REPORT NO.: RDM/WE/00/CON/ORDM/0916

DEVELOPMENT OF PROCEDURES TO OPERATIONALISE RESOURCE DIRECTED MEASURES

PROJECT NO: WP 10951

GROUNDWATER, HYDROLOGY, HYDRAULICS TOOL ANALYSIS AND STANDARDISATION REPORT

AUGUST 2016

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

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Title: ***GROUNDWATER, HYDROLOGY, HYDRAULICS*** **TOOL ANALYSIS AND STANDARDISATION REPORT**

Authors: ***Van Rooyen P, Birkhead D, Hughes D, Sami K.***

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Chief Director: Water Ecosystems

REPORT AND DELIVERABLE INDEX

Index Number	DWS Report Number	Report Title and Deliverables
1	RDM/WE/00/CON/ORDM/0116	Lessons Learnt Report
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3	RDM/WE/00/CON/ORDM/0216	Inception Report
4		Integrated framework Workshop
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19	RDM/WE/00/CON/ORDM/1016	Socio-economics and Ecosystem services tool analysis and standardisation Report
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21	RDM/WE/00/CON/ORDM/1216	RDM Communications Framework Report
22	RDM/WE/00/CON/ORDM/0117	Main Report
23	RDM/WE/00/CON/ORDM/0217	Capacity Building Report
24	RDM/WE/00/CON/ORDM/0317	Project Close-Up Report

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REPORT SCHEDULE

Version	Date
First draft	August 2016
Final	October 2016

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ACRONYMS AND ABBREVIATIONS

ACRU	Agricultural Catchment Research Unit
BHNR	Basic Human Needs Reserve
CD: WE	Chief Directorate: Water Ecosystems
CD:WE	Chief Directorate: Water Ecosystems
D:RDM	Directorate: Resource Directed Measures
D:RQIS	Directorate: Resource Quality Information Services
DAFF	Department of Agriculture, Forestry and Fisheries
DDM	Daily Dam Model
DEA	Department of Environmental Affairs
DM	District Municipality
DWA	Department Water Affairs (Name change applicable after April 2009)
DWAF	Department Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category
EcoSpecs	Ecological specifications
EFZ	Estuary Functional Zone
EGSA	Ecological Goods and Services Attributes
ESBC	Ecological Sustainability Base Configuration
EWR	Ecological Water Requirements
GIS	Geographic Information System (GIS)
GRA II	Groundwater Resource Assessment Phase II
GRDM	Groundwater Resource Directed Measures
GRU	Groundwater Resource Unit
GRYM	Groundwater Yield Model for the Reserve
HGM	Hydro-geomorphic
HO	Head Office
ISP	Internal Strategic Perspective
IUA	Integrated Units of Analysis
IWRM	Integrated Water Resource Management
LM	Local Municipality
MAR	Mean Annual Runoff
MRU	Management Resource Unit
NFEPA	National Freshwater Ecosystem Priority Area
NWRCS	National Water Resource Classification System
NGA	National Groundwater Archive
PES	Present Ecological State
PESEIS	Present Ecological State and Ecological Importance-Ecological Sensitivity
PSC	Project Steering Committee
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RMP	Resource Management Plan
RQO	Resource Quality Objective
RU	Resource Unit
SANBI	South African National Biodiversity Institute
SFR	Streamflow reduction
SPATSIM	Spatial and Time Series Modelling
SQ	Sub quaternary reach
TDS	Total Dissolved Solids
TEC	Target Ecological Category
TTG	Technical Task Group
WSAM	Water Situation Assessment Model
WARMS	Water Use Authorisation and Registration Management System
WMS	Water Management System
WRCS	Water Resource Classification System
WRC	Water Resource Class (I, II or II)
WRSM2000	Water Resources Simulation Model 2000

WRYM	Water Resource Yield Model of DWS
WRPM	Water Resource Planning Model of DWS
WReMP	Water Resource Modelling Platform
ZQM	South Africa Water Quality Monitoring programme

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 tools 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, tools 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 was 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:

Standardisation of methods focused on standardising the inputs and outputs of the tools used in the sub-steps to define the information and data that flow between the processes and steps. This ensures 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. The work was undertaken during a series of specialist work sessions.

1.4 PURPOSE OF THIS REPORT

During a range of specialist meetings held in July 2016, all relevant available tools and methods for each of the sub-steps was identified, evaluated and documented in a range of Specialist Reports (RDM/WE/00/CON/ ORDM/0516 to RDM/WE/00/CON/ORDM/1216. This report serves to document the outcomes of the specialist workshops covering the sub-steps and actions relating to surface and groundwater hydrology as well as hydraulic components (18 to 21 July 2016) (RDM/WE/00/CON/ ORDM/0916).

2 APPROACH

2.1 BACKGROUND

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

- Water Resource Classification System (DWAF, 2006a).
- 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, 2006a) and 2011 (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 all be referred to.

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. The Integrated Framework consists of eight steps. Each step is broken down into sub-steps described through a list of actions grouped together under various labels. The format is described below:

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

- Blocks with no numbers and shaded a light blue refer to KEY outputs (not all the outputs) of the step. These key outputs are those that are essential for use in the next step. This reflects the sequential manner of the Integrated Framework steps.

The integrated steps are provided in Figure 2.1.

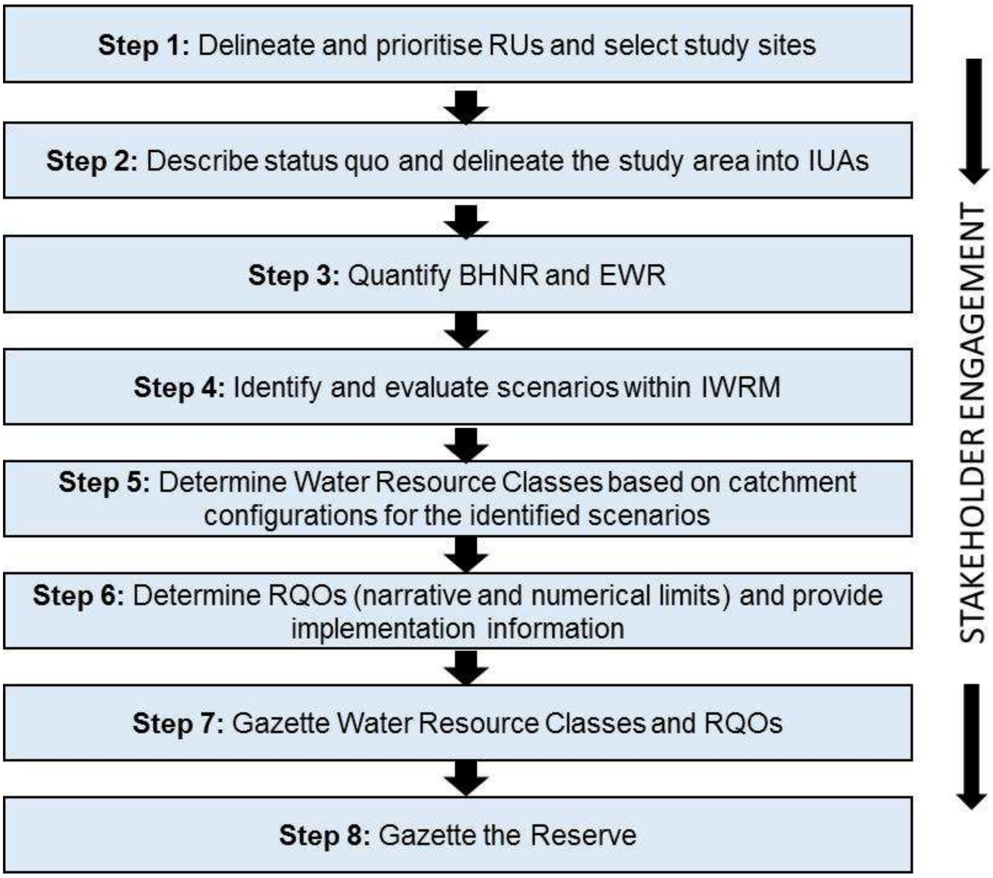

Figure 2.1 Integrated steps for the determination of the Reserve, Classification and Resource Quality Objectives

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

2.3 STANDARDISATION OF TOOLS, METHODOLOGIES, METHODS AND APPROACHES

Since 1987, Instream Flow Requirements (known now as the Ecological Reserve) 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 Reserve – specifically 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 to 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 of these studies must be compatible with the prevailing IWRM practices. This of course also implies that the input used in tools, especially around the driver components (hydrology, geohydrology, water quality etc.), require standardisation.

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

2.4 CONSIDERATIONS FOR STANDARDISATION

The focus of the standardisation process was on the input and output, rather than the tool or method themselves. The key requirements for standardisation were:

- Aim to achieve coherent application throughout the RDM steps and processes.
- Application of RDM processes is part of Integrated Water Resource Management implying that the prevailing water resource management activities need to define the focus.
- What is meant by input and output of a sub-step or actions is best described by the following example for the step to quantification the river EWR: 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 focused on standardising the inputs and outputs of the tools or methods applied in the sub-steps and 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. At the workshops Excel spreadsheet containing all sub-steps and all actions were populated with information for the component relevant to surface and groundwater hydrology as well as hydraulics.

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

2.5 TOOL IDENTIFICATION

The identification of tools was undertaken by considering those applied during studies carried out for DWS (directly or indirectly) 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 tools. The models could be detail hydrological models, spreadsheet formulas, methodical procedures and techniques.

In cases where a Sub-step did not require a tool, it was noted that there is no tool needed and if tools are not available, this was identified as a gap.

In general the following approach were applied for identification of tools:

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

A generic set of criteria to rate the tools were identified and described (see Section 2.7). The tools were rated using an Excel spreadsheet during the workshop proceedings. Note that not all criterion will be applicable to a tool or 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 capture the necessary information on the Excel spreadsheets and in the report. The steps (process) that was followed for each Integrated Framework Sub-step are provided 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 any of 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 were then ignored.
- The identified tools were evaluated according to the given criteria. Note, that depending of the nature of the tool, all the criteria may not be valid and in these cases, the spreadsheet was not populated.
- The information in the spreadsheet was transferred t to this MS Word report with added explanatory test where applicable.

2.7 EVALUATION CRITERIA

The criteria for the tool evaluation, the ratings 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 tool be applied at a catchment level?	Yes/No	Some tools can only be applied at a site and have to be repeated for every site, i.e. the tool 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, 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.

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 an 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 delineate the study area into appropriate catchments and 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 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 information that is gazetted is RUs 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 therefore involves the delineation and prioritization of RUs, Study sites where more detailed field work is undertaken and are selected within High priority RUs, i.e. sites can only be selected after the prioritisation process.

This step has 6 sub-steps which are discussed below. Note that for easy reference, all sub-steps which are described with a second or third tier number (e.g. 1.1, 1.2) are referred to as e.g. Step 1.1. The numbering format implies that it is a sub-step.

[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.

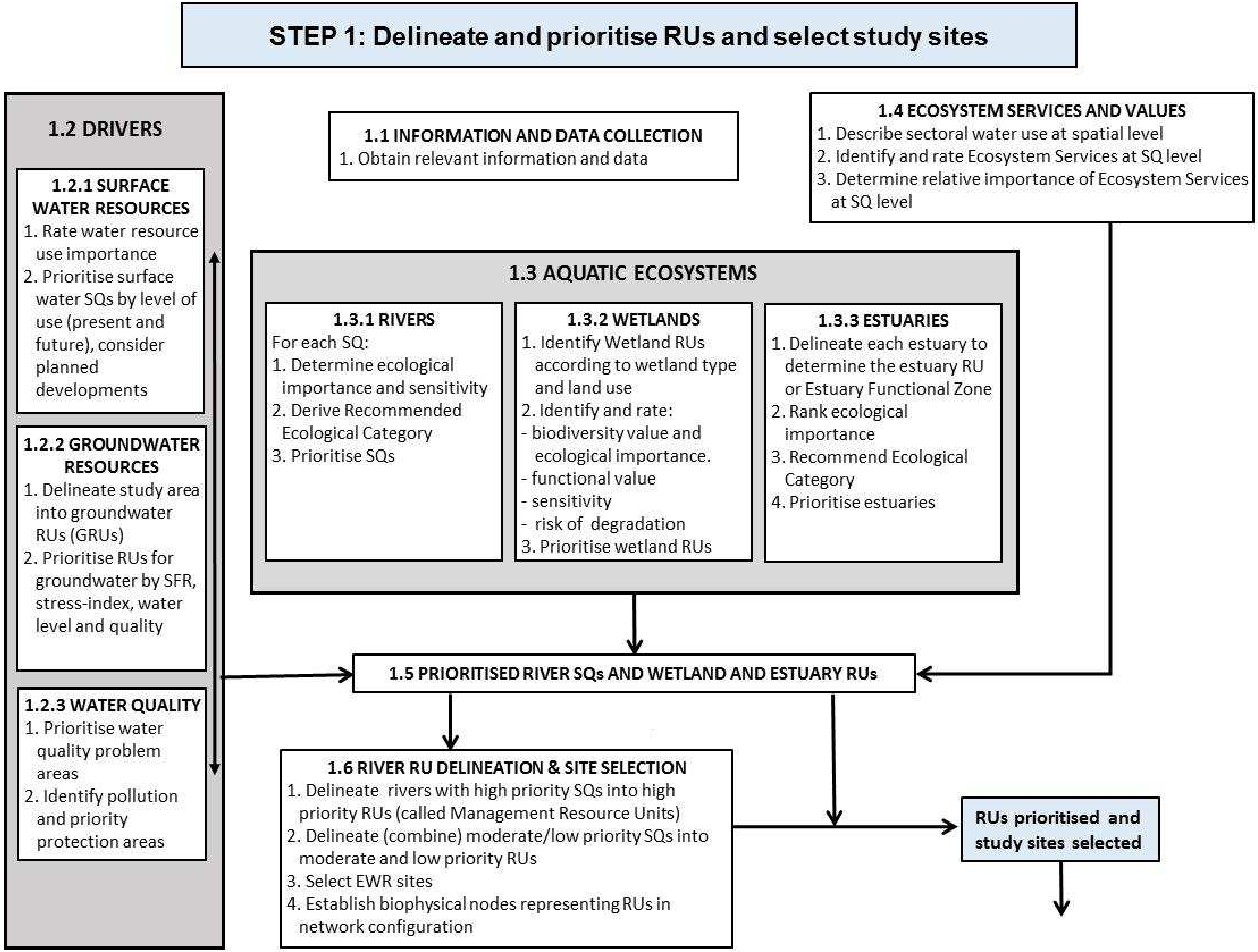

Figure 3.1 Illustration of the sub-steps for Integrated Step 1: Delineate and prioritise RUs and select study sites

3.1 STEP 1.2.1 SURFACE WATER RESOURCES: ACTIONS

The bullets below describe the actions required.

- **1. Rate water resource use importance**

Water resource use importance are rated using a scoring system and considering aspects such as; the current water balances in the upstream catchment, utilisation of a river reach for operational purposes, possible future developments and/or water uses expected in the catchment, the presence and extent of wastewater discharges in the catchment as well as evidence of water quality related problems need to be highlighted. Groundwater utilisation is incorporated as a component and rated in accordance with the water use relative to availability, extent of SFR activities and water quality.

- **2. Prioritise surface water SQs by level of use (present and future), consider planned developments**

The result of the water resource use importance ratings, derived in the item above, is applied to prioritise the surface water RUs. The prioritisation gives guidance to where the focus should be of the work to be carried out in subsequent steps.

3.2 STEP 1.2.1 SURFACE WATER RESOURCES: STANDARDISED INPUT AND OUTPUT

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

Table 3.1 Standardised input and output per action

Action	Output	Comment
1. Rate water resource use importance	Relative rating of water use. Apply a typical five tier scale from limited use (1) up to Heavily used (5)	The rating should be at Quaternary catchment resolution, also considering Sub-quaternary reaches
2. Prioritise surface water SQs by level of use (present and future), consider planned developments	Prioritise according to relative ratings. Apply appropriate integration methods and weights to obtain integrated scores if required	Provide narrative descriptions of the reasons for the selected priorities

3.3 STEP 1.2.1 SURFACE WATER RESOURCES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

- **Action 1: Rate Water Resource Use Importance**

Table 3.2 Evaluation of Water Resource Use Importance (WRUI) spreadsheet tool

Criteria	Evaluation	Explanatory comment	Additional Comment
Frequency of use of the application?	Very High	Since 2004 in most Reserve and 4 Classification studies.	
Can the tool be applied at a catchment level?	Yes	Designed for catchment level use.	
Is the method described?	Yes	In study reports.	
Indicate the status of publication of the method	Internal		
Are there existing training courses?	Not applicable		Simple spreadsheet tool.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes		
Time efficient (link to assessment level)		Quick application is possible.	Qualitative assessment of available data

Criteria	Evaluation	Explanatory comment	Additional Comment
Is the data available to apply the method?	Always		
Compatibility?	Yes		Method incorporate rating of groundwater use compared to availability.
Must software be purchased?	Not applicable		
Licencing requirements?	Not applicable		
Enhancement flexibility or adaptability of algorithms?		Very flexible.	
Is the method validated and verified?	Not applicable		
Descriptions available of mathematical algorithms and model structure?	Not applicable	Spreadsheet formula.	
Is the model robust?	Yes		
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	However, qualitative confidence rating forms part of rating method.	

Note there is no separate standardised tool or methods for prioritisation – Action 1.2.1(2).

3.4 STEP 1.2.2 GROUNDWATER RESOURCES: ACTIONS

The bullets below describe the actions required.

- **1. Delineate study area into groundwater RUs (GRUs).**

Delineate, categorise or classify GRUs based on stresses on baseflow from (SFRs and abstraction, and stresses on groundwater levels and groundwater use, such as water levels and groundwater quality, borehole yields, aquifer type, hydraulic boundaries, topography, recharge, aquifer vulnerability, or any factors that warrant differentiating aquifer management practices.

- **2. Prioritise RUs for groundwater by SFR, stress-index, water level and quality**

Identify and prioritise GRUs based on stresses. In some areas groundwater stresses which may occur, such as new mines, or groundwater schemes, may not exist yet, and may create future high priority areas.

3.5 STEP 1.2.2 GROUNDWATER RESOURCES: 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

Action	Input	Output	Comment
1. Delineate study area into groundwater RUs (GRUs).	Data requirements are presented in Step 2.	Classified GRUs. GIS maps. Narrative description of GRUs.	
2. Prioritise RUs for groundwater by SFR, stress-index, water level and quality	Groundwater use by sector and GRU. Recharge and Exploitation potential. SFR growth over time. Contamination sources. Water quality distribution. Time series of water levels.	Time series of natural and present day baseflow. Aquifer vulnerability map. Stress index map. Plotted water levels and long term trends. Aquifer classification.	Narrative description of the reason for selected priorities.

3.6 STEP 1.2.2 GROUNDWATER RESOURCES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

- **Action 2: Prioritise RUs for groundwater by SFR, stress-index, water level and quality**

In some cases, aquifer vulnerability may warrant prioritisation. Some aquifers are susceptible to contamination from surface due to shallow groundwater tables, thin soil cover, coarse soils with low clay content and unconfined aquifer conditions. Fractured aquifers allow rapid entry and migration of contaminants via preferred pathways and have the potential to contaminate vast areas along the fracture network.

Table 3.4 Evaluation of DRASTIC tool

Criteria	Evaluation
Frequency of use of the application?	High
Can the tool be applied at a catchment level?	Yes
Is the method described?	Yes
Indicate the status of publication of the method	International
Are there existing training courses?	No
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes
Time efficient (link to assessment level)	1
Is the data available to apply the method?	Usually
Compatibility?	Yes
Must software be purchased?	No
Licencing requirements?	None
Enhancement flexibility or adaptability of algorithms?	Open script
Is the method validated and verified?	Yes
Descriptions available of mathematical algorithms and model structure?	Algorithm based
Is the model robust?	Yes
Does the method include an objective assessment of uncertainty such as may influence confidence?	No

Note that WRSM2000 (Pitman model) evaluation is provided in Integrated Step 2.

3.7 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.

- **Evaluation of Water Resource Use Importance (WRUI) spreadsheet tool**

This is a spreadsheet tool capturing the relevant information and applies the basic prioritisation ratings and weights to calculate the relative importance rating.

- **Evaluation of DRASTIC tool**

The DRASTIC Approach to aquifer vulnerability assessment is based on superimposing various layers of data with prescribed ratings. The final outcome/rating is then used to categorise the level of vulnerability. Higher ratings are associated with aquifers that have higher vulnerability and susceptibility to contamination from surface. The term DRASTIC originates from:
D - Depth to groundwater.

R - Recharge rate (net recharge).
A - Aquifer media.
S - Soil media.
T – Topography.
I - Impact on vadose zone, and
C – Conductivity (Hydraulic Conductivity).

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, to delineate IUAs. The status quo information for the study area is then used to describe the status quo for each IUA.

This step has 9 sub-steps which are discussed below. Note that for easy reference, all sub-steps which are described with a second or third tier number (e.g. 2.1, 2.2) are referred to as e.g. Step 2.1. The numbering format implies that it is a sub-step.

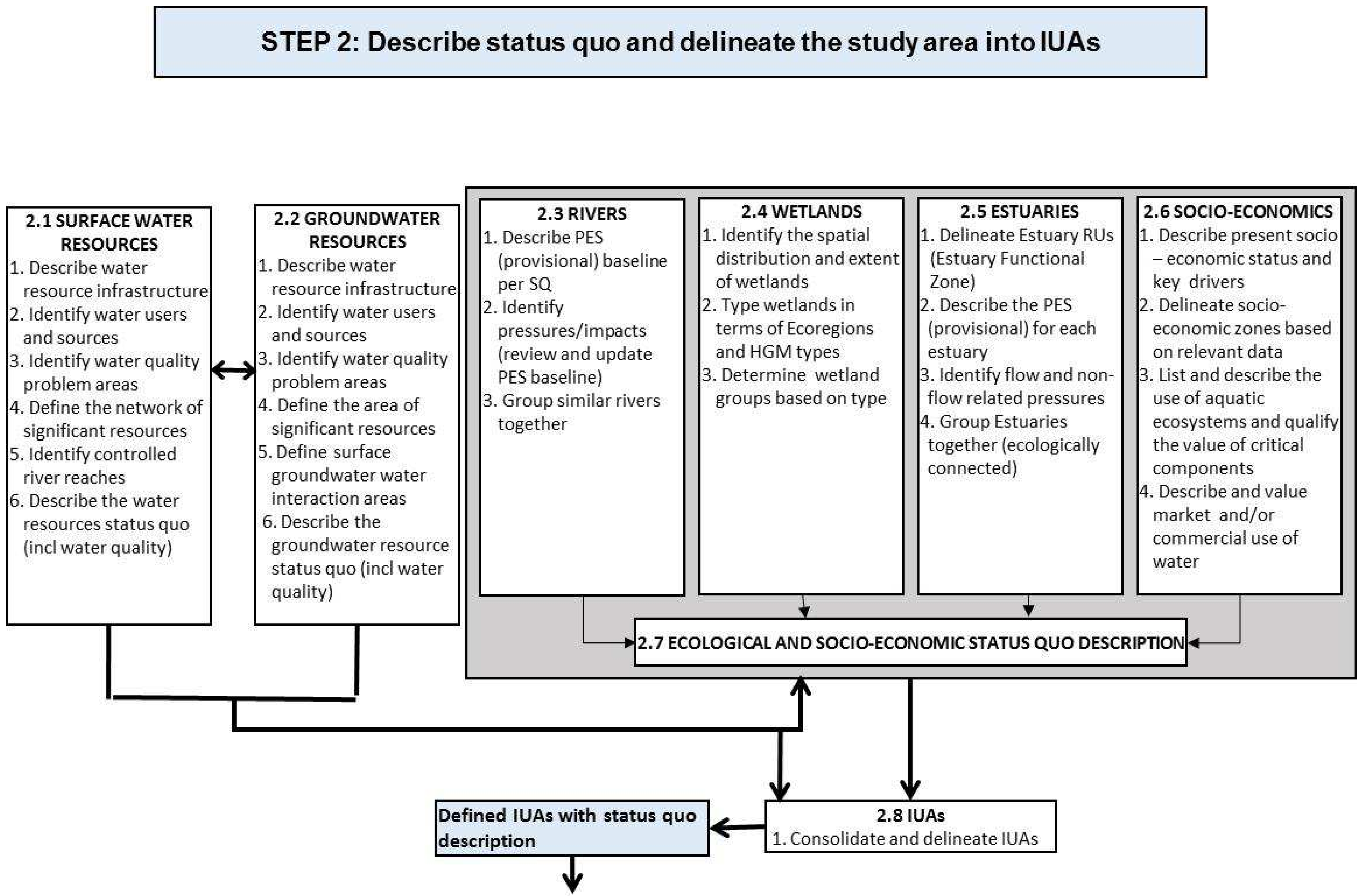

Figure 4.1 Illustration of the sub-steps for Integrated Step 2: Describe status quo and delineate the study area into IUAs

4.1 STEP 2.1 SURFACE WATER RESOURCES

Objective: Define and describe the surface water resources in the study area by following a catchment-by-catchment approach and identify key river reaches where flow is controlled by current or future operational activities. The information must be sourced from past hydrological and water resource assessment studies using the Quaternary Catchment definitions as the primary delineation for the descriptions. The descriptions should focus on where there are significant alterations of river flows caused by regulating water infrastructure and water use.

The status quo description must also present the hydrological data requirements and availability for application in subsequent steps, particularly for Integrated Step 3. The level of uncertainty associated with the hydrological information and data must be presented along with a qualitative rating which indicates how representative the data is and to what degree the available data could deviate from the actual conditions in the catchments.

The availability and status of water resource simulation models need to be documented with due reference to the resolution of the networks configured for the catchments in the study area. This review must reflect how the available models will be applied for the simulation of scenarios as part of Integrated Step 4.

The water resource information must be packaged in such a way that the recommended IUA delineation can be determined after integrating the water resource information with the outputs from all the other steps indicated in Figure 4.1.

The bullets below describe the actions required in this sub-step. Note that the numbers relate to the numbers in the flow diagram.

- **1. Describe water resource infrastructure**

Provide descriptions of the water resource infrastructure by listing where regulating storages (dams), conveyance infrastructure, river diversions as well as abstractions and discharges are present in the river system and catchments. Where applicable provide an overarching description of the water resource system followed by the catchment-by-catchment narratives. Provide appropriate Geographic Information System (GIS) maps and river system network diagrams to illustrate the connectivity of the rivers and infrastructure. Interdependent operational activities that affect river flow should also be highlighted (note, if many river systems are applicable it may involve the assessment of infrastructure operations that are linked to but outside of the study area.)

- **2. Identify water users and sources**

This involves identifying and describing the water users and their water sources. A systems approach rather than a strict catchment view should the followed to ensure users that receive water from the water resources in this study area but are located outside of the study boundary is also taken into consideration. This sources-and-user information feeds into the evaluations of the other component steps, in particular for defining how the socio-economic activities are linked to the water supplied from the resources in the study area.

In order to ensure efficient utilisation of human and financial resources in the execution of the work for this step the intensity and extent of these descriptions should be governed by some foresight of what the prevailing integrated water resource management activities are or being planned in the study area (note that this information is usually available from previous water resource assessments, reconciliation and planning studies that have been carried out for study areas).

- **3. Identify water quality problem areas**

Information collated during Step 2.1 is used to rate the Sub-Quaternary reaches (SQs) according to potential problem areas. The identified land uses in the existing PESEIS database and the refinement undertaken during Step 2.3, will lead to the potential causes and sources of water quality problems to be broadly identified.

- **4. Define the network of significant resources**

The point of departure for defining the significant surface water resources is the sub-quaternary reaches as delineated in the PESEIS database (DWS, 2014a). The PESEIS information set is refined by considering information from each of the component steps and adjusted where appropriate (see Integrated Step 3 for further details on the information to be produced for a significant water resource, also known as a bio-physical node).

The resolution of hydrological data and the system's models network configurations that are available in the various catchments are considered when delineating the significant resources.

- **5. Identify controlled river reaches**

The river reaches where the flow can be controlled through releases from dams, diversion weirs or water transfer schemes need to be identified and described. This information provides an inventory of river reaches where alternative operation regions could be considered as part of the scenario evaluations. The characterisations of these river reaches should include a description of the current operating practices and how flexible those release rules are to consider possible alternative more ecologically beneficial flow regimes.

- **6. Describe the water resource status quo (including water quality)**

The products from the preceding activities are presented as relevant chapters of the status quo report covering the entire study area. This report provides the rationale and motivation for the proposed IUA selection and serves as a communication document to stakeholders while also providing a reference of information when implementing the subsequent steps.

4.2 STEP 2.1 SURFACE WATER RESOURCES: 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 (Step 2.1)

Action	Input	Comment	Output	Comment
1.Describe water resource infrastructure	Study area, the extent of the resource and bulk supply system.		a. Location and connectivity of existing water resource components. b. Narrative of water conveyance operations. c. Proposed water resource developments. d. GIS maps.	Synthesis of information and data to provide the require output collectively. Typical information sources are: • WRYM / WRPM & other model system networks. • WRSM2012 networks and catchment data. • Operating analysis data. • Water resource planning and strategy related data.
2.Identify water users and sources			a. Water user type. b. Water source. c. If Irrigation: crop type, application system, areas, water use volume. d. Historical water use volume. e. Licenced water allocations. f. Narrative of water abstraction operations. g. Future proposed water uses. h. GIS maps, location of abstractions from resource.	Synthesis of information and data to provide the require output collectively. • WARMS database • WRSM2012 water use data. • Operating analysis, current and projected future water use. • Water resource planning and strategy related water use information.
3.Identify water quality problem areas		This action is described in the Water quality tool analysis and standardisation report.		
4. Define the network of significant resources			River reach & catchment on GIS map.	Selected river reaches, PES/EIS as minimum.
5. Identify controlled river reaches			River reach on GIS map / schematic diagram.	Provide descriptions of the operation control mechanisms and indicate if there is opportunity for adjustments (flexibility) to consider alternative flow patterns that could be ecologically beneficial.
6. Describe the water resource status quo (including water quality)			Document the status quo information in a consolidated report.	

Note that there are no standardised tools or methods to implement the actions for Step 2.1.

4.3 STEP 2.1 GROUNDWATER RESOURCES: ACTIONS

Objective: The objective of this sub-step is to define and describe Groundwater Resources for the purpose of Groundwater Resource Unit (GRU) delineation.

Quaternary catchments form the basic unit of delineation. These can be grouped into similar geohydrological properties by aquifer type, or be further subdivided if significant geohydrological features cut through catchments. Areas of similar character are grouped and mapped into distinct units, termed GRUs. Criteria that can be utilised to group or disaggregate catchments to form GRUs include:

- Interaction with other components of the hydrological cycle such as wetlands and rivers.
- Nature of the aquifers (primary, secondary dolomitic, alluvial etc.).
- Groundwater depth.
- Lithology when it affects borehole yields and groundwater quality.
- Topography.
- Groundwater dependence and use.
- Groundwater quality.
- Recharge and available groundwater resources.

For the status quo description, additional data requirements and shortcomings should be identified and stressed regions highlighted. The level of uncertainty associated with the data should be presented. The data should be presented in a manner suitable for GRU and IUA delineation.

The bullets below describe the actions required.

- **1. Describe water resource infrastructure**

This involves identifying hydrogeological units of significance and their boundaries. Identifying groundwater sourced water supply schemes, their geographical location as well as current and potential users to be supplied.

- **2. Identify water users and sources**

This involves identifying and describing the water users, groundwater dependent communities, and should include towns, industrial, mining and major irrigation users as well as an estimate of Schedule 1 and livestock water users. Water Use Authorisation and Registration Management System (WARMS) data and the All Towns studies (DWS, 2012-2015) are potential sources, but do not include Schedule 1 and smaller users. Census data, verification and validation studies etc. must also be considered. The stress on a GRU should define the level of detail and effort expended in quantifying groundwater use. Streamflow Reduction (SFR) activities also need to be quantified due to their role in baseflow reductions.

- **3. Identify water quality problem areas**

Problematic water quality areas, both in terms of natural constituents which hinder some uses and contamination must be identified. This can be done by listing the percentage or number of samples falling into various water quality categories.

- **4. Define the area of significant resources**

Areas of significant resources that need to be identified include:

  - Areas where groundwater is the sole source of supply.
  - Areas where groundwater contributes a significant component of baseflow and the catchment Mean Annual Runoff (MAR), and where abstraction could impact on these volumes.
  - Areas where large volumes of groundwater exist (based on recharge and the Harvest Potential) and where the existing stress index is low.

  - Areas where groundwater is of good quality.

- **5. Define surface groundwater interaction areas**

Catchments where surface-groundwater interactions exist can be identified from Groundwater Resource Assessment Phase II (GRA II) (DWA, 2006b). The degree of interaction in terms of a time series of baseflow needs to be defined for natural and present day conditions using appropriate models. The model needs to be calibrated so that simulated recharge approximates recharge estimates from other methods and baseflows fit observed baseflows. The information required for the above pertains to:

  - Obtaining a groundwater balance of rainfall recharge and transmission losses from rivers to discharge as baseflow, abstraction, and evapotranspiration under natural and present conditions.
  - Quantifying the volumetric contribution of baseflow to rivers.
  - Quantifying the degree to which SFR and abstraction have reduced baseflow, and to which abstraction impacts on baseflow.
  - Observed gauging weir data to calibrate baseflow volumes and cumulative frequency or flow duration curves.

- **6. Describe the groundwater quantity and quality status quo**

The information obtained is utilised to define GRUs and describe the existing status quo of each identified GRU.

4.4 STEP 2.2 GROUNDWATER RESOURCES: STANDARDISED INPUT AND OUTPUT

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

Table 4.2 Standardised input and output per action

Action	Input	Comment	Output	Comment
1.Describe water resource infrastructure	Lithological/Hydrogeological units. Borehole yields. Geological Structures. Catchment boundaries. Aquifer compartment boundaries. Groundwater schemes.		Groundwater regions by aquifer type and hydraulic connection. Groundwater Dependent communities. GIS Maps.	
2.Identify water users and sources	WARMS. All Towns strategy reports and ISP reports. Groundwater Resource Assessment Phase II. Census data 2011 or later. DWS regional office information databases.	Check for duplication of WARMS licences under surface and groundwater. All Towns and ISP reports have actual use and towns not registered under WARMS. GRAII has livestock water use. Census data has source of water by household to identify BHNR requirements, Schedule 1 users and groundwater dependence.	Water use by sector. Licenced Water allocation.	
3.Identify water quality problem areas	ZQM data. WMS surface water quality at gauging stations. NGA. WSAM quality data (potability index).	Regional and historical data and water quality trends are required.	Distribution of water quality classes for potability for TDS, F, Nitrates, metals etc.	Required for Classification and for setting RQO thresholds.
4.Define the area of significant resources	GRAII. Harvest Potential. Groundwater maps. Groundwater use.	Groundwater use provides qualitative information on the presence of significant resources.	Recharge and exploitable groundwater resources.	
5. Define surface groundwater water interaction areas	GRAII. GRDM software. Rainfall, runoff, water use data. Area and type of SFR activity. Gauging station data. Google Earth and other satellite imagery. NFEPA wetlands database.		Natural and present day baseflow time series.	The derived time series should be based on a calibrated time series and be compatible and consistent with the data requirements of the surface water hydrology as well as the EWR.
6. Describe the groundwater resource status quo (incl. water quality)	Recharge. Exploitation or Harvest Potential. Groundwater use. Groundwater Quality by potability class.		Groundwater baseflow and interflow. Water quality classification. Groundwater balance.	The status quo report should provide the information required for GRU delineation.

4.5 STEP 2.2 GROUNDWATER RESOURCES: IDENTIFIED TOOLS AND EVALUATION PER ACTION

- **Action 5: Define surface groundwater water interaction areas.**

These tools are utilised to derive natural and present day time series of baseflow.

Table 4.3 Evaluation of tools

Criteria	WRSM2000 (Pitman model - Pitman *et al*., 2008)			SPATSIM (Pitman model - Hughes *et al*., 2012)	
	Evaluation	Explanatory comment	Additional Comment	Evaluation	Explanatory comment
Frequency of use of the application?	High	Setup for most catchment is SA.	Existing hydrology from studies is often used.	High	
Can the tool be applied at a catchment level?	Yes	Functionality to simulate catchment based groundwater-surface impacts.	Long track record of application and calibrated for many catchments in SA.	Yes	
Is the method described?	Yes	User manual and theoretical descriptions.		Yes	
Indicate the status of publication of the method	National		International journal peer reviewed.	International	
Are there existing training courses?	Yes	DWS and WRC arrange training courses from time to time.		No	
Is the method applicable to all levels of assessment (Desktop to Comprehensive)	Yes	The level of uncertainty in the results differs based on the availability of data for calibration **and** the human resource effort (intensity) of a study.		Yes	
Time efficient (link to assessment level)		Depends on the extent of the study area.		1	Can be quick depending on available data
Is the data available to apply the method?	Always	Calibration in not always possible due to unavailable data. Rainfall-runoff models are available for all catchments.		Always	
Compatibility?	Yes	The model provides the data for DWS water resource models (WRYM/ WRPM) and WReMP.		Yes	
Must software be purchased?	No			No	
Licencing requirements?	Simple			None;	

Criteria	WRSM2000 (Pitman model - Pitman *et al.*, 2008)			SPATSIM (Pitman model - Hughes *et al.*, 2012)	
	Evaluation	**Explanatory comment**	**Additional Comment**	**Evaluation**	**Explanatory comment**
Enhancement flexibility or adaptability of algorithms?	WRC			Open source	
Is the method validated and verified?	Yes		By means of calibration.	Yes	
Descriptions available of mathematical algorithms and model structure?	Algorithm based			Detail explanation	
Is the model robust?	Yes			Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	No			Yes	

Criteria	GRYM (DWA, 2010)		ACRU (Schulze and Pike, 2004)	
	Evaluation	**Explanatory comment**	**Evaluation**	**Explanatory comment**
Frequency of use of the application?	Low	Easy to use but very conservative estimates	Low	Used once this year (2016) and twice in the previous 5 years
Can the tool be applied at a catchment level?	Yes		Yes	Used predominantly for agricultural catchment and research studies. Mainly small catchments 1 to 3.
Is the method described?	Yes	In existing studies as an Appendix. No formal manual	Yes	Developed over decades of research (MSc and PhDs) Thesis and user manuals.
Indicate the status of publication of the method	Internal		International	MSc and PhD theses and journal publications.
Are there existing training courses?	No	No formal course but can be provided	Yes	The UKZN pmb campus offers annual courses
Is the method applicable to all levels	Yes	New version caters for time series and Monte Carlo	Yes	the model is input data intensive depending on the level of data available one could potentially perform a comprehensive reserve determination.

Criteria	GRYM (DWA, 2010)		ACRU (Schulze and Pike, 2004)	
	Evaluation	Explanatory comment	Evaluation	Explanatory comment
of assessment (Desktop to Comprehensive)?		statistical approach		
Time efficient (link to assessment level)	1	Can be quick. Excel to numerical model level		
Is the data available to apply the method?	Usually		Seldom	The model is input data intensive, ACRU is a physical conceptual daily model and is not calibrated. Which conducts multi layered soil balances and is sensitive to landuse input data.
Compatibility?	Yes		Yes	
Must software be purchased?	No		No	
Licencing requirements?	None		None;	
Enhancement flexibility or adaptability of algorithms?	Open source	Contact Koos Vivier	WRC	
Is the method validated and verified?	Yes	Can calibrate against time series	Yes	The model uses physical characteristics of the catchment to produce streamflow from daily rainfall and where gauging data is available the model can be verified
Descriptions available of mathematical algorithms and model structure?	Algorithm based		Algorithm based	
Is the model robust?	Yes		Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	Yes		Yes	The method is physically based the best measure of results is to compare against gauged flows where available. ACRU View is a visualisation and statistical package that is used to analyse data produced by ACRU.

Note: Evaluation of ACRU was carried out by Siyabonga Sikosana from Aecom.

4.6 SUMMARY OF METHOD DESCRIPTIONS AND ASSOCIATED PUBLICATIONS

All methods identified and used during Integrated Step 2 are listed below. The associated publications (e.g. source of a manual and/or description of the methods) are listed in this section.

- **WRSM2000 (Pitman model)**

WRSM2000 is a monthly river-runoff simulation model representing a river system as a network of elements and calibrated against recorded flow data. The model provides the basic hydrological data for the WRYM, WRPM and WReMP models.

Documentation, network configurations and related data is accessible from the following link: http://waterresourceswr2012.co.za/
It is important to note that the data and configurations obtained from the above link is compiled as a country wide product and that there are detail hydrological studies carried out by DWS which enhances this general country wide information. Care should be taken to obtain all relevant hydrological information and select the most appropriate for RDM studies.

Related documentation is listed below:
Pitman, W.V., Kakebeeke, J.P. and Bailey, A.K. 2008. WRSM2000 (enhanced) Water Resources Simulation Model for Windows, User's Guide. WRC, Pretoria.

WRSM2000 (Enhanced) Water Resources Simulation Model for Windows Theory Document July 2008. Report by SSI compiled for the Department of Water Affairs and Water Resource Commission.

- **SPATSIM (Pitman model)**

SPATSIM is an integrated data management and modelling program developed in Delphi using the spatial data handling functions of Map Objects. It has been designed to allow the efficient management, processing and modelling of the type of data associated with a range of water resource assessment approaches used in South Africa.

Link to download the software: http://spatsimv2r12-8.software.informer.com/2.0/

The following reference is one of several that can be obtained on the internet:
Hughes, D.A., Forsyth, D.A., Stassen, J.J.M., van Niekerk, E. 2012. Deployment, maintenance and further development of SPATSIM-Hydrological Decision Support Framework (HDSF) Volume 2: National Database of Ecological Reserve and EWR Management, August 2012. Project No: K5/1870., Compiled by Institute for Water Research, Rhodes University; Hilton, South Africa for the Water Research Commission.

- **GRYM**

Department of Water Affairs (DWA), South Africa. 2010. Resource Directed Measures: Reserve Determination studies for selected surface water, groundwater, estuaries and wetlands in the Outeniqua (Knysna and Swartvlei) catchment. Groundwater Report. Compiled by: Vivier J.J.P. (AGES) 2010. Report No. RDM/K000/02/CON/0507. Department of Water Affairs, Pretoria.

ACRU

"The ACRU agrohydrological modelling system has been developed in the Department of Agricultural Engineering (now the School of Bioresources Engineering and Environmental Hydrology) at the University of Natal. The ACRU model is described by the developers as a multi-purpose and multi-level integrated physical conceptual model that can simulate streamflow, total evaporation, and land cover/management and abstraction impacts on water resources at a daily time step"

Link: http://cwrr.ukzn.ac.za/acru

Schulze, R.E. and Pike, A. 2004. Development and Evaluation of an Installed Hydrological Modelling System. School of Bioresources Engineering and Environmental Hydrology, University of Kwa-Zulu-Natal, Pietermaritzburg, South Africa. With contributions by LA Hallowes, MJC Horan, SLC Thornton-Dibb, DJ Clark, V Taylor, GPW Jewitt, DJM Dlamini and WMA Consultants. Report to the Water Research Commission. WRC Report No. 1155/1/04. ISBN No. 1-77005-127-9.

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.**

Integrated Step 3 determines the BHNR and the EWR components that describe the Reserve once the IUAs have been classified. EWRs are set at desktop level for the desktop biophysical nodes and at detailed level at the study sites that are selected during Integrated Step 2. 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 EC which happens in later steps in the process.

This step has 6 sub-steps which are discussed below. Note that for easy reference, all sub-steps which are described with a second or third tier number (e.g. 2.1, 2.2) are referred to as e.g. Step 2.1. The numbering format implies that it is a sub-step.

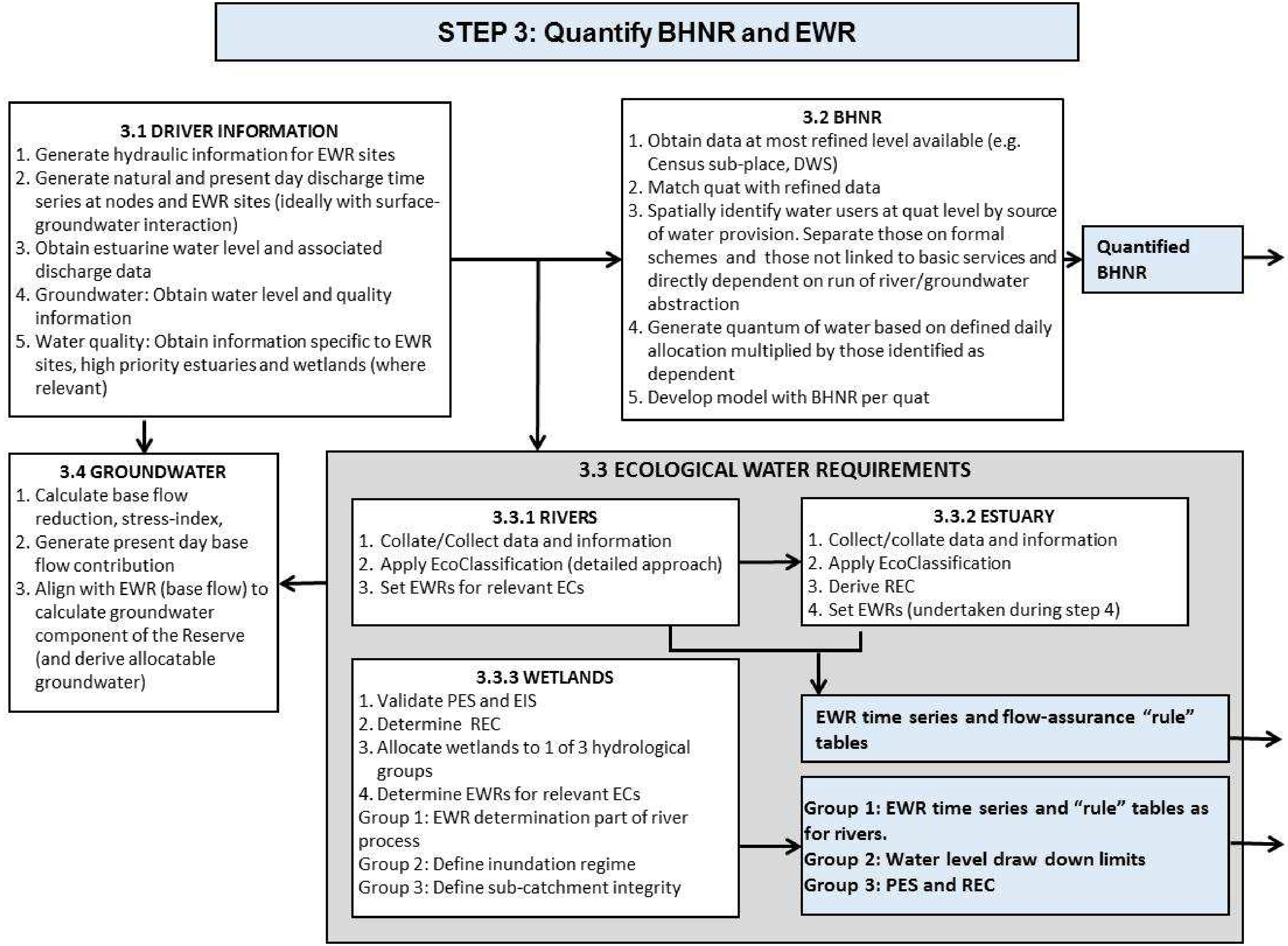

Figure 5.1 Illustration of the sub-steps for Integrated Step 3: Quantify BHNR and EWR

5.1 STEP 3.1 DRIVER INFORMATION: ACTIONS

Objective: The required hydrological and hydraulic data is produced that is needed to determine the ecological water requirements. The hydrological time series data is usually generated by a river-runoff and/or water resource simulation model assuming the catchment development is constant (stationary) over the simulation period. The time series data record period must cover several wet and dry periods that will ensure the derived EWRs are representative of the full spectrum of flow conditions.

The bullets below describe the actions required.

- **1. Generate hydraulic information for EWR sites**

EcoHydraulic modelling needs to be undertaken to translate ecological requirements in terms of depth, velocity, wetted perimeter etc. into discharge and finally, the EWR. This information requires cross-sectional surveys, discharge and level information to calibrate the hydraulic model.

- **2. Generate natural and present day discharge time series at nodes and EWR sites (ideally with surface-groundwater interaction)**

The process of deriving the natural and present day time series data is by applying appropriate river-runoff modelling and/or water resource simulation **models. The hydrological analyses should apply rigorous screening processes to validate the consistency of the results and ensure compliance to standard hydrological acceptance criteria. The derivation of present day flows should include the impacts of groundwater abstraction. This** process typically requires further delineation of existing river network configuration models to be able to provide time series data for all the selected biophysical nodes.

- **3. Obtain estuarine water level and associated discharge data**

This data is sourced from the DWS hydrometrical database, data recorded by Local Authorities, Water Service Providers, research institutions and in some instances environmental interest groups.

- **4. Groundwater: Obtain water level and quality information**

This information is sourced from existing groundwater databases.

- **5. Water quality: Obtain information specific to EWR sites, high priority estuaries and wetlands (where relevant)**

This step will involve the identification and collection of physico-chemical data (e.g. DWS's Water Management System (WMS) database) that will be used in the EcoClassification step, i.e. setting the present state for water quality (part of Step 3.3).

5.2 STEP 3.1 DRIVER INFORMATION: 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	Comment
1. Generate hydraulic information for EWR sites	a. Morphological reach type, width, slope, of channel. b. Catchment area. c. Topographical surveys of channel and flood plain. d. Rating data (Q and stage). e. Channel substrate. f. Marginal vegetation.	Hydraulic habitat definitions.	Items a and b are applied to desktop level investigations and c-f for higher confidence evaluations.
2. Generate natural and present day discharge time series at nodes and EWR sites (ideally with surface-groundwater interaction)	Calibrated model for study area.	Monthly time series of natural flows.	Attributes of output: Simulated flow data. Minimum of 80 years (historical period) in length including the 1930 drought. Derived by means of naturalisation processes and calibrated for study area. Stationary time series.
	Calibrated model for study area.	Monthly time series of simulated present day flows.	Attributes of output: Consistent with natural flow time series. Minimum of 80 years (historical period) in length including the 1930 drought. Stationary time series. Account for base flow reduction due to groundwater abstractions.
3. Obtain estuarine water level and associated discharge data	This action is covered in the Estuaries and Marine tool analysis and standardisation report.		
4. Groundwater: Obtain water level and quality information	ZQM data	Identification and classification of water quality	
5. Water quality: Obtain information specific to EWR sites, high priority estuaries and wetlands (where relevant)	This action is covered in the Water quality tool analysis and standardisation report.		

5.3 STEP 3.1 DRIVER INFORMATION: IDENTIFIED TOOLS AND EVALUATION PER ACTION

- **Action 1: Generate hydraulic information for EWR sites**

Table 5.2 Evaluation of HABFLOW tool

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	High	Used over approximately the last decade, at levels of determination from Rapid III and higher.
Can the tool be applied at a catchment level?	No	NA
Is the method described?	Yes	Water Research Commission reports and International literature for the velocity distribution component of the model.
Indicate the status of publication of the method	International	Journal publication/s for the velocity distribution component of the model.
Are there existing training courses?	No	Model targeted at eco-hydraulicians, and documentation should suffice.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	
Time efficient (link to assessment level)		Rapid, can be applied in a few hours.
Is the data available to apply the method?		For Rapid Level III and higher level of assessment, hydraulic data are collected as part of the assessment, the analysis of which forms input to HABFLO.
Compatibility?	Yes	Standalone model used as part of hydraulic analyses.
Must software be purchased?	No	
Licencing requirements?	None;	
Enhancement flexibility or adaptability of algorithms?	Open source;	
Is the method validated and verified?	Yes	
Descriptions available of mathematical algorithms and model structure?	Detail explanation	Refer to previous comments regarding documentation.
Is the model robust?	Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	

- **Action 2: Generate natural and present day discharge time series at nodes and EWR sites (ideally with surface-groundwater interaction)**

Note that the following list of tools generates natural and present day flow time series and were evaluated in Step 1.3:

- WRSM2000 (Pitman model).
- SPATSIM (Pitman model).
- GRYM.
- ACRU.

The following models are applied to generate present day flows as well as simulate alternative flow time series for scenarios, which form part of Step 4 - the scenario evaluation processes.

- Water Resource Yield Model (WRYM).
- Water Resource Planning Model (WRPM).
- WReMP – (Water Resources Modelling Platform).

Table 5.3 Evaluation of WRYM tool

Criteria	Evaluation	Explanatory comment	Additional Comment
Frequency of use of the application?	Very High	Most water resource systems in SA have been simulated with WRYM.	
Can the tool be applied at a catchment level?	Yes	Interlined river systems at different levels of network resolution can be simulated.	
Is the method described?	Yes	User and procedure manual.	The model can also be applied through DWS's Information management system (Water Resource Management Framework)
Indicate the status of publication of the method	International	Methods published in a book and several papers.	
Are there existing training courses?	Yes	DWS arranges training courses on a regular basis.	Short courses are given at University of Pretoria and Stellenbosch.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes		
Time efficient (link to assessment level)		Study area size dependant.	
Is the data available to apply the method?	Always		
Compatibility?	Yes	One of the primary water resource simulation model applied by DWS.	Compatible with WRSM2000. Simulates groundwater/surface water interaction.
Must software be purchased?	No		
Licencing requirements?	Simple		
Enhancement flexibility or adaptability of algorithms?	DWS		
Is the method validated and verified?	Yes	Using calibrated hydrology	
Descriptions available of mathematical algorithms and model structure?	Conceptual description.	0	
Is the model robust?	Yes		
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	Research was carried out, not yet applied in practice.	A form of uncertainty is addressed by stochastic steamflow analysis.

Table 5.4 Evaluation of WRPM tool

Criteria	Evaluation	Explanatory comment	Additional Comment
Frequency of use of the application?	High	All the large water resource systems in SA have been simulated with WRPM.	
Can the tool be applied at a catchment level?	Yes		
Is the method described?	Yes	User and procedure manuals to be improved.	The model is also applied through an information management system. (Water Resource Management Framework)
Indicate the status of publication of the method	International	Methods published in a book and several papers.	
Are there existing training courses?	Yes	DWS arranges training courses on a regular basis.	Short courses are given at University of Pretoria and Stellenbosch.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes		
Time efficient (link to assessment level)		Study area size dependant.	
Is the data available to apply the method?	Always		
Compatibility?	Yes	One of the primary water resource simulation models applied by DWS.	Compatible with WRSM2000. Simulates groundwater surface interaction.
Must software be purchased?	No		
Licencing requirements?	Simple		
Enhancement flexibility or adaptability of algorithms?	DWS		
Is the method validated and verified?	Yes	Using calibrated hydrology	
Descriptions available of mathematical algorithms and model structure?	Conceptual description		
Is the model robust?	Yes		
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	Research was carried out, not yet applied in practice.	A form of uncertainty is addressed by stochastic steamflow analysis.

Table 5.5 Evaluation of WReMP tool

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Low	
Can the tool be applied at a catchment level?	Yes	
Is the method described?	Yes	
Indicate the status of publication of the method	National	
Are there existing training courses?	Yes	
Is the method applicable to all levels of	Yes	

Criteria	Evaluation	Explanatory comment
assessment (Desktop to Comprehensive)?		
Time efficient (link to assessment level)		Study area size dependant.
Is the data available to apply the method?	Usually	
Compatibility?	Yes	
Must software be purchased?	No	
Licencing requirements?	None	
Enhancement flexibility or adaptability of algorithms?	Commercial	
Is the method validated and verified?	Yes	
Descriptions available of mathematical algorithms and model structure?	Conceptual description	
Is the model robust?	Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	Yes	Uncertainty is dealt with via stochastic hydrology

The following tool, Daily Dam Model (DDM), is applied to perform a daily time step spill analysis of dams. (Information provided by Gerald de Jager from Aecom)

Table 5.6 Evaluation of Daily Dam Model tool

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Medium	Developed in 2012; Used on 3 major studies: uMWP Feasibility Study, Noordoewer/Vioolsdrift Feasibility Study; Mzimvubu Water Project Hydropower Energy Optimization.
Can the tool be applied at a catchment level?	Yes	The current model version can handle relatively simple systems (one or two dams), with user-defined catchments, system characteristics (inter-linkages, etc.) and operating rules.
Is the method described?	Yes	Model description; SANCOLD paper, study documentation.
Indicate the status of publication of the method	International	EWR Workshop, ICOLD 2016 Conference, Johannesburg, SA.
Are there existing training courses?	No	-
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	Uses available EWR information.
Time efficient (link to assessment level)	1	Uses available EWR information.
Is the data available to apply the method?	Usually	Dependent on daily monitored (or simulated) hydro-meteorological data for daily time-step modelling
Compatibility?	Yes	Yes, but requires pre- and post-processing.
Must software be purchased?	No	-
Licencing requirements?	None	-
Enhancement flexibility or adaptability of algorithms?	Open script	Allows full flexibility.
Is the method validated and verified?	Yes	Results applied in dam designs on two feasibility studies
Descriptions available of mathematical algorithms and	Conceptual description	Entirely adaptable based on needs of user / study.

Criteria	Evaluation	Explanatory comment
model structure?		
Is the model robust?	Yes	Yes
Does the method include an objective assessment of uncertainty such as may influence confidence?	Yes	Use of scenario-based analysis methodology allows for assessment of relevant uncertainties, with inputs from ecological and water resources specialists.

Table 5.7 Evaluation of Revised Desktop Reserve Model[2]

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Medium	
Can the tool be applied at a catchment level?	Yes	
Is the method described?	Yes	
Indicate the status of publication of the method	International	
Are there existing training courses?	No	There have been courses, however, none are currently scheduled.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	The model can be used as a pure desktop or to support specialist ecological inputs.
Time efficient (link to assessment level)		Rapid application in hours is possible.
Is the data available to apply the method?	Always	
Compatibility?	Yes	
Must software be purchased?	No	
Licencing requirements?	None	
Enhancement flexibility or adaptability of algorithms?	Open source	
Is the method validated and verified?	Yes	
Descriptions available of mathematical algorithms and model structure?	Detail explanation	In papers, WRC report and PhD thesis.
Is the model robust?	Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	

Table 5.8 Evaluation of Fish River Seasonal EWR method

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very Low	Only used in Fish River (Namibia), but for DWS related work as part of the international steering committee
Can the tool be applied at a catchment level?	Yes	
Is the method described?	Yes	Fish River report.

[2] This model estimates EWRs for rivers. As the overall link in the model is to hydrology, the evaluation of the model is documented in this report.

Criteria	Evaluation	Explanatory comment
Indicate the status of publication of the method	Internal	Report to ORASECOM.
Are there existing training courses?	No	0
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	
Time efficient (link to assessment level)		Hydraulics part is complex.
Is the data available to apply the method?	Seldom	
Compatibility?	Yes	
Must software be purchased?	No	
Licencing requirements?	None	
Enhancement flexibility or adaptability of algorithms?	Open source;	
Is the method validated and verified?	Yes	In the Fish River
Descriptions available of mathematical algorithms and model structure?	Detail explanation	
Is the model robust?	Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	The method does include a standard evaluation of confidence of all the different inputs to the methodology

Table 5.9 Evaluation of the Original Desktop Model

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Very High	
Can the tool be applied at a catchment level?	Yes	
Is the method described?	Yes	
Indicate the status of publication of the method	International	
Are there existing training courses?	No	There have been training sessions in the past.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	The model can be used as a pure desktop or to support specialist ecological inputs
Time efficient (link to assessment level)		Rapid application is possible in hours.
Is the data available to apply the method?	Always	
Compatibility?	Yes	
Must software be purchased?	No	
Licencing requirements?	None	
Enhancement flexibility or adaptability of algorithms?	2 Open source	
Is the method validated and verified?	Yes	

Criteria	Evaluation	Explanatory comment
Descriptions available of mathematical algorithms and model structure?	Detail explanation	
Is the model robust?	Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	

- **Action 3: Obtain estuarine water level and associated discharge data**

This action is covered in the Estuaries and Marine tool analysis and standardisation report.

- **Action 4: Groundwater: Obtain water level and quality information**

No tools are applicable for evaluation to perform this action.

5.4 STEP 3.4 GROUNDWATER: ACTIONS

Objective: The objective is to define, in a quantitative manner, the groundwater contribution to baseflow, which is required to calculate the groundwater component of the Reserve, and its contribution to the EWR.

The bullets below describe the actions required.

- **1. Calculate natural baseflow**

This step is necessary to determine the impact of current landuse and abstraction in step2. . .

- **2. Generate present day base flow contribution base flow reduction, stress-index**

Present day and natural baseflow are required, based on a model calibrated against a baseflow time series and recharge, to quantify stress. This allows the quantification of SFRs and groundwater abstraction on baseflow and the importance of groundwater to the EWRs.

- **3. Align with EWR (base flow) to calculate groundwater component of the Reserve (and derive allocatable groundwater)**

Present baseflows compared to the EWR provide a measure of how much further abstraction can be sustained before baseflows reach the EWR. In some cases, the EWR may preclude the abstraction of available groundwater resources. This then follows that this action depends on the EWR determination and therefore the linked arrow from EWR to groundwater.

5.5 STEP 3.4 GROUNDWATER: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 5.10.

Table 5.10 Standardised input and output per action

Action	Input	Comment	Output	Comment
1 Calculate base flow reduction, stress-index	Calibrated time series of baseflow.	Calibration should be against a time series of baseflow and against recharge.	Naturalised baseflow time series.	Obtained by removing abstraction and SFRs from the calibrated model.
2. Generate present day base flow contribution	Groundwater abstraction SFR activities.		Baseflow time series at present day use Stress at present day use.	
3. Align with EWR (base flow) to calculate groundwater component of the	Present day baseflow EWR.		% of time baseflow is less than EWR.	

Action	Input	Comment	Output	Comment
Reserve (and derive allocatable groundwater)				

5.6 STEP 3.4 GROUNDWATER: IDENTIFIED TOOLS AND EVALUATION PER ACTION

- **Action 1: Calculate base flow reduction, stress-index**

WRSM2000, WRYM and other simulation models were evaluated in previous step.

- **Action 2: Generate present day base flow contribution**

WRSM2000, WRYM and other simulation models were evaluated in previous step.

- **Action 3: Align with EWR (base flow) to calculate groundwater component of the Reserve (and derive allocatable groundwater)**

Models were evaluated in previous steps.

5.7 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.

- **HABFLOW tool**

This is a software utility to determine the habitat – flow response characteristics that is used in the processes to determine of the flow requirements for rivers.

- **Water Resource Yield Model, Water Resource Planning Model**

The techniques and methods applied in establishing the water resource models consists of a suit of analytical tools including hydrological data preparation software, rainfall runoff simulation models, water quality modules, stochastic hydrological time series generation procedures, long term yield analysis and, the main decision support system, the Water Resource Planning Model (WRPM).

The WRPM consists of four main procedures (modules) that are integrated in a single modelling system for simulating the interdependencies and compare the outcomes of alternative scenarios:

- The main simulation engine of the model is a network solver which defines the water resource system as a network of reservoirs, rivers, conveyance infrastructure and water abstractions. The network simulation engine implements the required operating rules by means of data entries as dictated by the definition of the intended scenario to be analysed.
- The water availability risk is simulated by means of a rigorous stochastic streamflow generation model that accounts for the statistical characteristics of the rainfall and runoff in multi catchments by maintaining the serial and cross correlation as it was observed historically.
- Apply a drought curtailment algorithm that deals with multi risk criteria water uses in the same system ranging from irrigation that can tolerate lower assurances of supply as well as strategic water users for energy production which require supply at a 99.5% reliability.
- Water quality (Total Dissolved Solids – TDS) is simulated in the Vaal River System and this feature provides the ability to evaluate management options such as dilution, blending and desalination of mine water effluent.
- Integration of various interdependent water resource management aspects including:
  - Inter-basin transfer rules for major conveyances such as the Vaal River Eastern Sub-system Augmentation Project (VRESAP), Thukela-Vaal and transfer from the LHWP, transfers from the Caledon and Orange rivers in support of users in the Riet/Modder

catchment (Bloemfontein), transfers to the Eastern Cape are all incorporated in the simulation analyses.

- Increasing water requirements and return flows of multiple water users spread throughout the system.
- Hydro-power requirements and related operating rules in the Orange River System at Gariep and Vanderkloof Dams by taking into account the requirements of other users and the environment along the Orange River down to Alexander Bay at the River mouth.
- Commissioning characteristics of new infrastructure such as the filling of Polihali Dam are taken into consideration and the respective effects on the subsequent risk of water supply from the Vaal River System.

Relevant references:

- **WReMP**

Information can be found using the following link: http://www.waterresources.co.za/

- **Revised Desktop Reserve Model**

The following references and internet links provide access to relevant documentation:

Hughes, D.A., Desai A.Y., Louw, D. and Birkhead, A.L. 2012. Development of a revised desktop model for the determination of the Ecological Reserve for rivers. Water Research Commission (WRC) Report no. 1856/1/12. WRC, Pretoria, South Africa. Available at http://www.wrc.org.za.

Hughes, D.A., Desai, A.Y., Birkhead, A.L. and Louw, D. 2014. A new approach to rapid, desktop-level, environmental flow assessments for rivers in southern Africa. Special Issue: Hydrological Sciences Journal, Hydrological Science for Environmental Flows. http://dx.doi.org/10.1080/02626667.2013.818220.

- **Fish River Seasonal EWR method**

The following is relevant reference documentation:

Hughes, D., Birkhead, D., Bockmuhl, F., Mallory, S. 2013. River and Estuary EFR assessment, Hydrology and River Hydraulics. Research project on environmental flow requirements of the Fish River and the Orange-Senqu River Mouth. Produced by Rivers for Africa for ORASECOM and UNDP-GEP. Orange Senqu Strategic Action Programme.

Louw, D., Deacon, A., Koekemoer, S., Koekemoer, J., Kotze, P., Mackenzie, J., Palmer, R., Rountree, M., Scherman, P. 2013. River EFR assessment, Volume 1: Determination of Fish River EFR. Produced by Rivers for Africa for ORASECOM and UNDP-GEP. Orange Senqu Strategic Action Programme.

- **Original Desktop Model**

The following is relevant reference documentation:
Hughes, D.A. and Hannart, P. 2003. A desktop model used to provide an initial estimate of the ecological instream flow requirements of rivers in South Africa. Journal of Hydrology 270(3-4), 167-181.

- **Other References**

Department of Water Affairs and Forestry (DWAF), South Africa. 2008. Maintenance and Updating of Hydrological and System Software Phase 3: Procedural Manual for the Water Resources Simulation Model (WRSM) compiled for the Department of Water Affairs and Forestry by the consulting team consisting of Hydrosol (Pty) Ltd and WRP Consulting Engineers (Pty) Ltd.

Lesotho Highlands Water Commission (LHWC). 2008. Lesotho Highlands Water Project: Consulting Services for the Feasibility Study for Phase II – Stage 2: System Analysis Supporting Report. Lesotho Highlands Water Project Contract LHWC 001. Study executed by Consult 4 Consortium and SEED Consult on behalf of the Directorate: National Water Resource Planning, 2008.

Permanent Water Commission. 2004. Pre-Feasibility Study into Measures to Improve the Management of the Lower Orange River: Hydrology, Water Quality and System Analysis (Volumes A and B). Compiled by a consortium of consultants including Burmeister & Partments, Ninham Shand (Pty) Ltd, Windhoek Consulting Engineers and WRP Consulting Engineers (Pty) Ltd for the Permanent Water Commission, Republic of Namibia and Republic of South Africa. October 2004.

Department of Water Affairs and Forestry (DWAF), South Africa. 1999. Orange River Development Project Replanning Study Main Report compiled by BKS (Pty) Ltd and Ninham Shand (Pty) Ltd for the Directorate of Project Planning of the Department of Water Affairs and Forestry. September 1999.

Basson, M.S., Allen, R.B., Pegram, G.G.S. and Van Rooyen, J.A. 1994. Probablistic Management of Water Resources and Hydropower Systems. Published by Water Resource Publications. ISBN Number 918334-89-6, 1994.

Department of Water Affairs and Forestry (DWAF), South Africa. 1993a. Orange River System Analysis: Yield analysis up to PK le Roux Dam. Compiled by BKS Incorporated and SSO Consulting Engineers for the Directorate of Project Planning of the Department of Water Affairs and Forestry. Report number P D000/00/1292. January 1993.

Department of Water Affairs and Forestry (DWAF), South Africa. 1993b. Orange River System Analysis: Phase 2. Development of options to increase hydropower generation and yield of the Orange River System. Compiled by BKS Incorporated and SSO Consulting Engineers for the Directorate of Project Planning of the Department of Water Affairs and Forestry. Report number P D000/00/3493. September 1993.

Van Niekerk, P.H. and Basson, M.S. 1993. Practical Experience in the Probabilistic Based Management of Large Water Resource Systems. ASCE Symposium on Engineering Hydrology, San Francisco. 1993.

O'Connel, P., Thorn, D. and McKenzie, R. 1991. Multisite synthetic streamflow modelling in a semi-arid region. Paper presented at the 16th General Assembly of the European Geophysical Society, Wiesbaden, April, 1991.

Pegram, G. and McKenzie, R. 1991. Synthetic streamflow generation in the Vaal River System Study. Transactions of the South African Institution of Civil Engineers, Vol 31 No 1 pp 15-24 January 1991. Winner of SAICE award for best paper of 1991.

McKenzie, R. and Allen, R. 1990. Modern water resource assessment techniques for the Vaal System. Proceedings of the Institution of Civil Engineers, Part 1 pp 995-1014, December 1990. Winner of Telford Premium.

Department of Water Affairs and Forestry (DWAF), South Africa. 1986. Stochastic Modeling of Streamflow. Report No. PC000/00/5186 by BKS Water Resources Associates for the Department of Water Affairs and Forestry as part of the Vaal River System Analysis, Pretoria, SA.

Pegram, G.G.S. 1983. Stochastic Hydrology - an Overview. SA National Hydrological Symposium, sponsored by the Department of the Environment and the Water Research Commission.

6 STEP 4: IDENTIFY AND EVALUATE SCENARIOS WITHIN IWRM

Objective: Integrated Step 4 consists of the preliminary identification and description of operational scenarios within Integrated Water Resource Management (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 by the identified simulation and the outputs are evaluated to determine a range of consequences which is then compared in order to rank the scenarios.

This step has 7 sub-steps which are discussed below. Note that for easy reference, all sub-steps which are described with a second or third tier number (e.g. 4.1, 4.1.2) are referred to as e.g. Step 4.1. The numbering format implies that it is a sub-step.

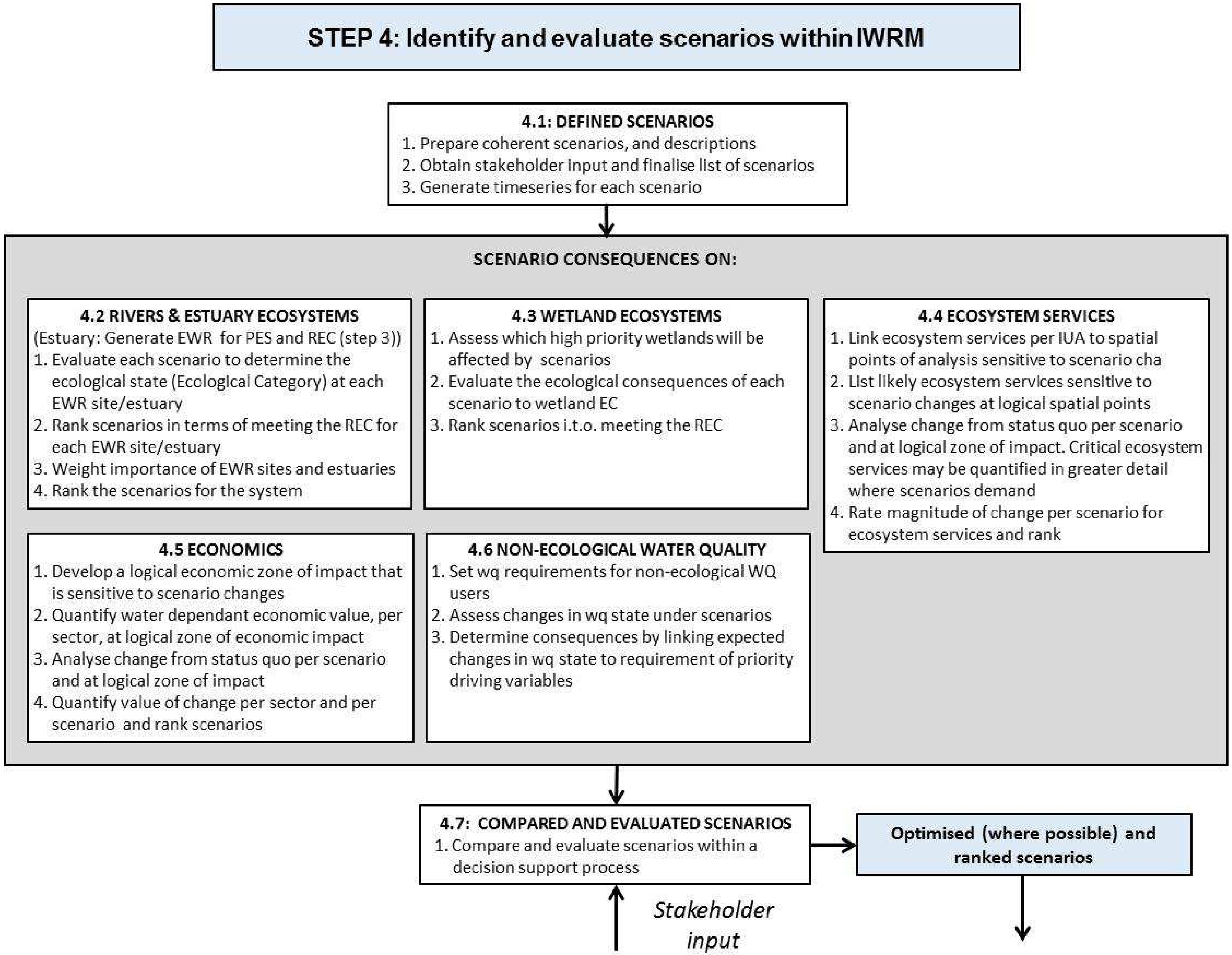

Figure 6.1 Illustration of the sub-steps for Integrated Step 4: Identify and evaluate scenarios within IWRM

6.1 STEP 4.1 DEFINED SCENARIOS: ACTIONS

This step encompasses the identification and description of scenarios that will be evaluated to arrive at the desirable balance between the protection of the ecology and the utilisation of the water resource for socio-economic purposes.

The scenarios need to be coherent by appropriately accounting for the all relevant aspects (variables) in the catchment's water balance pertaining to each scenarios narrative.

Definition: Scenarios, in the context of water resource management and planning are plausible definitions (settings) of all the factors (variables) that influence the water balance and water quality in a catchment and the system as a whole.

The scenario narrative definitions are tested with stakeholders to ensure that a complete list of scenarios has been identified. Then the scenario narrative definitions are interpreted and applied to provide alternative hydrological flow time series for river reaches at relevant bio-physical nodes using water resource modelling tools. The modelling results are the base information used for quantifying the ecological and socio-economic consequences (implications) of each of the identified scenarios.

6.2 STEP 4.1 DEFINE SCENARIOS: 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	Output	Comment
1. Prepare coherent scenarios, and descriptions	Water resource planning information and strategies.	Narrative descriptions and tubular scenario variable matrix.	Inclusive of include groundwater use scenarios. Water Quality scenarios. Water treatment costs. Site specific scenarios can be identified.
3. Generate timeseries for each scenario		Monthly simulated flow time series for all relevant nodes affected by scenarios.	Output used in all ecological consequences assessments.
		Water availability (yield) information.	Output applied in socio-economic consequences assessment.
		Simulated water quality timeseries of the variables of concern.	Calibrated water quality models are seldom available for study areas.

6.3 STEP 4.1 DEFINE SCENARIOS: IDENTIFIED TOOLS AND EVALUATION PER ACTION

- **Action 1 - 4: Prepare coherent scenarios, and descriptions, obtain stakeholder input, generate time series for each scenario and finalise list of scenarios**

There are no tools applicable to these actions.

6.4 STEP 4.7 COMPARE AND EVALUATED SCENARIOS: ACTIONS

Objective: The objective of this step is to carry out a systematic process of evaluating and comparing the identified scenarios and apply a form of decision support analysis to assist with the selection of the proposed Water Resource Classes. The activities of this decision support process are broadly two-fold, firstly, an analytical approach is undertaken for comparing and ranking scenarios preferably by means of a set of quantitative metrics. Secondly, stakeholders are engaged to seek their views and preferences as to what Class would constitute as an appropriate balance between the protection and use for the water resources in question. Ultimately the full package of information (from the decision support process and all the other steps' outputs) is considered by the designated person(s) of the DWS as the delegated authority to set the Water Resource Class.

6.5 STEP 4.7 COMPARE AND EVALUATED SCENARIOS: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 6.2.

Table 6.2 Standardised input and output per action

Action	Input	Comment	Output	Comment
1. Compare and evaluate scenarios within a decision support process	Coherent sets of quantitative results for each scenario, including: Consequence ratings of all bio-physical nodes (Ecology, Ecosystem Services) Set of relative importance weights for the bio-physical nodes. Socio-Economic metric. Importance weights for each of the main comparison variables.	The main comparison variables are typically: Ecology Ecosystem Services, Economics, and Social metrics.	Individual variable and integrated rating of scenarios for comparison, ranking and selection of preferred (best) scenario.	Undertake sensitivity analysis of a range of importance weights for the main comparison variable.

6.6 STEP 4.7 COMPARE AND EVALUATED SCENARIOS: IDENTIFIED TOOLS AND EVALUATION PER ACTION

- **Action 1: Compare and evaluate scenarios within a decision support process**

Table 6.3 Evaluation of Multi Criteria Decision Analysis and WRC determination tool

Criteria	Evaluation	Explanatory comment
Frequency of use of the application?	Medium	Applied in three of the recently completed reconciliation studies.
Can the tool be applied at a catchment level?	Yes	Account for metric at all biophysical nodes and multiple IUAs.
Is the method described?	Yes	Detailed descriptions of the method are contained in the study reports of three classification studies.
Indicate the status of publication of the method	Internal	Reviewed by stakeholder of three classification studies.
Are there existing training courses?	No	However, basic training was provided as part of the classification studies.
Is the method applicable to all levels of assessment (Desktop to Comprehensive)?	Yes	
Time efficient (link to assessment level)		Study area dependant.
Is the data available to apply the method?	Usually	Metric can readily be produced for input to the tool from the various evaluation processes.
Compatibility?	Yes	The tool also performs the calculations for the Water Resource Classes of multiple IUAs for all scenarios analysed.

Criteria	Evaluation	Explanatory comment
Must software be purchased?	No	
Licencing requirements?	None	
Enhancement flexibility or adaptability of algorithms?	Open script;	
Is the method validated and verified?	Yes	
Descriptions available of mathematical algorithms and model structure?	Algorithm based	The tool is an Excel spreadsheet and all calculations can be verified.
Is the model robust?	Yes	
Does the method include an objective assessment of uncertainty such as may influence confidence?	No	Sensitivity analyses capability provides the form of uncertainty assessment.

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

Objective: The objective of this step is to

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

Note that the PES, REC, TEC and operational scenarios all form part of the suite of identified scenarios that are evaluated.

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

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

TEC definition:

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

STEP 5: Determine Water Resource Classes based on catchment configurations for the identified scenarios

5.1 WATER RESOURCE CLASSES FOR IUAs

1. Define rules to calculate Class
2. Apply the selected to derive the Class for catchment configurations depicting PES, REC and all scenarios

↓

5.2 PREPARED TECS AND IMPLICATIONS (ECOLOGICAL AND MANAGERIAL) FOR NODES AND CLASSES PER IUA BASED ON THE RECOMMENDED CATCHMENT CONFIGURATION

1. Identify interventions required to achieve the REC
2. Identify where the REC is problematic to meet
3. Derive the proposed TEC based on best balanced scenario as well as attainability criteria
4. Provide implications of the TEC

↓

5.3 INTERNAL AND EXTERNAL STAKEHOLDER INPUT

1. Obtain DWS and relevant government authorities' comments on 5.2
2. Adjust TEC and Classes from Step 5 output
3. Prepare for external stakeholder consultation

↓

5.4 RECOMMENDED CLASSES AND CATCHMENT CONFIGURATION

1. Consolidate (DWS) and adjust TEC and classes
2. Recommend TEC and classes for legal notice

↓

Classes and catchment configuration available for preparation of legal notice

Information Block: Target Ecological Category (TEC)

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

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

7.1 STEP 5.1 DERIVE WATER RESOURCE CLASSES FOR IUAs

The bullets below describe the actions required.

- **1. Define rules to calculate Class**

The rule typically defines the portion of the resource in each Ecological Categories relative to the total resource. (The unit of measure is typically river lengths or footprint area of wetlands and estuaries within an IUA.)

- **2. Apply the selected rule to derive the Class associated with the PES, REC and all scenarios**

Use an appropriate model to calculate the Class following the selected ecological resource weighted rule.

7.2 STEP 5.1 DERIVE WATER RESOURCE CLASSES FOR IUAs: 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	Output	Method
1. Define rules to calculate Class	Rules to calculate the Class	n/a
2. Apply the selected rule to derive the Class associated with the PES, REC and all scenarios	Class for the various scenarios for each IUA	See tool evaluated in Step 4.

7.3 STEP 5.2 PREPARED TECs AND IMPLICATIONS (ECOLOGICAL AND MANAGERIAL) FOR NODES AND CLASSES PER IUA BASED ON THE RECOMMENDED CATCHMENT CONFIGURATION

The bullets below describe the actions required.

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

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

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

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

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

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

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

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

Table 7.2 Standardised input and output per action

Action	Output	Method
1. Identify interventions required to achieve the REC 2. Identify where the REC is problematic to meet	REC and actions required to meet REC for each SQ	Catchment Reserve RU priority spreadsheet
3. Derive the proposed TEC based on best balanced scenario as well as attainability criteria 4. Provide implications of the TEC	TEC for each RU and implications	

7.4 STEP 5.3 INTERNAL AND EXTERNAL STAKEHOLDER INPUT

The bullets below describe the actions required.

- **1. Obtain DWS and relevant government authorities' input on Step 5 output**

To prepare for the information that will be presented to stakeholders, DWS and relevant government authorities (e.g. DEA, DAFF and SANBI) which share legal responsibilities in some areas (such as estuaries) must be consulted. The resulting recommendation at this stage will then be utilised during the next steps.

- **2. Adjust TEC and Classes from Step 5 output**

If the input and the recommended classes and its catchment configurations differ from the Step 5 output, the TECs and resulting Classes per IUA are adjusted accordingly.

- **Prepare for external stakeholder consultation**

The information generation during this step is then consolidated in a user-friendly format for discussion at a stakeholder meeting.

7.5 STEP 5.4 RECOMMENDED CLASSES AND CATCHMENT CONFIGURATION

The bullets below describe the actions required.

- **1. Consolidate (DWS) and adjust TEC and classes**

Stakeholder input is provided, the information is consolidated, and DWS decide on the Classes and catchment configuration for the legal notice.

- **2. Recommend TEC and classes for legal notice**

The recommended Classes and catchment configuration (TECs) are prepared in a format suitable for the legal notice.

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

Objective: ROQs (narrative and numerical) are specified for the Classes and catchment configuration per Resource Unit. Different RQO levels, according to the RU priority (as determined during step 2), will be determined. The output will be to provide appropriate level of RQOs for all RUs with the high priority RQOs being 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 2) 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.

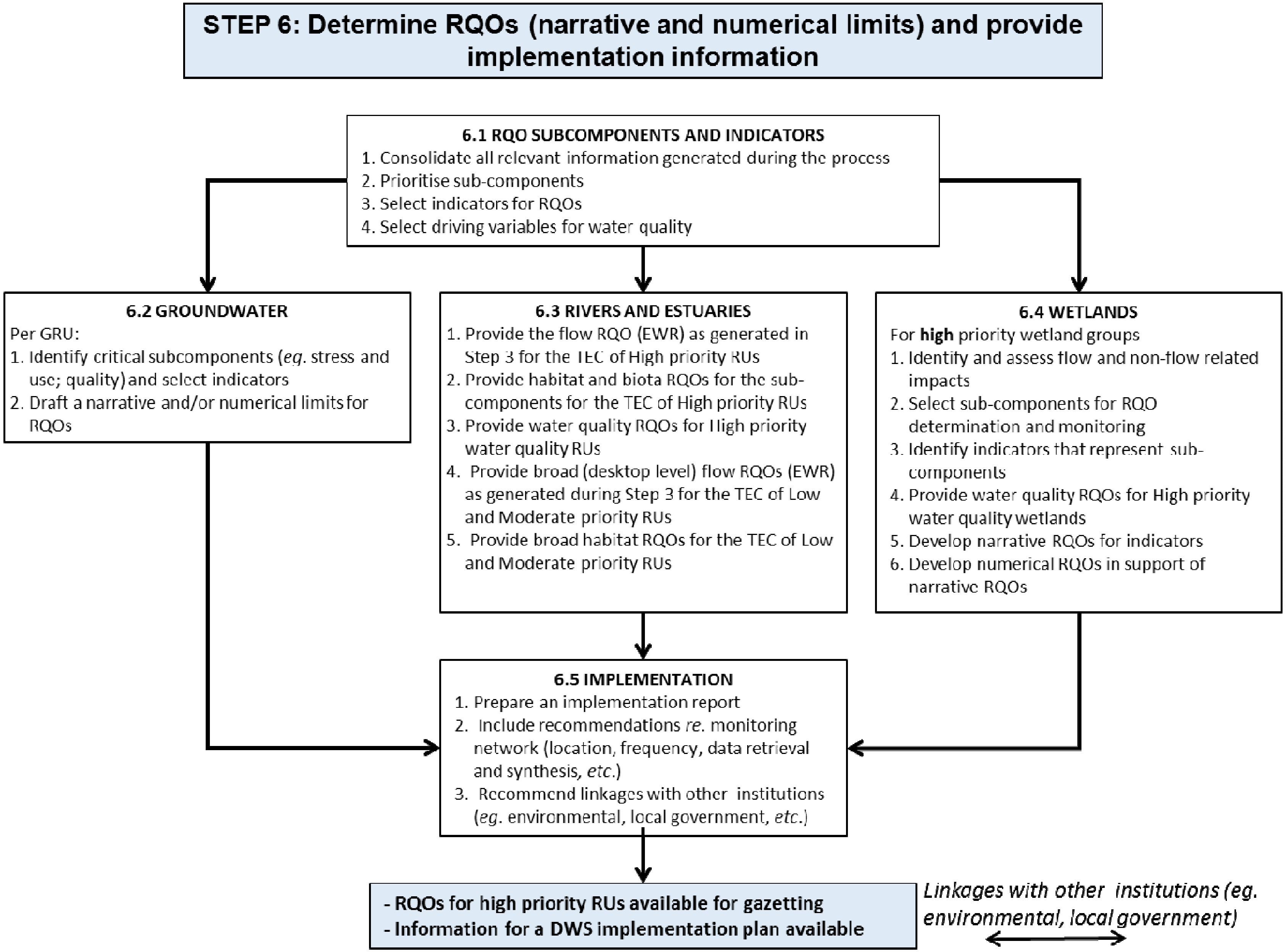

Figure 8.1 Illustration of the sub-steps for Integrated Step 6: Determine RQOs (narrative and numerical limits) and provide implementation information

8.1 STEP 6.2 GROUNDWATER: ACTIONS

The bullets below describe the actions required for each GRU.

- **1. Identify critical subcomponents (e.g. stress and use; quality) and select indicators**

Identifying subcomponents and indicators is necessary as the specific stresses need to be identified and an indicator provided for monitoring management actions. These stresses could include groundwater use, baseflow reduction, water quality changes, water level declines and gradients.

- **2. Draft a narrative and/or numerical limits for RQOs**

This step involves drafting simple and measurable RQOs, with quantitative thresholds where data exists to monitor compliance. Where no data exists, monitoring recommendations are provided in the Implementation report.

8.2 STEP 6.2 GROUNDWATER STANDARDISED INPUT AND OUTPUT

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

Table 8.1 Standardised input and output per action

Action	Input	Comment	Output	Comment
1. Identify critical subcomponents (e.g. stress and use; quality) and select indicators	Water use and recharge.	Required for stress index.	Threshold	Water use monitoring is seen as a requirement for enforcement.
	Baseflow reduction.	Required for EWR comparison.	Threshold	
	Water quality time series.	Undertake a trend analysis.	Threshold	
	Water levels time series.	Hydraulic gradient towards rivers.	Narrative output	Where baseflow exists, gradients towards river should remain positive.
	Water level time series.	Water level trends at a point over years discounting natural and seasonal fluctuations.	Thresholds for water level trends.	
	Aquifer parameters.	To use in calculations of distance of abstraction from a river and baseflow reduction.	Distance from a river at which to control abstraction.	
2. Draft a narrative and/or numerical limits for RQOs			Simple and measureable RQOs	

No specific tools were evaluated to the actions of Step 6.4.

8.3 STEP 6.5 IMPLEMENTATION: ACTIONS

Objectives: The rollout actions needed to implement the WRC 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 take that 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 WRC and RQOs.

The bullets below describe the actions required for each prioritised wetland.

- **1. Prepare an implementation report**

Compile a document detailing the processes needed for implementation along with motivated specifications of the temporal and spatial resolution of the required measurements and monitoring. Such a plan could include an activity Gant Chart providing a schedule of proposed processes over a period of 10 to 20 years.

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

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

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

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

8.4 STEP 6.5 IMPLEMENTATION: STANDARDISED INPUT AND OUTPUT

The standardised input and output for each action (if relevant) are provided in Table 8.2.

Table 8.2 Standardised input and output per action

Action	Input	Output	Comment
1. Prepare an implementation report	Relevant information from preceding Steps.	Define all processes within the Action> Monitor>Adaptation circular implementation framework.	
2. Include recommendations regarding monitoring network (location, frequency, data retrieval and synthesis, etc.)		Describe existing monitor network. Present study area specific processes for monitoring. Prepare timeline programme of implementation activities.	
3. Recommend linkages with other institutions (e.g. environmental, local government)		Define the need for institutional business plans to incorporated requirements from RDM. Identify the institutional linkages and key liaison requirements.	Objective is to attain efficient utilisation of resources across institutional boundaries.

No tools were identified for Step 6.5.

9 GAPS AND RECOMMENDATIONS

The following gaps (relating to surface and groundwater hydrology as well as hydraulic activities) have been identified which, if that is filled, will improve the effectivity of RDM operationalisation:

Since hydrological information is one of the driver components of all RDM processes improvements in recorded data of rain fall, water use, river flow and water quality sampling to apply in the various assessments and for monitoring is considered to be the one key aspect that will enhance the effective implementation of RDM processes. The measuring requirement is study area and system specific and should be captured in the Implementation Report compiled as part of Step 7.5.

Going forward with RDM process applications, provision should be made for “orderly” evaluation and adoption of alternative or enhanced methods that aim to (a) improve productivity of application and (b) incorporate knowledge from ongoing research by integrating with what we have.

The transfer and multiplication of scientific skills for the application of all the specialist activities as well as process coordination expertise, to ensure coherent applications across all the steps, should receive a high priority in human resource and skills development strategies.

A current gap is the absence of integrated multi-constituent water quality models that are calibrated for study areas. This shortcoming hampers the ability to evaluate and compare scenario consequences of alternative water quality management measures.

The need for daily flow data that is consistent with the main stream monthly hydrological models has been identified as a gap. Current research is being carried out to address this requirement and once the methods have been proven, production tools (software) should be developed for application in RDM studies.

Overarching recommendations:
Ensure RDM processes are executed within Integrated Water Resource Management and the prevailing focus activities (other than RDM) should be guiding the intensity and extent of the human resource efforts.

10 REFERENCES

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11 APPENDIX A: REPORT COMMENTS REGISTER

Page Number	Chapter /Section /Step	Comment	Addressed in report?	Comment/explanation
Christa Thirion: 16 September 2016				
ii		Spelling of names	Yes	
3-7	5	We had a lot of questions about this model and the way it is written here seems to suggest it was endorsed. Please can we state only what the model can do and remove it from here. Please rephrase the sentence to reflect the comment above.	Yes	
3-9	3.4	Can't remember this mentioned at the workshop but might be wrong. We agreed to remove this at the workshop.	Yes	
3-6	3.3	What is meant by this? Include reference	Yes	
4-5	4.6	Why are there no comments?	Yes	Removed columns.
5-4	5.2	Will the rest of the information still be filled in?	Yes	Details are provided in another study report.
Boitumelo Sejamoholo: 20 September 2016				
Cover		Incorrect report number on cover page	Yes	
		On table Change "Company" to "DWS Component" and decide whether to use Chief Directorate or Directorate names.	Yes	ACKNOWLEDGEMENTS
1-1	1.3	"Section 1.3: Purpose of this task" is written as if the workshop is still going to take place.	Yes	
1-2	1.4	The grammar in the first paragraph in Section 1.4 need to corrected.	Yes	
1-2	1.4	Change the term "Specialist Meetings" to "Specialist Reports". Note that the project contract refers to specialist workshops.	Yes	Added clarification.
1-2	1.4	Rephrase the first sentence in Section 1.4	Yes	
1-2	1.4	The following reference RDM/WE/00/CON/ORDM/01116 included in Section 1.4 is incorrect	Yes	
		Step 2 and Step 2: Most of what it captured in this report (for step 1 and step 2) is a duplication of what is in the integrated framework report. It is not clear why the changes that were made in step 1 and step 2 are not captured in this report since the purpose of this report is said to be "to document the outcomes of the specialist workshops covering the sub-steps and actions relating to surface and groundwater hydrology as well as hydraulic components (18 to 21 July 2016)".	Yes	Steps were rearranged and adjusted subsequent to further discussions after the workshops.

Page Number	Chapter /Section /Step	Comment	Addressed in report?	Comment/explanation
5-6	5.3.2	On the last bullet above Table 5.3, the acronym must be placed in brackets, after the full name (similar to the first two bullets above it).	Yes	
5-6	5.3.2	Correction on Additional Comment made in Table 5.3 under compatibility – should read as follows "simulates groundwater/surface water interaction"	Yes	
7-2	7.1	Figure 8.1: the numbering of items in this figure is confusing, the step is shown as step 6 yet sub steps are indicating that it is step 7 and this numbering is not aligned to the numbering referenced in Section 8	Yes	Figure 8.1 now refers to Step 5.
8-1	8.2	Section 8 does not touch on quantity RQOs, it does not show how the quantity RQOs link to this RQO step.	No	Stress index, water use, baseflow reduction and water levels are related to quantity RQOs.
Mmaphefo Thwala: 24 October 2016				
Cover pages		Date on the cover page and the 1st page don't correspond.	Yes	
		Update the finalization date on the report schedule	Yes	
3-3		Page3-3 is blank, fix figure3.1's title so that it is on the same page as the figure itself.	Yes	
11-1		Issues and response register_ make the font the same for all the comments and perhaps add a title saying 'comments from PMC members'. I also think the names of the people who commented should be acknowledged in the acknowledgement section at least.	Yes	