Day per site.	Day per site.
Is the data available to apply the method?	Evaluation[6]	Always	Always	Always	Always	Always	Always	Always	Always
	Explanatory Comment			Historical aerial photos, field assessment and Google Earth overview of the catchment are the minimum requirements.	Historical aerial photos, field assessment and Google Earth overview of the catchment are the minimum requirements.	Historical aerial photos, field assessment and Google Earth overview of the catchment are the minimum requirements.	Model dependent on site hydraulics, daily PD (and ideally daily natural) flows over a long record and site sediment data.	requires measured data to complete.	requires measured data to complete
Compatibility	Evaluation	Yes	Yes			Yes		Yes	Yes
	Explanatory Comment	Complies with standardised input and output.	Complies with standardised input and output.	Complies with standardised input and output.	Complies with standardised input and output.	Complies with standardised input and output. [7]	n/a	Complies with standardised input and output.	Complies with standardised input and output.
Description of mathematical algorithms and model structure	Evaluation	Algorithm based	Algorithm based	Algorithm based	Algorithm based	Algorithm based	Conceptual description	Algorithm based	Algorithm based
	Explanatory Comment	Rule based model within Excel.	Rule based model within Excel.	Rule based model within Excel.	Rule based model within Excel.	Rule based model within Excel.	Approach is a conceptual modelling approach for determining important geomorphological flows.	Rule based model within Excel.	Rule based model within Excel.
Is the model	Evaluation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[5] Evaluation excludes the site visit (which is part of Step 2.5).

[6] Assumption is that site surveys which is a requirement for these applications have been undertaken.

[7] This revised GAI method provided output scores that are somewhat different (different category in some cases) to the earlier versions, so some incompatibility with scores exists.

Methods		FRAI Ver 2.0 (Level IV EcoCI)	MIRAI[4]	GAI IV (2006)	GAI III (2006)	GAI IV (2013)	Potential Bed Material Transport (PBMT)	VEGRAI (IV)	VEGRAI (III)
robust?									
	Explanatory Comment	If the same type of specialists with same dataset applies model it would come out with similar answers.	If the same type of specialists with same dataset applies model it would come out with similar answers. (Evaluation with results from 2 versions of MIRAI also indicates that the different versions give compatible results.)	Fairly reliable and consistent PES estimation approach.	Fairly reliable and consistent PES estimation approach.	n/a	Based on international published sediment transport approaches.	If similarly, trained specialists are users and have access to the same data.	If similarly, trained specialists are users and have access to the same data.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Evaluation	No	No	No	No	No	No	No	No
	Explanatory Comment	Does include qualitative assessment of confidence.	Does include qualitative assessment of confidence.	Level of confidence in inputs can be input to the model.	Level of confidence in inputs can be input to the model.	Level of confidence in inputs can be input to the model.	Comment usually included on the confidence of the input (flow, site hydraulics) data.	Does include qualitative assessment of confidence.	does include qualitative assessment of confidence.

Methods		IHI (2008)	IHI (1996, ver2)	EcoStatus	EIS (2009, site based)	EIS (1999)	EIS (2014 - PESEIS)
Frequency of application use	Evaluation	5 - Very High	4 - Very High	5 - Very High	4 - High	5 - Very High	5 - Very High
	Explanatory Comment	Been in use since 2007.	Was developed in 1996, extensively used, now updated and in use again.	Was developed in 2007 and extensively used.	Refined EIS (1999) model in 2009 and used since for site based EIS.	Was developed in 1999, used extensively site based until 2009 where generally the above version is used.	Was applied at sub-quaternary level for SA.
Can the method be applied at a catchment level?	Evaluation	No	Yes	Yes	No	No	Yes
	Explanatory Comment	Site based method.	Site based method but can also be used to derive catchment based single integrity.		Site (or originally quat) based method.	Site based method.	Designed for catchment level.
Is the method described?	Evaluation	Yes	Yes	Yes	Yes	Yes	Yes
	Explanatory Comment	WRC manual.	RDM manual 1999 (and in Excel itself).	2007 manual.	In study documents.	RDM manual.	Described in model.
Indicate the	Evaluation	4 National	5 International	4 National	3 Internal	3 Internal	3 Internal

Methods		IHI (2008)	IHI (1996, ver2)	EcoStatus	EIS (2009, site based)	EIS (1999)	EIS (2014 - PESEIS)
status of publication of the method.	Explanatory Comment	WRC document.	Journal of Ecosystems Health.	WRC document.	Study documents.	1999 Reserve Manual.	
Are there existing training course?	Evaluation	Yes	Yes				No
	Explanatory Comment	Has been provided in the past.	Part of REMP training.	Not required.	Not required.	Not required.	Interpretation of data requires training course.
Is the method applicable to all levels of assessment (Desktop to Comprehensive) ?	Evaluation	Yes	Yes	Yes	Yes	Yes	No
	Explanatory Comment			(n/a for desktop as desktop result provided as EcoStatus and not derived from individual component ECs).	Yes	Yes	Applicable for desktop level at SQ level, more detail required to apply for site basis.
Time efficient (link to assessment level)	Evaluation	Yes	Yes	Yes	Yes	Yes	Yes
	Explanatory Comment	An hour per site.	An hour per site.	Takes 5 minutes or automated per site.	Takes half an hour per site.	Takes half an hour per site.	n/a
Is the data available to apply the method?	Evaluation	Always	Always	Always	Always	Always	Always
	Explanatory Comment			Always available where EcoStatus is required at detailed level.			N/A as a given databases. If model is used on standalone basis – always.
Compatibility	Evaluation	Yes	Yes	Yes	Yes	Yes	
	Explanatory Comment	Complies with standardised input and output.	Complies with standardised input and output.	Complies with standardised input and output.	Complies with standardised input and output.	Complies with standardised input and output.	Complies with standardised input and output.
Enhancement flexibility or adaptability of algorithms	Evaluation						
	Explanatory Comment	Rule-based model in Excel.	Rule-based model in Excel.	Rule-based model in Excel.	Rule-based model in Excel.	Rule-based model in Excel.	Rule-based model in Excel.
Is the model robust?	Evaluation	Yes	Yes	Yes	Yes	Yes	Yes
	Explanatory Comment	If the same type of specialists with same dataset applies model it would come out with similar answers.	If the same type of specialists with same dataset applies model it would come out with similar answers.	If the same type of specialists with same dataset applies model it would come out with similar answers.	If the same type of specialists with same dataset applies model it would come out with similar answers.	If the same type of specialists with same dataset applies model it would come out with similar answers.	If the same type of specialists with same dataset applies model it would come out with similar answers.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Evaluation	No	No	No	No	No	No
	Explanatory Comment	Includes confidence assessment.	Includes confidence assessment.	Confidence embedded in the input.	Confidence evaluated in model.	Confidence evaluated in model.	Confidence evaluated in model.

Table 5.3 Evaluation of methods used to set the discharge component of EWRs

Methods		BBM	FIFHA[8]	FFHA[7]	HFSR	DRIFT
Frequency of application use	Evaluation	3 - Medium	1 - Very Low	4 - High	5 - Very High	4 - High
	Explanatory Comment	Used in most (all?) early Reserve Assessments - many of which have been redone with more modern methods.	Recently developed and applied by DWS on the Olifants River.	Developed in 2009 and used in all studies where HFSR is applied. Likely to be replaced by FIFHA as it incorporates a version of the FFHA.	Was applied for first time during 2000. Consistently used afterwards for most South African EWR studies. Also extensively used outside of South Africa in Africa.	Use in Berg, Breede, Olifants Doring, Olifants Mpumalanga, Palmiet, Some Outeniqua rivers, Pongola river and Floodplain, Lake Sibaya, Mfolozi, Assegai, Mkuze, Nseleni.
Can the method be applied at a catchment level?	Evaluation	No	No	No	No	No
	Explanatory Comment	Site specific method (Desktop Reserve Model based on BBM exists on Catchment Level).	Site specific method.	Site specific method.	Designed as a site based method. (Revised Desktop Reserve Model largely based on HFSR can be used at catchment level).	It remains site based - but since response curves are flow/habitat/species based and not location based it has been used at catchment level in RSA and outside (Olifants-Doring, Okavango, Nile, Jhellum, Poonch, Mekong, etc.).
Is the method described?	Evaluation	Yes	Yes	No	Yes	Yes
	Explanatory Comment	King and Louw (1998); BBM manual.	In the model.	Summarised in study documents (not detail description).	In a manual (currently out of date) and thereafter in study documents.	WRC manual.
Indicate the status of publication of the method.	Evaluation	5 International	3 Internal	3 Internal	5 International	5 International
	Explanatory Comment	Both national and international.	In model.		2 International papers.	Both national and international.
Are there existing training course?	Evaluation	Yes	Yes	No	No	Yes
	Explanatory Comment	Current training courses all outside of RSA.	Currently in place.	Replaced by FIFHA training	Training done on every RDM application.	Workshop run in Cape Town March 2016, more to follow. Training done an every RDM application. Several training workshops held outside of RSA.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Evaluation	Yes	Yes	Yes	Yes	Yes
	Explanatory Comment	Intermediate and Comprehensive only.	Excludes desktop.	Excludes desktop.	Applicable for Rapid III to Comprehensive.	Intermediate and Comprehensive DRIFT applied in RSA. Desktop/Rapid DRIFT applied outside of RSA.
Time efficient (link to assessment	Evaluation					
	Explanatory	Intermediate >+ 1 month	When all data and field	4 hours per site	Intermediate >+ 1 month;	Intermediate >+ 1 month;

[8] These methods are not stand-alone methods but tools applied within the HFSR methodology.

Methods		BBM	FIFHA[8]	FFHA[7]	HFSR	DRIFT
level)	Comment	Comprehensive >= 6 months.	surveys are available 1 day or less.		Comprehensive ≥ 6 months. The method is based on seasonality and the time provided here is according to the stand alone method and based on the assumption that all field data has been collected.	Comprehensive ≥ 6 months.
Is the data available to apply the method?	Evaluation	Usually	Seldom	Seldom	Seldom	Seldom
	Explanatory Comment		Dependant on external models	Dependant on other inputs that has to be generated.	Method is based on field data which has to be collected (site specific so not available) and hydrological data which is always available at some level.	Method is based on field data which has to be collected (site specific so not available) and hydrological data which is always available at some level.
Compatibility	Evaluation	Yes			Yes	Yes
	Explanatory Comment	Handling of scenario is inefficient.	N/a as feeds into the larger processes.	N/a as feeds into the larger processes.	Complies with standardised input and output.	Has been used successfully as part of RDM process many times. Is particularly useful for RQOs because of timeseries quantitative approach.
Must software be purchased?	Evaluation	No	Yes	Yes	No	Yes
	Explanatory Comment	No software.	Requires Data Curve Fit Creator, and Multiple Goal Seek[9]	Requires Data Curve Fit Creator	SPATSIM in which the models which provide the output and the RDRM is embedded in is free of charge.	www.DRIFT-EFlows.com. But very low cost for RSA citizens if applied in RSA.
Licencing requirement	Evaluation	None	Simple	Simple	None	Simple
	Explanatory Comment					
Enhancement flexibility or adaptability of algorithms	Evaluation	4 WRC;				4 WRC;
	Explanatory Comment	Low risk - it is a set of activities - no software.			See SPATSIM.	Low risk - active update process in place.
Is the method validated and verified?	Evaluation	No	No	No		Yes
	Explanatory Comment		Requires monitoring.	Requires monitoring.	Dependant on monitoring.	Calibration: DRIFT can be calibrated through comparison of time-series outputs for baseline scenario for specific indicators with monitoring datasets - where these exist.
Description of	Evaluation	Detail explanation				

[9] The newest version uses open source software rather than Data Curve Fit Creator (post the evaluation).

Methods		BBM	FIFHA[8]	FFHA[7]	HFSR	DRIFT
mathematical algorithms and model structure	Explanatory Comment		Rule based model.	Rule based model.	See SPATSIM.	Varied. The most recent software comprises the DRIFT Decision Support System (DSS), written in Delphi, which links hydrological, hydraulic, sediment, water quality and any other model outputs with ecological consequences and socio-economic outcomes, through response curves, to produce predictions of ecological and social change for multiple scenarios.
Is the model robust?	Evaluation		No	No	Yes	Yes
	Explanatory Comment	Not a model - not applicable.	Trained persons will come up with same answers.	may be variable interpretations of input.		Once calibrated the model is extremely robust.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Evaluation	No	No	No	No	Yes
	Explanatory Comment		Does not explicitly include confidence.		Extensive confidence evaluation included. Does include stress band for ECs so indirectly may address uncertainty.	The model allows for upper and lower limits of change to be used in Response Curves. These are carried through the whole assessment and reported in the final outputs.

5.4 OTHER METHODS NOT YET APPLIED IN SOUTH AFRICA

The information below regarding PROBFLO was provided by Dr Gordon O'Brien.

PROBFLO is an ecological risk assessment based holistic E-flow assessment method developed and applied in Phase II of the Lesotho Highlands Development Authority Polihale Dam and in case studies in the Nile Basin with various stakeholders. Although new the approach builds onto existing holistic methods and formally integrates a regional scale ecological risk assessment approach to E-flow assessments which includes the use of the established Relative Risk Model and Bayesian Network probability modelling techniques. This approach has been designed to meet current international best practice risk assessment principles and include a dedicated uncertainty and sensitivity modelling component.

The approach is being published but these are the existing references that can be referred to:

- Nile Basin Initiative (NBI, 2016): Preparation of NBI Guidance Document on Environmental Flows: Nile E-flows Framework Technical Implementation Manual. Prepared by HYDROC GmbH on behalf of the Nile Basin. Initiative and Deutsche Gesellschaft für Internationale Zusammenarbeit. Contract No. 81178948. Siegum.
- Lesotho Highlands Development Authority (LHDA, 2014): Final report: Specialist Consultants to Undertake Baseline Studies (Flow, Water Quality and Geomorphology) and Instream Flow Requirement (IFR) Assessment for Phase 2 6001/5 Instream Flow Requirements for the Senqu River. Instream Flow Requirements for the Senqu River. LHDA Contract 6001. Maseru.

Below follows a short overview of the approach:

O'Brien *et al*., (in preparation) has recently demonstrated the use of established regional scale ecological risk assessment procedures to evaluate the socio-ecological consequences of altered flows on multiple spatial scales using a new approach called 'PROBFLO'. As described, the approach has been established to address recommendations from the Ecological Limits of Hydrologic Alteration (ELOHA) and Sustainable Management of Hydrologic Alteration (SUMHA) frameworks while being flexible enough to be applied in reach scale case studies where the uncertainty is reduced. PROBFLO allows for the application of the environmental flow assessment on multiple scales, to evaluate the socio-ecological consequences of altered flows within local, regional and international legislative and policy contexts. This transparent, adaptable, evidence based risk assessment approach allows for the consideration of trade-offs between a range of management options, evaluated as scenarios so that the socio-ecological consequences of altered decision making can be considered. The outcomes of the assessment, and many of the flow-ecology and flow-ecology-social relationships in an assessment are related to testable hypotheses with associated uncertainties that can be reduced if tested. This results in improvements of the outcomes. The approach has been established to direct managers towards current best scientific practice and decision making. These include decisions that;

1. Consider both social and ecological requirements for ecosystem services,
2. Minimise socio-ecological impacts of new flow alteration developments,
3. Direct water development to least-sensitive water bodies, and
4. Prioritise flow restoration efforts on a regional environmental flow management scale.

5.5 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 8.

- **FRAI Ver 2.0 (Level IV EcoClassification)**

Kleynhans, CJ. 2007. Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 330/08.

- **MIRAI Ver 2**

Thirion, C. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.

Thirion, C. 2016. The determination of flow and habitat requirements for selected riverine macroinvertebrates. Unpublished PhD thesis. North West University, Potchefstroom, South Africa.

- **GAI IV (2006 version - Rowntree and du Preez)**

Only available as a draft report: Rowntree, K. and L. du Preez (draft model from 2006). MODULE B: Geomorphology Driver Assessment Index (GAI), in River EcoClassification: Manual For EcoStatus Determination (Version 2). Water Research Commission Report, Pretoria, South Africa.

- **GAI III (2006 version - Rowntree and du Preez)**

Only available as a draft report: Rowntree, K. and L. du Preez (draft model from 2006). MODULE B: Geomorphology Driver Assessment Index (GAI), in River EcoClassification: Manual For EcoStatus Determination (Version 2). Water Research Commission Report, Pretoria, South Africa.

- **GAI (Rowntree *et al.*, 2013)**

Rowntree, K.M. 2013. Module B: Geomorphology Driver Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 551/13.

- **VEGRAI (IV)**

Kleynhans, C.J., Mackenzie, J. and Louw, M.D.. 2007. Module F: Riparian Vegetation Response Index. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

- **VEGRAI (III)**

Kleynhans, C.J., Mackenzie, J. and Louw, M.D. 2007. Module F: Riparian Vegetation Response Index. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

- **IHI (Kleynhans *et al.,* 2009)**

Kleynhans, C.J., Louw, M.D., and Graham, M. 2009. Module G: EcoClassification and EcoStatus determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical manual)

Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.

- **IHI (Kleynhans, 1996, ver2)**

Publication:
Kleynhans, C.J. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa). Journal of Aquatic Ecosystem Health 5: 41-54, 1996. 41 © 1996 Kluwer Academic Publishers. Printed in the Netherlands.

Manual:
Department of Water Affairs and Forestry, South Africa (DWAF). 1999. Resource directed measures for the protection of water resources. Volume 3: River ecosystems, version 1.0.

- **EcoStatus model**

Kleynhans, C.J. and Louw, M.D. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT329-08.

- **EIS (2009, site based)**

Department of Water Affairs and Forestry (DWAF), South Africa. 1999. Resource directed measures for the protection of water resources. Volume 3: River ecosystems, version 1.0.

Louw M.D. and S Koekemoer (Eds). 2010. Deliverable 12: Volume 1: Environmental Flow Requirements Produced for WRP as part of Support to Phase II ORASECOM Basin Wide Integrated Water Resources Management Plan. 193 pp.

- **EIS (1999)**

Department of Water Affairs and Forestry (DWAF), South Africa. 1999. Resource directed measures for the protection of water resources. Volume 3: River ecosystems, version 1.0.

- **EIS (2014 - PESEIS)**

Department of Water and Sanitation (DWS), South Africa. 2014a. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. Compiled by RQIS-RDM: http://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx

- **PBMT**

Dollar, E.S.J. and Rowntree, K.M. 2003. Geomorphological research for the conservation and management of southern African rivers, Volume 2, Managing flow variability: the geomorphic response, Water Research Commission Report No. 849/2/03, Water Research Commission, Pretoria, 283pp.

- **HFSR**

Publications:
O'Keeffe, J.H., Hughes, D.A., and Tharme, R. 2002. Linking ecological responses to altered flows, for use in enviromental flow assessments: The Flow Stress-Response method. Proceedings of the International Association of Theoretical and Applied Limnology, 28, 84-92.

Hughes, D.A. and Louw, D. 2010. Integrating hydrology hydraulics and ecological response into a flexible approach to the determination of environmental water requirements. Environmental Modelling and Software, Volume 22/Issue 8, 2010, pages 910 – 918.

Manual:
IWR Source-to-Sea (eds). 2004. A Comprehensive Ecoclassification and Habitat Flow Stressor Response Manual. Prepared for IWQS: DWAF, Project no: 2002-148.

- **DRIFT**

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.

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

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.

- **FIFHA (part of HFSR)**

PRELIMINARY REFERENCE:
Kleynhans, C.J. and Thirion, C. 2016. Fish Invertebrate Flow Habitat Assessment (FIFHA): A model for use in the monitoring of instream flow requirements at Ecological Water Requirement sites in South Africa. Beta version: Department of Water and Sanitation, RQIS.

- **FFHA (part of HFSR)**

- **BBM**

Publication:
King, J.M., and Louw, D. 1998. Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. Aquatic Ecosystem Health and Management 1: 109-124.

Manual:
King J.M., Tharme, R.E. and De Villiers, M.S. (Editors). Environmental flow assessment for rivers: Manual for the Building Block Methodology. Water Research Commission report. WRC Report No. TT 131/00.

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 which are discussed below. Second tier numbering e.g. Step 4.1 represents a sub-step within Integrated Step 4.

All methods identified and used during Integrated Step 4 are listed in Section 6.4.

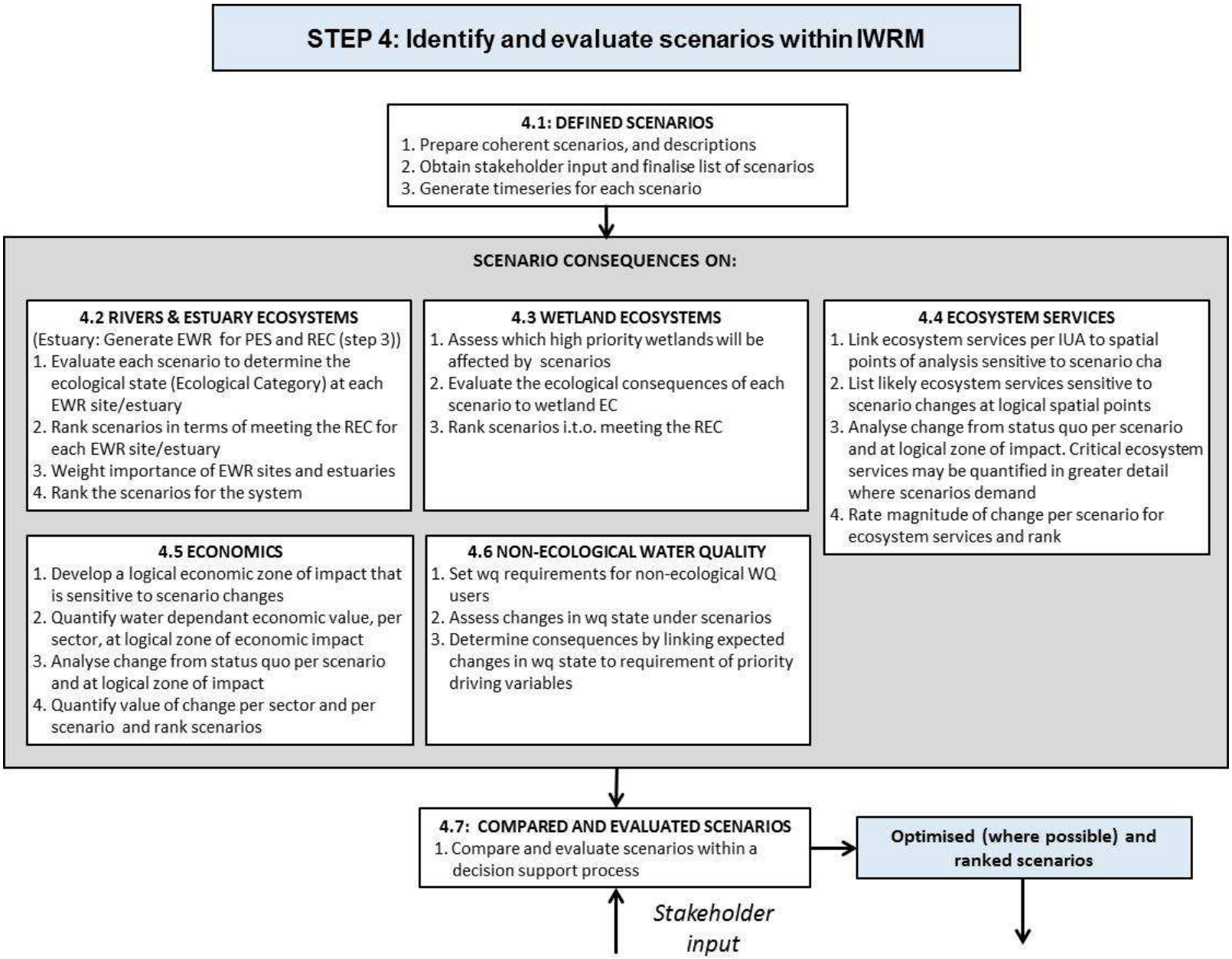

Figure 6.1 Illustration of the sub-steps for Integrated Step 4: Identify and evaluate scenarios within IWRM

6.1 STEP 4.2 RIVERS

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

The bullets below describe the actions required for rivers.

- **1. Evaluate each scenario to determine the ecological state (Ecological Category) at each EWR site and/or estuary**

Scenarios are evaluated to determine the predicted EC for each scenario.

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

The predicted EC can then be compared to the PES and REC; thereby providing the ranking of the scenarios in terms of how successful the scenarios meets the ecological objectives, i.e. the 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 RIVERS: STANDARDISED INPUT AND OUTPUT

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

Table 6.1 Standardised input and output per action

Action	Input	Comment	Output	Method
1. Evaluate each scenario to determine the ecological state (Ecological Category) at each EWR site	Daily data, Daily spill analysis	Method to disaggregate data not available yet but there is a current project to address this (refer to RDM/WE/00/CON/ORDM/0916)	Impact on EC	Embedded in DRIFT and HFSR (including FFHA, FIFHA) Scenario comparison Method (ScenComp) (refer to RDM/WE/00/CON/ORDM/0916)
2. Rank scenarios in terms of meeting the REC for each EWR site			Ranked scenario for each EWR site	River Scenario evaluation ranking method
3. Weight importance of EWR sites and estuaries	REC information		Weight per EWR site	River Scenario evaluation ranking method
4.Rank the scenarios for the system	EIS		Ranked scenarios for the system	River Scenario evaluation ranking method

6.3 STEP 4.2 RIVERS: IDENTIFIED METHODS AND EVALUATION PER ACTION

Table 6.2 Evaluation of the River Scenario Evaluation method

Methods		River scenario evaluation ranking method
Frequency of application use	Evaluation	5 - Very High
	Explanatory Comment	Qualitative ranking method has been in place since 2001 and applied on many Reserve studies. The rule based approach formalised in a spreadsheet has been in place since 2012 and applied on 3 large Classification studies and a Reserve study.

Methods		River scenario evaluation ranking method
Can the method be applied at a catchment level?	Evaluation	Yes
	Explanatory Comment	It is a site based method applied for as many sites there is within a coherent grouping.
Is the method described?	Evaluation	Yes
	Explanatory Comment	Within study documents.
Indicate the status of publication of the method.	Evaluation	3 Internal
	Explanatory Comment	
Are there existing training course?	Evaluation	No
	Explanatory Comment	Rule based method and training not required.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Evaluation	Yes
	Explanatory Comment	As operational scenarios are not evaluated for desktop studies, it will not be applicable for that component.
Time efficient (link to assessment level)	Evaluation	Yes
	Explanatory Comment	Once the evaluation is complete, the population of the spreadsheet will take less than a day.
Is the data available to apply the method?	Evaluation	Always
	Explanatory Comment	Standard data generated during this and previous step.
Compatibility	Evaluation	Yes
	Explanatory Comment	Complies with output and input.
Must software be purchased?	Evaluation	No
	Explanatory Comment	
Description of mathematical algorithms and model structure	Evaluation	
	Explanatory Comment	Rule based in Excel spreadsheet.
Is the model robust?	Evaluation	Yes
	Explanatory Comment	
Does the method include an objective assessment of uncertainty such as may influence confidence?	Evaluation	No
	Explanatory Comment	The confidence assessments are embedded in the various individual aspects of this step.

6.4 METHOD DESCRIPTIONS AND 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 8.

- **River Scenario evaluation ranking method**

Chapter 2, Section 2.2.2
IN
Department of Water and Sanitation (DWS), South Africa. 2014c. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Volume 7a: Recommended Water Resource Classes for the uMkhomazi (U1) and Mvoti (U4) River systems. 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/1114. September 2014.

7 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 which are discussed below. Second tier numbering e.g. Step 6.1 represents a sub-step within Integrated Step 6.

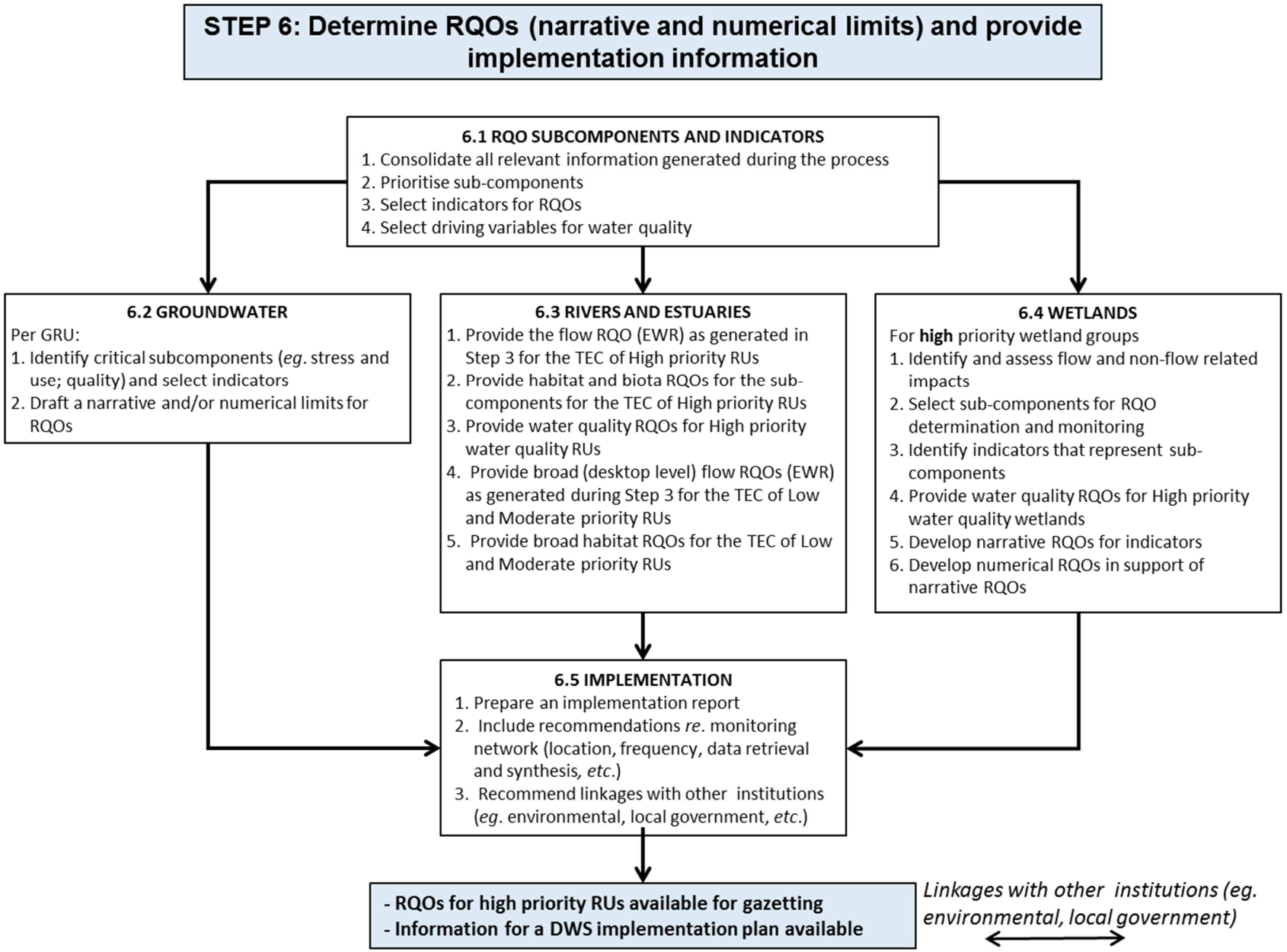

Figure 7.1 Illustration of the sub-steps for Integrated Step 6: Determine RQOs (narrative and numerical limits) and provide implementation information

7.1 STEP 6.3 RIVERS

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 Step 3 for the TEC of High priority RUs**

EWRs are determined for different EC 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. Rivers: 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 Integrated 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 ecological categories as in DWAF (2008); (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.

7.2 STEP 6.3 RIVERS: STANDARDISED INPUT AND OUTPUT

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

Table 7.1 Standardised input and output per action

Action	Input	Output	Method
1. Provide the flow RQO (EWR) as generated in Step 3 for the TEC of High priority RUs	EWR or yield model time series and flow duration table	Numerical hydrology (EWR) RQO (time series and flow duration table)	
2. Provide habitat and biota RQOs for the sub-components for the TEC of High priority RUs	TEC, EcoStatus models	Fish, Riparian veg, Geomorph, WQ, IHI, Inverts numerical RQO that can be monitored	FRAI, MIRAI, IHI, VEGRAI, GAI analysed data for the TEC
4. Provide broad (desktop level) flow RQOs (EWR) as generated during Step 3 for the TEC of Low and Moderate priority RUs	EWR or yield model time series and flow duration table	Numerical hydrology (EWR) RQO (time series and flow duration table)	RDRM or DRM
5. Provide broad habitat RQOs for the TEC of Low and Moderate priority RUs	EWR or yield model time series and flow duration table	Broad qualitative habitat RQOs	

7.3 STEP 6.5 IMPLEMENTATION: 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 bullets below describe the actions required for each prioritised RU.

- **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.

7.4 STEP 6.5 IMPLEMENTATION

The standardised input and output for each action (if relevant) are provided in Table 7.2.

Table 7.2 Standardised input and output per action

Action	Input	Comment	Output
2. Include recommendations regarding monitoring network (location, frequency, data retrieval and synthesis, etc.)	Standardised input according to DWS standards	This aspect documented here specifically refers to ecological monitoring	Completed REMP

It has been indicated that the REMP is the preferred programme for monitoring of rivers. As such, this DWS initiative does not require evaluation. The Rapid Habitat Assessment Method (RHAM – DWAF, 2009) component within the REMP has been evaluated by RQIS and is provided in Table 7.3. For further information, RQIS must be contacted.

Table 7.3 Evaluation of the RHAM

Methods		River scenario evaluation ranking method
Frequency of application use	Evaluation	4 - High
	Explanatory Comment	Used in more recent EWR studies.
Can the method be applied at a catchment level?	Evaluation	No
	Explanatory Comment	Site based tool only.
Is the method described?	Evaluation	Yes
	Explanatory Comment	Description in model.
Indicate the status of publication of the method.	Evaluation	3 Internal
	Explanatory Comment	Description in model.
Are there existing training course?	Evaluation	Yes
	Explanatory Comment	Training has been offered the past few years but not currently.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Evaluation	Yes
	Explanatory Comment	
Time efficient (link to assessment level)	Evaluation	1
	Explanatory Comment	Once all information has been collected a few sites can be done per day.
Is the data available to apply the method?	Evaluation	Seldom
	Explanatory Comment	Data needs to be collected.
Compatibility	Evaluation	Yes
	Explanatory Comment	Information collected can be used in all methods.
Must software be purchased?	Evaluation	No
	Explanatory Comment	Excel spreadsheet.
Description of mathematical algorithms and model structure	Evaluation	2 Open source;
	Explanatory Comment	Simple excel based model, password protected.
Is the model robust?	Evaluation	Yes
	Explanatory Comment	Different users with same level of expertise get similar results.
Does the method include an objective assessment of uncertainty such as may influence confidence?	Evaluation	N/a
	Explanatory Comment	

8 CONCLUSIONS

In general, the rivers tools are well developed and most have been used extensively. The most obvious gap is clear and updated user manuals that integrate the tools into processes.

- **Step 1.3.1 Rivers:** In terms of the prioritisation, two tools are on the table. The Catchment Reserve RU priority spreadsheet has been in use since 2004. Another method was designed during 2010 to accommodate RQOs (RU Prioritisation tool). This tool is similar to the Catchment Reserve RU priority spreadsheet but is complex and time consuming. It has recently become clear that DWS requires the evaluation of SQs and in large catchments and the RU prioritisation tool does not accommodate this. As both tools comply with the standardised output, the choice would be based on the size of study area and resources that are available. Manuals for both tools would be essential as both tools in its current format are only explained in actual study specific reports.

- **Step 3 Ecological Water Requirements:** This step forms the basis of the quantification of the Ecological Reserve. The Comprehensive and Intermediate Ecological Reserve Methodologies have been in place and the two current methods have been well applied since about 2008. A current manual for the Habitat Flow Stressor Methodology is a gap that has been identified. To estimate EWRs at desktop level, the Desktop Reserve Model has been widely applied since the early 2000's. The update of this model (the Refined Desktop Reserve Model) has been extensively used, but the lack of a manual and complexities in the model has limited the use. These issues are currently being addressed through a WRC project.

- **Step 4 Evaluation of operational scenarios:** Tools to be used for this are built in within the EcoClassification models, the HFSR and the DRIFT. The issues regarding these processes are linked to the gaps described in the bullet above.

- **Step 6 Determine RQOs:** The determination of EcoSpecs and setting of monitoring programmes have been part of the HFSR from the design there-of. However, approaches and detail component specific methods are still lacking. With the design of the NWRCS as well as the guidelines of the RQOs, further attention has been given to these issues. However, these guidelines did not provide any reference to the quantification of EcoSpecs and just refers to the Reserve methodology. This is an important gap that should be addressed.

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10 APPENDIX A: REPORT COMMENTS REGISTER

Page Number	Chapter /Section /Step	Comment	Addressed in report?	Comment/explanation
Page 4.5	Table 4.4	Was the Resource Unit Prioritisation Tool (Guideline version) not applied in the Vaal.	No	No, the modified (simplified version) was used in the Vaal – see next column in the table.
		Specify which two classification studies.	Yes	These referred to those participated by DWS (RQIS) and Southern Water, i.e. Olifants-Doorn, Olifants MPU.
Page 4-9	4.10	Any other methods that were considered that were produced by other study teams other than yourselves?	No	The RU prioritisation Tool which was evaluated in the document by the developer was produced by other study teams. Apart from these processes listed, no others exist.
		Page numbering not visible on portrait pages.	No	This may be a Microsoft version glitch, but the original version sent to DWS has no problem
		Table listing DWS representatives that participated at the specialist meeting held 20 to 21 February: Okonkwo and Boitumelo have been misspelled and Barbara's Directorate is wrong.	Yes	
		The item "Identified methods and evaluation per action" is missing for STEP 6. The use of the Resource Unit Evaluation Tool to select sub-components and associated indicators has not been identified and evaluated.	No	This step has been dealt with in the water quality report, specifically 6.1 Action 3 and 4 as it is more relevant for water quality than the other components. The tool mentioned has been evaluated in this report under step 2 as the main focus of the tool is to prioritise RUs. This was done in this way in consultation with one of the developers of the method who was present at the workshop.
		Also include Neels Kleynhans and Christa Thirion.	Yes	The names were included in the evaluator table but has now also been included in the table below.
Page 4.3	Table 4.2	Maybe include references to these documents somewhere in the report as well.	No	The references have been included in section 4.10. Only the most recent application of the methods has been referenced and not every study in which it has been used.
		This does not make sense.	Yes	
Page 4.5	Table 4.4	Provide reference to Guideline document.	Yes	
		Asked why the sections were not completed.	Yes	The evaluators did not provide the information on these cells.
Page 4.8	Table 4.5	Which EcoRegion Level.	Yes	
		What are the inputs.	No	Included a n/a as not all actions have standardised input or output.
Page 5.3	Table 5.1	Rather use MIRAI ver 2. The further updates to version 2 deals with the reference taxa functionality and does not actually modify the model as such. Also note that the 2007	Yes	

Page Number	Chapter /Section /Step	Comment	Addressed in report?	Comment/explanation
		WRC publication refers to MIRAI version 1. You can add Thirion 2016 for MIRA version 2.		
Page 5.5	Table 5.2	This actually refers to MIRAI version 1. As the 2 versions of MIRAI give very similar results we should maybe just leave it as MIRAI and mention that the latest version of MIRAI should be used.	Yes	
Page 5.5	Table 5.2	Also include unpublished PhD thesis for MIRAI version 2.	Yes	
Page 5.6		Evaluation with results from 2 versions of MIRAI also indicates that the different versions of MIRAI give compatible results (R2 >0.9).	Yes	
Page 5.8		Replaced by the more recently developed FIFHA.	Yes	
Page 5.9	Table 5.3	Replaced by the more recently developed FIFHA.	Yes	
		No training offered as it has been replaced by FIFHA.	Yes	
		The FIFHA actually takes considerably less than 1 day if all data is available.	Yes	This is based on the last 5 years of application of the FFHA. I would rather not change this to specific times till it has been applied more. But will add 1 day or less.
		The latest version uses opensource software instead of Data Curve Fit Creator. Please confirm with Neels.	Yes	
		If trained persons will come up with the same answers the model should sure be regarded as robust.	No	This evaluation was provided at the workshop.
Whole document		All editorial comments.	Yes	