Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the INKOMATI WATER MANAGEMENT AREA, MPUMALANGA

PROJECT NO: WP 9133

Extrapolation and Estimation of EWR Results for various Hydronodes in the Crocodile and Sabie-Sand Catchments

INKOMATI

NOVEMBER 2010

REPORT NO.: 26/8/3/10/12/007

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COMPREHENSIVE RESERVE DETERMINATION STUDY FOR SELECTED WATER RESOURCES (RIVERS, GROUNDWATER AND WETLANDS) IN THE INKOMATI WATER MANAGEMENT AREA. MPUMALANGA

SABIE AND CROCODILE RIVER SYSTEMS : DESKTOP ESTIMATION REPORT

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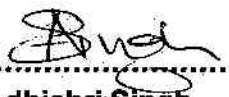

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Inkomati Reserve study: Reports as part of this project:

Report no	Report title
26/8/3/10/12/001	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Inception report
26/8/3/10/12/002	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Desktop EcoClassification report
26/8/3/10/12/003	Newsletters
26/8/3/10/12/004	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Basic Human Needs Reserve report
26/8/3/10/12/005	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Groundwater report
26/8/3/10/12/006	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Resource Unit report
26/8/3/10/12/007	**Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Desktop Estimation report**
26/8/3/10/12/008	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Wetland report
26/8/3/10/12/009	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: EcoClassification report
26/8/3/10/12/010	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: EWR scenario report
26/8/3/10/12/011	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Operation scenarios and consequences report
26/8/3/10/12/012	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: EcoSpecs report
26/8/3/10/12/013	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Socio Economic Present State Evaluation Report
26/8/3/10/12/014	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga:Training audit and report
26/8/3/10/12/015	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Main report
26/8/3/10/12/016	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Electronic information and data

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Mokolo Reserve study: Reports as part of this project:

Report no	Report title
26/8/3/10/14/001	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province: Inception report
26/8/3/10/14/002	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province: Desktop EcoClassification report
26/8/3/10/14/003	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Newsletters
26/8/3/10/14/004	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Basic Human Needs Reserve report
26/8/3/10/14/005	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Groundwater report
26/8/3/10/14/006	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Resource Unit report
26/8/3/10/14/007	**Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province: Desktop Estimation report**
26/8/3/10/14/008	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province: EcoClassification report
26/8/3/10/14/009	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:EWR scenario report
26/8/3/10/14/010	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province: Ecological, Goods & Services and Socio-Economic consequences of various Operational Scenarios.
26/8/3/10/14/011	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:EcoSpecs report
26/8/3/10/14/012	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Socio Economic Present State Evaluation Report
26/8/3/10/14/013	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Training audit and report
26/8/3/10/14/014	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Main report
26/8/3/10/14/015	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Wetland report
26/8/3/10/14/016	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Electronic information and data
26/8/3/10/14/017	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province:Mokolo Pools Report

Bold indicates this report

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This report is to be referred in bibliographies as:
Inkomati Reserve study:
Department of Water Affairs, South Africa. 2010. Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie-Sand and Crocodile Systems: Estimation and extrapolation of Ecological Water Requirements (EWRs) at selected hydronodes. Prepared by Rivers for Africa, Authored by Louw, MD and Birkhead, AL.RDM Report no 26/8/3/10/12/007.

Or
Mokolo Reserve study:
Department of Water Affairs, South Africa, 2010.Intermediate Reserve determination study for Selected Water Resources (Rivers and Groundwater) in the Mokolo Catchment. Estimation and extrapolation of EWRs at selected hydronodes.Prepared by Rivers for Africa, Authored by Louw, MD and Birkhead, AL. Report no: 26/8/3/10/14/007

NOTE: Any reference to the analysis of the results, the use of the maps, or the processes described in Chapter 9 must be referenced to Louw and Mallory, 2010 (see below). This work was not part of the TOR of these studies and the development work, generation of maps and time spent on undergoing the analysis were at the cost of Rivers for Africa and additional to the contract.

Inkomati Reserve study:
Louw, MD & Mallory, SM, 2010. Chapter 9. Analysis of Results in the Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie-Sand and Crocodile Systems: Estimation and extrapolation of EWRs at selected hydronodes.Prepared by Rivers for Africa, Authored by Louw, MD and Birkhead, AL for the Department of Water Affairs, 2010.RDMReport no 26/8/3/10/12/00.

Or
Mokolo Reserve study:
Louw, MD & Mallory, SM, 2010. Chapter 9. Analysis of Results in Intermediate Reserve determination study for Selected Water Resources (Rivers and Groundwater) in the Mokolo Catchment. Estimation and extrapolation of EWRs at selected hydronodes. Prepared by Rivers for Africa, Authored by Louw, MD and Birkhead, ALfor Department of Water Affairs, 2010. Report no: 26/8/3/10/14/007.

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The Desktop Reserve model adjustments for hydronodes in the Sabie, Crocodile and Mokolo River catchments were performed by D Birkhead, D Louw, J Mackenzie, A Desai and M Uys.

Dr CJ Kleynhans developed and ran the models to determine the biophysical similarity of sites and predict the indicator fish guilds.

Stephen Mallory and Delana Louw developed the methods to present the results based on the yield modelling.

EXECUTIVE SUMMARY

INTRODUCTION

A comprehensive EWR study has been undertaken for the Mokolo, Crocodile and Sabie River systems in support of strategic, national and catchment development. A comprehensive Reserve study assesses EWRs at EWR sites that are usually situated on the main rivers and large tributaries. For the purpose of, amongst others, Compulsory Licensing and general licensing, Reserves have to be determined at many points (hydronodes) in the catchment. EWR sites to at each of these nodes where EWRs are determined at a comprehensive level will become time consuming and therefore costly.

The objective of this task is to provide an estimate which will be of higher confidence than the Desktop Reserve Model at every hydronode in the Sabie, Crocodile and Mokolo systems (the Komati information has already been supplied through a WRC/DWAF research project). The report therefore deals with the extrapolation/estimation approach, methods and results.

APPROACH

Extrapolation consists of determining which sites are sufficiently similar to the comprehensive EWR sites in terms of biophysical similarity as well indicator guilds used for setting EWRs; and deriving the EWRs for these sites using the comprehensive EWR results at the EWR sites.

Estimation consists of a process to estimate the EWRs at each hydronode for the Recommended Ecological Category (REC) (using the information generated as part of the Desktop EcoClassification (Kleynhans & Louw, 2007). This estimation will entail the prediction of indicator species at various hydronodes, and the determination of the EWRs at these hydronodes using a higher confidence method than the Desktop Ecological Reserve Model.

The decision-making process to determine whether to estimate or extrapolate is summarised in the flow diagram below (Figure 1).

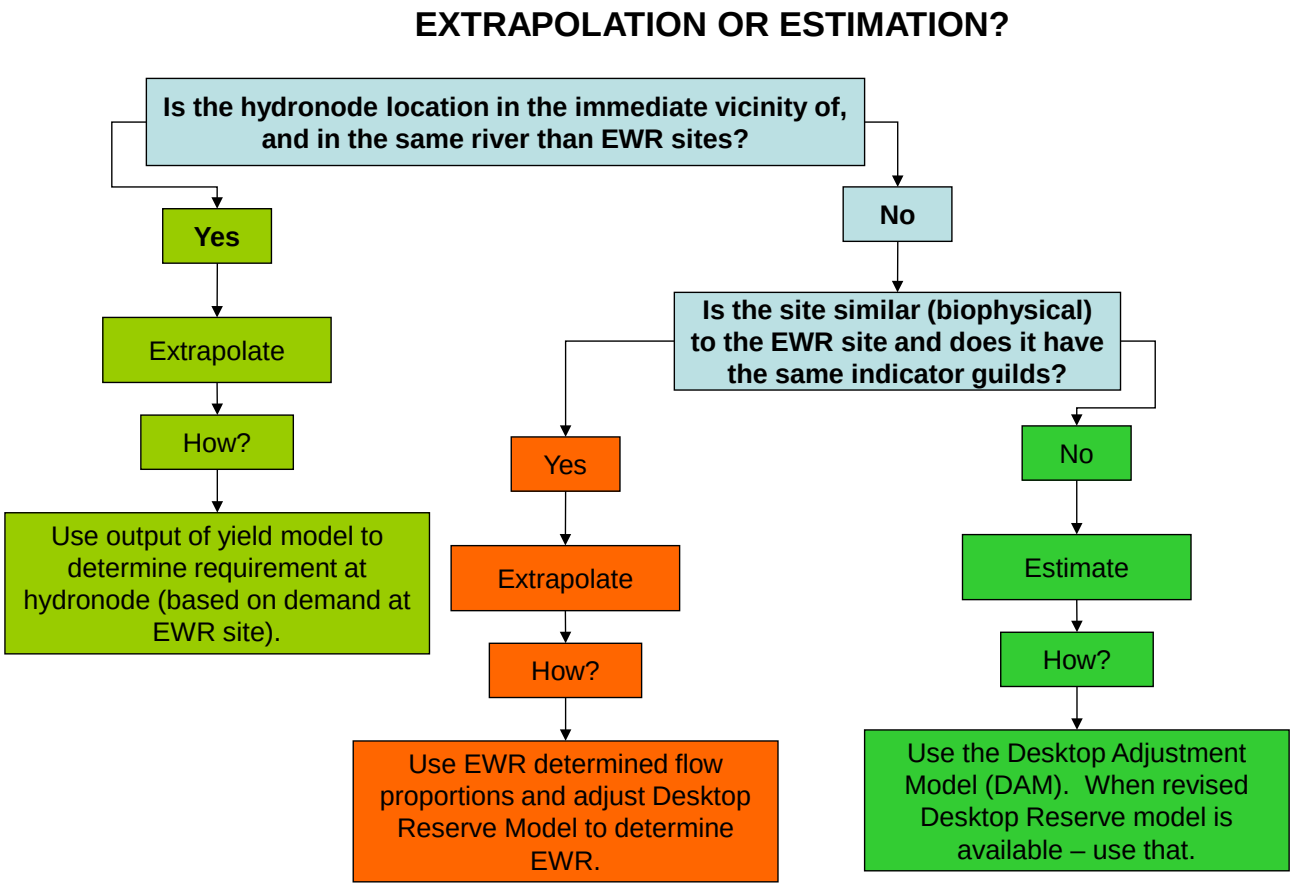

Figure 1: Flow diagram showing when it is appropriate to extrapolate or when estimation is required.

HYDRONODES AND DATABASE

Hydronodes are points on a map which represents a catchment, usually at the quinary scale. These points were provided and were included in an Excel database. Additional points were also provided in the database, the so-called known fish sites. This inclusion was required as the database was finally used to compare the known fish sites with hydronodes to derive the indicator fish guild for which the EWR must be set. For each point in the database, a range of biophysical information was provided to characterise the nodes and fish sites.

PREDICTION OF INDICATOR FISH GUILDS

Conceptually the prediction approach is based on the physical similarity between sites were fish information is available and hydronodes without fish information. If sites are physically similar to a high degree (many variables the same), then the assumption can be made that the same indicator fish guild would be present at both sites.

The indicator fish guilds of the Mokolo, Crocodile and Sabie River Systems are provided in excel format as part of the electronic information (RDM Report no (26/8/3/10/14/016 and 26/8/3/10/12/016)). This work was undertaken by CJ Kleynhans (DWA, RQS).

CALIBRATION SITES USED FOR EWR ESTIMATION

Various EWR sites (Rapid Level III, Intermediate and Comprehensive) were used to develop an EWR estimation method for hydronodes where no hydraulic data existed. These sites focussed on smaller rivers (to add to the database which is based on comprehensive determinations focussing on large rivers) in the Mokolo, Komati, Crocodile, Sabie and Upper Vaal catchments.

EWR ESTIMATION METHOD

The EWR data for the sites in the above table were provided (for the comprehensive level sites) from the Reserve studies. These results are for specific Ecological Categories (ECs) (may include the Present Ecological State (PES), Recommended Ecological Category (REC) and/or the Alternative Ecological Category (AEC)), specified separately for fish and macroinvertebrates. For the Rapid Level III sites (Komati, Sabie, Crocodile, Mokolo and upper Vaal River catchments), the Fish Flow Habitat Assessment (FFHA) model (developed by Dr C.J. Kleynhans) was used for estimating the EWRs (the model was modified for application to macroinvertebrates). The FFHA model provides a consistent procedure for estimating EWRs (at the Rapid Level III and higher) and gives requirements for the A to D range of Ecological Categories (ECs).

The EWR data were entered into an Excel data base for processing, together with the tabulated (modelled) hydraulic information (or lookup tables) for the site cross-sections. Code was written in Visual Basic Applications (VBA) to compile EWR and hydraulic data as a function of ecological and hydrological parameters. The ecological information included the indicator fish guild and macroinvertebrate taxa, and the hydrological information included the season and percentage (time) exceedance of maintenance and drought conditions on the flow duration table (FDT).

For each of the four fish guilds (Small Semi-Rheophilic (SSR), Large Semi-Rheophilic (LSR), Small Rheophilic (SR) and Large Rheophilic (LR), and a single macro-invertebrate taxa (flow dependant cobble dwelling (FDCD)), there were three variables to consider. These included hydrological season (wet or dry), percentage point on the FDT (the points denoting maintenance and drought conditions) and EC (B, C or D - the FFHA model considered an A to be natural). Thirty-six data sets for fish and 12 for macroinvertebrates were used.

For each of these 48 data sets, the EWR requirement (from the Comprehensive and Rapid Level III (FFHA model) studies), hydrological (natural flow) and relevant hydraulic information (wetted channel width, maximum depth, average depth and average velocity) were compiled. Following from the findings of a previous EWR estimation study (Birkhead, 2008), the data was analysed to assess whether the EWR could be expressed as a constant unit-width value (i.e. a constant discharge per unit (wetted) width of channel).

A regression procedure was coded (using VBA) to automate the curve-fitting for the 48 data sets, and allowed the regressions to be easily re-determined with changes to the data sets.

APPLICATION OF ESTIMATION TO HYDRONODES

A procedure for applying the EWR estimation method as a Desktop Adjustment Method (DAM - refer to Birkhead, 2008) was developed using MS-Excel and VBA. The procedure consists of the various steps which were used to provide EWR estimates for 66, 85 and 37 hydronodes in the

Sabie, Crocodile and Mokolo River catchments, respectively. The above spreadsheet and data are provided in the electronic data (RDM Report no 26/8/3/10/12/016 and 26/8/3/10/14/016) as well as the .rul and .tab tables.

ANALYSIS OF THE RESULTS: DETERMINATION OF THE DEGREE TO WHICH THE RESERVE IS BEING MET UNDER CURRENT OPERATING RULES

An analysis was undertaken to determine whether the Ecological Reserve is being met under current operating rules and, if not, to what degree it was not being met. The results were rated (0 – 5) and these results were used to accordingly shade the different quaternary catchments. The shading is described below and the maps and conclusions are provided below. Tables with the results are provided in the report, chapter 9.

RED (5): Insufficient water is available to meet the Ecological Reserve under present conditions.
No licenses that will decrease flow should be considered as the Reserve is currently not being met. This means that there will be no yield available for additional users. Even if the Reserve is a low confidence Reserve based on an estimate, it is unlikely that revision will change the situation sufficiently that the Reserve will be met, AND that there will be yield available. It must be considered however that these are broad estimates and that there is uncertainty in the hydrology as well as the EWR estimates. Therefore, as a first check to confirm the red evaluation, the confidence in the hydrology and the reasons why the Reserve is not being met should be checked. E.g., it is often the case that the hydrological modelling results in an underestimate of hydrology in areas high up in the catchment such as first order stream. In those cases, the estimated EWR is often higher than the modelled hydrology and shows an Ecological Reserve deficit when that is not really the case. All results must therefore be treated with caution and prior to decisions being made on these ratings, the specific situation should be evaluated and the results unpacked. It must also be noted that the application of the Desktop Level EcoClassification to derive at the REC is only done for a specific river within the catchment under consideration. A future development may be applicable for a tributary of the river that was assessed and the EC and specific EWR may well be very different.
ORANGE (4): There is a high likelihood that there is not enough water to meet the REC under present conditions.
This means that there is a high likelihood that there will be no yield available for additional users. See section in red above.
PALE ORANGE (3): There is a moderate likelihood that there is not enough water to meet the REC.
Assess the most cost-effective steps needed to investigate the situation. Confirmation of the REC as part of a Rapid III should be sufficient as a first step. If the EcoClassification results have changed, the level of Reserve such as this estimate might not be appropriate. Once the Reserve has been refined (if necessary), then the yield analysis must be recalculated.
CREAM (2): There is a low likelihood that there is not enough water to meet the REC.
Assess the most cost-effective steps to take to investigate the situation. Confirmation of the REC

through scoping should be sufficient as a first step. A Desktop assessment of the flows if the scoping assessment of the REC results in a different REC changes should be sufficient for a revision of the water balance. Even if the Reserve is infrequently not met, this still means that there could be yield available in this system. Refer to 9.2 to determine whether yield will be available and the scale of the available yield.
WHITE (1): There is a high likelihood that there is sufficient water in the system to meet the REC.
This does not necessarily mean that there is yield available for additional users. Refer to section 9.2 to determine whether yield is available and the scale of available yield.

Conclusions: Mokolo

The EWRs for the REC cannot be met currently are concentrated in the upper Mokolo. This is due to the many farm dams, as well as illegal water use. The other area of concern is in the lower Sterkstroom where there is intensive irrigation. The red area indicated in the Tambotie system is highly likely a result of inaccurate hydrology as the river is seasonal and there are very little developments present in the Tambotie system. It is therefore unlikely that the Reserve will not be met.

Taking into account the problems in the Sterkstroom currently, steps should be taken to ensure the protection of this resource. The Sterkstroom is a strong perennial tributary and is currently one of the only refuges for the biota in the Mokolo River when the Mokolo River stops flowing. These refugia require protection as any further use that can impact on the refugia; will result in the Mokolo River PES degrading, even without any flow changes in the Mokolo.

Conclusions: Crocodile

The Crocodile catchment does not show many areas where the Reserve is currently not being met. However, it MUST be remembered that the REC in the main Crocodile River downstream of Kwena Dam has not been signed off due to the socio-economic impacts. This situation (i.e. that the REC is not available) is not illustrated as the main Crocodile has been modelled on the basis that the present operation and hydrology will be signed off to maintain the PES.

Conclusions: Sabie-Sand

There are very few stressed areas in this catchment. The red areas in the upper Sand are probably a result of the modelled hydrology inaccurately reflecting very low to zero flows. **It must be noted that there is low confidence in the Sand hydrology and this should be considered when decisions are being made. It must furthermore be noted that the Sellick-rule[1] is currently NOT in place and the evaluation of the Sand River would show mostly a red rating if this rule is not applied.**

[1]The Sellick Rule refers to the operational scenario 1 which was evaluated in Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Operation scenarios and consequences report Volume 1 report number 26/8/3/10/12/011 and recommended as the accepted scenarios.

MAPS

ANALYSIS OF THE RESULTS: AVAILABLE YIELD IN CATCHMENTS WHERE THE RESERVE IS CURRENTLY BEING MET

The above information illustrated in the so-called 'red' map does not indicate whether there is spare yield available for future development in the areas where the Reserve is being met (white shaded and light cream shaded areas rated zero or one). An analysis was undertaken to determine the available yield in the study areas (Mokolo, Crocodile and Sabie-Sand Rivers. Results from tables (Chapter 9) are illustrated in Figures 2, 3 and 4. The colour grading used on the maps is provided below.

Grey: Information already available (through the assessment to determine whether the Reserve is currently being met) that no yield available and the EWR cannot be met under current operation.
The grey catchments reflect all the catchments that were rated in section 9.1 from a 1.1 to 5. I.e., the Ecological Reserve cannot be met under current circumstances which automatically indicate that there is no yield available. If licenses and further developments are considered in these areas, appropriate work (such as described below) should be undertaken to confirm the degree to which the Reserve is not being met as well as to whether the proposed development will have an impact.
No yield available (5)
No licenses that will decrease flow should be considered. If however, further confirmation is required, more detailed studies are required to confirm these results. The first step should be to confirm the REC in the catchments where the REC has been derived from the Desktop EcoClassification. This is necessary as this is usually a low confidence estimate, and if the EC is found (after more detailed investigation) to be lower than the EC used in this yield modelling, then the EWR will be lower. The water balance will then have to be recalculated.
Very low yield (4)
As the likelihood of no water being available is high, licences should be considered only for special cases. If further confirmation is required, follow the same process as above.
Low yield (3)
Assess the most cost-effective steps to investigate the situation if development or licences are required. It is likely that a Level 3 EcoClassification and a Rapid III Reserve assessment might be sufficient. Then check water balance to see whether yield increases if the Rapid III Reserve results are less than the estimation Reserve used for this analysis.
Moderate yield (2)
Assess the most cost-effective steps to investigate the situation if development or licences are required. It is likely that a Level 3 EcoClassification and a Rapid III Reserve assessment might be sufficient. Then check water balance to see whether yield increases if the Rapid III Reserve results are less than the estimation Reserve used for this analysis.
High yield (1)
Assess the most cost-effective steps to take to investigate the situation. Confirmation of the REC through scoping should be sufficient as a first step. If the EC changes, the appropriate estimation results for the changed EC (provided electronically) should be sufficient to use within a revision of the water balance.
Very high yield (0)
See steps described in Figure 5

Conclusions: Mokolo

As the EWR on the main river has been signed off as the present flows, there is no available yield in the system for additional use in terms of abstraction. This is a very stressed catchment and the results in terms of the yield, illustrates this.

Conclusions: Crocodile

As the EWR at the main river has been signed off as the present flows, there will be no available yield in the system for future development regarding abstraction. This is a very stressed catchment and potentially over-allocated in its lower reaches so the lack of available yield is not surprising.

Conclusions: Sabie-Sand

Approximately 30% of the catchment includes rivers that more or less lie completely within the Kruger National Park. These rivers were not evaluated and were shaded gray as available yield is not applicable within these areas (see grey areas north of the Sand and Sabie Rivers within the KNP)

The REC is available in the Sabie River under current operation. However, limited to no spare yield is available in the Sabie River downstream from EWR 2. Therefore, even if the map illustrates that there is yield available upstream of EWR 2, any development in that area could result in the REC not being met in the lower Sabie River.

It must be noted that any results that is based on hydrology in the Sand River is inherently of low confidence during to the lack of gauging stations in the system. Local use and mismanagement of the current infrastructure has resulted in heavy river losses and problems in the lower Sand River. The signed off Reserve will be on the basis that Scenario 1 (Sellick-Rule) (26/8/3/10/12/011) will be implemented. This will result in the Ecological Reserve being available. The available yield calculations are based on this scenario being implemented. Therefore, apart from the additional yield which will be available once this rule is implemented, no further additional yield will be available.

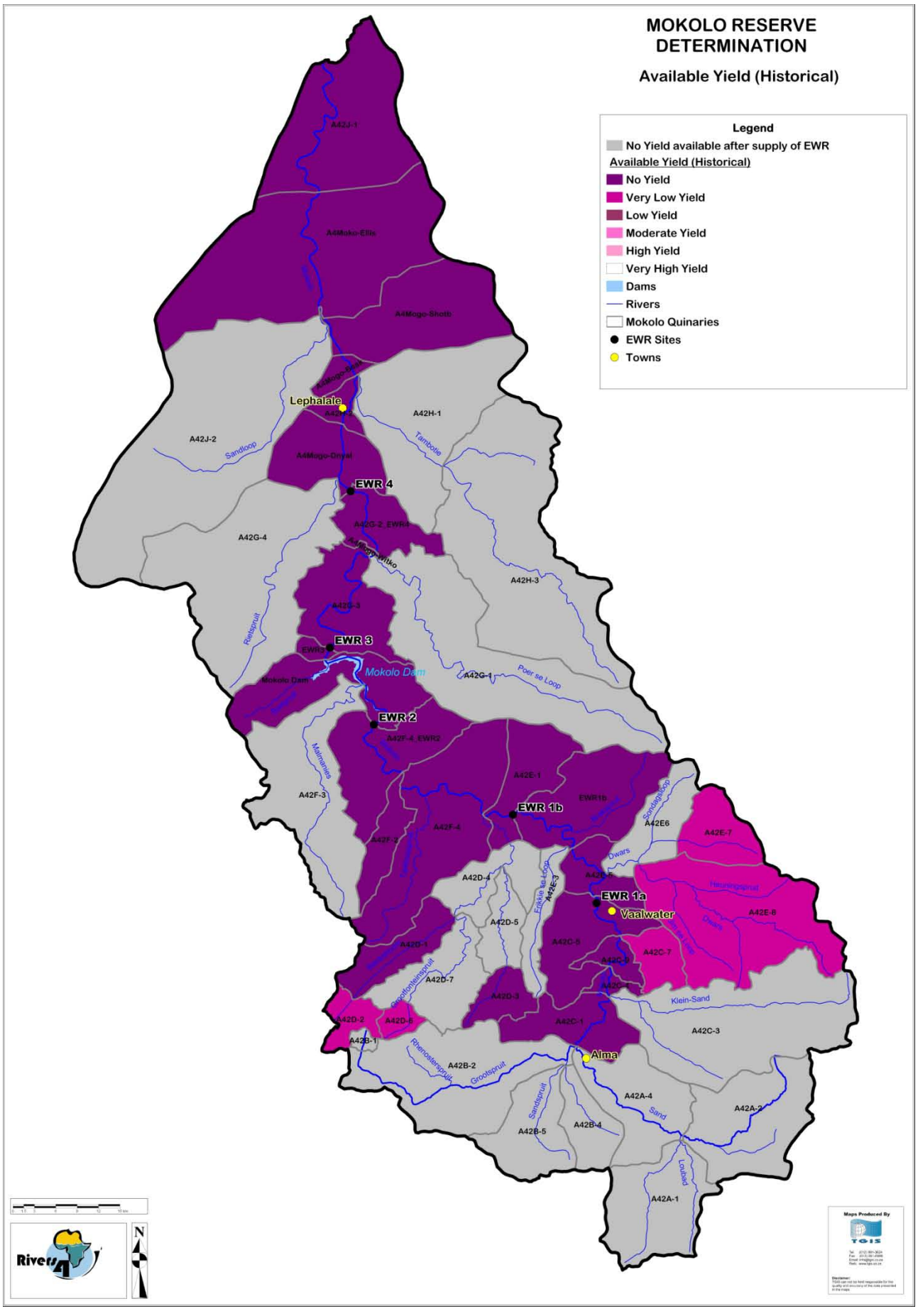

Figure 2: Mokolo available yield map

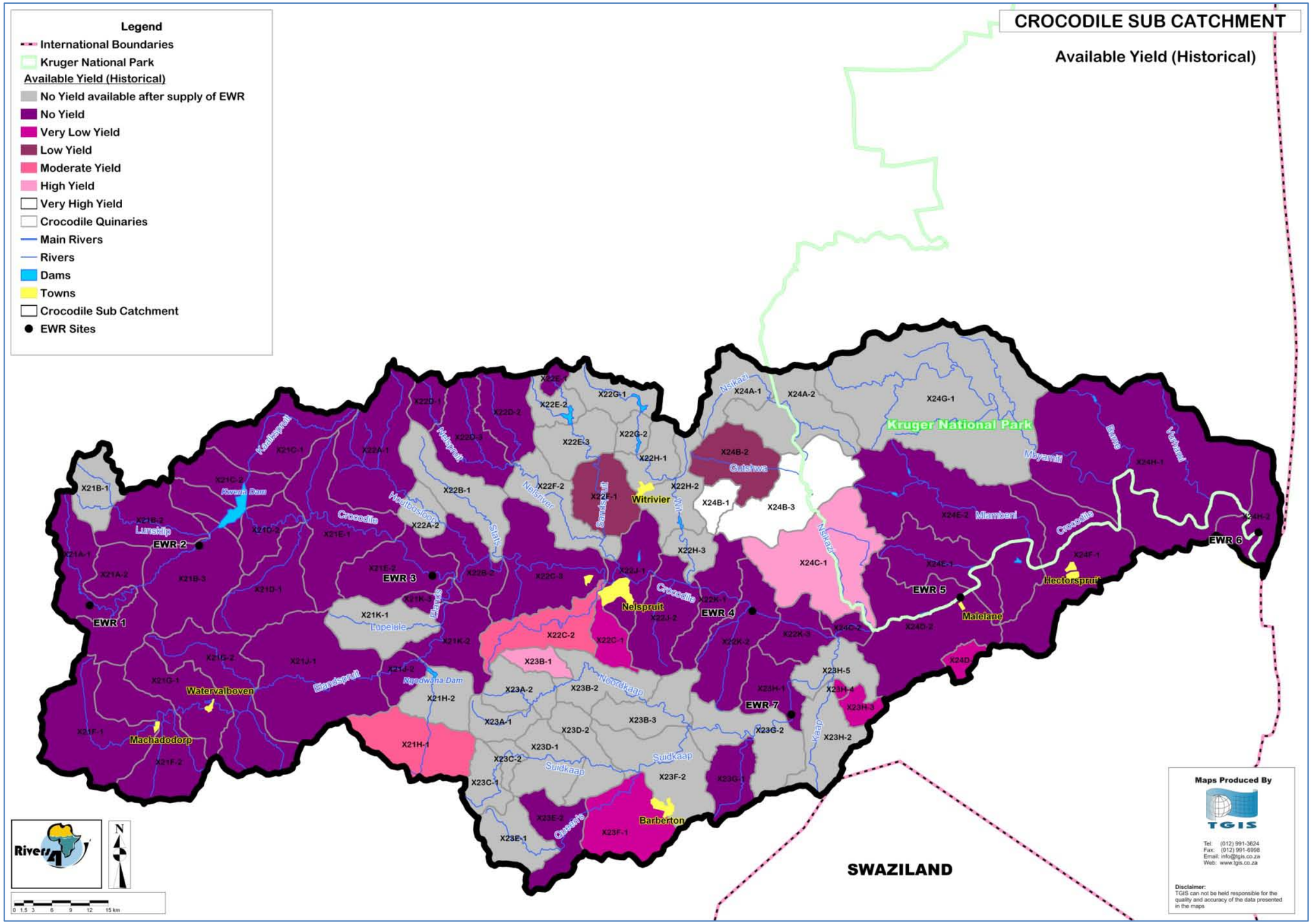

Figure 3: Crocodile available yield map

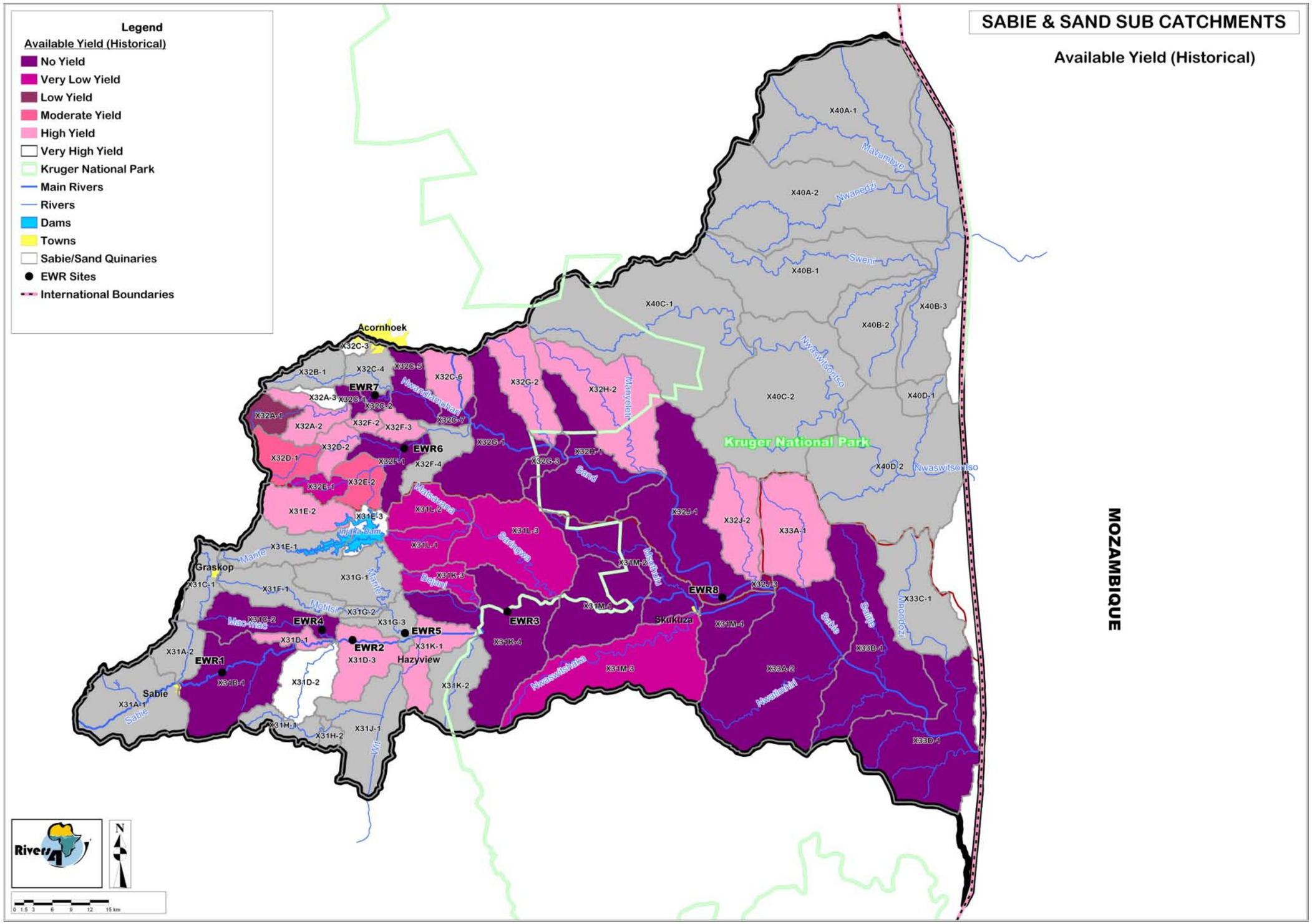

Figure 4: Sabie-Sand available yield map

GUIDANCE ON THE USE AND INTERPRETATION OF THE EWR AVAILABILITY AND AVAILABLE YIELD MAPS

Both maps contain information at various levels of confidences and must therefore be used with care when further development is considered. This information can be an extremely useful aid when considering further development and water use in the catchment. However, all the other information available within these Reserve study results should be considered in combination with this yield analysis.

A process summarised in a flow diagram that can be used as a guideline for decision-making is provided.

GUIDELINE: USE OF EWR AVAILABILITY & AVAILABLE YIELD MAPS IN PLANNING & LICENSING (applicable for estimated EWRs only)

EWR availability map – Red map Available yield map – Purple map
Point of interst (POI) – POI refers to the point or area in the catchment where information is required for, eg licensing

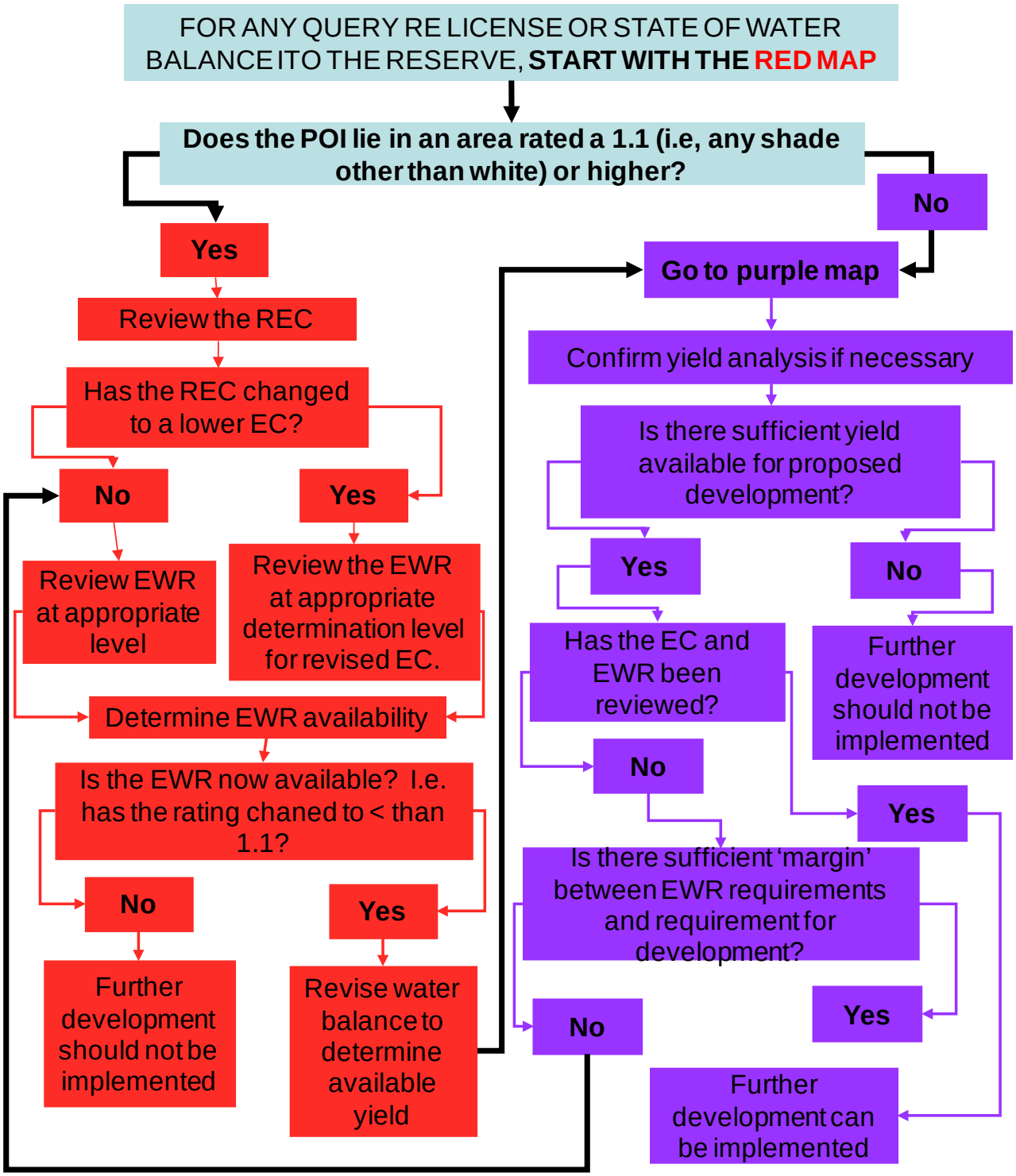

Figure 5: Flow Diagram That Can Be Used As A Guideline For Decision-Making

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ABBREVIATIONS, ACRONYMS AND GLOSSARY OF TERMS

AEC	Alternative Ecological Category
Alt	Altitude
DAM	Desktop Adjustment Method
DRM	Desktop Reserve Model
Dry	Driest month
EC	Ecological Category
DWA	Department Water Affairs
DWAF	Department Water Affairs and Forestry
ECOR	EcoRegion
EWR/EFR	Ecological Water Recommendations/Environmental Flow Recommendations. Also referred to as Instream Flow Requirements (IFR)
FDCD	Flow Dependant Cobble Dwelling
FDT	Flow Duration Table
FFHA	Fish Flow Habitat Assessment
FROC	Fish frequency of occurrence
GEOM	Geomorphic
HabSpecs	Habitat specifications
Ind	Indicator
Invert	Macroinvertebrates
LL	Large Limnophilic
LR	Large Rheophilics
LSR	Large Semi-Rheophilics
Maint	Maintenance
MAR	Mean Annual Runoff
ML	Medium Limnophilic
MS	Microsoft
MSR	Medium Semi-Rheophilics
Mm^3	Million cubic metres
m^3/a	Cubic metres per annum
m^3/s	Cubic metres per second
nMAR	Natural mean annual runoff
nr	number
PES	Present Ecological State
Q	discharge
Qnat	Natural discharge
Quat	Quaternary catchment
REC	Recommended Ecological Category
RDM	Resources Directed Measures
RHP	River health programme
RQS	Resources quality services
rul	Reserve Desktop model EWR results in FDT (or rule) format
SL	Small Limnophilic
SR	Small Rheophilics
SSR	Small Semi-Rheophilics
tab	Reserve Desktop model EWR results in table format
VBA	Visual Basic Applications
W	Wetted channel width (m)
WAAS	Water Availability Assessment Study

WAR	Water Allocation Reform
Wet	Wetted month
WRC	Water Research Commission
% pt	percentage point (time equalled or exceeded)

1. BACKGROUND

Various studies led and contributed to a current Water Research Commission (WRC) study, K5/1856: DEVELOPMENT OF A REVISED DESKTOP RESERVE ESTIMATION MODEL. In essence, the purpose of this WRC study was to revise the Desktop Reserve Model (DRM) (Hughes & Hannart, 2003). This model can then be applied on a catchment wide basis to supply Reserve estimates to various nodes. As the Revised Desktop Ecological Reserve model will only be available in 2011, a process had to be determined in the interim to estimate Reserves to various nodes that were of higher confidence than the existing DRM. The background to all the preceding studies is provided below.

1.1 2007 WRC AND DWAKOMATI STUDY

The following is an extract of Kleynhans *et al.* (2008): Principles of a process to estimate and/or extrapolate environmental flow requirements (Report produced for the Water Research Commission, South Africa by Water for Africa (Pty) Ltd. KV 210/08).

The Department of Water Affairs and Forestry (DWAF) has announced its Water Allocation Reform (WAR) programme as an important component of the roll out of the National Water Act of 1998. The main focus of the WAR programme is to reconcile existing and future water demands with its availability. Water resource planning requires recognition of the Ecological Reserve, and estimates of Ecological Water Requirements (EWRs) are therefore required.

Ecological Reserve (quantity) determinations at the Comprehensive and Intermediate levels have generally been determined for sites located along main-stem rivers and major tributaries, where water resources are often in high demand. Frequently, no EWR information is available for the smaller tributaries. The establishment of sites to provide EWRs at all locations of interest necessary for water resource planning is not pragmatic and beyond available resources. There is therefore a need to develop a cost-effective and efficient method for estimating EWRs for numerous river locations with reasonable levels of accuracy. This requirement is necessary to support the WAR initiative and to better evaluate individual water use licence applications.

The primary objective of this project was to develop a procedure for extrapolating EWR low-flow result from Reserve sites to additional locations (termed hydronodes) that have a degree of ecologically similarity. The extrapolation procedure refers to hydrological extrapolation by adjusting default parameters in the Desktop Reserve model, and is the current approach for estimating EWRs for additional river locations. The Desktop Reserve model is based on the results of previous EWR assessments, and therefore almost entirely on EWR-hydrological relationships derived for rivers with substantial runoff. With the exception of Rapid level III estimates, little cognisance is given as to whether hydrological extrapolation is ecologically justified. The "extrapolation" concept was extended to the "estimation" concept at an early stage of the study. The reason for this is that an "estimation" approach does not limit the method to the use of existing Ecological Reserve results, but rather allows for the development of a method that explicitly incorporates biological information, flow preferences for the biota present, and availability of hydraulic habitat.

A procedure has been developed for establishing the extent to which different river locations have physical similarity. Based on this, the assumption is that physical similarity implies similar fish

guilds under natural conditions. The identification of likely indicator species may subsequently be used for informing ecological flow requirements at additional (un-sampled) river locations.

Estimation of EWRs requires the definition of habitat preferences or requirements. These have been provided through habitat specifications (or HabSpecs), which are numerical values for a combination of hydraulic parameters and flow-classes that define required hydraulic habitat and hence flows for "groups" of biota that exploit environmental resources in a similar way (referred to as guilds for fish and communities for invertebrates). Habitat specifications are a function of hydrological variability (e.g. drought, maintenance and season) and Ecological Category (EC) for the river. In this study, HabSpecs were determined for two fish guilds: small rheophilic fish and large semi-rheophilic fish and a single community of invertebrates - cobble-dwelling rheophilics. Habitat specifications were computed using an optimisation method based primarily on the results of previous EWR studies. This effectively provides "calibrated" numerical rules that are based on the collective knowledge and understanding of river ecologists involved in previous ecological flow assessments. Habitat specifications provide a simple and consistent rule-based approach for estimating EWRs where hydraulic characterisation of flow conditions is available - presently at Rapid level III assessments and higher.

The HabSpecs indicate that hydraulic habitat is more sensitive to changes in low flows in smaller rivers (MAR <–30 Mm^3/a) than larger rivers, with the relevant fish guilds and invertebrate communities used, which supported by studies in the international literature.

The Nkomati Water Availability Assessment Study (WAAS) formed the basis for application of the methods (site similarity and EWR estimation) developed within this study. Overall, the HabSpec predicted ecological flows for 10 tributary sites were considered to provide more reasonable estimates, compared with Desktop model generated values, for the smaller streams with lower MARs (below – 30 Mm^3/a) and small rheophilic fish. Desktop model estimates were considered to provide increasing underestimates of EWRs with reducing stream size below approximately 30 Mm^3/a. For sites with mean annual runoff in excess of approximately 30 Mm^3/a, Desktop model estimates were considered reasonable recommendations for ecological low-flows. Since the HabSpec estimation method is independent of hydrology, estimates should be confined to between Desktop and natural (albeit modelled) flows. For the sensitive rheophilic biota considered, the application of HabSpecs for EWR estimation indicates that higher proportions of natural flows are required with reducing stream size and during the drier season.

The HabSpec generated low-flows for the selected (tributary) river sites were expressed as a function of the inundated low-flow channel width, and unit-width discharges were found to be remarkably constant. These flows were used to define the minimum seasonal drought and maintenance discharges required to achieve the recommended EC for the sensitive rheophilic biota. It needs to be emphasized that the unit-width EWR results from this study are applicable to specific fish guilds and invertebrate communities and hydrological characteristics of the Nkomati River catchment. Further study is required for the reasoning behind this (unit width) finding, as well as the development of more generalised and tested procedures for estimating EWRs for different biota and geomorphologies. This is taking place during concurrent research projects funded by the Water Research Commission as well as DWAF Reserve studies.

1.2 K8/795: COLLATION AND SYNTHESIS OF HYDRAULIC INFORMATION FROM ENVIRONMENTAL FLOW REQUIREMENT STUDIES

The above analysis was undertaken by Birkhead and Desai. The following is an extract of the draft WRC report.

Large quantities of river hydraulic information have been collected over the past decade in the course of undertaking Environmental Flow Requirement (EFR) assessments (including Instream Flow Requirements), and more recently, Ecological Reserve studies. The clients involved have been mainly the Department of Water Affairs (South Africa), as well as private organisations and government departments in neighboring countries (e.g. Swaziland, Lesotho and Mocambique). These data are in electronic format and hardcopies in the form of project reports, electronic files (workbook data), and total approximately 46 projects, 218 sites and 821 cross-sections.

Kleynhans et al. (2008) discuss the principles of a process to estimate and/or extrapolate Environmental Flow Requirements. The estimation component requires the prediction, at the desktop level, of the (ecologically relevant) low-flow inundated channel width. The (current) Water Research Commission (WRC) project (K5/1856), requires the development of a hydraulics sub-model for estimating hydraulic habitat. This information will be used for the WRC project but was also extensively used in the determinations of the approaches used in the interim to estimate Ecological Reserves at various nodes.

The objectives of this project have been to:

- Collate available hydraulic and relevant site-related information from previous (mainly) EFR studies, and
- Determine whether the data display empirical relationships.

1.3 CURRENT WRC STUDY (K5/1856)

The Desktop Reserve model (Hughes & Hannart, 2003) was developed to enable quick estimates to be made of the Ecological Reserve for rivers at any site within the country. The Reserve estimates are currently based on a three stage process and are strongly associated with the concepts of the Building Block Methodology. The first stage is to determine the annual volumes of the low flow maintenance and drought requirements, as well as the maintenance high flow requirements as percentages of the mean annual runoff.

The second stage is to translate the annual requirements into seasonal distributions. This is based on the seasonal distributions of the reference hydrology time series. The third stage is to combine the monthly maintenance and drought flow Reserve estimates into complete tables (or curves) of assurance rules (equivalent to flow duration curves). The shapes of the assurance rule curves are determined in the model from the values of the maintenance and drought flow estimates as well as the flow duration curve characteristics of the reference flows.

It is clear, therefore, that the existing Desktop Reserve model is very dependent upon the characteristics of the reference hydrology used and that it largely ignores the advances in understanding of habitat-flow-ecology relationships that have emerged in the last 5 years or so. It also ignores regional differences in these relationships that are related to regional differences in the natural biotic assemblages and ecological functioning, as well as differences in the

relationships between flow, hydraulics and habitat. The latter are assumed to vary across different geomorphological zones.

The pressures on DWA to generate Reserve estimates are well known and partly related to the Water Allocation Reform (WAR) program and the need to give effect to the National Water Act. The Desktop Reserve model has been demonstrated to be an appropriate analysis tool, whether used with default parameters or after adjustment through a Rapid Reserve assessment. However, the uncertainty associated with the outputs from the Desktop Reserve model remains a major concern, especially if these outputs are ever likely to be challenged in a court of law.

Improvements to the desktop model require the incorporation of more of our understanding of the ecological processes into the model so that it is not only driven by hydrology.

The ecological component of the WRC study follows directly on from the existing project (K8/657) where the major focus has been to establish the principles and concepts of ecological similarity of sites and using filter models to identify the indicator species at approximately 800 fish sites in the country. The broad principles to specify habitat requirements (linked to the indicator species/groups, geomorphological zones and river width/size) were determined and tested on the cobble bed systems in the Komati River.

2. INTRODUCTION

A comprehensive EWR study has been undertaken for the Mokolo, Crocodile and Sabie River systems in support of strategic, national and catchment development. A comprehensive Reserve study assesses EWRs at EWR sites that are usually situated on the main rivers and large tributaries. For the purpose of, amongst others, Compulsory Licensing and general licensing, Reserves have to be determined at many points (hydronodes) in the catchment. EWR sites to at each of these nodes where EWRs are determined at a comprehensive level will become time consuming and therefore costly.

.

The objective of this task is to provide an estimate which will be of higher confidence than the Desktop Reserve Model at every hydronode in the Sabie, Crocodile and Mokolo systems (the Komati information has already been supplied through a WRC/DWAF research project). The report therefore deals with the extrapolation/estimation approach, methods and results.

The Desktop Reserve Model is being refined as part of the current WRC project K5/1856. This should give higher confidence answers than the current Desktop Reserve Model but will highly likely only be finalised in 2011. A prototype approach, applied for this study and described in the report, is however available that can be used in the interim. This process is further refined from the approach used on the Komati River (Kleynhans *et al*, 2008).

2.1 TERMS OF REFERENCE OF THIS TASK

Determine estimated EWRs at selected hydronodes in the Sabie-Sand, Crocodile and Mokolo catchments.

2.2 APPROACH

The approach consisted of two processes, extrapolation and estimation.

Extrapolation consists of determining which sites are sufficiently similar to the comprehensive EWR sites in terms of biophysical similarity as well indicator guilds used for setting EWRs. The relevant EWR results are then hydrologically extrapolated to those points.

Estimation consists of the following:

- The collection of Rapid III level hydraulic information at selected sites in the catchments of the Sabie-Sand, Crocodile, Mokolo and upper Vaal Rivers.
- The analysis of the field data and provision of hydraulic characterisations for the sites in accordance with the procedures described by Birkhead (2010).
- Examining the EWR results for these (Rapid III) sites in conjunction with (Intermediate and Comprehensive level) flow requirements for the purpose of developing a simple method for estimating EWR at hydronodes in these catchments.
- Predicting the indicator fish guilds at each hydronode.
- Estimating the EWRs at each hydronode for the Recommended Ecological Category (REC) (using the information generated as part of the Desktop EcoClassification (Kleynhans & Louw, 2007).

Bullet 1 and 2 above are well documented in Birkhead (2010) and therefore no further explanations are provided.

The decision-making process to determine whether to estimate or extrapolate is summarised in Figure 2.1.

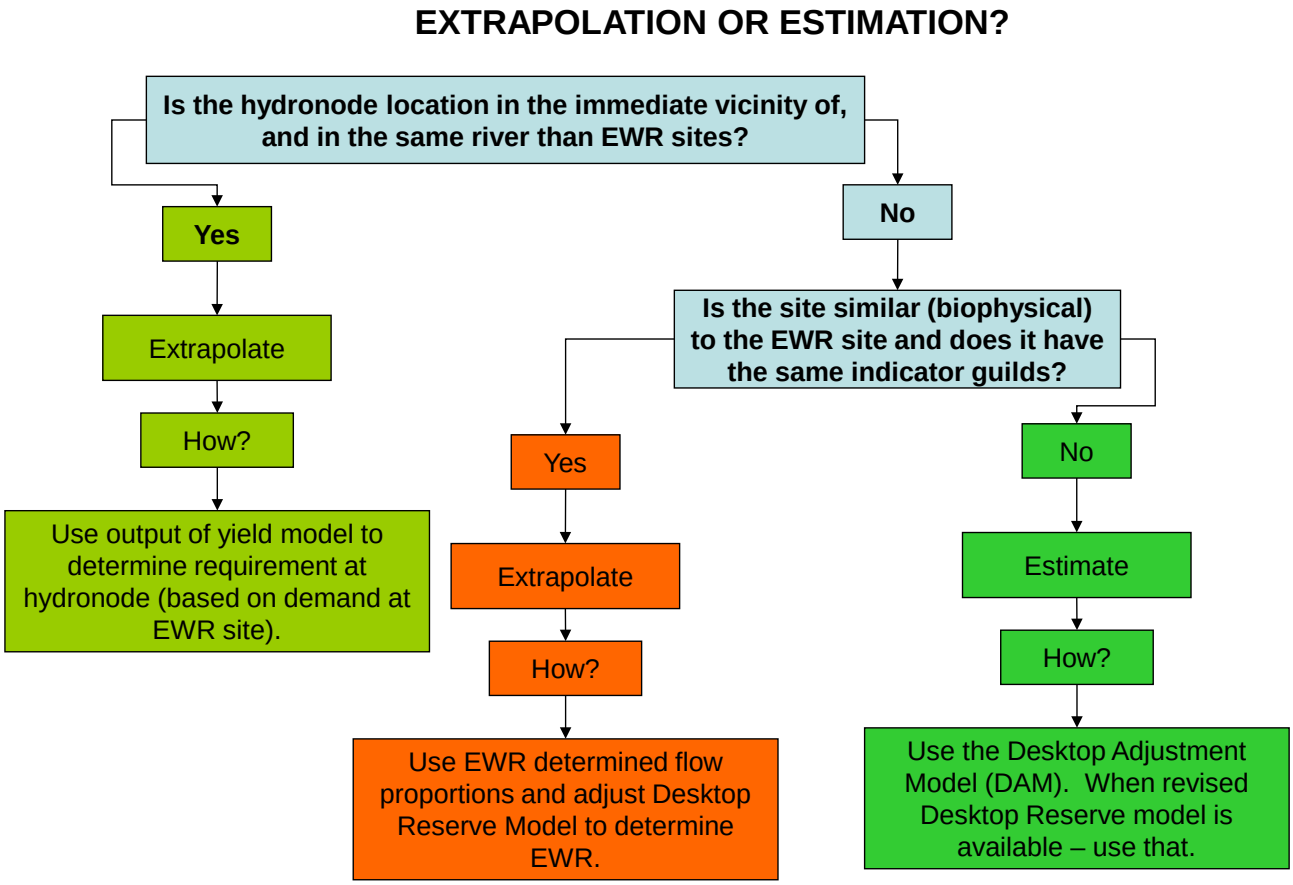


Figure 2.1 Flow diagram showing when it is appropriate to extrapolate or when estimation is required

2.3 PURPOSE OF THIS REPORT

The purpose of this report is to describe the approach and results of the extrapolation and estimation process applied to the Sabie, Crocodile and Mokolo River catchments.

The estimation of EWR requirements at hydronodes in the Komati River catchment is described in the Water Research Commission (WRC) Report of Kleynhans *et al.* (2008). This report should be consulted for background information.

3. HYDRONODES AND HYDRONODE DATA BASE: MOKOLO SYSTEM

The hydronodes were selected by WRP (DWAF, 2007) and the localities are illustrated in Figure 3.1.

A data base was set up in an Excel spreadsheet to characterise all the hydronodes. To aid in the determination of the prediction of indicator guilds, all other sites with 'known' fish information (Figure 3.2) were included in the data base. These 'known' fish sites consist of any sites where fish surveys have been undertaken and were extracted from:

- Reference Frequency of Occurrence of Fish species in South Africa (Kleynhans *et al.,* 2007a)
- Fish surveys undertaken as part of the current Reserve study at EWR sites and at Estimation Calibration (Figure 3.2) sites.

The data base is provided electronically (RDM Report no 26/8/3/10/14/016). The information that is provided in each column of the data base is described below. Note that reference to a site can mean an actual site or a node which represents a point on a map and which might not have been visited.

- ***Column A:*** SITE NAME: The final site name compiled after considering all the names allocated to the site (column B, C, E and F).
- ***Column B:*** HYDROLOGICAL NODE: Hydrological nodes as provided by the WRP study.
- ***Column C:*** EWR SITE: EWR sites listed according to their names within this study.
- ***Column D:*** PHOTOS?: This indicates whether photos exist of the sites. Photos with a code of MK 45 are available as electronic data (RDM Report no 26/8/3/10/14/016).
- ***Column E:*** RHP SITE: Sites that are National River Health Programme sites (so-called macro sites) are listed (Dallas, 2005) as well as provincial RHP sites.
- ***Column F:*** FISH INFORMATION SITES: The codes as provided in the FROC data base (Kleynhans *et al*., 2007) are provided as well as the EWR and Estimation Calibration sites. ***Column G:*** LATITUDE is provided in the decimal degree format.
- ***Column H***: LONGITUDE is provided in the decimal degree format
- ***Column I:*** QUAT: Refers to the quaternary catchment in which the site is situated.
- ***Column J:*** MAJOR RIVER: This refers to the major river into which the river flows where the site is located. E.g. a site located in the Mokolo will be represented by the Limpopo as the major river. A site/node located in the Rietspruit will be represented by the Mokolo as the major river. If any sites were located in the Limpopo, only the major river column will be completed.
- ***Column K:*** TRIBUTARY: This represents the river in which the site is located.
- ***Column L:*** ECOR: EcoRegion (Level 2) (Kleynhans *et al*., 2007b) in which the site is situated.
- ***Column M:*** GEOM ZONE: Geomorphic Zone (Rountree and Wadeson, 1999) in which the site is situated.
- ***Column N:*** ALT (m): Altitude obtained from Google Earth.
- ***Column O:*** Shreve: Shreve system to provide the stream order (Shreve, 1967)
- ***Column P:***Strahler: Strahler system to provide the stream order (Strahler 1952, 1957)

- ***Column Q:*** nMAR: Natural Mean Annual Runoff according to the modelled hydrology as supplied by WRP (and modified where required by IWR Water Resources) and IWR Water Resources.
- ***Column R:*** WIDTH: Estimated width of the channel (see Chapter 7)
- ***Column S:*** Comment: Provides additional information on where the site is located. E.g., it is often difficult to determine by means of the locality only whether a site is on the tributary or the main river when the site is near a confluence.
- ***Column T –AB:*** Information on the fish guilds that occur at the site.
- ***Column AC***: REC: Provides the Recommended Ecological Category as derived from the EIS from the Desktop EcoClassification (RDM Report no 26/8/3/10/12/002).
- ***Column AD:*** Hydroregion: Provides the hydroregion according to the Desktop Reserve Model.
- ***Column AE – CF:*** Information on fish species as copied from the FROC (Kleynhans *et al.*, 2007).

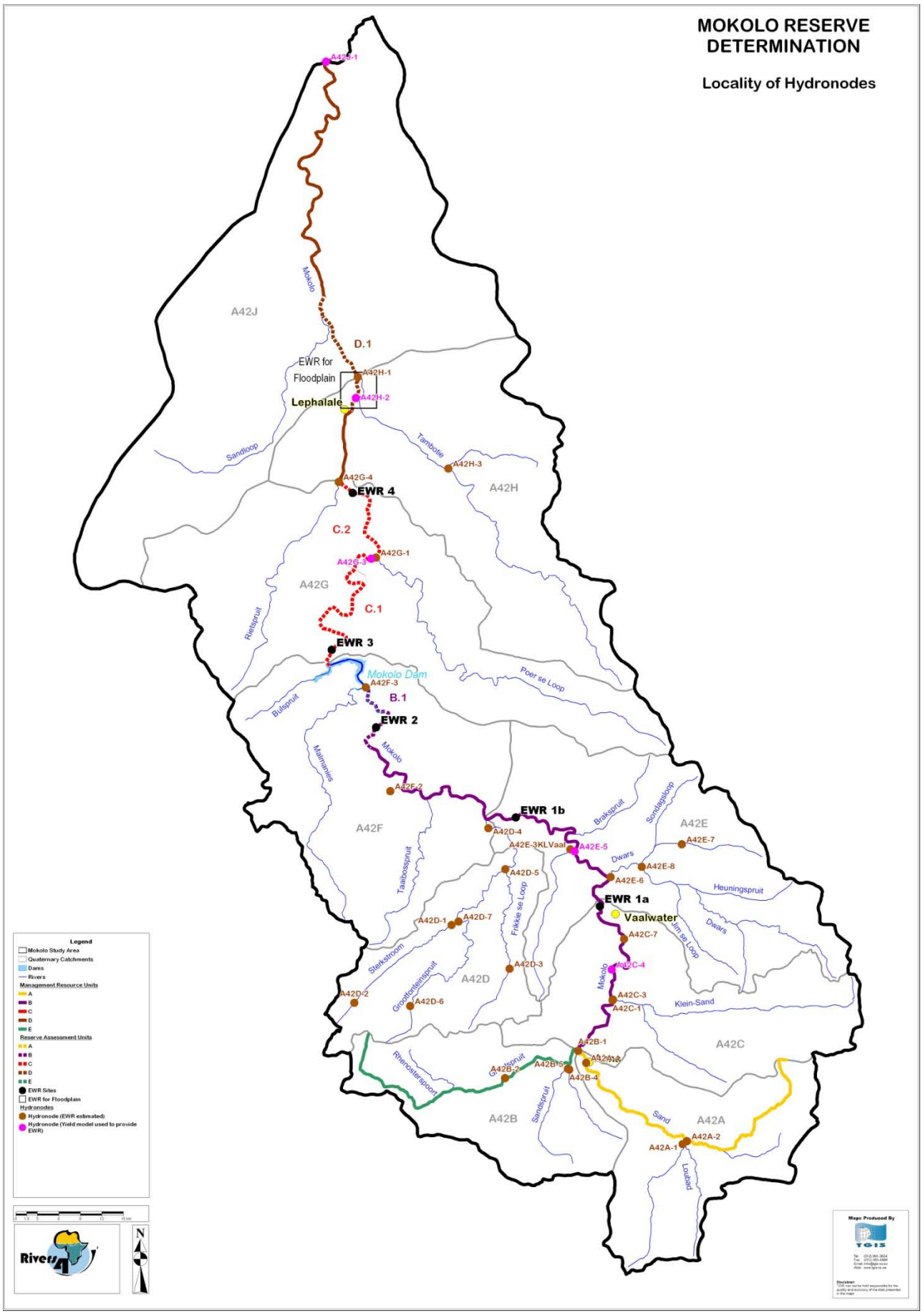


Figure 3.1 Localities of Mokolo hydronodes

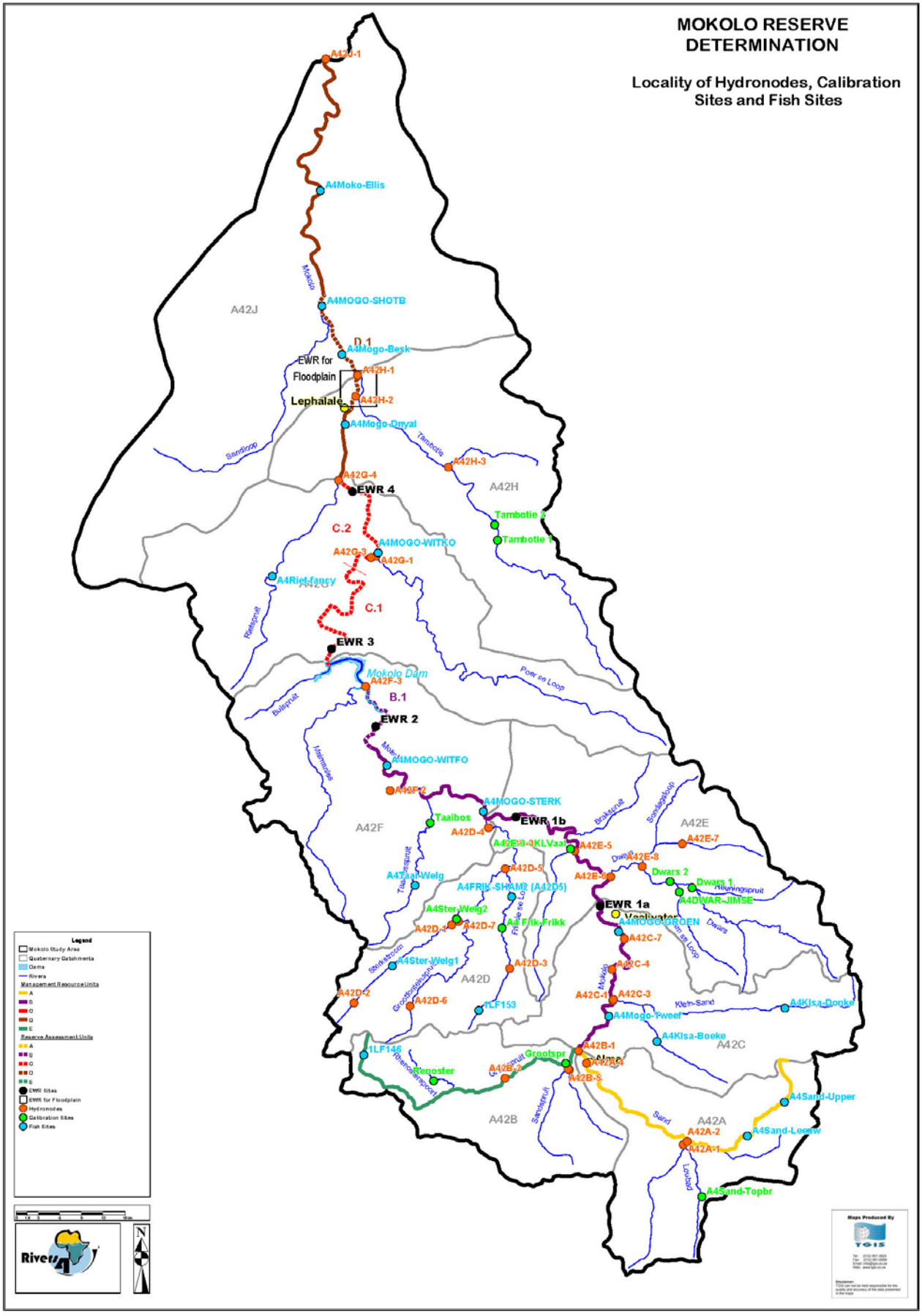


Figure 3.2 Localities of fish and calibration sites (Mokolo River)

4. HYDRONODES AND HYDRONODE DATA BASE: CROCODILE AND SABIE SYSTEMS

The hydronodes were selected during a study undertaken by Water for Africa (DWAF 2009a, 2009b, 2009c, 2009e) and the localities are illustrated on Figure 4.1 and 4.2.

A data base was set up in an Excel spreadsheet to characterise all the hydronodes. To aid in the determination of the prediction of indicator guilds, all other sites with 'known' fish information (Figure 4.3 and 4.4) were included in the data base. These 'known' fish sites consist of any sites where fish surveys have been undertaken and were extracted from:

- Reference Frequency of Occurrence of Fish species in South Africa (Kleynhans *et al.,* 2007a)
- Fish surveys undertaken as part of the current Reserve study at EWR sites and at Estimation Calibration sites (Figure 4.3 and 4.4).

The data base is provided electronically (RDM Report no 26/8/3/10/12/016 and RDM Report no 26/8/3/10/14/016). The information that is provided in each column of the data base is described below. Note that reference to a site can mean an actual site or a node which represents a point on a map and which might not have been visited. The Sabie and Crocodile Rivers information is provided on separate sheets.

- ***Column A:*** SITE NAME: The final site compiled after considering all the names allocated to the site (column B, C, E and F).
- ***Column B:*** HYDROLOGICAL NODE: Hydrological nodes as provided by the WRP study.
- ***Column C:*** EWR SITE: EWR sites listed according to their names within this study.
- ***Column D:*** RHP SITE: Sites that are National River Health Programme sites (so-called macro sites) are listed (Dallas, 2005) as well as provincial RHP sites.
- ***Column E:*** FISH INFORMATION SITES: The codes as provided in the FROC data base (Kleynhans *et al.*, 2007a) are provided as well as the EWR and Estimation Calibration sites.
- ***Column F:*** RIVER POINT FALLSON? This provides information about the locality of the site
- ***Column G:*** Comment: Provides additional information on where the site is located. E.g., it is often difficult to determine by means of the locality only whether a site is on the tributary or the main river when the site is near a confluence.
- ***Column H:*** SHREVE: Shreve system to provide the order.
- ***Column I:*** STRAHLER: Strahler system to provide the order.
- ***Column J:*** LATITUDE is provided in the decimal degree format.
- ***Column K***: LONGITUDE is provided in the decimal degree format
- ***Column L:*** QUAT: Refers to the quaternary catchment in which the site is situated.
- ***Column M:*** MAJOR RIVER: This refers to the major river into which the river flows on which the site is located. E.g., a site located in the Crocodile will be represented by the Incomati as the major river. A site/node located in the Mac Mac will be represented by the Sabie as the major river. The major river therefore is the river into which the river flows in which the site is located.
- ***Column N:*** TRIBUTARY: This represents the river in which the site is located.

- ***Column O:*** ECOR: EcoRegion (Level 2) (Kleynhans *et al.*, 2007b) in which the site is situated.
- ***Column P:*** GEOM ZONE: Geomorphic Zone (Rountree &Wadeson, 1999) in which the site is situated.
- ***Column Q:*** ALT (m): Altitude obtained from Google Earth.
- ***Column R:*** nMAR: Natural Mean Annual Runoff according to the modelled hydrology as supplied by WRP (and modified where required by IWR Water Resources) and IWR Water Resourced.
- ***Column S:*** WIDTH: Estimated width of the channel (see chapter 6).
- ***Column T –AA:*** Information on the fish guilds that occur at the site.
- ***Column AB***: REC: Provides the Recommended Ecological Category as derived from the EIS from the Desktop EcoClassification (RDM Report no 26/8/3/10/12/002).
- ***Column AC:*** Hydroregion: Provides the hydroregion according to the Desktop Reserve Model.
- ***Column AD – CT:*** Information on fish species as copied from the FROC (Kleynhans *et al.*, 2007).

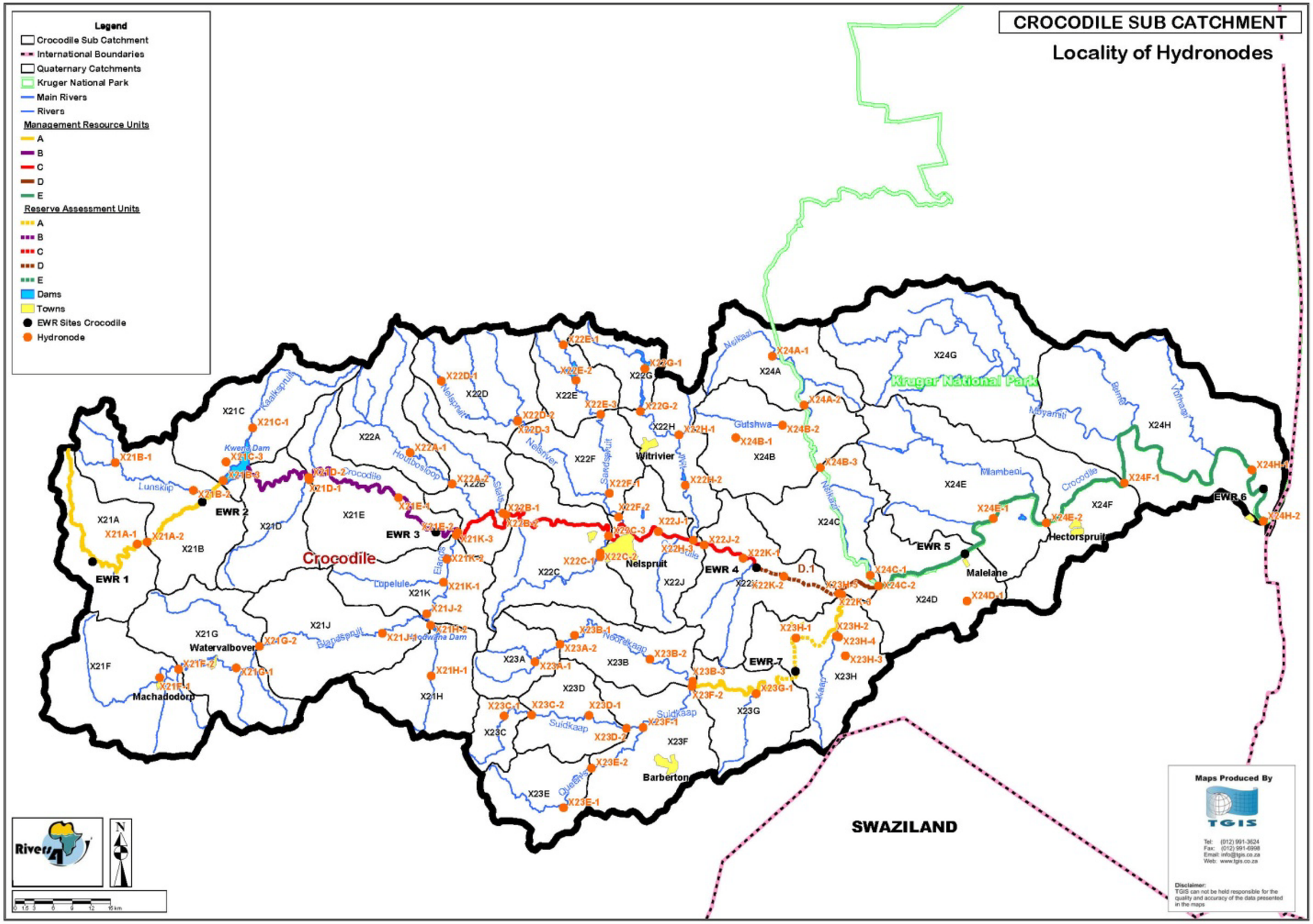


Figure 4.1 Localities of Crocodile catchment hydronodes.

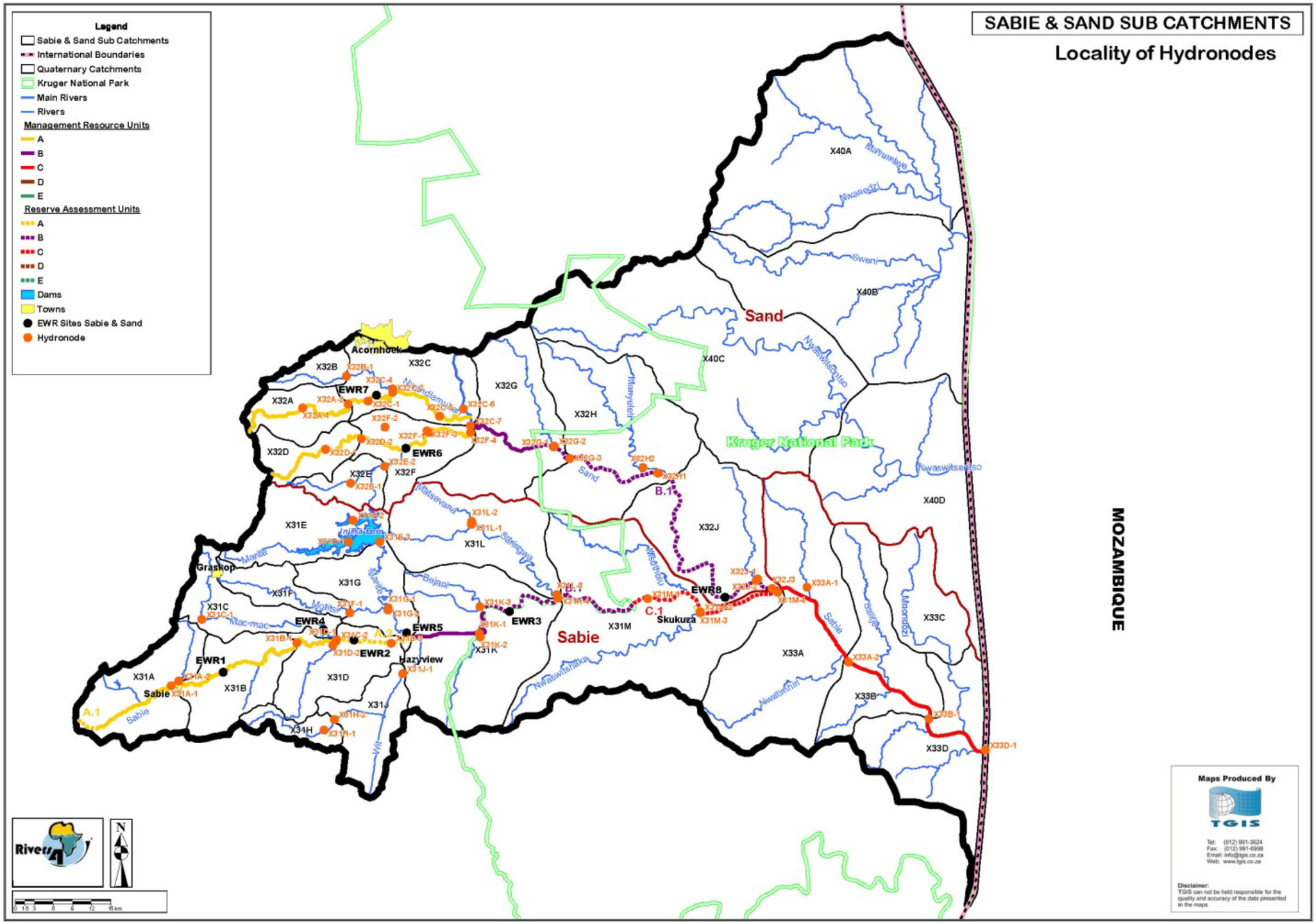


Figure 4.2 Localities of Sabie catchment hydronodes

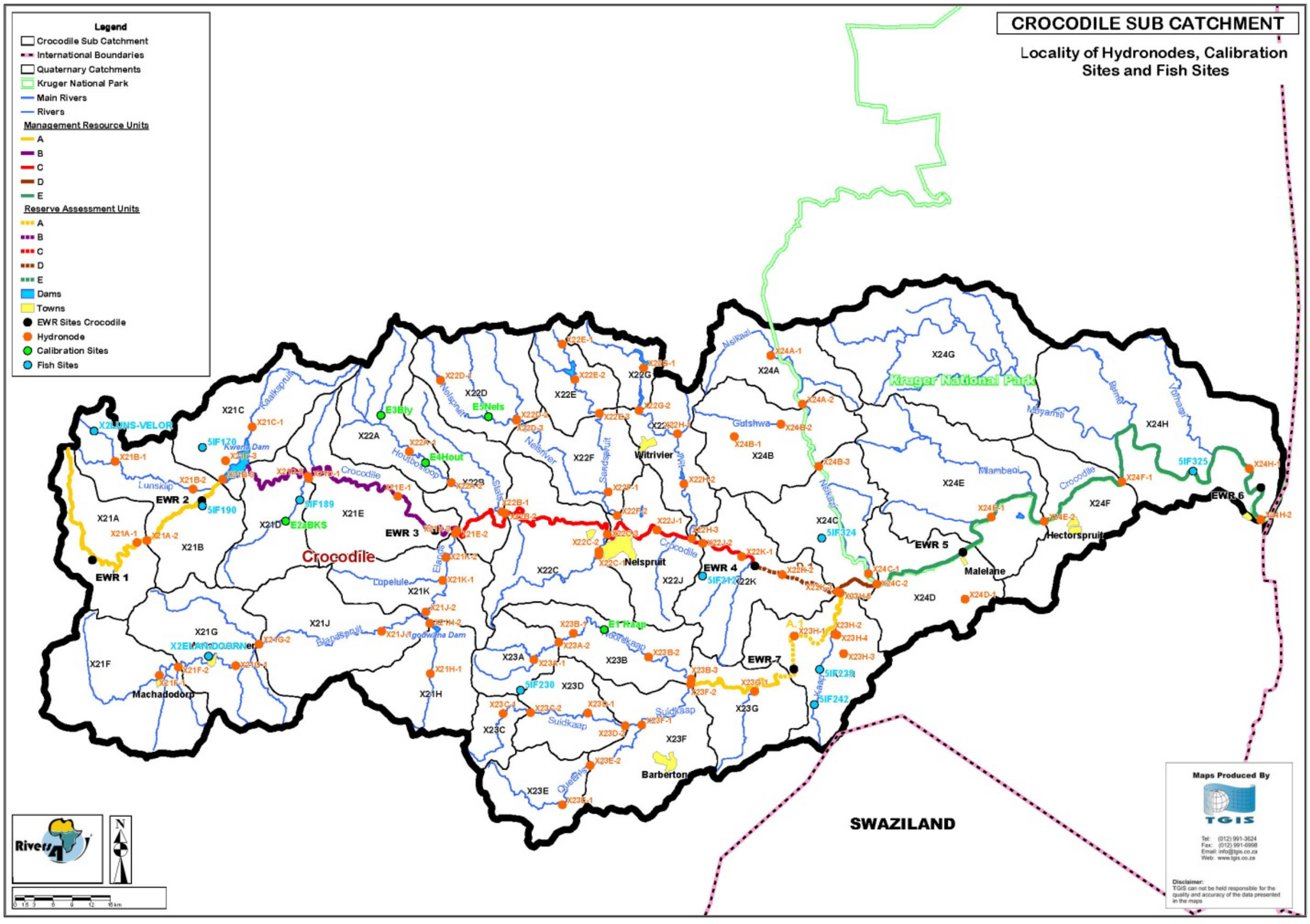


Figure 4.3 Localities of fish and calibration sites in the Crocodile system

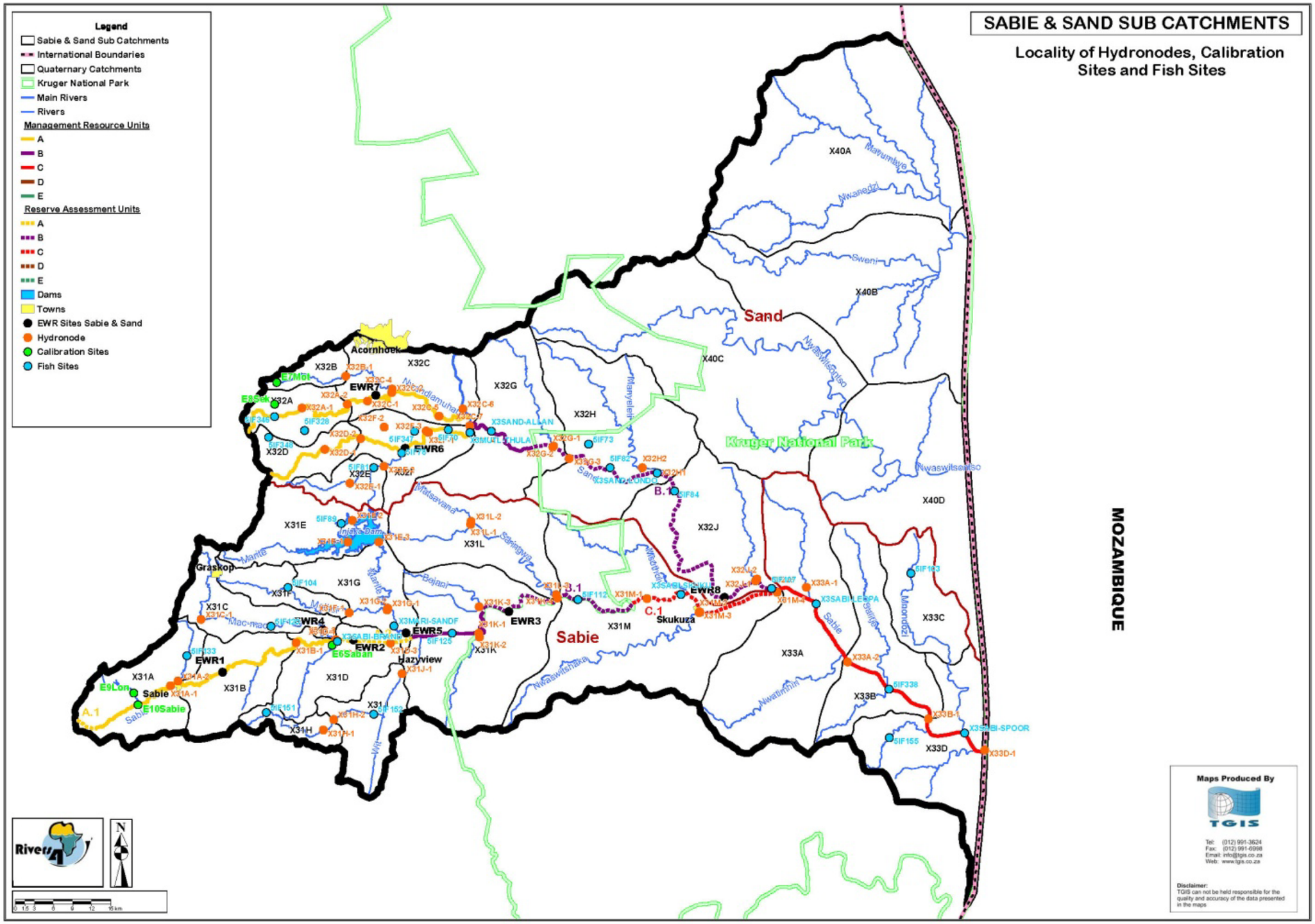


Figure 4.4 Localities of fish and calibration sites in the Sabie system

5. PREDICTION OF INDICATOR FISH GUILDS

This work followed on from the prediction of indicator species as undertaken for the Komati River and documented in Kleynhans *et al.* (2008). Kleynhans further refined the process using various methods for the Mokolo, Crocodile and Sabie River catchments.

Conceptually the prediction approach is based on the physical similarity between sites were fish information is available and hydronodes without fish information. If sites are physically similar to a high degree, then the assumption can be made that the same indicator fish guild would be present at both sites.

The results of the Mokolo, Crocodile and Sabie River Systems are provided in excel format as part of the electronic information (RDM Report no (26/8/3/10/14/016 and 26/8/3/10/12/016)). Note that this work was undertaken by CJ Kleynhans (DWA, RQS) and the results are listed in the tables below as provided to Rivers for Africa.

The results of the identified and predicted indicator fish guilds is provided in Tables 5.1 to 5.4. The various abbreviations of the different fish guilds provided in the tables below are as follows:

SR:	Small Rheophilic	SL:	Small Limnophilic	SSR:	Small Semi-rheophilic
LR:	Large Rheophilic	ML:	Medium Limnophilic	MSR:	Medium Semi-rheophilic
		LL:	Large Limnophilic	LSR:	Large Semi-rheophilic

Table 5.1 Sabie River: Indicator fish guilds per hydronode (based on comparison with sites with highest similarity (Euclidian distance[2]), perennial sites)

FISH SITE	X31A-1	X31E-3	5IF151	X3MARI-SANDF	5IF152	X31C-2	EWR6	5IF152	5IF120	X31C-2	5IF112	X3SABI-SKUKU	X3SABI-SKUKU	X3SABI-SKUKU	5IF152	5IF152	EWR7	5IF78	5IF78	5IF70	X3MUTL-THULA	5IF155	EWR7	5IF81	5IF70	5IF73	5IF82	EWR8	5IF155	X3SABI-SPOOR
HYDRO-NODE	X31A-2	X31B-1	X31C-1	X31D-1	X31F-1	X31G-1	X31G-2	X31H-1	X31H-2	X31J-1	X31K-4	X31M-1	X31M-2	X31M-4	X32A-1	X32A-2	X32C-1	X32C-2	X32C-4	X32C-5	X32C-7	X32D-1	X32D-2	X32E-2	X32F-1	X32G-2	X32G-3	X32J-1	X32J-2	X33D-1
AAEN																														
AMAR												LL	LL	LL																LL
AMOS				LL		LL				LL		LL	LL	LL						LL					LL					LL
ANAT		SR		SR																				SR				SR		
AURA		SR		SR	SR	SR		SR	SR	SR					SR	SR						SR							SR	
BANN									SL		SL	SL	SL	SL				SL	SL	SL	SL				SL	SL	SL			SL
BANO			SL								SL																	SL		
BARG		SR																												
BBRI	SR	SR				SR			SR	SR										SR				SR	SR					
BEUT	SR			SR	SR	SR		SR		SR	SR	SR	SR	SR	SR	SR				SR	SR			SR	SR					
BFRI																					SL									SL
BIMB									SL		SL	SL	SL	SL													SL			SL
BLIN	SR																													
BMAR		LSR		LSR	LSR	LSR	LSR	LSR	LSR	LSR	LSR	LSR	LSR	LSR	LSR	LSR		LSR	LSR	LSR	LSR			LSR	LSR	LSR				LSR
BPAU											SL	SL	SL	SL				SL	SL	SL	SL			SL	SL		SL	SL		
BPOL		LSR		LSR		LSR				LSR																				
BRAD									SL		SL	SL	SL	SL				SL	SL	SL	SL			SL	SL		SL	SL		SL
BTOP											SL	SL	SL	SL							SL									
BTRI		SL		SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL		SL	SL	SL	SL	SL		SL	SL		SL	SL	SL	SL
BUNI	SL	SL		SL	SL	SL	SL	SL		SL		SL	SL	SL	SL	SL		SL	SL	SL	SL			SL	SL		SL	SL		SL
BVIV							SL		SL			SL	SL	SL				SL	SL	SL	SL	SL			SL	SL	SL		SL	SL
CANO		SR		SR	SR	SR	SR	SR	SR	SR		SR	SR	SR	SR	SR		SR	SR		SR	SR		SR					SR	
CGAR						LL	LL			LL		LL	LL	LL				LL	LL	LL	LL			LL	LL					LL
CPAR				SR			SR		SR		SR	SR	SR	SR							SR						SR			SR

2 The Euclidean distance or Euclidean metric is the "ordinary" distance between two points that one would measure with a ruler (en.wikipedia.org/wiki/Euclidean_distance)

FISH SITE	X31A-1	X31E-3	5IF151	X3MARI-SANDF	5IF152	X31C-2	EWR6	5IF152	5IF120	X31C-2	5IF112	X3SABI-SKUKU	X3SABI-SKUKU	X3SABI-SKUKU	5IF152	5IF152	EWR7	5IF78	5IF78	5IF70	X3MUTL-THULA	5IF155	EWR7	5IF81	5IF70	5IF73	5IF82	EWR8	5IF155	X3SABI-SPOOR
HYDRO-NODE	X31A-2	X31B-1	X31C-1	X31D-1	X31F-1	X31G-1	X31G-2	X31H-1	X31H-2	X31J-1	X31K-4	X31M-1	X31M-2	X31M-4	X32A-1	X32A-2	X32C-1	X32C-2	X32C-4	X32C-5	X32C-7	X32D-1	X32D-2	X32E-2	X32F-1	X32G-2	X32G-3	X32J-1	X32J-2	X33D-1
CSWI						SR			SR	SR		SR	SR	SR							SR					SR				SR
GCAL											SR	SR	SR	SR						SR	SR				SR		SR	SR		SR
GGIU									LL			LL	LL	LL							LL									LL
HVIT									LL			LL	LL	LL																LL
LCON												LL	LL	LL																LSR
LCYL				MSR	MSR	MSR		MSR	MSR	MSR		MSR	MSR	MSR	MSR	MSR		MSR	MSR	MSR	MSR	MSR		MSR	MSR				MSR	MSR
LMOL	ML			ML	ML	ML		ML	ML	ML		ML	ML	ML	ML	ML		ML	ML	ML	ML			ML	ML		ML			ML
LROS	LL								LL			LL	LL	LL																LL
LRUD									LL			LL	LL	LL																LL
MACU	SSR			SSR	SSR		SSR	SSR	SSR			SSR	SSR	SSR	SSR	SSR		SSR	SSR	SSR	SSR			SSR	SSR		SSR	SSR		SSR
MBRE							SL		SL			SL	SL	SL				SL	SL	SL	SL			SL	SL		SL			SL
MMAC	LSR			LSR	LSR	LSR		LSR	LSR	LSR		LSR	LSR	LSR	LSR	LSR	LSR				LSR		LSR	LSR		LSR	LSR	LSR		LSR
OMOS	LL			LL	LL		LL	LL	LL		LL	LL	LL	LL	LL	LL				LL	LL				LL					LL
OPER		SR		SR		SR			SR	SR	SR	SR	SR	SR						SR					SR		SR			
PCAT	SSR			SR		SSR				SSR		SSR	SSR	SSR							SSR									SSR
PPHI					SL	SL	SL	SL	SL	SL		SL	SL	SL	SL	SL		SL	SL	SL	SL				SL					SL
SINT	LL								LL			LL	LL	LL							LL						LL	LL		LL
SMER									LL			LL	LL	LL				LL	LL	LL	LL			LL	LL		LL	LL		LL
SZAM												LL	LL	LL																LL
TREN	LL						LL		LL			LL	LL	LL				LL	LL	LL	LL				LL		LL			LL
TSPA				ML																										
VNEL			LR	LR		LR				LR	LR																			

Table 5.2 Sabie River: Indicator fish guilds per hydronode (based on comparison with sites with highest similarity (Euclidian distance), non-perennial sites)

FISH SITE	5IF347	X32C-6	X32C-6	X32C-6	X32C-6	X32H2	5IF103	X32B-1	X32B-1	X32B-1	5IF347	5IF348	5IF103	5IF103	5IF103	5IF103	5IF103	5IF103	5IF103
HYDRO-NODE	X32F-2	X31K-2	X31K-3	X31L-1	X31L-2	X31L-3	X31M-3	X32A3	X32C-3	X32E-1	X32F-3	E7Mot	X33A-1	X33C-1	X40A-1	X40A-2	X40B-1	X40B-2	X40B-3
AMOS												LL							
ANAT												SR							
BBRI						SR													
BEUT	SR										SR								
BMAR	LSR	LSR	LSR	LSR	LSR						LSR								
BPAU	SL										SL								
BRAD							SL						SL	SL	SL	SL	SL	SL	SL
BTRI		SL	SL	SL	SL														
BUNI		SL	SL	SL	SL			SL	SL	SL									
BVIV		SL	SL	SL	SL			SL	SL	SL									
CANO	SR					SR					SR								
CGAR		LL	LL	LL	LL														
CPAR	SR										SR								
LCYL								MSR	MSR	MSR									
LMOL	ML										ML								
LROS							LL						LL	LL	LL	LL	LL	LL	LL
MACU	SSR	SSR	SSR	SSR	SSR		SSR	SSR	SSR	SSR	SSR		SSR	SSR	SSR	SSR	SSR	SSR	SSR
MBRE	SL	SL	SL	SL	SL		SL	SL	SL	SL	SL		SL	SL	SL	SL	SL	SL	SL
OMOS	LL	LL	LL	LL	LL		LL	LL	LL	LL	LL		LL	LL	LL	LL	LL	LL	LL
PCAT							SSR						SSR	SSR	SSR	SSR	SSR	SSR	SSR
PPHI	SL							SL	SL	SL	SL								
SMER		LL	LL	LL	LL		LL						LL	LL	LL	LL	LL	LL	LL
SZAM						LL													
TREN	LL	LL	LL	LL	LL		LL	LL	LL	LL	LL		LL	LL	LL	LL	LL	LL	LL
TSPA		ML	ML	ML	ML														

Table 5.3 Crocodile River: Indicator fish guilds per hydronode (based on comparison with sites with highest similarity (Cluster analysis))

Sites with identified geomorphic zones			Sites with identified geomorphic zones		
HYDRONODES	FISH SITES	SUGGESTED GUILDS	HYDRONODES	FISH SITES	SUGGESTED GUILDS
X21A-1	EWR 1	SL	X22J-2	EWR 4	SR
X21A-2	EWR 2	SR	X22K-1	EWR 4	SR
X21B-1	EWR 1	SL	X22K-2	EWR 4	SR
X21B-3	EWR 2	SR	X22K-3	EWR 4	SR
X21D-1	5IF189	SR	X23A-2	X23D-2	SR
X21D-2	X22A-1	SR	X23B-2	E1 Kaap	SR
X21E-1	EWR 3	SR	X23B-3	X23D-2	SR
X21E-2	X22F-2	SR	X23C-1	X23D-2	SR
X21F-1	EWR 1	SR	X23C-2	E1 Kaap	SR
X21F-2	EWR 1	SR	X23D-1	X23D-2	SR
X21G-1	X2ELAN-DOORN	SR	X23E-1	E1 Kaap	SR
X21G-2	X2ELAN-DOORN	SR	X23E-2	E1 Kaap	SR
X21H-1	X21K-1	SR	X23F-1	E1 Kaap	SR
X21H-2	X21K-1	SR	X23F-2	X23D-2	SR
X21J-1	X21J-2	SR	X23G-1	X23D-2	SR

Sites with identified geomorphic zones			Sites with identified geomorphic zones		
HYDRONODES	**FISH SITES**	**SUGGESTED GUILDS**	**HYDRONODES**	**FISH SITES**	**SUGGESTED GUILDS**
X21K-2	X21K-1	SR	X23G-2	EWR 7	SR
X21K-3	X21K-1	SR	X23H-1	EWR 7	SR
X22C-3	X22B-2	SR	X23H-5	EWR 7	SR
X22D-1	E5Nels	SR	X24A-2	X24A-1	MSR
X22D-3	E5Nels	SR	X24B-2	X24A-1	MSR
X22E-1	E3Bly	SR	X24B-3	X24C-1	SR
X22E-2	X22E-3	SR	X24C-2	EWR 5	SR
X22F-1	X22F-2	SR	X24D-2	EWR 5	SR
X22G-1	X22E-3	SR	X24E-1	EWR 5	SR
X22G-2	X22E-3	SR	X24E-2	EWR 5	SR
X22H-1	X22E-3	SR	X24G-1	X24A-1	MSR
X22H-2	X22F-2	SR	X24H-1	EWR 6	SR
X22H-3	X22F-2	SR	X24H-2	EWR 6	SR
X22J-1	EWR 4	SR			

Sites with geomorphic zones not identified.*		
HYDRONODES	**FISH SITES**	**SUGGESTED GUILDS**
X22B1	5IF212	LSR
X22C-1	5IF212	LSR
X22D-2	X21C-3	SR
X23A-1	5IF230	LSR
X23B-1	5IF230	LSR
X23G-1	5IF228	SR
X23H-2	5IF228	SR
X23H-3	5IF242	SR
X23H-4	5IF212	LSR
X24B-1	5IF324	SR
X24D-1	5IF242	SR
X22B-1	**STATSPRUIT: BASED ON HISTORICAL DATA**	SR

* Some sites are situated on really small rivers which are not in the 1:500 000 scale and therefore have not been calculated by D:RQS, DWA.

Table 5.4 Fish guilds per hydronode based on comparison with sites of highest similarity (Cluster analysis), Mokolo River system

HYDRONODES	FISH SITES	SUGGESTED GUILDS	HYDRONODES	FISH SITES	SUGGESTED GUILDS
A42A-2	A42A-1	SR	A42G-1	A4Ster-Welg2	SR
A42D-5	A4Ster-Welg1	SR	A42G-3	A42G-2_EWR4	MSR
A42B-2	A42A-1	SR	A42G-4	A4Riet-fancy	MSR
A42B4	A42A-1	SR	A42H-1	Tambotie 1	MSR
A42B-5	A42A-1	SR	A42H-3	A4Riet-fancy	MSR
A42C-1	A42A-4	SR	A42J-1	A4Moko-Ellis	SR
A42C-3	A42A-4	SR	A42J-2	A4Riet-fancy	MSR
A42C-4	A42C9_EWR1a	SR	A4MOGO-STERK	A42F-4_EWR2	SR
A42C-7	Tambotie 1	MSR	A4MOGO-WITFO	A42F-4_EWR2	SR
A42D-1	A4 Frik-Frik	SR	A4Mogo-Dnyal	A42H2	SR
A42D-2	A4 Frik-Frik	SR	A4Mogo-Besk	A42H2	SR
A42D-3	A4 Frik-Frik	SR	A4MOGO-SHOTB	A42H2	SR
A42D-5	A4Ster-Welg1	SR	A4MOGO-WITKO	A42G-2_EWR4	SR
A42D-6	1LF153	SL	A42A-1	A4Sand-Topbr	SR
A42D-7	A42B-1_Grootspr	MSR	A4Klsa-Boeke	A42B-1_Grootspr	MSR
A42E-5	EWR1b	SR	A4Klsa-Donke	A42A-1	SR
A42E-6	Dwars 1	SL	A4Mogo-Tweef	A42A-4	SR
A42E-7	A4DWAR-JIMSE	SL	A4MOGO-GROEN	A42C9_EWR1a	SR

HYDRONODES	FISH SITES	SUGGESTED GUILDS	HYDRONODES	FISH SITES	SUGGESTED GUILDS
A42E-8	Dwars 1	SL	A4Sand-Upper	BATZUUR	SR
A42F-2	A42E-3	SL	A4Sand-Leeuw	A4Sand-Topbr	SR
A42F-3	A42F-4_EWR2	SR			

This information supplied formed the basis for the estimation process as it was now known which relationship for which guild to apply at each site.

6. CALIBRATION SITES

6.1 CALIBRATION SITES USED FOR EWR ESTIMATION

Photographs of the EWR sites (Rapid Level III, Intermediate and Comprehensive) used to develop an EWR estimation method for hydronodes where no hydraulic data existed (and specifically applicable to these catchments), are illustrated in Table 6.1 for the Sabie River and Crocodile River catchments, Table 6.2 for the Mokolo River catchment, and Table 6.3 for the Upper Vaal River[3] catchment. Their locality and other pertinent information are provided in Table 6.4.**The calibration sites for estimation from the Nkomati River catchment (refer to Birkhead, 2008) were included in this study to extend the EWR and hydraulic data base.**

Certain Rapid III, Intermediate and Comprehensive sites were omitted for various reasons, and included sites:

- Where present day flow conditions were substantially modified from natural flow conditions (primarily due to upstream flow regulation by large dams), since EWR estimation (Section 7) is related to natural flows.
- With inappropriate geomorphic characteristics (riffle and rapid units were favoured with gravel, cobble and small boulder substrates).
- With high uncertainty in the (modelled) natural hydrology.

Table 6.1 Calibration sites in the Sabie and Crocodile River systems used for EWR estimation (Photographs: D. Louw)

SABIE AND CROCODILE RIVER SYSTEMS: CALIBRATION SITES FOR ESTIMATION	
	
Sekgamarago	**Buffelskloofspruit (cross-section A)**
	
Buffelskloofspruit (cross-section B)	**Lonely Creek**

[3]Note: The inclusion of the Vaal River (and e.g. the Komati) is not an error. All the recent estimation studies were used to develop the methods.

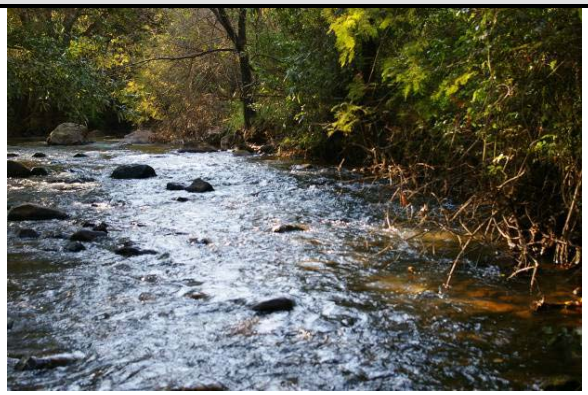
	
Sabane	**Blystaanspruit**
	
Sabie	**Nels**
	
NoordKaap	**Houtbosloop**

Table 6.2 Calibration sites in the Mokolo River system used for EWR estimation (Photographs: D. Louw)

MOKOLO SYSTEM RIVER SYSTEM: CALIBRATION SITES FOR ESTIMATION	
	
Renosterbosspruit (cross-section A)	**Renosterbosspruit (cross-section B)**

Sand

Klein Vaalriverspruit

Jim se Loop

Tambotie (cross-section A)

Tambotie (cross-section B)

Frikkie se Loop,

Upper Dwars

Lower Dwars (Cross-section B)

	
Sterk	**Taaibos**

Table 6.3 Calibration sites in the Upper Vaal River system used for EWR estimation (Photographs: D. Louw)

UPPER VAAL RIVER SYSTEM: CALIBRATION SITES FOR EWR ESTIMATION	
	
Klip	**Grootspruit (cross-section B)**
	
Cornelius	**Skulpspruit**
	
Kromelmboogspruit	**Kromspruit**

Meul (cross-section A)

Meul (cross-section B)

Holspruit

Waterval

Table 6.4 Sites used for hydronode EWR estimation

Quat	Site nr	River	Alt (m)	Co-ordinates		MAR (Mm^3)	Discharge (m^3/s)[1]	Ind fish guild[2]		Ind invert taxa[3]		% pt FDT[4]	
				Latitude	Longitude			Dry	Wet	Dry	Wet	Maint[5]	Dry
NKOMATI RIVER CATCHMENT													
Calibration sites													
X12K	X12K1	Phalangampepe	731	-26.0453	31.0503	4.2	0.050	SR	SR	FDCD[6]	FDCD	70	95
X12G	X12G2	Bergstroom	1200	-25.9678	30.8333	4.8	0.026	SR	SR	FDCD	FDCD	70	95
X11F	X11F1	Bankspruit	1545	-25.8469	30.3506	6.7	0.075	SR	SR	FDCD	FDCD	70	95
X12G	X12G1	Mawelawala	1144	-25.9652	30.8216	9.9	0.037	SR	SR	FDCD	FDCD	70	95
X12H	X12H2	Sandspruit	800	-26.0497	30.8972	10.5	0.037	SR	SR	FDCD	FDCD	70	95
X11A	X11A1	Vaalrivierspruit	1531	-26.0069	30.02664	10.6	0.019	SR	SR	FDCD	FDCD	70	95
X11D	X11D1	Klein Komati	1640	-25.8881	30.1203	10.7	0.050	SR	SR	FDCD	FDCD	70	95
X12K	X12K2	Mlondozi	1098	-26.0472	31.0442	14.2	0.17	SR	SR	FDCD	FDCD	70	95
X11E	X11E1	Swartspruit	1444	-25.93695	30.235	15.4	0.045	SR	SR	FDCD	FDCD	70	95
X12B	X12B1	Buffelspruit	1562	-26.0628	30.3939	27.9	0.086	SR	SR	FDCD	FDCD	70	95
X11G	X11G3	Komati	935	-25.9531	30.7249	370	1.5	LSR	LSR	FDCD	FDCD	70	95
SABIE and CROCODILE RIVER CATCHMENTS													
Calibration sites													
X32A	E8Sek	Sekgamarago	886	-24.69327	30.92953	1.0	0.02	SR	SR	FDCD	FDCD	70	95
X21D	E2aBKS	Buffelskloofspruit	1184	-25.43842	30.44713	10.8	0.10	SR	SR	FDCD	FDCD	70	95
X21D	E2bBKS	Buffelskloofspruit				10.8	0.10	SR	SR	FDCD	FDCD	70	95
X31G	E9Lon	Lonely Creek	1146	-25.10324	30.71097	11.2	0.34	SR	SR	FDCD	FDCD	70	95
X31D	E6Saban (a)	Sabane	533	-25.03414	31.01989	16.4	0.031	SSR	SSR	FDCD	FDCD	70	95

X31D	EcSaban (b)	Sabane						SSR	SSR	FDCD	FDCD	70	95
X22A	E3Bly	Blystaanspruit	1032	-25.28752	30.59633	19.3	0.51	SR	SR	FDCD	FDCD	70	95
X31A	E10Sab	Sabie	1099	-25.12100	30.71700	26.5	0.41	SR	SR	FDCD	FDCD	70	95
X22D	E5Nels	Nels	1065	-25.28945	30.76464	30.4	1.2	SR	SR	FDCD	FDCD	70	95
X32B	E1Kaap	Kaap(North)	678	-25.60761	30.97650	43.5	0.27	SR	SR	FDCD	FDCD	70	95
X22A	E4Hout	Houtbosloop	865	-25.35516	30.66591	56.8	0.78	SR	SR	FDCD	FDCD	70	95
EWR sites													
X31B	EWR 1	Sabie	862	-25 04.424	30 50.924	140.2		SR/LR	SR/LR	FDCD	FDCD	70	95
X31D	EWR 2	Sabie	463	-25 01.675	31 03.099	262.1		SR/ R	SR/LR	FDCD	FDCD	70	95
X31K	EWR 3	Sabie	369	-24 59.256	31 17.572	495.9		SR/SR	SR/SR	FDCD	FDCD	70	95
X31C	EWR 4	Mac Mac	582	-25 00.800	31 00.243	65.8		SR/ R	SR/LR	FDCD	FDCD	70	95
X31G	EWR 5	Marite	457	-25 01.077	31 07.997	157.1		SR/ R	SR/LR	FDCD	FDCD	70	95
X32C	EWR 7	Tlulandziteka	543	-24 40.829	31 05.188	28.9		SR/LSR	SR/LSR	FDCD	FDCD	40	95
X21A	EWR 1	Crocodile	1852	-25 29.647	30 08.656	15.2				FDCD	FDCD	70	95
X21B	EWR 2	Crocodile	1207	-25 24.555	30 18.955	47.1		SR	SR	FDCD	FDCD	70	95
X24H	EWR 6	Crocodile	470	-25 38.968	31 14.572	1063		SR/LSR	SR/LSR		FDCD	70	95
MOKOLO RIVER CATCHMENT													
Calibration sites													
A42F	8	Taaibos	1011	-24 11.128	27 51.673	1.8	0.49	SSR	MSR	FDCD	FDCD	50	95
A42B	2XSA	Renosterbossprui t	1284	-24.50804	27.86574	1.9	0.081	SSR	MSR	FDCD	FDCD	50	95
A42B	2XSB	Renosterbossprui t						SR	SR	FDCD	FDCD	50	95
A42A	1	Sand	1356	-24.65283	28.231	2.1	0.14	SR	SR	FDCD	FDCD	50	95
A42E	11	Klein Vaalrivierspruit	1098	-24.21941	28.05363	2.7	0.42	SSR	LSR	FDCD	FDCD	50	95
A42E	6	Jim se Loop	1209	-24.27184	28.20002	2.8	0.19	SSR	MSR	FDCD	FDCD	50	95
A42H	7XSB	Tambotie	983	-23.81291	27.94885	2.8	0.52	MSR	MSR	FDCD	FDCD	50	95
A24D	9	Frikkie se Loop	1221	-24.31397	27.95724	3.9	0.66	SR	SR	FDCD	FDCD	50	95
A42E	4	Upper Dwars	1188	-24.26661	28.21718	10.3	0.46	SSR	LSR	FDCD	FDCD	50	95
A42E	5XSA	Lower Dwars	1212	-24.26736	28.21873	14.1	0.66	SSR	LSR	FDCD	FDCD	50	95
A42E	5XSB	Lower Dwars						SSR	LSR	FDCD	FDCD	50	95
A24D	10	Sterk	1191	-24.30554	27.89699	26.1	2.2	SR	SR	FDCD	FDCD	50	95
UPPER VAAL RIVER CATCHMENT													
C13C	8 (UVKlip)	Klip	1757	-27.82105	29.64983	5.75	0.14	SSR	SSR	FDCD	FDCD	60	95
C82F	3B(UV36)	Grootspruit	1643	-27.49946	28.95117	6.24		LSR	LSR	FDCD	FDCD	60	95
C82A	7(UVCor)	Cornelius	1852	-27.83821	29.35921	7.93	0.006	LSR	LSR	FDCD	FDCD	60	95
C11E	9(UV9)	Skulpspruit	1635	-27.02988	29.88956	12.11	0.004	LSR	LSR	FDCD	FDCD	60	95
C23B	1(UV53)	Kromelmboogspr uit	1416	-26.79594	27.56550	14.36	0.006	LSR	LSR	FDCD	FDCD	60	95
C83K	2(UV45)	Kromspruit	1492	-27.25842	28.40691	25.72	0.006	LSR	LSR	FDCD	FDCD	60	95
C81L	6B(UV25)	Meul	1691	-27.97461	29.31991	26.50	0.35	LSR	LSR	FDCD	FDCD	60	95
C82G	5(UV31)	Holspruit	1558	-27.67999	28.79244	32.93	0.049	SR	LSR	FDCD	FDCD	60	95
C81M	6A(UV28)	Meul	1588	-27.96968	28.89911	103.85	0.94	LSR	LSR	FDCD	FDCD	60	95
C12G	4(UVWV)	Waterval	1499	-26.96028	28.74577	176.80	0.48	LR	LR	FDCD	FDCD	60	95

1Single measured discharge for Rapid III level assessment
2 Indicator fish guild
3 Indicator invertebrate guild
4 Percentage point (time equalled or exceeded) on the flow duration table
5 Maintenance
6 Flow Dependant Cobble Dwelling invertebrates

7. EWR ESTIMATION METHOD

7.1 EWR DATA AND SYNTHESIS

The EWR data for the sites in Table 6.4 were provided (for the Comprehensive level sites) from the Reserve study. These results are for specific Ecological Categories (ECs) (may include the Present Ecological State (PES), Recommended Ecological Category (REC) and/or the Alternative Ecological Category (AEC)), specified separately for fish and macroinvertebrates. For the Rapid Level III sites (Nkomati, Sabie, Crocodile, Mokolo and upper Vaal River catchments), the Fish Flow Habitat Assessment (FFHA) model (developed by Dr C.J. Kleynhans) was used for estimating the EWRs (the model was modified for application to macroinvertebrates). The FFHA model provides a consistent procedure for estimating EWRs (at the Rapid Level III and higher) and gives requirements for the A to D range of Ecological Categories (ECs).

The EWR data were entered into an Excel data base for processing, together with the tabulated (modelled) hydraulic information (or lookup tables) for the site cross-sections. Code was written in Visual Basic Applications (VBA) to compile EWR and hydraulic data as a function of ecological and hydrological parameters. The ecological information included the indicator fish guild and macroinvertebrate taxa, and the hydrological information included the season and percentage (time) exceedance of maintenance and drought conditions on the flow duration table (FDT).

For each of the four fish guilds (Small Semi-Rheophilic (SSR), Large Semi-Rheophilic (LSR), Small Rheophilic (SR) and Large Rheophilic (LR) – (there was insufficient data to consider Medium Semi-Rheophilic (MSR))), and a single macro-invertebrate taxa (flow dependant cobble dwelling (FDCD)), there were three variables to consider. These included hydrological season (wet or dry), percentage point on the FDT (the points denoting maintenance and drought conditions) and EC (B, C or D - the FFHA model considered an A to be natural). Therefore, there were twelve permutations (or data sets) per guild or taxa. However, for the small and large fish guilds, the semi-rheophilic and rheophilic guilds were taken to have the same flow requirements in the wet season (refer to Table 6.4). This effectively increased the EWR data base for the wet season. There were therefore 36 data sets for fish and 12 for macroinvertebrates.

For each of these 48 data sets, the EWR requirement (from the Comprehensive and Rapid Level III (FFHA model) studies), hydrological (natural flow) and relevant hydraulic information (wetted channel width, maximum depth, average depth and average velocity) were compiled. Following from the findings of a previous EWR estimation study (Birkhead, 2008), the data was analysed to assess whether the EWR could be expressed as a constant unit-width value (i.e. a constant discharge per unit (wetted) width of channel). Unfortunately (since this was previously found to be a simple means of expressing the flows), the flow requirements were noted to vary as a function of the natural flow. The reason for this difference (i.e. compared with the previous study) is uncertain, but could be related to a different method (FFHA) being used to estimate the EWRs - where the natural hydrology was more explicitly taken into account. Building on the findings of this previous study, the data were analysed by plotting the relative EWR (as proportion of the natural flow) against the natural flow per unit width of wetted channel (e.g. Figure 7.1).

According to previous findings, the proportional requirement should generally increase with reducing natural discharge per unit width (the latter parameter being related to stream size). For the data sets used in this study, the EWR data from the Comprehensive sites (generally main stem rivers) form the upper range of the natural unit width discharge (x-axis), and the FFHA-derived requirements (for generally the tributaries) plot at the lower range. Although there is substantial scatter in the data, they again (refer to Birkhead, 2008) indicate general trends of increasing proportional requirement with reducing stream size (for the data analysed).

A regression procedure was coded (using VBA) to automate the curve-fitting for the 48 data sets, and allowed the regressions to be easily re-determined with changes to the data sets. A power function given by $Q(\text{EWR})/Q\text{nat} = a - b(Q\text{nat}/W)^w$ as used for the curve fitting, and the regression coefficients (a, b and c) are given in Table 7.1 (W is the wetted channel width).

The EWR data and fitted regression curves are plotted in Figure 7.1 to Figure 7.8 for the 48 data sets given in Table 6.4. From these plots it may be noted that the drought requirements were different for the different ECs. This differs from the rationale used in the Desktop Reserve Model (Hughes and Münster, 2000), quoted below with corrected (current) terminology provided in parentheses:

"It does not really make ecological sense to think in terms of varying the drought requirements with class [category], *as drought flows are considered to be the minimum required to prevent the system from collapsing. After some discussion amongst experienced IFR [EWR] specialists it was decided that the drought low flow requirements for all the management classes* [Ecological Categories] *should be the same and similar to maintenance D requirement"*

The reason for varying the drought requirements in this study, in accordance with the EWR data supplied from the FFHA model is (Kleynhans, *pers. comm*.):

"For 'large' streams the above (Hughes and Münster, 2000) rationale may be valid, but for 'smaller' streams with higher (than D) ECs, a D category maintenance flow does not provide sufficient hydraulic habitat (e.g. depth and velocity) for rheophilic (fish) guilds to survive. Physico-chemical (e.g. temperature and oxygen) conditions also enter strongly into the overall habitat condition. The size and habitat guild of the indicator species need to be considered."

The regression relationships plotted in Figure 7.1 to Figure 7.8 are only applicable for the data ranges to which they were fitted, and maximum values of the natural unit width discharges are provided in Table 7.1. Application of this method for EWR estimation at hydronodes is described in Chapter 8.

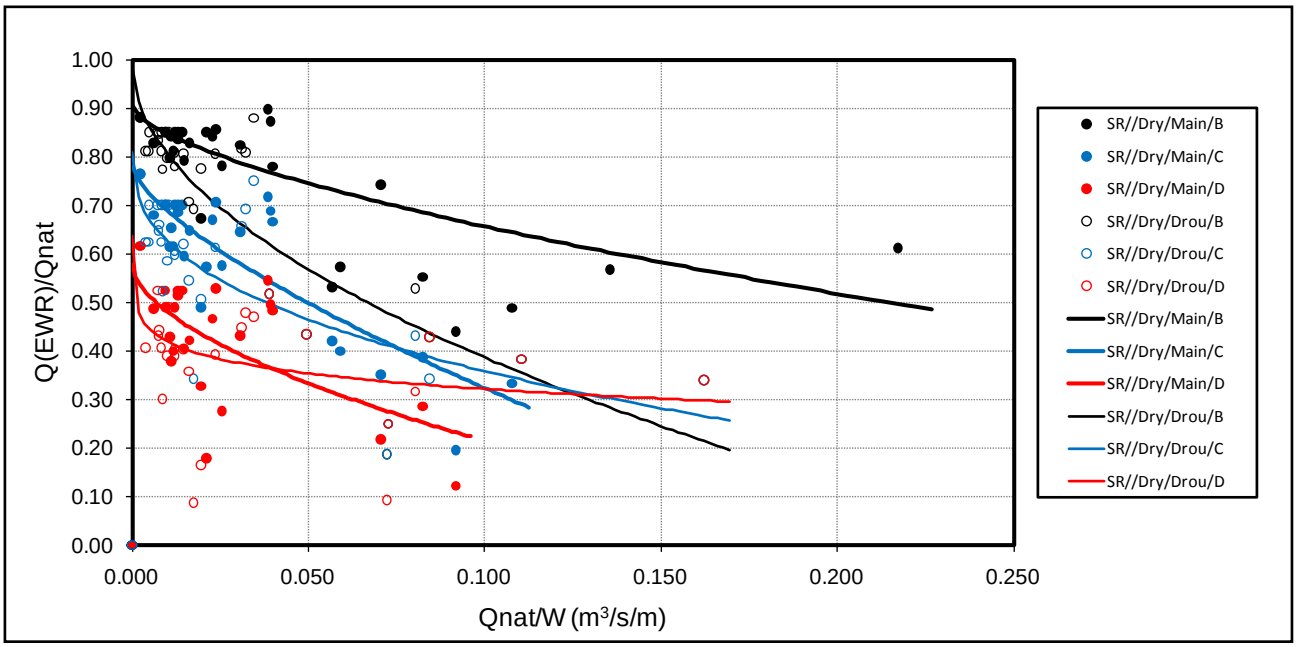


Figure 7.1 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for SR fish for the dry season (drought and maintenance conditions, B to D categories)

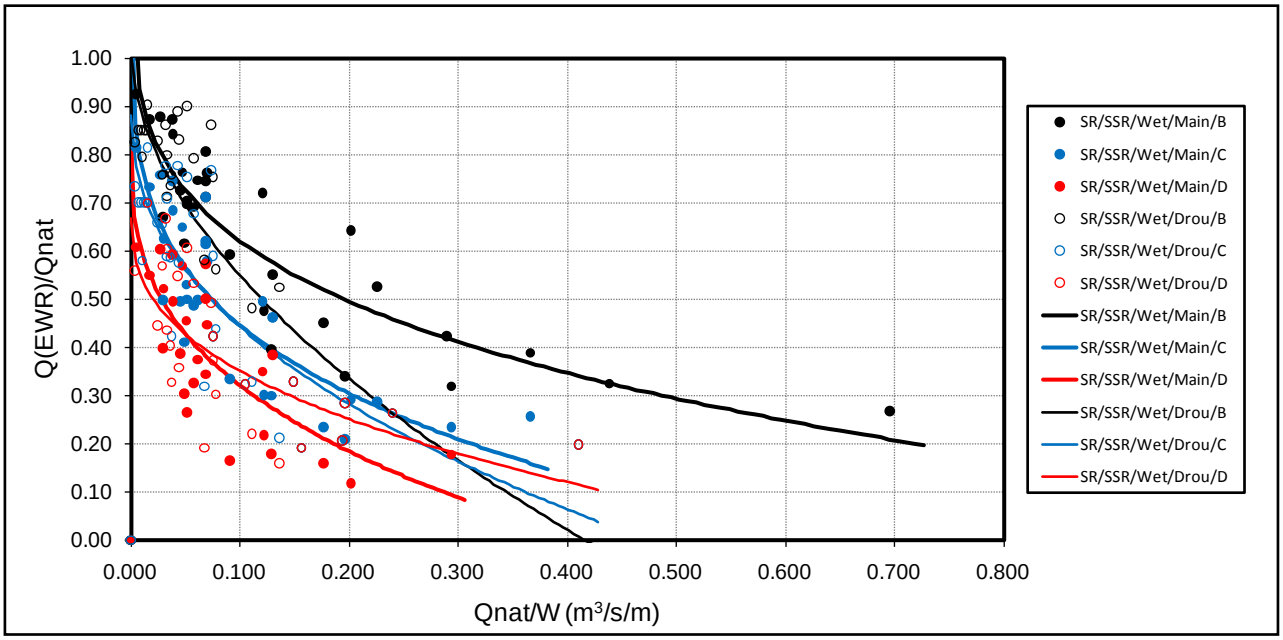


Figure 7.2 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for SR and SSR fish for the wet season (drought and maintenance conditions, B to D categories)

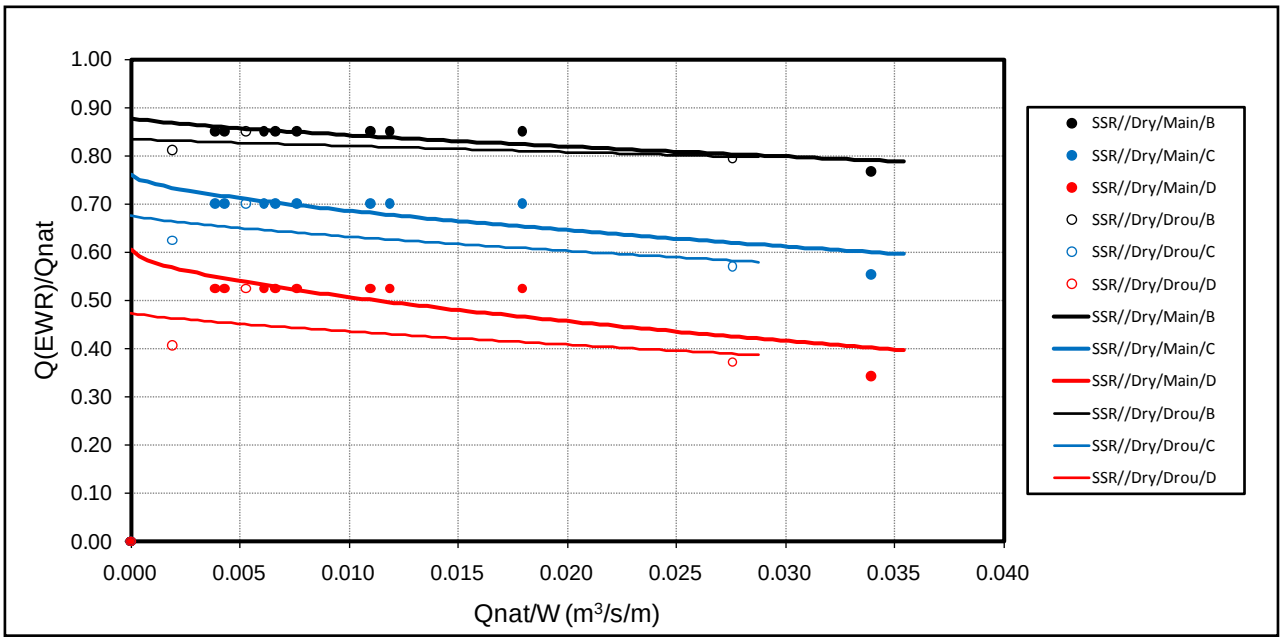


Figure 7.3 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for SSR fish for the dry season (drought and maintenance conditions, B to D categories)

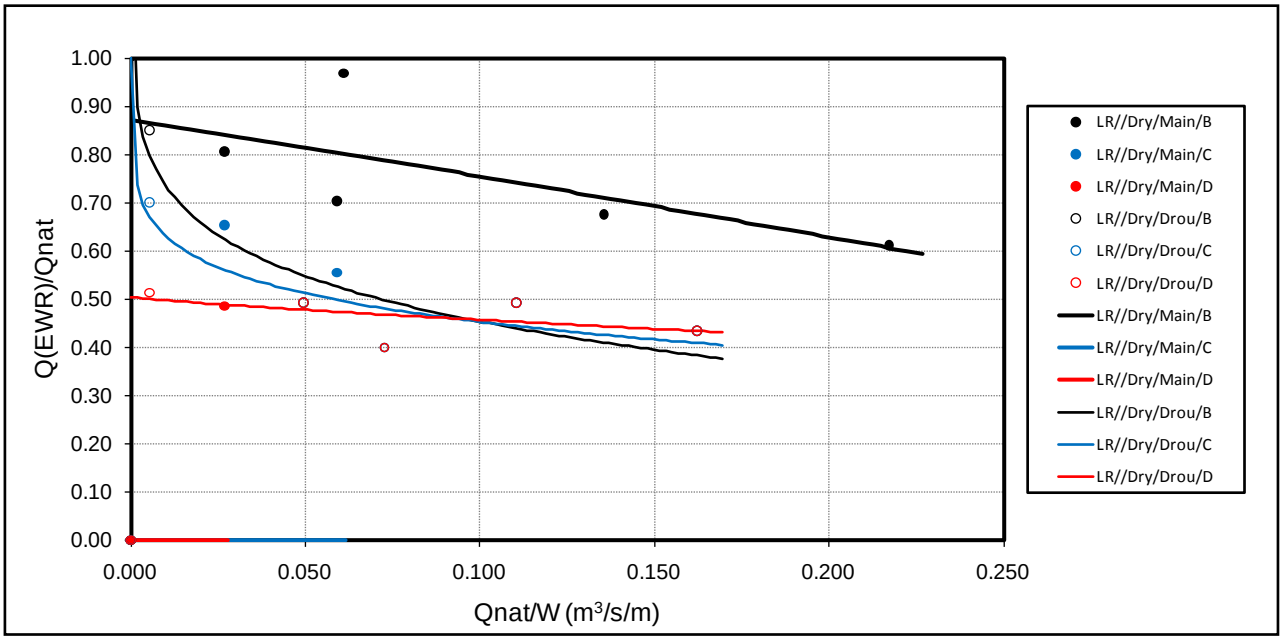


Figure 7.4 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for LR fish for the dry season (drought and maintenance conditions, B to D categories). Note: insufficient data for relationships for C and D categories

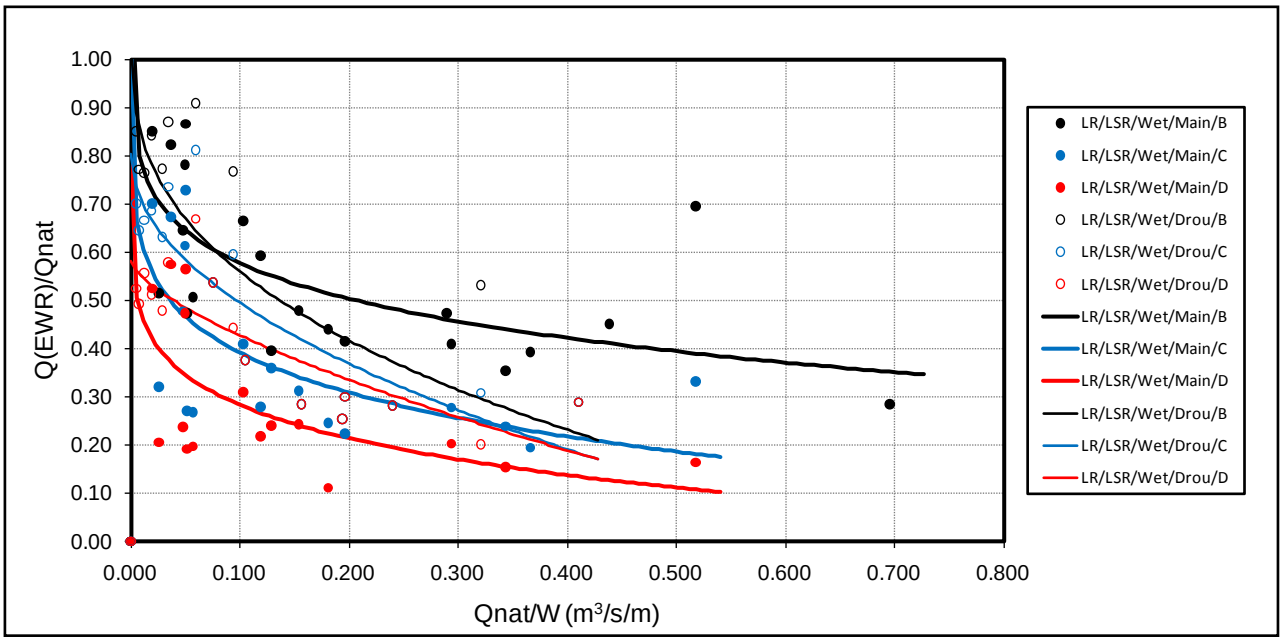


Figure 7.5 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for LR and LSR fish for the wet season (drought and maintenance conditions, B to D categories)

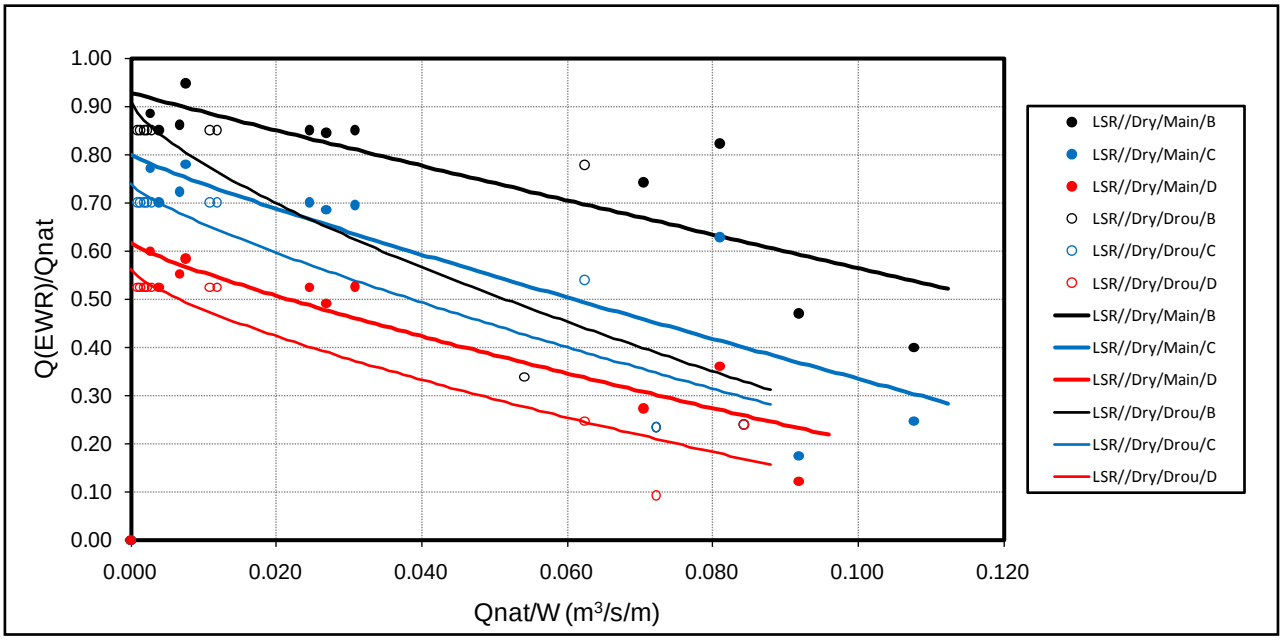


Figure 7.6 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for LSR fish for the dry season (drought and maintenance conditions, B to D categories)

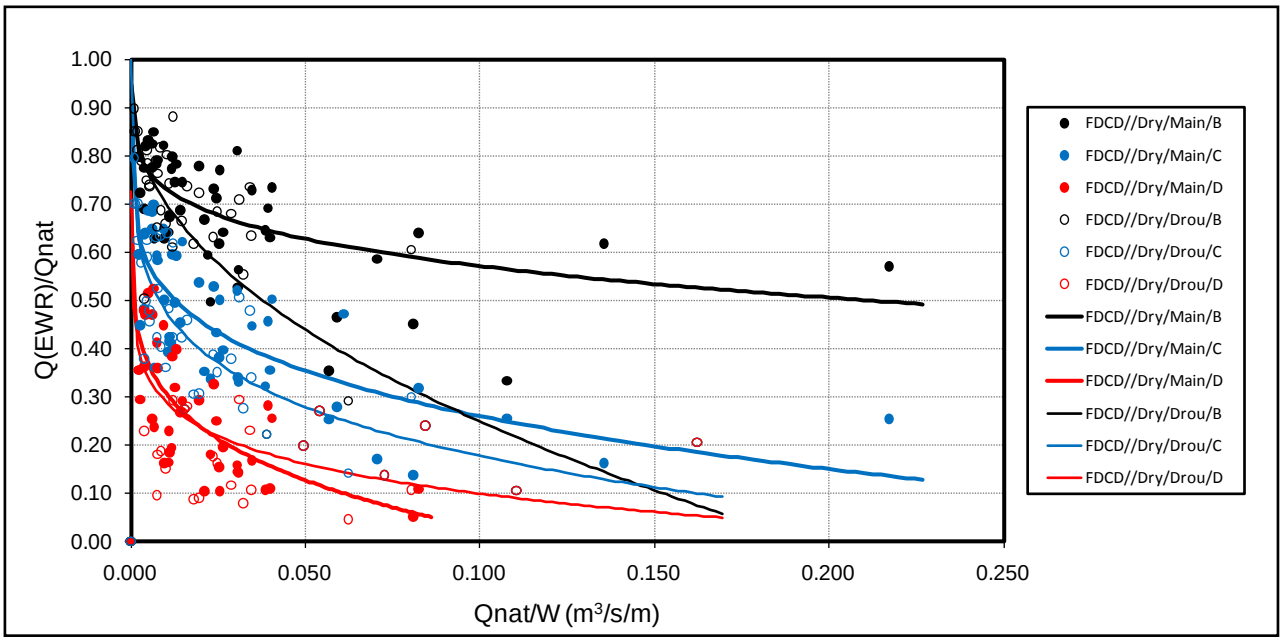


Figure 7.7 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for FDCD macroinvertebrates for the dry season (drought and maintenance conditions, B to D categories)

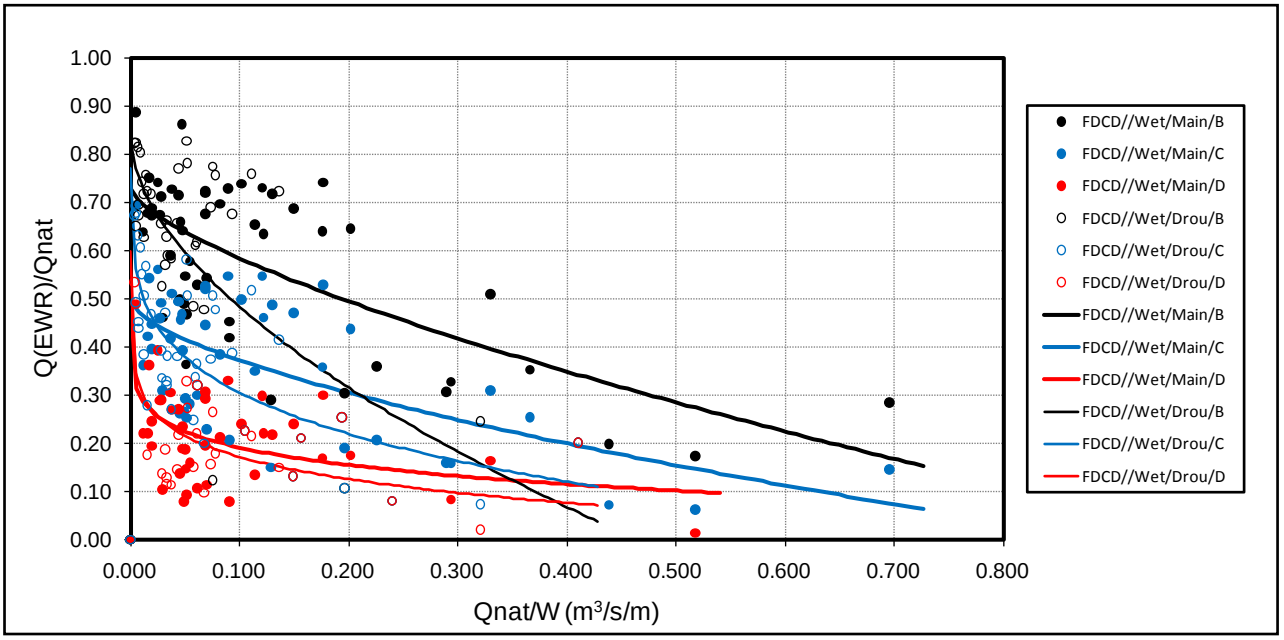


Figure 7.8 EWR requirement as a proportion of the natural unit discharge as a function of the natural unit width discharge for FDC) macroinvertebrates for the wet season (drought and maintenance conditions, B to D categories)

Table 7.1 Regression coefficients in $Q(\text{EWR})/Q\text{nat} = a - b(Q\text{nat}/W)^c$

Series	Guild/taxa		Season	Position on FDT	Ecological Category	Max.: Qnat/*W*	Regression coefficients		
	Indicator 1	Indicator 2					*a*	*b*	*c*
1	SR		Dry	Maintenance	B	0.217	0.904	1.084	0.642
2	SR		Dry	Maintenance	C	0.108	0.780	2.276	0.697
3	SR		Dry	Maintenance	D	0.092	0.578	1.354	0.573
4	SR		Dry	Drought	B	0.162	0.990	1.987	0.517
5	SR		Dry	Drought	C	0.162	0.816	1.100	0.381
6	SR		Dry	Drought	D	0.162	0.793	0.595	0.101
7	SR	SSR	Wet	Maintenance	B	0.695	1.301	1.192	0.244
8	SR	SSR	Wet	Maintenance	C	0.366	1.201	1.336	0.248
9	SR	SSR	Wet	Maintenance	D	0.294	0.823	1.118	0.348
10	SR	SSR	Wet	Drought	B	0.410	1.015	1.637	0.546
11	SR	SSR	Wet	Drought	C	0.410	0.888	1.236	0.444
12	SR	SSR	Wet	Drought	D	0.410	0.674	0.790	0.389
13	SSR		Dry	Maintenance	B	0.034	0.878	1.066	0.739
14	SSR		Dry	Maintenance	C	0.034	0.760	1.356	0.632
15	SSR		Dry	Maintenance	D	0.034	0.604	1.554	0.602
16	SSR		Dry	Drought	B	0.028	0.835	0.951	0.909
17	SSR		Dry	Drought	C	0.028	0.677	1.310	0.734
18	SSR		Dry	Drought	D	0.028	0.474	1.372	0.776
19	LR		Dry	Maintenance	B	0.217	0.870	1.341	1.065
20	LR		Dry	Maintenance	C	0.059	Insufficient data		
21	LR		Dry	Maintenance	D	0.027	Insufficient data		
22	LR		Dry	Drought	B	0.162	1.551	1.476	0.129
23	LR		Dry	Drought	C	0.162	1.223	1.001	0.114
24	LR		Dry	Drought	D	0.162	0.505	0.309	0.809
25	LR	LSR	Wet	Maintenance	B	0.695	1.368	1.065	0.129
26	LR	LSR	Wet	Maintenance	C	0.518	1.243	1.159	0.134
27	LR	LSR	Wet	Maintenance	D	0.518	0.953	0.928	0.141
28	LR	LSR	Wet	Drought	B	0.410	1.043	1.142	0.374
29	LR	LSR	Wet	Drought	C	0.410	0.805	0.963	0.492
30	LR	LSR	Wet	Drought	D	0.410	0.583	0.728	0.671
31	LSR		Dry	Maintenance	B	0.108	0.928	3.290	0.957
32	LSR		Dry	Maintenance	C	0.108	0.799	3.558	0.885
33	LSR		Dry	Maintenance	D	0.092	0.617	2.748	0.824
34	LSR		Dry	Drought	B	0.084	0.911	3.292	0.701
35	LSR		Dry	Drought	C	0.084	0.738	3.108	0.789
36	LSR		Dry	Drought	D	0.084	0.562	2.359	0.724
37	FDCD		Dry	Maintenance	B	0.217	0.993	0.681	0.208
38	FDCD		Dry	Maintenance	C	0.217	0.894	1.078	0.230
39	FDCD		Dry	Maintenance	D	0.082	0.755	1.183	0.212
40	FDCD		Dry	Drought	B	0.162	0.936	2.012	0.467
41	FDCD		Dry	Drought	C	0.162	1.190	1.440	0.153
42	FDCD		Dry	Drought	D	0.162	1.067	1.205	0.095
43	FDCD		Wet	Maintenance	B	0.695	0.727	0.718	0.700
44	FDCD		Wet	Maintenance	C	0.695	0.495	0.528	0.635
45	FDCD		Wet	Maintenance	D	0.518	0.614	0.556	0.119
46	FDCD		Wet	Drought	B	0.410	0.831	1.281	0.566

Series	Guild/taxa		Season	Position on FDT	Ecological Category	Max.: Qnat/*W*	Regression coefficients		
	Indicator 1	Indicator 2					*a*	*b*	*c*
47	FDCD		Wet	Drought	C	0.410	0.830	0.866	0.217
48	FDCD		Wet	Drought	D	0.410	0.893	0.886	0.090

7.2 ESTIMATING WETTED CHANNEL WIDTH

To apply the EWR estimation method at hydronodes, the wetted channel width as a function of discharge, is required. This would generally be provided through hydraulic analyses, but no site-specific hydraulic information is available at hydronodes. A general relationship between wetted channel width and discharge was derived using modelled (width *vs.* discharge) data for sites used in this study (Figure 7.9). Also plotted in Figure 7.9 are the data and relationship derived from measured hydraulic data from previous IFR/EWR studies (Birkhead and Desai, 2009), indicating that the relationships compare reasonably well, with deviations at the lower and upper data ranges. The width-discharge relationship derived from modelled data, and used in this study, is given by $W = 9.561Q^{0.309}$.

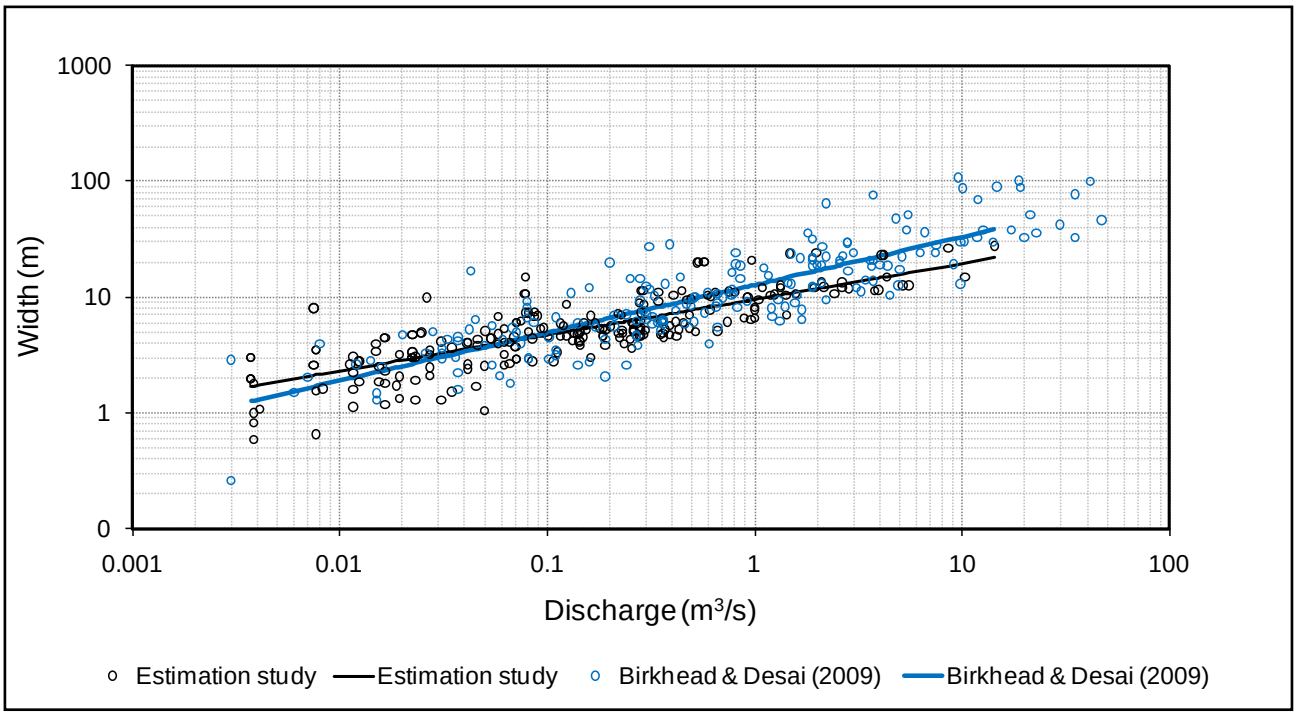


Figure 7.9 Data and relationships between wetted channel width and discharge for sites used in this study (i.e. modelled) and from the hydraulic data base of Birkhead and Desai (2009)

8. APPLICATIONOF ESTIMATION TO HYDRONODES

A procedure for applying the EWR estimation method (described in Chapter7) as a Desktop Adjustment Method (DAM - refer to Birkhead, 2008) was develop using MS-Excel and VBA. The procedure consists of the following steps:

- Compile a data base of the following information for the hydronodes where EWR estimates are required:
  - Hydronode number.
  - Quaternary number.
  - River name.
  - Locality comment.
  - Mean annual runoff.
  - Hydrology region (a Desktop Reserve parameter).
- Select from a drop-down menu for each hydronode:
  - The EWR estimation method. These include -
    - 'Extrap.', i.e. where the flow requirement will be directly extrapolated from the EWR site results using the Reserve Desktop Model (this method should, however, only be used where the two sites are ecologically similar - refer to Kleynhans et al. (2008) and Chapter 5 of this document),
    - 'DAM', i.e. apply the Desktop Adjustment Method described in this report.
    - 'Def. Desk', i.e. apply the default Reserve Desktop Model (no adjustments).
    - 'Fit Desk', i.e. fit the Reserve Desktop Model to the results of a flow assessment method (e.g. FFHA in this context).
    - 'Yield model', i.e. allow the yield model to derive flow requirements based on EWRs at hydronodes in close proximity (uses flow continuity).
- Enter the presence of fish indicator guilds. For the purposes of this study, these are limited to SR, LR, SSR and LSR. From a drop-down menu, model application computes (if selected, as this may also be entered manually) the relevant fish indicator fish guild, i.e. the guild with the highest flow requirements applicable to hydrological season (i.e. wet or dry) and the two exceedance points on the FDT (i.e. maintenance or drought). For medium-sized semi-rheophilics, large semi-rheophilics are assumed (since insufficient data exists for the former guild).
- For indicator macroinvertebrate taxa only FDCD are used, and if appropriate to the local morphology - otherwise macroinvertebrates should be excluded and only fish indicator guilds used.
- Enter the natural (modelled) discharge, as well as the default Desktop Reserve Model flow requirements. The natural flows (maintenance and drought, wet and dry seasons) were derived from appropriate exceedance values on the natural FDTs (EWR rule tables). These exceedances were determined by assessing the positions (of maintenance and drought default Reserve Desktop estimate values) on the corresponding EWR rule tables (i.e. 'Reserve flows without high flows').
- Execute (run) the DAM estimation procedure (VBA Macro), which computes:
  - Wetted channel width
  - For indicator fish guilds and macroinvertebrate taxa, the relative (to natural) EWR estimate.
  - The maximum (of the fish and macroinvertebrate) DAM estimate.

- The maximum of the DAM and default Reserve Desktop Model estimates (i.e. the DAM requirement is not permitted to be less than the default Reserve Desktop Model value, since the upper ranges of the fitted relationships in Figure 7.1 to Figure 7.8 were not determined with sufficient certainty).

- Finally, default Reserve Desktop Model parameters (maintenance and drought distributions and scaling factors) are adjusted (and recorded) to achieve the closest agreement with the DAM EWR estimates, and the standard EWR .rul and EWR .tab tables text files are saved for the ensuing yield modelling.

This procedure was used to provide EWR estimates for 66, 85 and 37 hydronodes in the Sabie, Crocodile and Mokolo River catchments, respectively. The above spreadsheet and data are provided in the electronic data (RDM Report no 26/8/3/10/12/016 and 26/8/3/10/14/016) as well as the .rul and .tab tables.

As explained previously and in Chapter 7, the EWR estimates were supplied using basically either an extrapolated or estimated approach. The extrapolation approach is undertaken in two different ways as follows:

- Where the flow requirement will be directly extrapolated from EWR site results using the Reserve Desktop Model ('Extrapolate' in Table 8.1, 8.2 and 8.3. See also Figure 2.1.).
- Allowing the yield model to derive flow requirements based on EWRs at hydronodes which will/can be overridden by the comprehensive EWR requirements. This will typically be a site upstream of an EWR site or between two EWR sites. (Yield model in Table 8.1, 8.2 and 8.3. See also Figure 2.1).

All the EWR rules for the extrapolated and estimated approach are provided electronically.

The hydronodes and method used to determine the EWRs are provided in the tables and figures below. The colour coding in the maps (Figure 8.1 – 8.3) coincides with those in the tables (Table 8.1 – 8.3).

Table 8.1 Estimation method followed at the Sabie System hydronodes

Hydronode or EWR site	Quat	River	Method
X31A-1	X31A	Sabie	Estimate
X31A-2	X31A	Klein Sabie	Estimate
X31B-1	X31B	Sabie	Estimate
X31C-1	X31C	Mac Mac	Estimate
X31C-2	X31C	Mac Mac	Yield model
X31D-1	X31D	Sabie	Yield model
X31D-2	X31D	Sabane	Estimate
X31D-3	X31D	Sabie	Yield model
X31E-1	X31E	Ngwaritsane	Estimate
X31E-2	X31E	Maritsane	Estimate
X31E-3	X31E	Marite	Estimate
X31F-1	X31F	Motitsi	Estimate
X31G-1	X31G	Marite	Yield model
X31G-2	X31G	Motitsi	Extrapolate

Hydronode or EWR site	Quat	River	Method
X31H-1	X31H	Witwaterspruit	Estimate
X31H-2	X31H	Witwaterspruit	Estimate
X31J-1	X31J	Noordsand	Extrapolate
X31K-1	X31K	Sabie	Yield model
X31K-2	X31K	Phabeni	Estimate
X31K-3	X31K	Bejani	Estimate
X31K-4	X31K	Sabie	Yield model
X31L-1	X31L	Saringwa	Estimate
X31L-2	X31L	Matsavana	Estimate
X31L-3	X31L	Saringwa	Estimate
X31M-1	X31M	Sabie	Yield model
X31M-2	X31M	Sabie	Yield model
X31M-3	X31M	Msimuku	Estimate
X31M-4	X31M	Sabie	Yield model
X32A-1	X32A	Sand	Estimate
X32A-2	X32A	Thulandiziteka	Estimate
X32B-1	X32B	Motlamogatsane	Estimate
X32C-1	X32C	Thulandiziteka	Yield model
X32C-2	X32C	Thulandiziteka	Yield model
X32C-4	X32C	Klein Sand	Extrapolate
X32C-5	X32C	Nwandlamuhari	Yield model
X32C-6	X32C	Sephiriri	Estimate
X32C-7	X32F	Mutlumuvi	Yield model
X32D-1	X32D	Mohlomobe (Mutlumuvi)	Estimate
X32D-2	X32D	Mutlumuvi	Extrapolate
X32E-1	X32E	Nwarhele	Estimate
X32E-2	X32E	Nwarhele	Extrapolate
X32F-1	X32F	Mutlumuvi	Estimate
X32F-2	X32F	Orinoco	Estimate
X32F-3	X32F	Orinoco	Estimate
X32F-4	X32F	Mutlumuvi	Estimate
X32G-1	X32G	Sand	Yield model
X32G-2	X32G	Khukhovula	Estimate
X32G-3	X32G	Sand	Yield model
X32H1	X32H	Sand	Yield model
X32H2	X32H	Manyeleti	Estimate
X32J-1	X32J	Sand	Extrapolate
X32J-2	X32J	Mutlumuvi	Estimate
X32J3	X32J	Sand	Estimate
X33A-1	X33A	Nwatinolopfu	Estimate
X33A-2	X33B	Sabie	Yield model
X33B-1	X33B	Sabie	Yield model
X33D-1	X33D	Sabie	Yield model

Table 8.2 Extrapolation/estimation method followed at the Crocodile System hydronodes

Hydronode or EWR site	River	Method
X21A-1	Crocodile	Yield model
X21A-2	Crocodile	Yield model
X21B-1	Lunsklip	Extrapolate
X21B-2	Lunsklip	Extrapolate
X21B-3	Crocodile	Extrapolate
X21C-1	Alexanderspruit	Estimate
X21C-3	Elandspruit	Estimate
X21D-1	Sterkloop	Estimate
X21D-2	Crocodile	Yield model
X21E-1	Crocodile	Yield model
X21E-2	Crocodile	Yield model
X21F-1	Elands	Yield model
X21F-2	Elands	Yield model
X21G-1	Elands	Yield model
X21G-2	Elands	Yield model
X21H-1	Ngodwane	Estimate
X21H-2	Ngodwane	Estimate
X21J-1	Elands	Yield model
X21J-2	Elands	Yield model
X21K-1	Lupelule	Estimate
X21K-2	Elands	Yield model
X21K-3	Elands	Yield model
X22A-1	Houtbosloop	Estimate
X22A-2	Houtbosloop	Estimate
X22B-1	Statsrivier	Estimate
X22B-2	Crocodile	Yield model
X22C-1	Brinkspruit	Estimate
X22C-2	Gladdespruit	Estimate
X22C-3	Crocodile	Yield model
X22D-1	Nelspruit	Estimate
X22D-2	No Name	Estimate
X22D-3	Nelspruit	Estimate
X22E-1	No Name	Estimate
X22E-2	Sandspruit	Estimate
X22E-3	Sandspruit	Estimate
X22F-1	Sandspruit	Estimate
X22F-2	Nelspruit	Estimate
X22G-1	Blikwaterspruit	Estimate
X22G-2	Blikwaterspruit	Estimate
X22H-1	Witrivier	Estimate
X22H-2	Witrivier	Estimate
X22H-3	Witrivier	Estimate
X22J-1	Crocodile	Yield model
X22J-2	Crocodile	Yield model
X22K-1	Crocodile	Yield model
X22K-2	Crocodile	Yield model
X22K-3	Crocodile	Yield model
X23A-1	NoordKaap	Estimate
X23A-2	NoordKaap	Estimate
X23B-1	Rietspruit	Estimate

Hydronode or EWR site	River	Method
X23B-2	NoordKaap	Estimate
X23B-3	NoordKaap	Estimate
X23C-1	SuidKaap	Estimate
X23C-2	SuidKaap	Estimate
X23D-1	SuidKaap	Estimate
X23D-2	SuidKaap	Estimate
X23E-1	Queensriver	Estimate
X23E-2	Queensriver	Estimate
X23F-1	Queens	Estimate
X23F-2	SuidKaap	Estimate
X23G-1	Figtree Creek	Estimate
X23H-1	Kaap	Yield model
X23H-2	Louw'sCreeK	Estimate
X23H-3	RevolversCreek	Estimate
X23H-4	RevolversCreek	Estimate
X23H-5	SuidKaap	Estimate
X24A-1	Nsikazi	Estimate
X24A-2	Nsikazi	Estimate
X24B-1	Gutshwa	Estimate
X24B-2	Gutshwa	Estimate
X24B-3	Nsikazi	Estimate
X24C-1	Nsikazi	Estimate
X24C-2	Crocodile	Yield model
X24D-1	Buffalocreek	Estimate
X24E-1	Crocodile	Yield model
X24E-2	Crocodile	Yield model
X24F-1	Crocodile	Yield model
X24H-1	Crocodile	Yield model
X24H-2	Crocodile	Yield model

Table 8.3 Extrapolation/estimation method followed at the Mokolo System hydronodes

Hydronode or EWR site	River	Method
A42A-1	Loubad	Estimate
A42A-2	Upper Sand	Estimate
A42A-4	Sand (Mogol)	Estimate
A42B-1	Lower Grootspruit	Estimate
A42B-2	Upper Grootspruit	Estimate
A42B-4	Venterspruit	Estimate
A42B-5	Sandspruit	Estimate
A42C-1	Mokolo	Estimate
A42C-3	Klein Sand	Estimate
A42C-4	Mokolo	Yield model
A42C-7	Wolwefontein	Estimate
A42D-1	Middle Sterkstroom	Estimate
A42D-2	Upper Sterkstroom	Estimate
A42D-3	Upper Frikkieseloop	Estimate
A42D-4	Sterkstroom	Estimate
A42D-5	Lower Frikkieseloop	Estimate
A42D-6	Upper Grootfontein	Estimate
A42D-7	Lower Grootfontein	Estimate
A42E-3KLVaal	Klein Vaalwater	Estimate

A42E-5	Mokolo	Yield model
A42E-6	Lower Dwars	Estimate
A42E-7	Bellevue	Estimate
A42E-8	Upper Dwars	Estimate
A42F-2	Platbosspruit	Estimate
A42F-3	Malmanies	Estimate
A42G-1	Poer se Loop	Estimate
A42G-3	Mokolo	Yield model
A42G-4	Riespruit	Estimate
A42H-1	Lower Tambotie	Estimate
A42H-2	Mogol	Yield model
A42H-3	Upper Tambotie	Estimate
A42J-1	Mokolo	Yield model

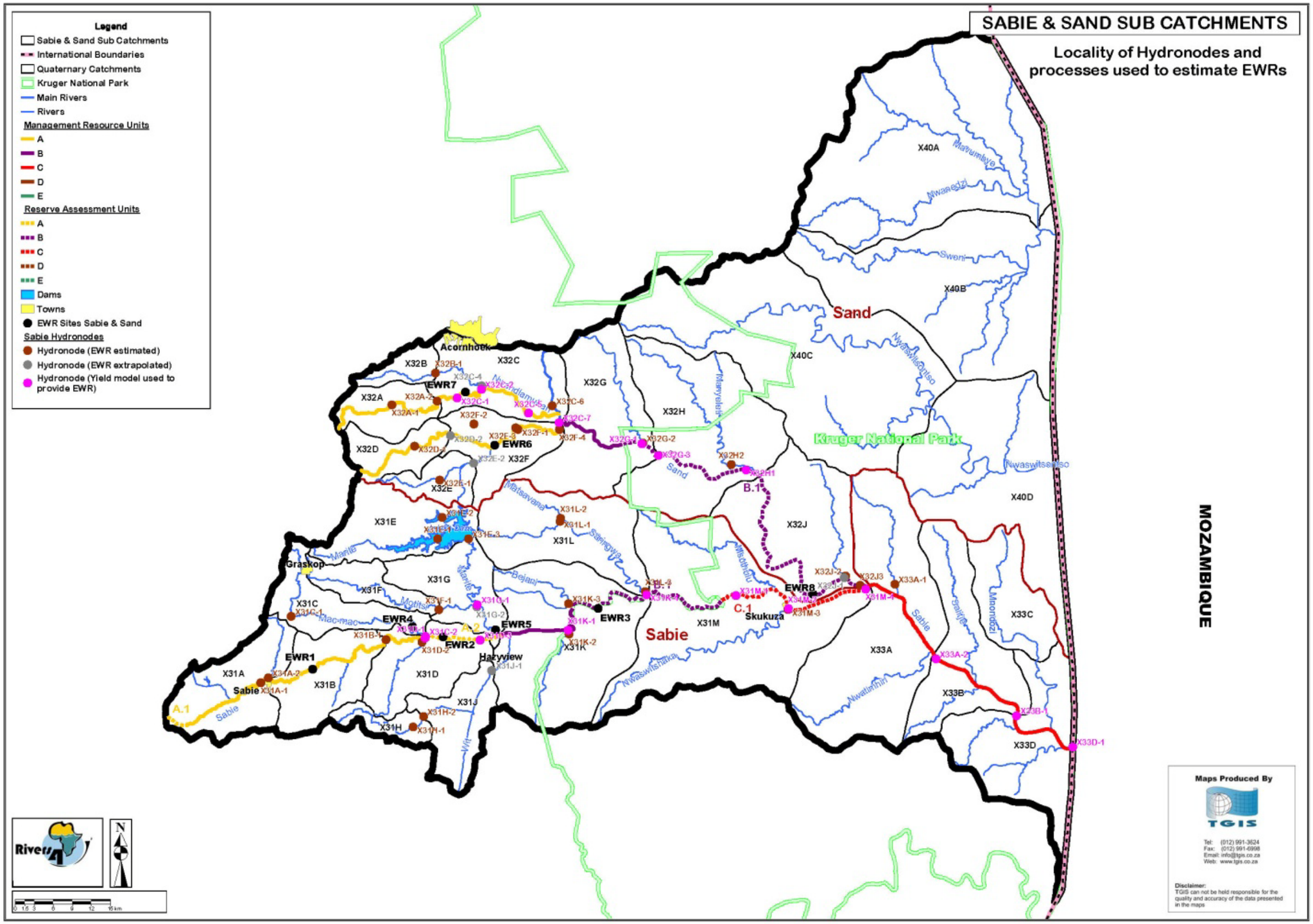


Figure 8.1 Hydronodes and tools used to estimate EWRs (Sabie)

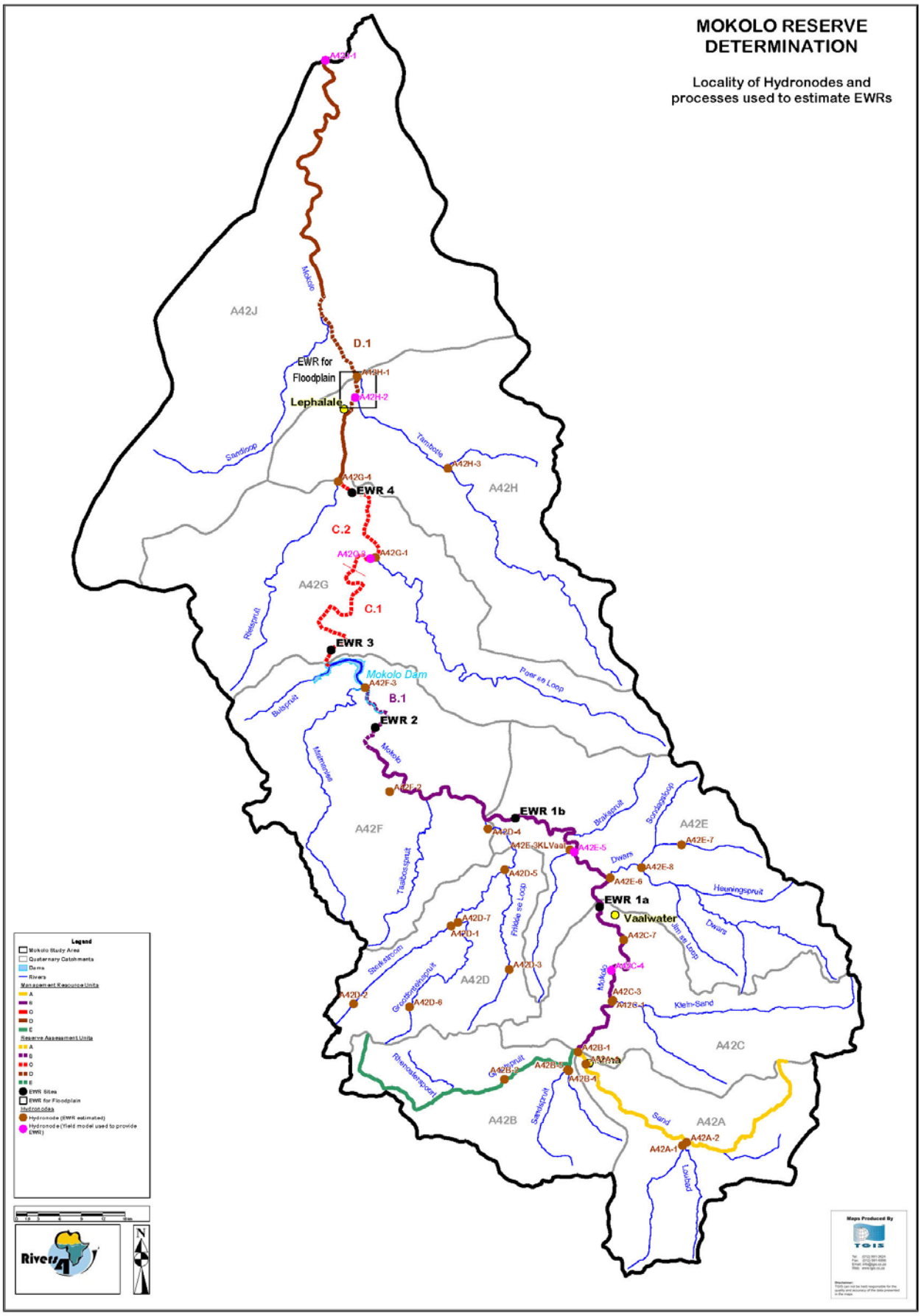


Figure 8.2 Hydronodes and tools used to estimate EWRs (Mokolo)

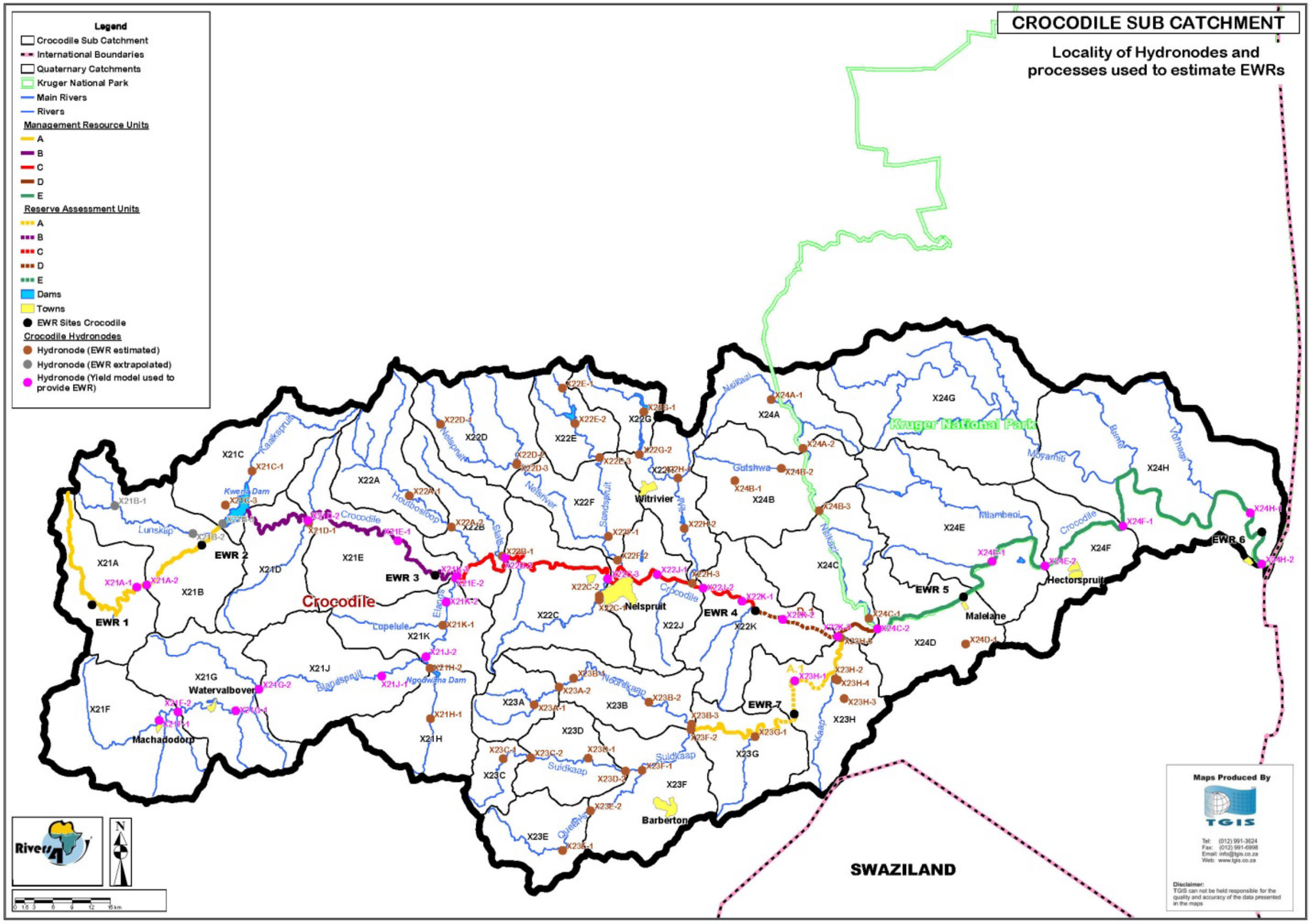


Figure 8.3 Hydronodes and tools used to estimate EWRs (Crocodile)

9. ANALYSIS OF RESULTS

Authors: Delana Louw (Rivers for Africa) and Stephen Mallory (IWR Water Resources)

9.1 DETERMINATION OF THE DEGREE TO WHICH THE RESERVE IS AVAILABLE UNDER CURRENT OPERATING RULES

9.1.1 Approach

The EWRs were provided for the Recommended Ecological Category (REC) (as flow duration tables) at various hydronodes. A water resources model was then used to simulate the flow throughout the system. The Water Resources Modelling Platform (www.waterresources.co.za/Research&Development) was used for this modelling.

During the course of this modelling, it was found that interpretation of whether the Ecological Reserve is met or not is not obvious. It is suggested that there are two components of failure:

- The number of failures within the modelled time period (referred to as assurance); and
- The volume of water available that could not be supplied (within this same time period) to the Reserve, referred to as a deficit.

The deficit (portion of Ecological Reserve that is not being met) can be very small while the assurance is very low (many small failures to meet the Ecological Reserve), while the opposite is also possible, namely, high assurance and high deficit (a few large failures). A method to interpret, in a scientific and consistent manner, the degree to which the Reserve requirement is met is required.

A methodology was developed and applied as part of this project as follows:

a) Rate assurance of supply on a scale of 1 to 5 as indicated in Table 9.1.

Table 9.1 Assurance rating

Assurance (% of time that the Reserve was fully met)	Rating
> 95	0
90 to 95	1
85 to 90	2
80 to 85	3
75 to 80	4
< 80	5

b) Rate the average volume of water available to the Reserve in each month on a scale of 1 to 5 as indicated in Table 9.2 and 9.3.

Note that the rating system for small rivers (defined as having a natural MAR of less than 30 million m^3/annum) differs from that of larger rivers (natural MAR greater or equal to 30 million m^3/annum).

Table 9.2 Volume rating: Large Rivers (MAR > 30 million m^3/annum)

Assurance (% of time that the Reserve was fully met)	Rating
> 95	0
90 to 95	1
85 to 90	2
80 to 85	3
75 to 80	4
< 80	5

Table 9.3 Volume rating: Small Rivers (MAR < 30 million m^3/annum)

Assurance (% of time that the Reserve was fully met)	Rating
> 90	0
85 to 90	1
80 to 85	2
75 to 80	3
80 to 75	4
< 75	5

c) Calculate an average score from the two ratings

The assurance and volume supplied received an equal weighting for determining the average rating. It is debatable whether this is the most appropriate approach and it is recommended that a more rigorous approach to determine the weighting given to assurance and volume should be developed by ecologists.

In addition to the above, a further criterion was introduced which assessed whether zero flows occurs (in the modelled data) under present conditions in naturally perennial systems. If this was found to occur in any month, then that month was rated as a 5 regardless of the volume or assurance rating. The reason for this is that the severity of changing a river from natural to perennial is ecologically severe.

The above ratings were done for every month; hence it is possible to obtain a good idea of the seasonality of Reserve failures. However, to keep this report concise, an annual rating has been determined using the same procedure given above. The ratings provided in Table 9.1 to 9.3 are hence annual ratings.

The results were modelled for the REC at the hydronodes. The EC for quaternary catchments as provided as part of the Desktop Level assessment (26/8/3/10/12/002) has been used for the hydronodes. The EWR sites are modelled for the EC recommended by DWA as the final result (the recommended Reserve to be signed off).The results at the hydronodes are provided in the tables (Table 9.4 to 9.6) and figures (Figure 9.1 to 9.3). All the flow duration tables for these sites are provided electronically.

The maps should be interpreted/used according the description of the different ratings below. An indication of the actions required to address uncertainty and to confirm the results is provided below. These are only a very preliminary guideline and do not necessarily address all steps that can be taken.

RED (5): Insufficient water is available to meet the Ecological Reserve under present conditions.
No licenses that will decrease flow should be considered as the Reserve is currently not being met. This means that there will be no yield available for additional users. Even if the Reserve is a low confidence Reserve based on an estimate, it is unlikely that revision will change the situation sufficiently that the Reserve will be met, AND that there will be yield available. It must be considered however that these are broad estimates and that there is uncertainty in the hydrology as well as the EWR estimates. Therefore, as a first check to confirm the red evaluation, the confidence in the hydrology and the reasons why the Reserve is not being met should be checked. EG, it is often the case that the hydrological modelling results in an underestimate of hydrology in areas high up in the catchment such as first order stream. In those cases, the estimated EWR is often higher than the modelled hydrology and shows an Ecological Reserve deficit when that is not really the case. All results must therefore be treated with caution and prior to decisions being made on these ratings, the specific situation should be evaluated and the results unpacked. It must also be noted that the application of the Desktop Level EcoClassification to derive at the REC is only done for a specific river within the catchment under consideration. A future development may be applicable for a tributary of the river that was assessed and the EC and specific EWR may well be very different.
ORANGE (4): There is a high likelihood that there is not enough water to meet the REC under present conditions.
This means that there is a high likelihood that there will be no yield available for additional users. See section in red above.
PALE ORANGE (3): There is a moderate likelihood that there is not enough water to meet the REC.
Assess the most cost-effective steps needed to investigate the situation. Confirmation of the REC as part of a Rapid III should be sufficient as a first step. If the EcoClassification results have changed, the level of Reserve such as this estimate might not be appropriate. Once the Reserve has been refined (if necessary), then the yield analysis must be recalculated.
CREAM (2): There is a low likelihood that there is not enough water to meet the REC.
Assess the most cost-effective steps to take to investigate the situation. Confirmation of the REC through scoping should be sufficient as a first step. A Desktop assessment of the flows if the scoping assessment of the REC results in a different REC changes should be sufficient for a revision of the water balance. Even if the Reserve is infrequently not met, this still means that there could be yield available in this system. Refer to 9.2 to determine whether yield will be available and the scale of the available yield.
WHITE (1): There is a high likelihood that there is sufficient water in the system to meet the REC.
This does not necessarily mean that there is yield available for additional users. Refer to section 9.2 to determine whether yield is available and the scale of available yield.

It must be noted that these results ONLY indicate the degree to which the Reserve is currently being met. It does NOT indicate whether additional yield is available for other

uses. This will be a separate analysis (see 9.2). E.g., even though a catchment is indicated as white, i.e. the Reserve is met; it does not necessarily mean that there is additional water available for other uses. These maps therefore only provide an indication of CURRENT PROBLEMS regarding meeting the EWR at the REC for the hydronodes.

9.1.2 Mokolo River results: Degree to which the Reserve is being met under current operation

The results are supplied in the Table 9.4 and illustrated in Figure 9.1.

Table 9.4 Mokolo: Rating values to describe the likelihood of insufficient water to be available to meet the Ecological Reserve at the REC hydronodes

Hydronodes	REC (PES)*	Rating (5)
A42A1	B (C)	5
A42A-2	D	5
A42A-4	D	5
A42B-1	D	5
A42B-2	D	5
A42B-4	D	4
A42B-5	D	5
A42C-1	C	0
A42C-3	C	5
A42C-4	C	0
A42C-7	C	0
A42D-1	C (IB/C)	1
A42D-2	B (C)	0
A42D-3	B	0
A42D-4	B (C)	5
A42D-5	B	2.5
A42D-6	B (C)	1
A42D-7	B (C)	3
A42E-3	C	2
A42E-5	C	0
A42E-6	C	3.5
A42E-7	C	0
A42E-8	C	1
A42F-2	B	1
A42F-3	B	2
A42G-1	B	2.5
A42G-3	B/C (C/D0	0
A42G-4	B	2
A42H-1	B	5
A42H-2	C (D)	0
A42H-3	B	3
A42J-1	B/C (C/D)	0

* PES are provided in brackets where it differs from the PES

The EWRs for the EWR sites had to be provided as first priority. As the decision was made that the current hydrology will be signed off as the Ecological Reserve, all the catchments which includes the Mokolo River are evaluated as a zero, i.e. the Ecological Reserve is currently being met under the present flow conditions.

The EWRs for the REC cannot be met currently are concentrated in the upper Mokolo. This is due to the many farm dams, as well as illegal water use. The other area of concern is in the lower

Sterkstroom where there is intensive irrigation. The red area indicated in the Tambotie system is highly likely a result of inaccurate hydrology as the river is seasonal and there are very little developments present in the Tambotie system. It is therefore unlikely that the Reserve will not be met.

Taking into account the problems in the Sterkstroom currently, steps should be taken to ensure the protection of this resource. The Sterkstroom is a strong perennial tributary and is currently one of the only refuges for the biota in the Mokolo River when the Mokolo River stops flowing. These refugia require protection as any further use that can impact on the refugia; will result in the Mokolo River PES degrading, even without any flow changes in the Mokolo.

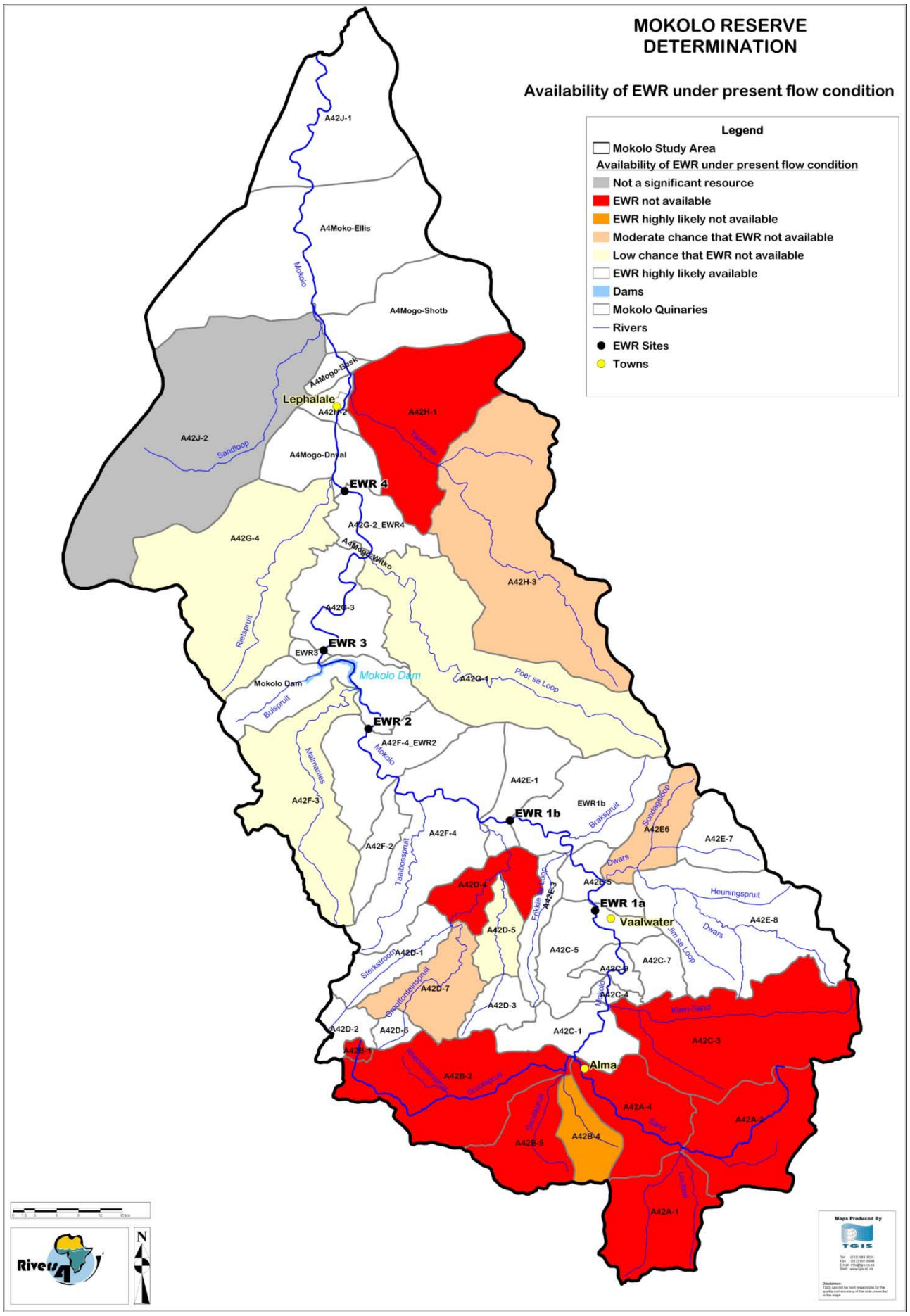


Figure 9.1 Mokolo Catchment: EWR availability

9.1.3 Crocodile River results: Degree to which the Reserve is being met under current operation

The results are supplied in the Table 9.5 and illustrated in Figure 9.2.

Table 9.5 Crocodile: Rating values to describe the likelihood of insufficient water to be available to meet the Ecological Reserve at the REC hydronodes

Hydronodes	REC (PES)*	Rating (5)
X21B-1	B	2.5
X21B-2	B	1
X21B-3	B	1
X21C-1	B (B/C)	0
X21C-2	B (B/C)	0
X21C-3	B (B/C)	0
X21D-1	B (B/C)	0
X21H-1	B	0
X21H-2	B	5
X21J-2	B	0
X21K-1	B	5
X21K-2	B	0
X22A-1	B	0
X22A-2	B	2
X22B-1	B (B/C)	5
X22C-1	C	0
X22C-2	C	0
X22D-1	B	0
X22D-2	B	0
X22D-3	B	0
X22E-1	D	0
X22E-2(Witklip)	D	5
X22E-3	D	5
X22F-1	C	0
X22F-2	C	4
X22G-1(Witklip)	C	5
X22G-2(Longmere)	C	5
X22H-1 (DD)	C	5
X22H-2 (Primkop)	C	5
X22H-3	C	2.5
X23A-1	B/C	2.5
X23A-2	B/C	2.5
X23B-1	C	1
X23B-2	C	2.5
X23B-3	C	5
X23C-1	B (B/C)	3
X23C-2	B (B/C)	2.5
X23D-1	C	2.5
X23D-2	C	5

X23E-1	B/C	1.5
X23E-2	B/C	1
X23F-1	B (C)	0
X23F-2	B (C)	5
X23G-1	C	0
X23H-2	C/D	5
X23H-3	C/D	0
X23H-4	C/D	0
X24B-1	D	0
X24B-2	D	0
X24B-3	D	0
X24C-1	B (C)	0
X24D-1	B (C)	0

* PES are provided in brackets where it differs from the PES

The results supplied were only for catchments with hydronodes. To determine the results, the EWRs for the EWR sites had to be provided as first option. As the decision was made that the current hydrology will be signed off as the Ecological Reserve, all the catchments which includes the Crocodile and the lower Kaap Rivers are evaluated as a zero, i.e. the Ecological Reserve is currently being met.

The Crocodile catchment does not show many areas where the Reserve is currently not being met. However, it MUST be remembered that the REC in the main Crocodile River downstream of Kwena Damhas not been signed off due to the socio-economic impacts. This situation (i.e. that the REC is not available) is not illustrated as the main Crocodile has been modelled on the basis that the present operation and hydrology will be signed off to maintain the PES.

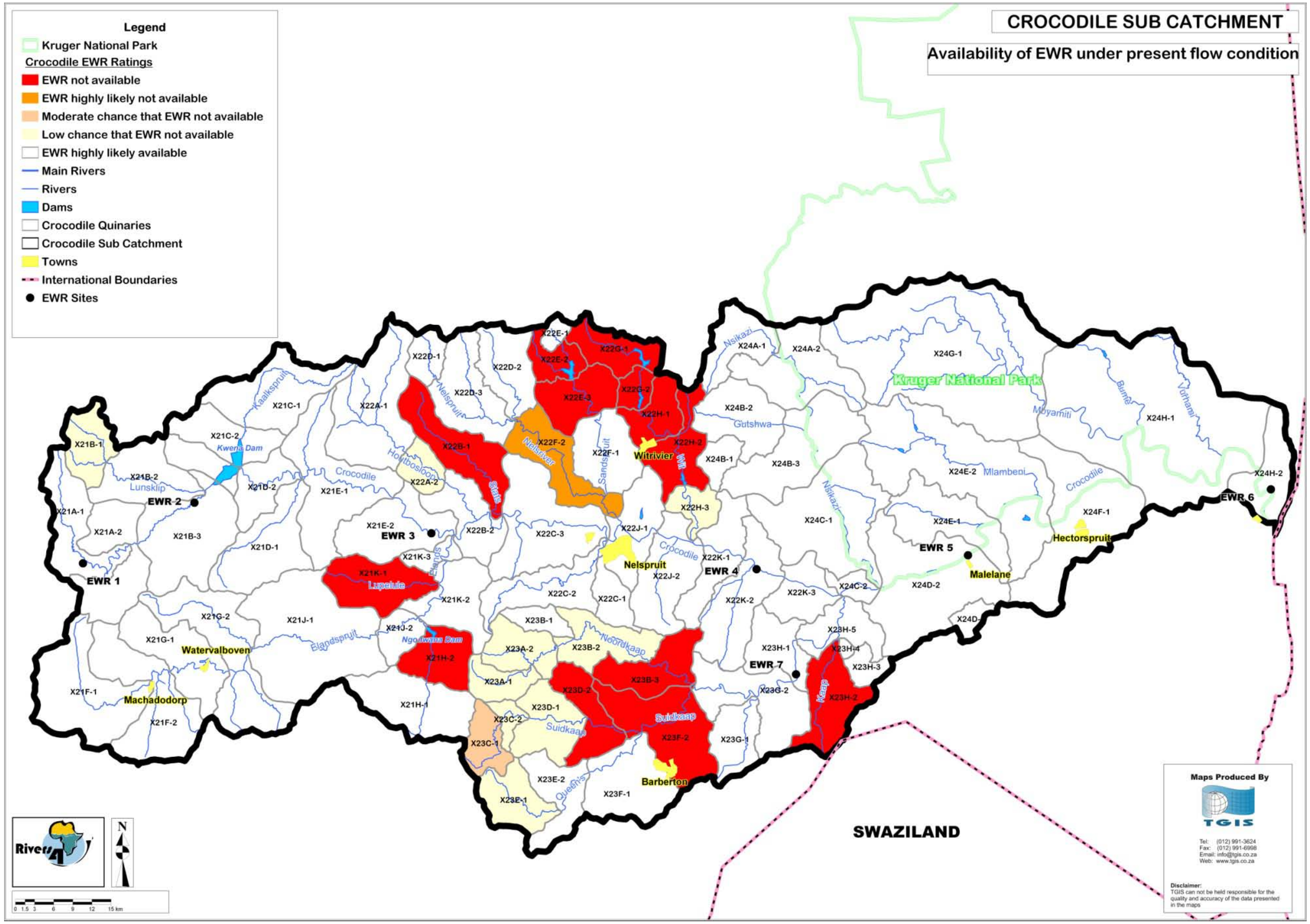


Figure 9.2 Crocodile: EWR availability

9.1.4 Sabie-Sand results: Degree to which the Reserve is being met under current operation

The results are supplied in the Table 9.6 and illustrated in Figure 9.3.

Table 9.6 Sabie-Sand: Rating values to describe the likelihood of insufficient water to be available to meet the Ecological Reserve at the REC hydronodes

Hydronodes	REC (PES)*	Rating (5)
X31A-1	B	2
X31A-2	B	2.5
X31B-1	B	0
X31C-1	A/B	2.5
X31D-2	B	0
X31E-1	B (C)	2.5
X31E-2	B (C)	0
X31F-1	B	2.5
X31G-2	B	2.5
X31H-1	C	2.5
X31H-2	C	2
X31J-1	C/D	5
X31K-2	B (C)	5
X31K-3	B (C)	0
X31L-1	D (E)	0
X31L-2	D (E)	0
X31L-3	D (E)	0
X31M-3	B (B/C)	0
X32A-1	B (C)	0
X32A-2	B (C)	0
X32B-1	B	3.5
X32C-3	C	0
X32C-4	C	5
X32C-6	C	1
X32D-1	B (C)	0
X32D-2	B (C)	1
X32E-1	B (C)	0
X32E-2	B (C)	0
X32F-1	C	0
X32F-2	C	1
X32F-3	C	1
X32F-4	C	2.5
X32G-2	C	1
X32H-2	B	1
X32J-1	B	0
X32J-2	B	1
X32J-3	B	0
X33A-1	A/B	1

* PES are provided in brackets where it differs from the PES

The results supplied were only for catchments with hydronodes. To determine the results, the EWRs for the EWR sites had to be provided as first option. The following was undertaken for this catchment:

- Sabie Catchment: REC
- Sand Catchment: The Sellick Rule (SC 1 – DWA (2010) is the accepted scenario and used in the model. This will result in the RECs being met at the three EWR sites. As the REC is available in the Sabie River, the Sabie from EWR 1 is evaluated as a zero, i.e. the Ecological Reserve is currently being met. The Sellick rule situation is similar.

There are very few stressed areas in this catchment. The red areas in the upper Sand are probably a result of the modelled hydrology inaccurately reflecting very low to zero flows. **It must be noted that there is low confidence in the Sand hydrology and this should be considered when decisions are being made. It must furthermore be noted that the Sellick-rule is currently NOT in place and the evaluation of the Sand River would show mostly a red rating if this rule is not applied.**

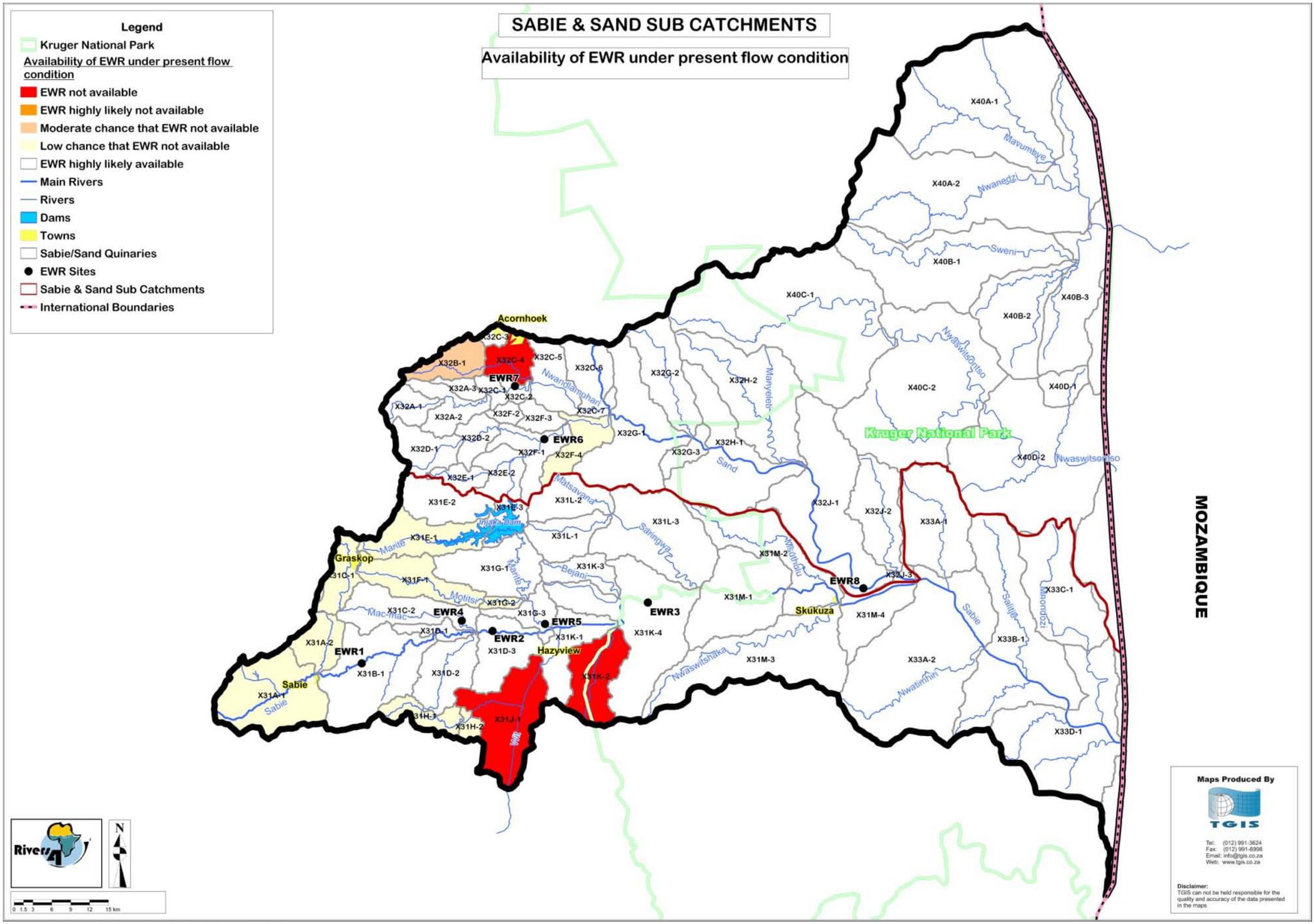


Figure 9.3 Sabie-Sand: EWR availability

9.2 AVAILABLE YIELD IN CATCHMENTS WHERE THE RESERVE IS CURRENTLY BEING MET

9.2.1 Approach

If the Reserve is met at a particular hydronode, as indicated by a rating of zero (or 1 to allow for uncertainty), it is probable that there will be utilisable yield available at that node. This available yield was estimated by including the recommended EWRs into the yield model as a high priority requirement and simulating the resulting flow through the system. Following this simulation, historic yields were calculated at all hydronodes with a rating of zero and one. These yields are presented in the following tables (Table 9.7 to 9.9). It is crucial to understand, however, that in most cases these are mutually exclusive yields. In other words you cannot obtain all these yields simultaneously, but only one of them. **If water is allocated at a hydronode to take up the available yield, the available yield at the downstream nodes will reduce, and possibly the Reserve at downstream nodes will then not be met. Hence these estimated yields only give an indication of where yield is available, but in every case more detailed analyses are required to determine the cumulative effects of allocating water.** As a general rule, if the EWR at the most downstream node cannot be met, then any allocation upstream of this point will exacerbate this situation. It is possible, however, through the development of sophisticated operation to make yield available in some cases - hence the necessity to consider license applications at nodes identified as having available yield in more detail should license application be received for allocations at these points. It is thus important to, where potential yield has been identified and Water Use Licences have been received, that the latter be assessed in terms of the available water schedules and the overall accumulative impact

The maps should be interpreted as follows:

Grey: Information already available (through the assessment to determine whether the Reserve is currently being met) that no yield available and the EWR cannot be met under current operation.
The grey catchments reflect all the catchments that were rated in section 9.1 from a 1.1 to 5. I.e., the Ecological Reserve cannot be met under current circumstances which automatically indicate that there is no yield available. If licenses and further developments are considered in these areas, appropriate work (such as described below) should be undertaken to confirm the degree to which the Reserve is not being met as well as to whether the proposed development will have an impact.
No yield available (5)
No licenses that will decrease flow should be considered. If however, further confirmation is required, more detailed studies are required to confirm these results. The first step should be to confirm the REC in the catchments where the REC has been derived from the Desktop EcoClassification. This is necessary as this is usually a low confidence estimate, and if the EC is found (after more detailed investigation) to be lower than the EC used in this yield modelling, then the EWR will be lower. The water balance will then have to be recalculated.
Very low yield (4)
As the likelihood of no water being available is high, licences should be considered only for special cases. If further confirmation is required, follow the same process as above.
Low yield (3)
Assess the most cost-effective steps to investigate the situation if development or licences are

required. It is likely that a Level 3 EcoClassification and a Rapid III Reserve assessment might be sufficient. Then check water balance to see whether yield increases if the Rapid III Reserve results are less than the estimation Reserve used for this analysis.
Moderate yield (2)
Assess the most cost-effective steps to investigate the situation if development or licences are required. It is likely that a Level 3 EcoClassification and a Rapid III Reserve assessment might be sufficient. Then check water balance to see whether yield increases if the Rapid III Reserve results are less than the estimation Reserve used for this analysis.
High yield (1)
Assess the most cost-effective steps to take to investigate the situation. Confirmation of the REC through scoping should be sufficient as a first step. If the EC changes, the appropriate estimation results for the changed EC (provided electronically – report no. 26/8/3/10/14/016) should be sufficient to use within a revision of the water balance.
Very high yield (0)
See steps described in Figure 9.7

9.2.2 Mokolo River results: Available yield

The results are supplied in the Table 9.7 and illustrated in Figure 9.4.

Table 9.7 Rating values to describe available yield in catchments where the Reserve is currently being met

Hydronode catchments	REC (PES)*	Available yield (historical) MCM/a	Rating (5)
A42C-1	C	0	5
A42C-4	C	0	5
A42C-5	B/C (C/D)	0	5
A42C-7	C	0.2	4
A42C-9	C	0	5
A42D-1	C (B/C)	0	5
A42D-2	B (C)	0.1	4
A42D-3	B	0	5
A42D-6	B (C)	0.1	4
A42E-5	B/C (C/D)	0	5
A42E-7	C	0.1	4
A42E-8	C	0.1	4
A42E-5	B (B/C)	0	5
EWR1b	B (B/C)	0	5
A42E-1	B (B/C)	0	5
A42F-4	B (B/C)	0	5
A42F-2	B	0	5
Bulspruit	B/C (C/D)	0	5
EWR3	B (B/C)	0	5
A42G-3	B (B/C)	0	5
A42Mogo-Witko	B (C)	0	5
A42G-2 EWR4	B (C)		5
A4Mogo-Dnyal	B/C (C/D)	0	5
A42H-2	C (D)	0	5
A4Mogo-Besk	C (D)	0	5
A4Mogo-Shotb	C (D)	0	5
A4Moko-Ellis	B/C (C/D)	0	5
A42J-1	B/C (C/D)	0.2	4

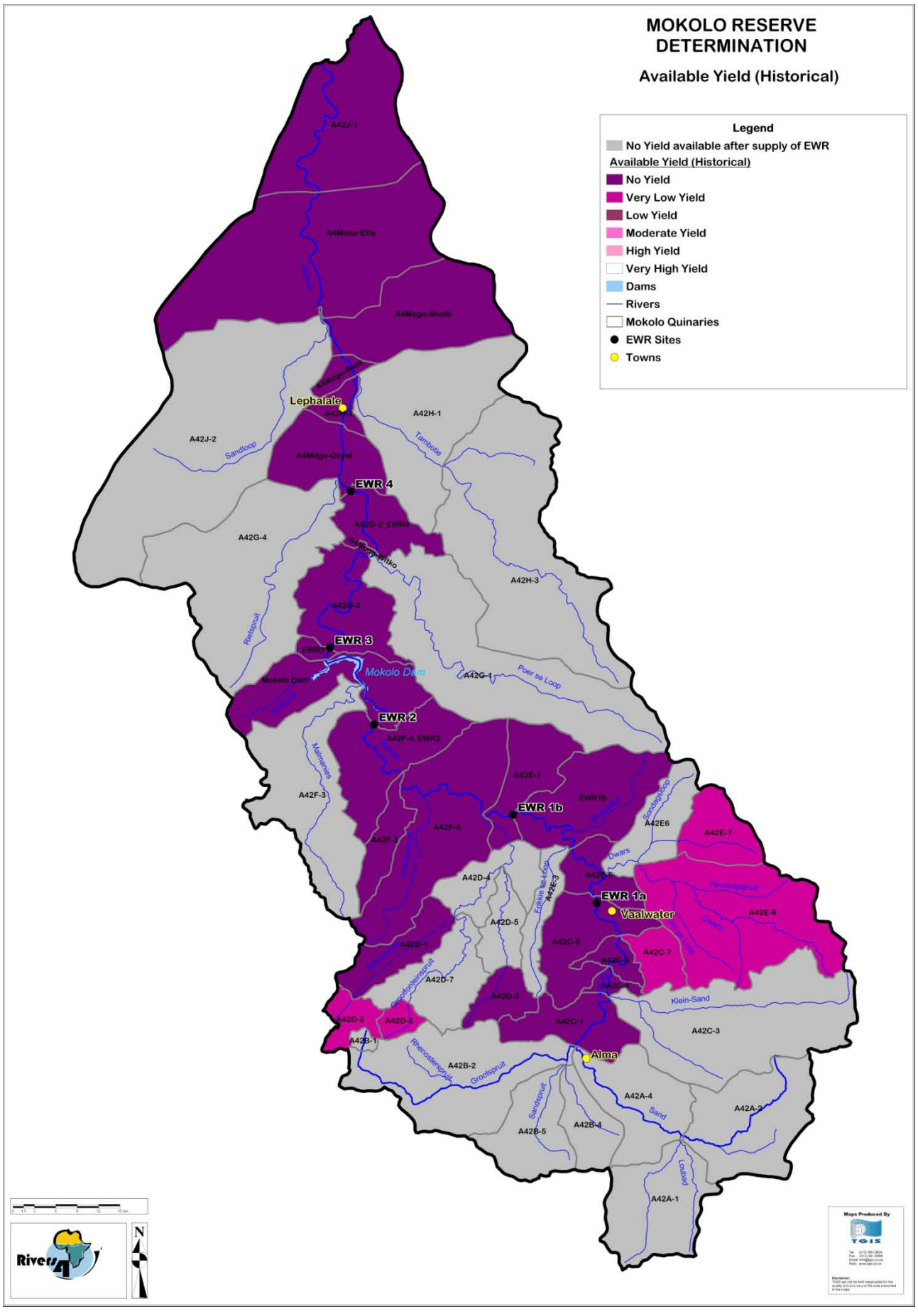


Figure 9.4 Mokolo: Yield availability

As the EWR on the main river has been signed off as the present flows, there is no available yield in the system for additional use in terms of abstraction. This is a very stressed catchment and the results in terms of the yield, illustrates this.

9.2.3 Crocodile River results: Available yield

The results are supplied in the Table 9.8 and illustrated in Figure 9.5.

Table 9.8 Rating values to describe available yield in catchments where the Reserve is currently being met

Hydronode catchments	REC (PES)	Available Yield (Historical) MCM/a	Rating (5)
X21A-1	A/B	0	5
X21A-2	A/B	0	5
X21B-2	B	0	5
X21B-3	B	0	5
X21C-1	B (B/C)	0	5
X21C-2	B (B/C)	0	5
X21C-3	B (B/C)	0	5
X21D-1	B (B/C)	0	5
X21D-2	B (B/C)	0	5
X21E-1	B (B/C)	0	5
X21E-2	B (B/C)	0	5
X21F-1	B	0	5
X21F-2	B	0	5
X21G-1	B	0	5
X21G-2	B	0	5
X21H-1	B	2.3	2
X21J-1	B	0	5
X21J-2	B	0	5
X21K-2	B	0	5
X21K-3	B	0	5
X22A-1	B	0	5
X22B-2	B (B/C)	0	5
X22C-1	C	0.2	4
X22C-2	C	2	2
X22C-3	C	0	5
X22D-1	B	0	5
X22D-2	B	0	5
X22D-3	B	0	5
X22E-1	D	0	5
X22E-2	B (B/C)	0	5
X22F-1	C	0.5	3

X22J-1	C (D)	0	5
X22J-2	C (D)	0	5
X22K-1	B (C)	0	5
X22K-2	B (C)	0	5
X22K-3	B (C)	0	5
X23B-1	C	0	5
X23E-2	B/C	0	5
X23F-1	B (C)	0.1	4
X23G-1	C	0	5
X23H-1	B (C)	0	5
X23H-3	C/D	0.2	4
X23H-4	C/D	0.3	4
X24B-1	D	0	5
X24B-2	D	0.4	3
X24B-3	D	4.5	0
X24C-1	B (C)	3.2	1
X24C-2	B (C)	0	5
X24D-1	B (C)	0.2	4
X24D-2	B (C)	0	5
X24E-1	B (C)	0	5
X24E-2	B (C)	0	5
X24F-1	B (C)	0	5
X24H-1	B (C)	0	5
X24H-2	B (C)	0	5

The relatively high yields available in the X24B and X24C catchments are due to return flows from the Nzikazi North urban area.

As the EWR at the main river has been signed off as the present flows, there will be no available yield in the system for future development regarding abstraction. This is a very stressed catchment and potentially over-allocated in its lower reaches so the lack of available yield is not surprising.

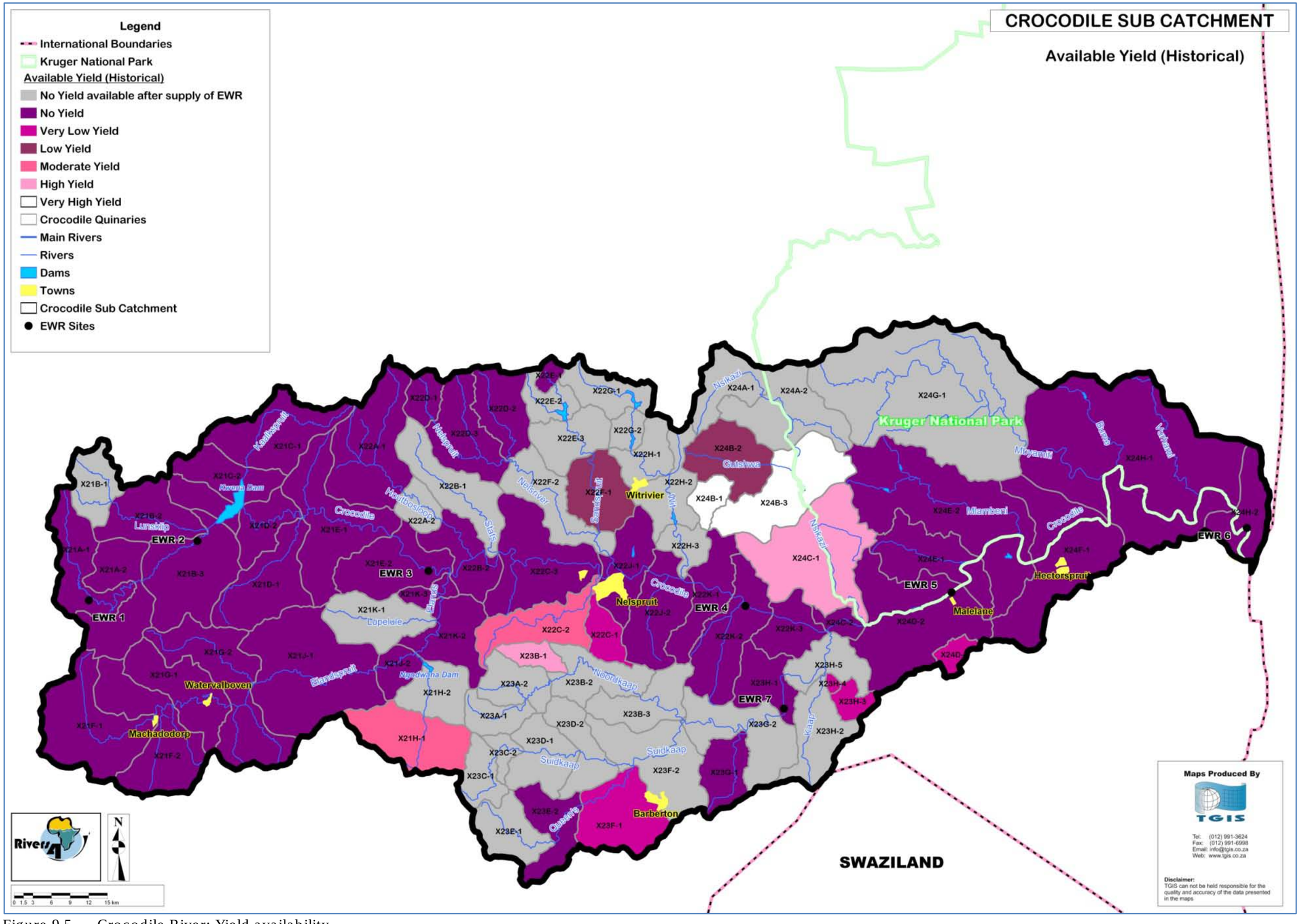


Figure 9.5 Crocodile River: Yield availability

9.2.4 Sabie-Sand results: Available yield

The results are supplied in the Table 9.9 and illustrated in Figure 9.6.

Table 9.9 Rating values to describe available yield in catchments where the Reserve is currently being met

Hydronode catchments	REC (PES)*	Available yield (historical) MCM/a	Rating (5)
X31B-1	B	22.4	0
X31C-2	B (A/B)	0	5
X31D-1	B	23.0	1
X31D-2	B	34.6	0
X31D-3	B	30.4	1
X31E-2	B (C)	2.6	1
X31K-1	C (B)	33.8	1
X31K-3	B (C)	0.2	4
X31K-4	A/B	0	5
X31L-1	D (E)	0.2	4
X31L-2	D (E)	0.2	4
X31L-3	D (E)	0.9	4
X31M-1	A/B	0	5
X31M-2	A/B	0	5
X31M-3	B (B/C)	0.4	4
X31M-4	A/B	0	5
X32A-1	B (C)	1.2	3
X32A-2	B (C)	3.2	1
X32C-1	C	0	5
X32C-2	C	0	5
X32C-3	C	0	0
X32C-5	C	0	5
X32C-6	C		1
X32C-7	C	0	5
X32D-1	B (C)	2	2
X32D-2	B (C)	2.9	2
X32E-1	B (C)	0.7	4
X32E-2	B (C)	1.8	2
X32F-1	C	0	5
X32F-2	C	0.3	1
X32F-3	C	0	5
X32G-1	C	0	5
X32G-2	C	0.1	4
X32G-3	C	0	5
X32H-1	B	0	5
X32H-2	B	0.2	4
X32J-1	B	0	5
X32J-3	B	0	5
X33A-2	A/B	0	5
X33B-1	A/B	0	5
X33D-1	A/B	0	5

Approximately 30% of the catchment includes rivers that more or less lie completely within the Kruger National Park. These rivers were not evaluated and were shaded gray as available yield is not applicable within these areas (see grey areas north of the Sand and Sabie Rivers within the KNP)

The REC is available in the Sabie River under current operation. However, limited to no spare yield is available in the Sabie River downstream from EWR 2. Therefore, even if the map illustrates that there is yield available upstream of EWR 2, any development in that area could result in the REC not being met in the lower Sabie River.

It must be noted that any results that is based on hydrology in the Sand River is inherently of low confidence during to the lack of gauging stations in the system. Local use and mismanagement of the current infrastructure has resulted in heavy river losses and problems in the lower Sand River. The signed off Reserve will be on the basis that Scenario 1 (Sellick-Rule) (26/8/3/10/12/011) will be implemented. This will result in the Ecological Reserve being available. The available yield calculations are based on this scenario being implemented. Therefore, apart from the additional yield which will be available once this rule is implemented, no further additional yield will be available.

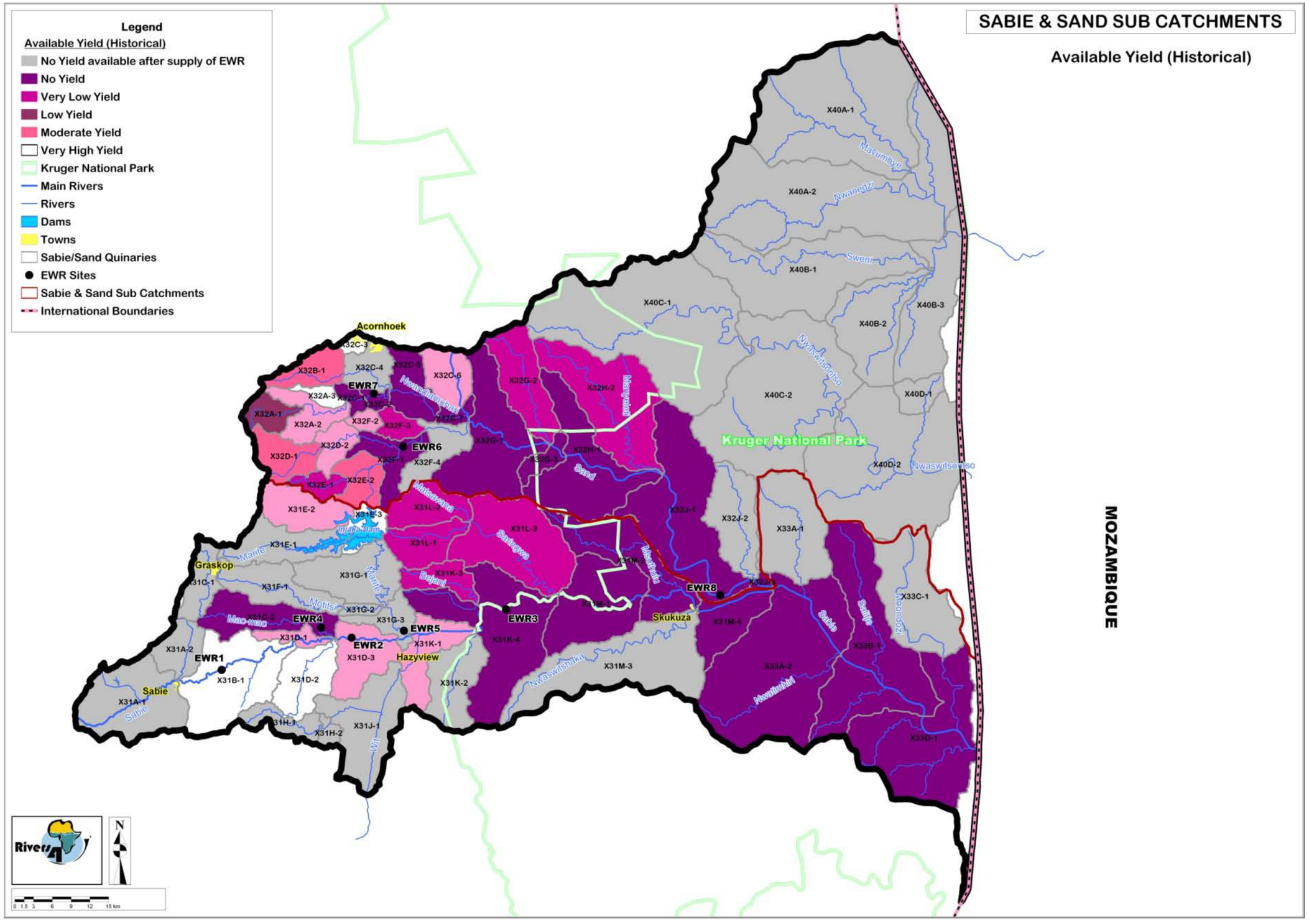


Figure 9.6 Sabie Sand: Yield availability

9.3 GUIDANCE ON THE USE AND INTERPRETATION OF THE EWR AVAILABILITY & AVAILABLE YIELD MAPS

Both maps contain information at various levels of confidences and must therefore be used with care when further development is considered. This information can be an extremely useful aid when considering further development and water use in the catchment. However, all the other information available within these Reserve study results should be considered in combination with this yield analysis.

A process was developed to act as a guideline for decision-making (Figure 9.7). The following must be noted:

- The process is applicable only for the catchments represented by hydronodes where EWRs have been estimated. Results for MRUs where comprehensive EWRs have been assessed will replace any of these Reserve estimates as they are of higher confidence.
- The EWR results have been generated through the estimation process and are therefore inherently of a lower confidence than that generated through more detailed studies.
- The EcoClassification results for the estimation sites have been derived at a Desktop EcoClassification level for the main rivers in the quaternary catchments. These results are inherently of lower confidence than that generated through the more detailed EcoClassification levels (Level 1 to 3). Confidence can further be affected by the fact that only the main rivers in a quaternary catchment were evaluated and one is now dealing on a subquaternary scale.
- The results of the Desktop EcoClassification ((26/8/3/10/12/002 and (26/8/3/10/14/002)) provide essential additional information and guidance on the use of the process described in Figure 9.7). For example, if the process indicates that a Reserve at the appropriate level should be undertaken for further refinement, the appropriate level will be provided on the maps within these reports.

The flow diagram (Figure 9.7) must be seen as a guide only and case by case interpretation is still required.

GUIDELINE: USE OF EWR AVAILABILITY & AVAILABLE YIELD MAPS IN PLANNING & LICENSING (applicable for estimated EWRs only)

EWR availability map – Red map Available yield map – Purple map
Point of interst (POI) – POI refers to the point or area in the catchment where information is required for, eg licensing

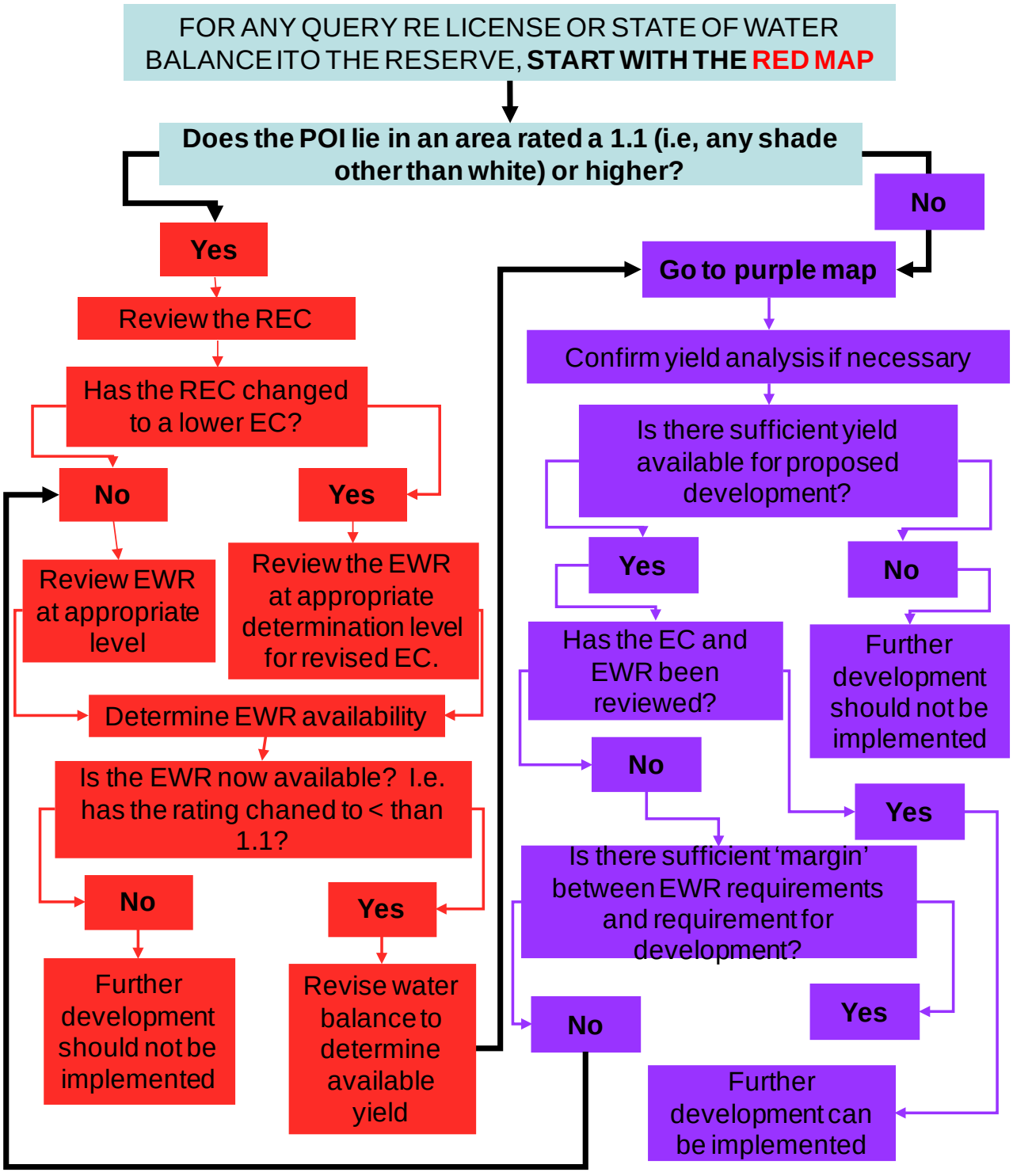


Figure 9.7 Guideline on the use of the EWR availability and yield availability maps for planning and Water Use Licencing.

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