ENVIRONMENTAL WATER REQUIREMENTS IN NON-PERENNIAL SYSTEMS

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Report to the Water Research Commission

by

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"Environmental water requirements in non-perennial systems"

A second report will be published on completion of Phase II of this research.

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EXECUTIVE SUMMARY

The South African National Water Act (NWA) (Act 36 of 1998) requires that the environmental reserve be determined for each significant water body before water licenses may be issued. Methods currently available for the determination of environmental water requirements for South Africa's rivers are based on perennial rivers, but about two-thirds of South Africa has non-perennial rivers.

Furthermore apart from differences found between perennial and non-perennial rivers, non-perennial rivers in drier climates may have different characteristics and may function very differently to rivers in wetter climates and therefore they require focused attention in terms of research and management. It is predicted that, due to climate change, they may become even more arid and variable in flow than at present (Seely et al., 2002). All such rivers are ecologically fragile and alterations to their hydrological systems may have far-reaching effects. It is, therefore, important that methods are developed to assess the environmental water requirements for non-perennial rivers with acceptable confidence.

The gravest risk associated with the use of some of the current approaches is that they may be used routinely and may become all that is sought and used, rather than investing in securing new knowledge of non-perennial river ecology to guide sound decision-making in the future. Arthington et al. (2003), cautioned that scientific panel methods should only be used where there is a genuine commitment to implement and monitor the recommended environmental flows, to support knowledge development, and to adapt water management strategies when better information about the river's responses to flow modification becomes available through monitoring and research.

The use of existing methods may often be unavoidable due to knowledge gaps and time constraints, but this is not a sufficient solution to ensure the long-term protection of non-perennial river systems.

The Terms of Reference for this study were the following:

1. Develop and begin to implement a communication strategy for the programme.

2. Perform scoping exercises to identify the strengths and weaknesses of knowledge at hand, as follows:
   i. Review international and national literature and initiatives on environmental water requirements in non-perennial systems.
   ii. Review environmental water requirements / Instream flow requirements (IFR) on non-perennial systems to date, on the systems that a rapid reserve determination has already been done (Mogalakwena, Matlabas, Shisa, Shingwedzi, Bushmans [E Cape] and Gonubie). So as to identify which areas need refinement of methods.

iii. Perform a rapid desktop reserve determination on each of the following data rich systems: - Kuiseb (Ephemeral), Limpopo (seasonal), Nylsvley (seasonal).
iv. Review available management tools and identify the knowledge gaps
v. Review ecosystem typing
vi. Review the linkages between drivers and responses
vii. Review people-ecosystem interactions

- Social cultural interactions
- Economics

This project is preliminary to a larger, main programme. The intention is to provide the background and to define the needs for the programme. This preliminary study should be done largely at a desktop level, but involving experts from the appropriate disciplines.

Part of the objective of this study was capacity building. The team members are all experienced people in their particular areas of expertise. However, part of the capacity building was to determine which part of their knowledge base was relevant to environmental flow requirement determination, especially for non-perennial systems. The group spent some time familiarising themselves with what is required to determine environmental flows (methodologies and procedures).

There were a number of constraints in the study:

- The Terms of Reference were inexplicit and the deliverables were very widely stated. The terms used were ambiguous. For example, it was stated that a "rapid" reserve determination should be done on the three data rich systems, but no site visits were included in the contract. This then had to be changed to "preliminary" or "desktop" and it was unclear what was then expected from a Desktop Reserve determination, as this is not included in the new revised RDM methodology.
- The revised RDM methodology was only available near the end of 2004 and limited the use of it for this study as the specialists had not had time to familiarise themselves with the new methodology.
- The definition of non-perennial rivers was unclear as there are various ideas and concepts on non-perennial systems. In particular, the difference between ephemeral, seasonal, episodic etc.; is still being debated and very few scientifically tested hypotheses are available.
- There is very little data available on non-perennial systems as they are so difficult to sample that most studies are done on perennial systems.
- Very little flow data for non-perennial systems is available.
- Only after trying to apply certain methods for the determination of ecological classes etc. in the non-perennial systems could we see what the shortcoming of the method was and this was very time consuming.

- To review the environmental water requirements / IFR determinations on non-perennial systems to date on systems on which a rapid reserve has been done (Mogalakwena, Matlabas, Shisa, Shingwedzi, Bushmans [E Cape] and Gonubie) to identify areas where refinement of methods is needed, was difficult as we had to wait for reports which made the time available to review these studies very short. We also had to identify gaps in these studies before we could test the methods used on non-perennial rivers.
- The Terms of Reference state that a desktop determination should be carried out on three data rich systems but when data was gathered it became clear that some of the systems had large gaps on the range of data available.
- Conceptualising new methods to use in non-perennial systems was constrained by the need first to apply the present methods before identifying shortcomings. No field verification could be done during this study and only after field verification is done can changes to current methods or new methods be suggested.
- As this study was limited to one year, no extensive work was feasible.

This report is a first attempt to structure an environmental water requirement determination approach for non-perennial rivers.

CHAPTER 2

Chapter two contains a review of international and national literature on current methodologies used to determine the environmental water requirements for especially non-perennial rivers. Differences between perennial and non-perennial rivers were also addressed.

CHAPTER 3

The methodology used to determine the environmental water requirements in three case studies (Limpopo, Nylsvley and Kuiseb Rivers) are briefly described in Chapter 3. The revised Resource Directed Measures methodology as set out in IWR Environmental (2004) was followed as far as possible for this project. This methodology does however not make provision for a desktop reserve determination as set out in the terms of reference for this project and therefore only the first 3 steps were followed.

As only a desktop reserve determination was required where no site visit was included the team decided to use a combination of the revised Reserve Determination Methodology (IWR Environmental, 2004) and the desktop methodology as set out by Kleynhans (1999b).

CHAPTER 4

Background information on the different elements that are part of the riverine ecosystem (hydrology, geohydrology, geomorphology, water quality, riparian vegetation, invertebrates, fish and people-ecosystem interaction) is presented in Chapter 4.

CHAPTERS 5, 6, 7 AND 8

The results of a workshop held in Bloemfontein at the Centre for Environmental Management from 18 to 22 October 2004 to determine the environmental water requirements with the emphasis on non-perennial systems including ecotyping and three case studies are described in Chapters 5 (Ecotyping), 6 (Nylsvley), 7 (Limpopo River) and 8 (Kuiseb River).

In Chapter 5 the concept of Ecotyping in South African river systems, is dealt with. This discussion focuses on the framework within which non-perennial systems will fit, as well as the definitions of non-perennial systems and levels of non-perenniality.

During the workshop a scale as presented in the following table was adopted which divides the country into areas of perenniality of rivers.

Table I: Categories of perenniality as proposed by the present study.

Perennial	**Non-perennial**				
	Semi-permanent	**Ephemeral**		**Episodic**	
May cease flowing in extreme drought	No flow 1%-25 % of time	No flow 26%-75% of time		No flow at least 76% of time	
	Flow for at least 9 months			Flow briefly only after flood	
		Seasonal	Non-seasonal	Seasonal	Non-seasonal
	e.g. Modder(F.State), Doring (W.Cape), Mogalakwena, 1^{st} order Table Mt. stream	e.g. Shisa		e.g. Kuiseb	

It was decided that the periodicity of inundation of quarters of the year was most appropriate, i.e. inundation for less than one quarter of the year on average resulted in an episodic river, for more than three quarters of the year on average a semi-permanent river, and the category in between, namely between one quarter of the year and three quarters of the year on average, an ephemeral river. The country is divided into four main areas, with the perennial rivers mostly in the southwest and east. The rest of the country is divided amongst the non-perennial rivers, namely the semi-permanent rivers in a narrow band to the interior of the perennial rivers, with their greatest concentration in the southeastern midlands, the ephemeral rivers covering most of the central and northern areas, and the episodic rivers in the northwestern arid areas of Namaqualand and the Kalahari.

Chapters 6 (Nylsvley), 7 (Limpopo River) and 8 (Kuiseb River) present data on the three case studies. Each chapter discusses the available data within each of the identified resource units (river reaches) for each of the elements that are part of the riverine ecosystem (hydrology, geohydrology, geomorphology, water quality, riparian vegetation, invertebrates, fish and people-ecosystem interaction). The quality of the data is also assessed.

Working within the constraints of not having current, present day data, an attempt was made to determine the environmental flow for each of the systems. As no hydrological data was available on the Kuiseb only the Attainable Management Class (AMC) was determined.

Results:

The Ecological Importance and Sensitivity Class (EISC) was determined for each resource unit as explained in Chapter 3. This was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

The Present Ecological State Class (PESC) for each resource unit was then compared with the DESC and the Attainable Ecological Management Class (AEMC) was determined by following methodology set out in Kleynhans (1999b) and explained in Chapter 3.

The AEMC was then used as an input into the updated hydrological model of Hughes and Münster (1999) and, where possible, also used in DRIFT as a comparison. It should be noted, however, that these methodologies cannot be used with confidence in rivers with a hydrological index of greater than 10, and further investigation is needed.

Table II. Summary table of the Ecological Importance and Sensitivity Class (EISC), Present Ecological Class (PESC), Attainable Ecological Management Class (AEMC), Hydrological Index (HI) and results produced by the Hughes and Downstream Response to Imposed Flow Transformation (DRIFT) models for Resource Units 1 and 2, Nylsvley.

System	**EISC**	**PESC**	**AEMC**	**HI**	**Hughes & Münster (1999)**	**DRIFT**
Nyl RU 1	2 (Possibly C)	3.4 B	B	9.1	30.64 %	> 50 – 58% MAR
Nyl RU 2	3 (Possibly B)	2.6 C	B	13.2	29.16 %	

Table III. Summary table of the Ecological Importance and Sensitivity Class (EISC), Present Ecological Class (PESC), Attainable Ecological Management Class (AEMC), Hydrological Index (HI) and results produced by the Hughes model for Resource Units 1, 2 and 3, Limpopo River.

System	EISC	PESC	AEMC	HI	Hughes & Münster (1999)
Limpopo RU 1	2 (Possibly C)	2.8 C	C	76.6	A41E 16.01 %
Limpopo RU 2	2 (Possibly C)	3 C	C	18.4 76.4 91.2 78.5	A50H 18.91 % A50J 17.19 % A63C 16.96 % A63E 17.00 %
Limpopo RU 3	2 (Possibly C)	2.8 C	C	13.4	A80J 19.57 %

Table IV. Summary table of the Ecological Importance and Sensitivity Class (EISC), Present Ecological Class (PESC), and Attainable Ecological Management Class (AEMC) for Resource Units 1, 2 and 3, Kuiseb River.

System	EISC	PESC	AEMC
Kuiseb RU 1	2 (Possibly C)	3.6 B	B
Kuiseb RU 2	4 (Possibly A)	2.8 C	B*
Kuiseb RU 3	2 (Possibly C)	1.6 E	D*

*Recommended, managers need to decide on scenarios – water use more efficient, water demand better managed

CHAPTER 9

Results of the review of the Mogalakwena River Dam feasibility study, and the ecological reserve determination studies done on the Matlabas, Shisa, Shingwedzi, Bushmans (Eastern Cape) and Gonubie Rivers, as indicated by the Terms of Reference, are summarised in Chapter nine. Each respective specialist identified possible areas where the methods need refinement.

CHAPTER 10

The current methodologies, as applied to the three case studies done on the Nyl, Limpopo and Kuiseb Rivers, as well as past environmental water requirement determinations done on the Mogalakwena, Matlabas, Shisa, Shingwedzi, Bushmans (Eastern Cape) and Gonubie Rivers, are assessed in Chapter 10.

Some of the main findings from the assessment were the following:

Hydrology and Geohydrology

There is still a great deal of research required to understand and shed more light on the issue of groundwater/surface water interaction. However, the increased importance of groundwater from perennial to non-perennial rivers (semi-permanent to ephemeral to episodic rivers) is emphasised, and groundwater should always be included in ecological reserve determinations.

Geomorphology

A model to classify quaternary catchments on the basis of parameters or variables useful for EFR (Environmental Flow Requirement) determination should be developed for South Africa. With regard to this time and spatial scales are important in the investigation of biological processes and physical processes. With the use of Geo-Information technology and currently available data, such a classification should put the existing EFR determination methods on a better scientific basis.

Water Quality

With regard to water quality a good scientific and technical understanding of the aquatic system is essential if it is to be effectively managed. Therefore existing methodology, which is strongly focused on water chemistry, is currently being revised. Previous studies indicate that changes in phytoplankton species composition and the loss of sensitive species from this assemblage are among the earliest reliable indicators of the ecosystem stress observed, and therefore should be included in such a methodology.

Riparian Vegetation

In ephemeral and episodic rivers the vegetation becomes increasingly important as a tool in the determination of the ecological reserve. In most cases vegetation is the only measurable biotic component as aquatic species such as fish, amphibians and invertebrates are absent in these rivers. Furthermore problems could arise if the riparian vegetation of non-pernnial streams and rivers are assessed when using the Riparian Vegetation Index (RVI) method and the IFR method.

Aquatic Invertebrates
Invertebrates are not ideal indicators to be used in a rapid or desktop reserve determination in non-perennial rivers, mainly due to a lack of long-term data and understanding of the ecology of non-perennial systems and therefore at present any method used would be of a relatively low confidence rating.

The complexity of the non-perennial river system in terms of flow variability (rivers are dry or have very low flow during certain seasons) makes sampling of invertebrates difficult. SASS [S.A. Scoring System (Invertebrate indexing system)] is not an ideal method to determine the presence of invertebrates in the river, as it was developed for use in perennial rivers where there is flow and a diverse habitat. Furthermore taxa in non-perennial rivers cannot be viewed to have the same sensitivity as taxa found in perennial rivers. As they may have adapted to these harsh conditions, and therefore not be sensitive to them.

Fish
Of the three methods currently used to determine the present ecological status of the fish community [FAII (Fish Assemblage Integrity Index); Qualitative FAII; and FRAI (FRA Fish Response Assessment Index)]. FRAI seems to be the one that is better suited to seasonal rivers with low species diversity, and has mostly generalist fish species and limited habitat heterogeneity, especially during conditions of low flow.

The four knowledge gaps that have been identified for some of the areas are as follows:

1. More information is needed on the importance of habitat connectivity and the functioning of aquatic refugia
2. More information is needed on the role that seasonality and disturbances may play in the maintenance of fish populations in intermittent streams
3. More information is needed on the life histories of most fish species, especially with regards to reproduction and migratory behaviour, and
4. Most importantly, an investigation into the applicability and suitability of the fish indices in non-perennial systems, especially ephemeral systems, is needed.

People-ecosystem interactions
Detailed socio-economic studies on the social uses of non-perennial rivers are scarce. The development of socio-economic matrixes, for the assessment of the river uses, is, however, a significant step towards the refinement of an appropriate social methodology for the study area. Such matrixes can only benefit from similar approaches and instruments which have been developed by practitioners in the area of social impact assessments.

The problems that are faced with dated socio-economic data are:

1. The past ten years have seen significant changes in the population structure and dynamics of the southern African region. In most cases available studies do not reflect these changes.

2. Since 1994 municipal boundaries in South Africa have changed drastically, making any regional comparison between existing socio-economic circumstances and those of the 1990s very difficult.
3. Lastly, it would appear that the methodology of participatory rural appraisal (PRA) has been neglected or ignored in most socio-economic studies looking into the social dependence on the river resource, thus no or little data can be found.

It is highly advised to adapt a methodology that could generate an optimum understanding of rural people's dependency on the river system and their interaction with the river ecosystem e.g., qualitative approaches such as PRA.

However it must be remembered that in southern Africa in particular, the religious, cultural and spiritual significance that indigenous people attach to rivers and lakes has a powerful impact on the utilisation and protection of natural water resources in the region. Such perceptions constitute a powerful mechanism for protecting water resources and for coping with fluctuations in flow systems.

Lastly, with regard to policy formulation the specific issues that may be of relevance are: a better understanding of the interaction between population dynamics and freshwater flow systems; policies should, amongst others, be sensitive to local contexts and draw on multidisciplinary knowledge; policies should further account for the upstream and downstream effects of river developments and interactions, and encourage communities to become involved in the design and implementation of river-basin management projects; the relationship between land tenure and freshwater rights; estimates of the economic value of water resources in various contexts; soil and water conservation techniques; indigenous water management strategies; coping strategies of communities in arid- and semi-arid regions during times of water scarcity; and, population-freshwater system relationships in or near protected areas and wetlands.

CHAPTER 11

Conclusions and recommendations for further research

This study is a first attempt to structure an environmental water requirement determination approach for non-perennial rivers. Although nearly half of South African rivers may be considered as non-perennial, current methods available for the determination of environmental water requirements for South Africa's rivers are based on perennial rivers. The use of existing methods may often be unavoidable due to knowledge gaps and time constraints, but this is not a sufficient solution to ensure the long-term protection of non-perennial river systems. Non-perennial rivers are ecologically and hydrologically fragile and alterations to their hydrological systems can have far-reaching effects. It is, therefore, of critical importance that new, sufficiently well-researched methods be developed to assess the environmental water requirements for these rivers with acceptable levels of confidence.

The following are more specific conclusions:

Ecotyping

A scale was adopted, supported by a map, which divided the country into areas of perenniality of rivers. The categories were based on the periodicity of inundation of quarters of the year, i.e. inundation for less than one quarter of the year on average resulted in an episodic river, for more than three quarters of the year on average, a semi-permanent river, and the category in between, namely between one quarter of the year and three quarters of the year on average, an ephemeral river.

Rapid reserve determinations on the Nyl, Limpopo and Kuiseb Rivers

As required by the Terms of Reference for the project, a rapid desktop reserve determination had to be done on the Nyl, Limpopo and Kuiseb Rivers. In consultation with the WRC, this was changed to a "preliminary" or "desktop" reserve determination, as no provision for field visits and field sampling was made in the contract. Because the new revised RDM methodology makes no provision for a desktop reserve determination, a combination of the procedures for desktop estimates of the water quantity component of the Ecological Reserve of Kleynhans (1999b) and the revised RDM methodology was used.

In the absence of field data, including adequate flow data, specialists were dependent on existing data sources. Although these rivers are considered to be relatively well-studied, existing information is patchy, and recent information was especially difficult to obtain. Confidence in the results of the reserve determinations is, therefore, low.

The study showed that flow in these three rivers is highly variable. Hydrological indices (HI) varied between 9.1 for the upper section of the Nyl River to 91.2 for the middle Limpopo. This is expected to be even higher for the Kuiseb River. In such flow variable rivers, groundwater plays a very important role in sustaining water levels in pools. Pools, both artifical (forming behind weirs) and natural, act as critically important refugia for aquatic biota and should, not only be considered in EWR determinations, but protected from over-utilisation. Protective measures, like for example, the specification of constraints on groundwater gradients towards the river, should be developed.

The high hydrological variability characteristic of these rivers, further presented problems with the application of Hughes DSS on these rivers, as a hydrological index (HI) of 10 and more is considered to fall beyond the acceptable range of accuracy (10 or less). Water allocated by the Hughes DSS model for the respective rivers is, therefore, most possibly an underestimation of the EWR of the river. A comparison between DRIFT and Hughes DSS for the upper Nyl River (HI of 9.1) indicated that DRIFT allocated 61% more water than Hughes DSS. It may be possible that the Hughes DSS allocate insufficient water to non-perennial systems. Further research is needed on this matter.

Recommendations for further research

- The applicability of the Hughes DSS of Hughes and Münster (1999) for non-perennial rivers should be further investigated. The possible insufficient allocation of water to non-perennial rivers by the model needs to be addressed.
- Further research is needed on the hydrological modelling for non-perennial rivers as the Hughes DSS is considered to be unsuitable beyond a hydrological index of 10. It is proposed that groundwater should be included in such a model.
- Measures for the protection of groundwater resources should be developed and implemented. For example, the setting of a specific drawdown water level for groundwater abstraction along a river should be considered.

Review of past EWR determinations

The Terms of Reference for the project required a review of IFR determinations previously done on non-perennial systems. Two studies were reviewed, namely a pre-feasibility study on the Mogalakwena River, and a study done by IWR Environmental (2000) to investigate improvements to the hydrological extrapolation method used in Desktop (Level 1) and Rapid (Level 2) determinations of the ecological reserve.

From the review it became evident that the methodologies used in the Mogalakwena pre-feasibility study underwent considerable development over the past eight years. Further research is, however, needed to determine the applicability of these methods for non-perennial rivers.

The study on the Matlabas, Shisha, Shingwedzi, Bushmans (Eastern Cape) and Gqonubie Rivers focused strongly on hydrology and very limited information was provided on the other components. The study again confirmed the need to investigate the applicability of the Hughes DSS on rivers with hydrological indices of 10 and more. Due to the growing importance of groundwater in semi-permanent to episodic rivers, it may be necessary to include groundwater in the hydrological modelling for non-perennial rivers.

Recommendations for further research

- A mechanism is needed to be put into place for the protection of groundwater. In a system fed by groundwater, boreholes are needed at each EWR site, as well as guidelines to control the gradient of the groundwater table.
- The relationship between flows and channel morphometry in non-perennial rivers needs further investigation.
- The use of remote sensing in desktop and rapid EWR assessments should be considered.
- Water quality should be considered as being equally important as the water quantity component, in reserve determinations.

- The methodology used to determine the PES for the riparian vegetation needs to be reviewed for non-perennial rivers. The method should also be improved with regards to repeatability.
- A central database on the invertebrates found in non-perennial rivers needs to be established.
- The correct timing for the sampling of invertebrates in non-perennial rivers should be investigated.
- The relationship between flow/no-flow and the nature of biota (invertebrates, fish and riparian) needs to be investigated.
- The methodology used to determine the PES based on the fish community may underestimate biological integrity in some non-perennial rivers due to lower species richness and habitat heterogeneity.
- More appropriate methodologies should be applied and recent data banks be accessed for socio-economic assessments such as the Mogalakwena study, and should be included in reserve determinations.

Assessment of current methodologies

The existing methodologies used by the respective specialists in an EWR determination, were reviewed.

Hydrology

The Hughes DSS is currently the only viable method by which the quantity component of the ecological reserve may be estimated (IWR Environmental, 2000). Deficiencies related to the range of hydrological indices are, however, a significant limitation to the use of the method in rivers that have a hydrological index in the range 10 to 80.

Geohydrology

Groundwater becomes increasingly important with increased non-perenniality. It is, therefore, of critical importance to place more emphasis on the groundwater component in EWR assessments for non-perennial systems. Further research, including field measurements, is required to shed more light on the interaction between groundwater and surface water.

Geomorphology

Time and spatial scales need to be investigated as biological processes and physical processes (such as geomorphology) do act on different scales. Evident is the lack of site (river) specific knowledge of experts. Remote sensed data can be used but will only give a broad indication of processes and not the detail as required from the BBM.

Water Quality

The rapid reserve determination methodology for water quality focuses strongly on chemical parameters. The inclusion of phytoplankton (algae) biomass (chlorophyll-*a*) and composition should, therefore, be included as a water quality indicator in future water quality assessments. The current methodology is, however, under review.

Riparian Vegetation

Two methods are currently used, namely the Riparian Vegetation Index (RVI) method (Kemper 2000) and the IFR method as described by Boucher and Kemper (2001). Both of these methods are applicable to perennial rivers, and are not ideally suited for use in non-perennial systems.

Invertebrates

The use of SASS as a method to determine the PES of a non-perennial river is questionable as the method was developed to be used in perennial rivers (with flow and habitat diversity as prerequisites). The use of IRAI as a method is more acceptable as it incorporates SASS data as well as the flow, water quality and habitat preferences of expected and observed invertebrates. This method however also needs historical data and where this is not available one has to rely on expert opinion which lowers the confidence of the results obtained.

Fish

Three indices, the Fish Assemblage Integrity Index (FAII; Kleynhans, 1999a, 2003), a qualitative version of the FAII, and the Fish Response Assessment Index (FRAI, Kleynhans, 2004) are used to determine the present ecological status (PES) of the river segments. Of these, FRAI seems to be better suited for use in non-perennial rivers.

People-ecosystem interaction

The methodology of participatory rural appraisal (PRA) has been either neglected or ignored in most socio-economic studies looking into the social dependence on the river resource. In circumstances where a population profile is typified by high levels of illiteracy and low socio-economic status (such as in the case of many deep rural populations), it is highly advised to adapt a methodology that could generate an optimum understanding of rural people's dependency on the river system and their interaction with the river ecosystem. Qualitative approaches such as PRA, focus group sessions and key informant interviews should therefore be integrated into a comprehensive methodological design suitable for the unique challenges posed by the different target populations in rural areas.

Recommendations for further research

- More emphasis should be placed on the groundwater component in EWR assessments for non-perennial systems.
- A model should be developed to classify quarternary catchments on the basis of parameters or variables useful for EWR determinations in South Africa. With the use of Geo-Information technology and currently available data, such a classification should put the existing EWR determination methods on a better scientific basis.
- Time and spatial scales need to be investigated as biological processes and physical processes (such as geomorphology) do act on different scales.

- Remote sensed data should be considered for use in rapid reserve assessments to give a broad indication of geomorphological processes.
- Phytoplankton (algae) biomass (chlorophyll-*a*) and composition should be included as a water quality indicator in future water quality assessments.
- A user friendly national database should be compiled from data available in reports, Rivers Database etc. and research in non-perennial rivers to collect data on invertebrates should be encouraged.
- Scientists doing studies on invertebrates should include accurate flow data and habitat descriptions in their results.
- Studies to determine the sensitivity of invertebrates, in terms of flow and length of dry period, in non-perennial rivers should be carried out as this would aid in the interpretation of flow conditions suggested during EWR studies.
- The applicability and suitability of the different fish indices, especially FRAI, in non-perennial systems, should be investigated.
- The intolerance index of certain fish species should be reviewed for non-perennial systems.
- The ideal time of fish and invertebrate sampling in non-perennial should be established, especially for rapid assessements where only one field visit is made.
- Knowledge of local fish communities and conditions should be valued and, where possible, included or consulted in reserve determination assessments.
- More information is needed on the importance of habitat connectivity and the functioning of aquatic refugia
- More information is needed on the role that seasonality and disturbances may play in the maintenance of fish populations in intermittent streams
- More information is needed on the life histories of most fish species, especially with regards to reproduction and migratory behaviour.
- The importance of conditions of no-flow to biota of non-perennial systems should be investigated.
- The lack of continuous hydrological records for the majority of non-perennial rivers should be addressed.
- It is of critical importance that the knowledge base on rivers is extended to seasonal and ephemeral river systems and reserves that have been determined should be implemented and monitored in order to give feedback.
- Qualitative approaches such as PRA, focus groups and key informant interviews should be integrated into a comprehensive methodological design suitable for the unique challenges posed by the different target populations in rural areas.
- A better understanding of the interaction between population dynamics and freshwater flow systems is needed to inform policies that will be able to make these relationships more sustainable.
- Specific issues that should be considered in policy formulation include the following: the relationship between land tenure and freshwater rights; estimates of the economic value of water resources in various contexts; soil and water conservation techniques; indigenous water management strategies; coping

strategies of communities in arid- and semi-arid regions during times of water scarcity; and population-freshwater system relationships in or near protected areas and wetlands.

- Standard participatory techniques such as Participatory Rural Appraisal (PRA) should be supplemented with approaches like in-depth interviews of key informants, triangulation, focus groups and participatory workshop sessions at the host villages.
- Close collaboration between social and biophysical scientists should be a priority throughout the participatory process, especially with regards to the setting of flow scenarios.

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LIST OF DEFINITIONS AND ABBREVIATIONS

AEMC	Attainable Ecological Management Class
AEV	Acute Effects Value
ASPT	Average score per taxa
BBM	Building Block Methodology
CER	Comprehensive Ecological Reserves
CEV	Chronic Effects Value
CV	Coefficient of Variation
DEMC	Default Ecological Management Class
DESC	Default Ecological Status Class
DO	Dissolved Oxygen
DRIFT	Downstream Response to Imposed Flow Transformation
DSS	Decision Support System
EFA	Environmental Flow Assessment (also known as Instream flow Assessment: IFA)
EFR	Environmental Flow Requirement (also known as IFR: Instream Flow Requirement)
EISC	Ecological Importance and Sensitivity Category
EMC	Ecological Management Class
ERC	Ecological Reserve Category
EWR	Ecological Water Requirement or Environmental Water requirements
FAII	Fish Assemblage Integrity Index
FRAI	Fish Response Assesment Index
FV	Fast flow through Vegetation
GIS	Geographical Information System
GSM	Gravel, Stones, Mud
HFSR	Habitat Flow Stressor Response
HI	Hydrological Index
HUGHES DSS	Decision Support System
IFIM	Instream Flow Incremental Methodology
IFR	Instream Flow Requirement (also known as Environmental/Ecological Flow Requirement:EFR)
IRAI	Invertebrate Response Assessment Index
MVI	Marginal Vegetation Invertebrates
NWA	National Water Act
NWBM	National Water Balance Model
NWRS	National Water Resource Stategy
PESC	Present Ecological Status Class
PRA	Participatory Rural Appraisal
RAM	Resource Assessment and Management
RDM	Resource Directed Measures
RQO	Resourse Quality Objectives
RVA	Range of Variability Approach
RVI	Riparian Vegetation Index
SASS	South African Scoring System (Invertebrate indexing system)
SI	Suitability Index (as in SI curve, also known as HIS curve)
SIC	Stones-in-Current
SRP	Soluble Ractive Phosphate
SS	Slow and Shallow
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
TWQR	Target Water Quality Range
WMA	Water Management Area

1. INTRODUCTION

The South African National Water Act (NWA; Act 36 of 1998) requires that the environmental reserve be determined for each significant water body before water licenses may be issued. Methods currently available for the determination of environmental water requirements for South Africa's rivers are based on perennial rivers, but about two-thirds of South Africa has non-perennial rivers.

All but the largest rivers in the semi-arid West of South Africa are non-perennial, and moving through the neighbouring states of southern Zimbabwe, Botswana, southern Angola and Namibia, the climate becomes increasingly dry. The people living in the region require an acceptable degree of assurance in their water supply, and conventionally groundwater as a resource is tapped. This will, however, continue to put pressure on groundwater and surface water resources, and may not be as sustainable an option as previously thought.

These non-perennial rivers may have different characteristics and may function very differently to rivers in wetter climates and require focused attention in terms of research and management. It is predicted that, due to climate change, they may become even more arid and variable in flow than at present (Seely et al., 2002). Application of a basin-wide management approach involving participation of all resource users and developers holds out one possible, partial solution to sustainable management of non-perennial rivers in the arid and semi-arid regions (Seely et al., 2002). All such rivers are hydrologically and ecologically fragile and alterations to their hydrological systems can have far-reaching effects (Seely et al., 2002). It is, therefore, important that methods are developed to assess the environmental water requirements for non-perennial rivers with acceptable confidence.

The gravest risk associated with the use of some of the current approaches is that they may be used routinely and may become all that is sought and used, rather than investing in securing new knowledge of non-perennial river ecology to guide sound decision-making in the future. Arthington et al. (2003), cautioned that scientific panel methods should only be used where there is a genuine commitment to implement and monitor the recommended environmental flows, to support knowledge development, and to adapt water management strategies when better information about the river's responses to flow modification becomes available through monitoring and research.

The use of existing methods may often be unavoidable due to knowledge gaps and time constraints, but this is not a sufficient solution to ensure the long-term protection of non-perennial river systems.

The Terms of Reference for this study were the following:

1. Develop and begin to implement a communication strategy for the programme.

2. Perform scoping exercises to identify the strengths and weaknesses of knowledge at hand, as follows:

   i. Review international and national literature and initiatives on environmental water requirements in non-perennial systems.

   ii. Review environmental water requirements / Instream flow requirements (IFR) on non-perennial systems to date, on the systems that a rapid reserve determination has already been done (Mogalakwena, Matlabas, Shisa, Shingwedzi, Bushmans [E Cape] and Gonubie). So as to identify which areas need refinement of methods.

   iii. Perform a rapid desktop reserve determination on each of the following data rich systems: - Kuiseb (Ephemeral), Limpopo (seasonal), Nylsvley (seasonal).

   iv. Review available management tools and identify the knowledge gaps

   v. Review ecosystem typing

   vi. Review the linkages between drivers and responses

   vii. Review people-ecosystem interactions

      - Social cultural interactions
      - Economics

This project is preliminary to a larger, main programme. The intention is to provide the background and to define the needs for the programme. This preliminary study should be done largely at a desktop level, but involving experts from the appropriate disciplines.

Part of the objective of this study was capacity building. The team members are all experienced people in their particular areas of expertise. However, part of the capacity building was to determine which part of their knowledge base was relevant to environmental flow requirement determination, especially for non-perennial systems. The group spent some time familiarising themselves with what is required to determine environmental flows (methodologies and procedures).

The team consisted of the following specialists:
Prof. M.T. Seaman – Project leader
Mrs. M.F. Avenant – Fish specialist and project communications
Dr. C.H. Barker – Geomorphologist
Dr. P.J. du Preez – Riparian vegetation specialist
Prof. A.J. Pelser – Socio-economic specialist
Dr. J.C. Roos – Water quality specialist
Mrs. L. Rossouw – Project coordinator
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Prof. G.J. van Tonder – Geohydrologist
Mrs. M. Watson – Invertebrate specialist
Dr. J.M. King – Methodology specialist and internal reviewer

This report is a first attempt to structure an environmental water requirement determination approach for non-perennial rivers.

It contains a literature review on current methodologies and differences between perennial and non-perennial rivers in Chapter 2. The methodology used to determine the environmental water requirements in three case studies are briefly described in Chapter 3. Background information on the different elements that are part of the riverine ecosystem (hydrology, geohydrology, geomorphology, water quality, riparian vegetation, invertebrates, fish and socio-economic aspects) is presented in Chapter 4. The aim of a workshop held in Bloemfontein at the Centre for Environmental Management, from 18 to 22 October 2004, was to determine the environmental water requirements with the emphasis on non-perennial systems including ecotyping and three case studies (Nylsvley, Limpopo and Kuiseb Rivers). The three case studies are discussed in Chapters 5, 6, 7 and 8.

Past environmental water requirement determinations for non-perennial rivers are discussed in Chapter 9 and the current methodologies are assessed in Chapter 10.

There were a number of constraints in the study:

- The Terms of Reference were inexplicit and the deliverables were very widely stated. The terms used were ambiguous. For example it was stated that a "rapid" reserve determination should be done on the three data rich systems, but no site visits were included in the contract. This then had to be changed to "preliminary" or "desktop" and it was unclear what was then expected from a Desktop Reserve determination, as this is not included in the new revised RDM methodology.
- The revised RDM methodology was only available near the end of 2004 and limited the use of it for this study as the specialists had not had time to familiarise themselves with the new methodology.
- The definition of non-perennial rivers was unclear as there are various ideas and concepts on non-perennial systems. In particular, the difference between

ephemeral, seasonal, episodic etc.; is still being debated and very few scientifically tested hypotheses are available.

- There is very little data available on non-perennial systems as they are so difficult to sample that most studies are done on perennial systems.
- Very little flow data for non-perennial systems is available.
- Only after trying to apply certain methods for the determination of ecological classes etc. in the non-perennial systems could we see what the shortcoming of the method was and this was very time consuming.
- To review the environmental water requirements / IFR determinations on non-perennial systems to date on systems on which a rapid reserve has been done (Mogalakwena, Matlabas, Shisa, Shingwedzi, Bushmans [E Cape] and Gonubie) to identify areas where refinement of methods is needed, was difficult as we had to wait for reports which made the time available to review these studies very short. We also had to identify gaps in these studies before we could test the methods used on non-perennial rivers.
- The Terms of Reference state that a desktop determination should be carried out on three data rich systems but when data was gathered it became clear that some of the systems had large gaps on the range of data available.
- Conceptualising new methods to use in non-perennial systems was constrained by the need first to apply the present methods before identifying shortcomings. No field verification could be done during this study and only after field verification is done can changes to current methods or new methods be suggested.
- As this study was limited to one year, no extensive work was feasible.

2. LITERATURE REVIEW

2.1 Terminology

Intermittent flow is common in a large proportion of South Africa's rivers; Davies et al. (1993) estimated that over 44% of our total river length is naturally temporary. Despite the numerical importance of these systems, they remain poorly understood because research attention here has been directed primarily towards perennial river systems, as it has worldwide (Williams, 1988).

Various authors such as Matthews (1988), and Comin and Williams (1994) have attempted to make a distinction between ephemeral, temporary and intermittent streams according to the percentage of annual flow, source of flow and periodicity of flow. Other descriptive terms such as non-perennial, seasonal and episodic further confuse the terminology.

In the absence of a functional classification for non-perennial rivers, a descriptive terminology was devised by Uys and O'Keeffe (1997) in an attempt to standardize definition of the different types of river regimes encountered in South Africa.

The aim of the Uys and O'Keeffe's (1997) paper was to firstly present a conceptual framework to illustrate the range of temporary river regimes in South Africa, and the influences on them, and secondly related to this, was to propose a systematic terminology for the description of temporary river regimes in the country. Therefore the conceptual framework is born out of the notion that a hydrological gradient exists between the most perennial and most non-perennial rivers (e.g., Williams, 1987).

Their terminology distinguishes different river regimes according to the hydrological features, which simply facilitate characterization of temporary river regimes.
Where applicable, they considered:

- Approximate duration and periodicity of flow and no-flow phases,
- Approximate time of year at which flow recommences, and
- Variability and unpredictability in flow regimes within and between years (within a five year time scale, which should allow for an assessment of the effects of variability on river fauna).

The terminology is designed to give a staged, systematic description of river regimes; and should be applicable at various spatial scales (from river reach upward).

The following is a brief description of the Uys and O'Keeffe (1997) paper.

The Continuum Concept

Classification exercises conventionally distinguish river types by recognizing geographical, geological, climatic, or biotic boundaries between them, i.e., on the basis of the outer limits of features that characterize them (e.g., Hart and Campbell, 1994). The conceptual framework developed here, in contrast, aims to discern different hydrological regimes according to the core characteristics or inner limits which typify them (Uys and O'Keeffe, 1997).

Different hydrological regimes are represented by points on the continuum. The gradual change in hydrological character between points is denoted by the space on the line between points, which they have termed the fuzzy zone to illustrate the transition in flow types between clearly definable hydrological regimes. The continuum is illustrated below in Figure 1.

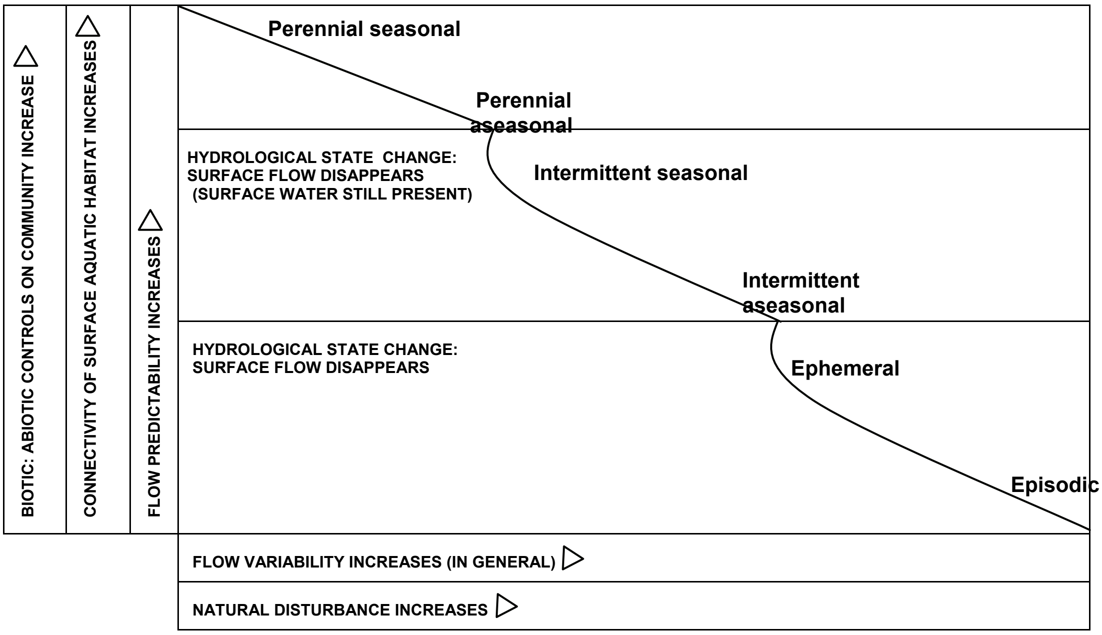

Figure 1 A conceptual illustration of the continuum concept, for hydrological regimes, according to core characterististics. Two hydrological state changes are shown: 1. One in which surface flow disappears (but some surface water is present), 2. One in which surface water disappears from the channel for long periods (After Uys and O'Keeffe, 1997).

Two hydrological state changes, which may result in major biotic and abiotic changes in lotic systems, are represented as steps in the continuum: (1) where surface flow disappears but surface water is still present (pools, etc.) in the majority of channel, and (2) where surface water disappears from the majority of the channel. The response (and the rate of response) of the biota to either of these state changes is a major component of temporary river research.

The *x* and *y* axes of the continuum represent gradients in the following:

- Flow intermittency (general increase towards the episodic state).
- Flow predictability (general decrease towards the episodic state).
- Flow variability—as measured by the coefficient of variation of flow (CVF). In temporary rivers, high flow variability indicates unpredictable periods of intermittent or flashy flow (i.e., periods of zero flow and/or drying), whereas in perennial streams high flow variability denotes fluctuations in flow volume in a context of continual flow. The ecological consequences of loss of flow or surface water are clearly different from the effects of altered flow volumes (although not necessarily more extreme): Boulton (1989) comments that loss of water in temporary systems is ‘‘probably the most influential environmental parameter affecting the aquatic biota.’’ CVFs in the country range from 0.33 (generally predictable perennial rivers in the Western Cape) to 2.58 [generally unpredictable temporary rivers of the northwest (King *et al.,* 1992)]. If variability is considered in terms of CVF, there will be a general increase towards the episodic state.
- Community structuring forces—the extent to which biotic and abiotic forces influence community structure. It is generally accepted that as physical conditions become increasingly harsh, community composition and species distribution are increasingly governed by abiotic rather than biotic factors (e.g., Peckarsky, 1983; Williams, 1987). Power *et al.* (1988); Poff and Ward (1989) suggest that rather than adopt an ‘‘either–or’’ approach, abiotic, biotic, and other influences should be considered to be acting as multilateral controls on community structure. This gradient is expressed as a ratio of biotic to abiotic controls (with a general increase in the ratio towards the perennial state).
- Natural disturbance increases in frequency towards the intermittent state, and in amplitude towards the episodic state.
- Connectivity relates to the continuity or connectedness of flow or surface water. Internal connectivity is considered to describe continuity of surface water or flow in a single river and external connectivity to describe the distance between a dry riverbed and the closest source of surface water. The scale at which connectivity is examined must be specified, and this makes it a difficult concept to measure but an important one to consider (Naiman, 1992), particularly with respect to the biota. The connectivity of the surface aquatic habitat only, with a general increase towards the perennial state, was considered.

The key considerations in establishing where a river regime fits along the continuum (i.e., which term would best describe its hydrology) are as follows:

1. Does flow stop, and if so, when and for what period of each year; how often and for what duration in a five year period?
2. For how long does surface water persist? This is of particular importance in relation to life-history adaptations of the biota, and their resilience and resistance to disturbances.

3. What is the connectivity of the system?

The limitations of the continuum should be recognized: Brierley (1994), while endorsing the concept, warned that ‘‘interpretation of a river as intermediary between two or more styles may be no more than describing the system as a meaningless mean.’’ To avoid this, fuzzy zones should be seen as transitional states between one and the next point, rather than as average states.

Intermittency, variability, and unpredictability in flow are among the characteristics shared by temporary rivers. Global and local classification exercises have grouped rivers based on their seasonal flow patterns and their flow characteristics (e.g. Haines et al., 1988; Poff and Ward, 1989; and Joubert and Hurly, 1994). Temporary rivers can be organized on the basis of their flow regime and the extent of their flow variability and unpredictability. These factors are largely determined by the climatic zone in which rivers occur.

In establishing their terminology, Uys and O’Keeffe borrowed from the three classifications already referred to: those of Haines et al. (1988), Poff and Ward (1989), and Joubert and Hurly (1994).

The continuum concept illustrated in Figure 1 will assist in locating the position of the flow regimes along the perennial-temporary gradient (Uys and O’Keeffe, 1997). Based on their continuum concept they described temporary, intermittent, ephemeral and episodic rivers as follows:

Temporary
Flow stops and surface water may disappear along parts of the channel either yearly or during two or more years in five. This is a blanket term for the description of all the flow regimes encountered in this and the following hydrological state.

Intermittent
These rivers cease to flow and may dry along parts of their lengths for a variable period annually, or for two or more years in five. Flow may recommence seasonally, or highly variably, depending on climatic influences and predictability of rainfall in the area. An intermittent river may experience several cycles of flow, e.g., no flow, and drying in a single year.

Intermittent Seasonal
Intermittent seasonal rivers exhibit seasonally predictable intermittent flow. Surface flow disappears for a period of each year or some of the five years, and the channel may be reduced to pools or may dry completely during the dry season. Flow commences in rainy season and may be sustained or intermittent over the wet season.

> ***Intermittent Seasonal Summer:*** Predictable floods/recommencement of flow in spring–summer months. Surface flow disappears and the channel may dry in parts during the year, certainly during winter months.

__Intermittent Seasonal Winter:__ Predictable floods/recommencement of flow in winter months. Surface flow disappears and the channel may dry in parts during the year, certainly during summer months.

Intermittent Aseasonal

These rivers exhibit intermittent, unpredictable and highly variable flow within and between years in a five-year period. Usually occur in climatic transition zones, semiarid areas, and marginal areas, e.g., southern African drought corridor. Although major rainfall and discharge events may be broadly seasonal, flow follows no distinct pattern and drying may occur in any season. Duration of flow, no flow, and drying events are highly variable within and between years, depending on antecedent climatic conditions.

Hydrological State Change: Surface Water

The following descriptions are for rivers where the channel disappears for some, or all of each year, or some years, in a five-year period.

Ephemeral

Ephemeral rivers flow for less time than they are dry. Flow or flood for short periods of most years in a five-year period, in response to unpredictable high rainfall events. Support a series of pools in parts of the channel.

Episodic

Highly flashy systems that flow or flood only in response to extreme rainfall events, usually high in their catchments. May not flow in a five-year period, or may flow only once in several years.

Their definitions were a preliminary attempt to encourage consistency in the use of terms, with the hope that this will improve information transfer between those involved in temporary river research.

Another generally accepted classification scheme distinguishes four main categories of streams (Boulton et al., 2000):

- Ephemeral streams – flow briefly (<1 month) with irregular timing and usually only after unpredictable rain has fallen;
- Intermittent or temporary streams – flow for longer periods (>1 – 3 months), regularly have an annual dry period coinciding with prolonged dry weather;
- Semi-permanent streams – flow most of the year but cease flowing during dry weather (<3 months), drying to pools. During wetter years, flow may continue all year round;
- Permanent streams – perennial flow. May cease to flow during rare extreme droughts.

The latter is much simpler but not as descriptive as the Uys and O'Keeffe classification. Other authors have suggested definitions for non-perennial streams:
An ephemeral river is usually defined as one in which water flows sporadically and for short duration, following heavy rain in its catchment area (Seely et al., 2002). Water may flow for a matter of hours or even days, but rarely longer.

Jacobson (1997) prefers to define an ephemeral river, as one in which measurable discharge occurs for less than 10% of the year.

Over time, a particular river can change from perennial (where water flow is constant) to ephemeral or vice versa depending upon climatic and environmental circumstances. Another important feature of the ephemeral river is that although the surface of the river channel may remain dry for most of the year, there is usually a significant volume of water stored beneath the channel (Jacobson et al., 1995; Seely et al., 2002).

Temporary rivers are broadly defined as those in which surface flow ceases and surface water may disappear for some period of most years. They are the dominant river systems in arid and semi-arid zones (Boulton and Suter, 1986).

2.2 Perennial versus Ephemeral river ecosystem

More information on differences between perennial and non-perennial rivers are presented in Chapter 4 under the different specialist headings, e.g., for invertebrates and fish.

2.2.1 Location of ephemeral rivers

Ephemeral rivers are located throughout the drylands (arid and semi-arid regions) of the world. These arid and semi-arid areas are centred along the tropics, north and south of the equator, where over a billion people in 110 countries live on more than 30% of the earth's surface (Turnbull, 2002). Twenty African countries have more than 90% of their productive lands in vulnerable drylands, illustrating the human dimensions of the issue (Turnbull, 2002). Very few perennial rivers cross the drylands of the world, the Nile in Africa being one exception, none of the other rivers have their origins there.

2.2.2 Geographical characteristics

Ephemeral rivers may be perennial in their upper reaches or where rocky substrata force groundwater to the surface in localised areas. Many ephemeral rivers are endorheic, they do not flow into the sea, even during the highest rainfall. This may be the result of insufficient water in their upper courses as, for example, the ephemeral rivers associated with the mountains of the Sahara. Alternatively, this may be the result of sand dunes or other obstacles blocking their course as, for example, the ephemeral Tsauchab River flowing into Sossus Vlei in Namibia. Other ephemeral rivers flow into the sea during high flow. In Namibia, ten of the twelve major westward flowing ephemeral rivers flow into the sea on occasion, and the southward flowing ephemeral Fish River joins the perennial Orange River that empties into the southern Atlantic Ocean (Seely et al., 2003).

Aridity and its associated rainfall variability are the key factors determining ephemerality of rivers. Also important in dry, arid areas is the very high rate of evaporation. In the western ephemeral catchments of Namibia, evaporation is more than six times greater than mean annual rainfall in the inland headwaters and more than one hundred times greater than in the arid west (Jacobson et al., 1995). Evaporation leads to rapid loss of rainwater from the system and where surface water is present at springs and wetlands, high evaporation frequently results in very saline soils. Because of limited water flow, salts build up and the only plants that can survive around these springs and wetlands are salt-tolerant species. This same high evaporation that contributes to the ephemeral nature of rivers also reduces the efficiency of dams in drylands, because of high evaporation rates and sediment build-up.

Drought, the result of variable rainfall in arid environments, is another factor correlated to ephemerality of rivers in drylands. Although drought is a normal occurrence in drylands, people are often unprepared for it when it occurs. Periods of drought often result in increased pressure on the surface and subsurface water as well as the vegetation associated with ephemeral rivers and endorheic systems (Seely et al., 2003).

2.2.3 Environmental characteristics

Ephemeral rivers have long been of importance to people and wildlife living in its proximity, as in Namibia where they provide linear oases or riparian corridors through otherwise dry landscapes (Jacobson et al., 1995). Today they still represent foci of human development and natural biodiversity in drylands. In Namibia, ephemeral rivers that flow toward the north and east start in and flow through regions of relatively high rainfall (300-600 mm) per year. The appearance of the vegetation that lines these river courses, is not very different from the surrounding savannas, because of the overall higher rainfall, both are lush with many trees and shrubs. In contrast, rivers that flow south toward the Orange River or west toward the coast begin in areas of higher rainfall but flow through very arid lands (100 mm rainfall or less per year). Due to the marked contrast between the riparian and desert vegetation, these linear oases provide essential water and food resources for people, livestock and wildlife living in these regions. These rivers and their catchments also provide water for several other facets: agriculture, tourism, mining and the major urban centres of Windhoek, Walvis Bay and Swakopmund. For Namibia, the westward flowing ephemeral rivers are of significance, not only to people living in the area, but to the nation as a whole. This disproportional importance of ephemeral rivers, for people, livestock and wildlife, is not unique to Namibia but is similar to the situation found in other drylands of the world (Seely et al., 2003).

Ephemeral rivers are not only important for their water resources but also for the vegetation and other biota that they support. The vegetation is partly dependent on and influenced by soil properties and hydrologic characteristics of ephemeral river flow. In the ephemeral Kuiseb River of the Namib, soils consist of layers of organic-rich silts, interstratified with fluvial and aeolian sands deposited during river flow (Jacobson et al., 2000). The most significant influence of the ephemeral flow regime is related to accumulation of soils downstream associated with decreased water flow in the lower river reaches. This causes increased proportions of silt in the riverine soils which are associated with organic carbon, nitrogen and phosphorus. At the same time, silt deposition influences patterns of moisture availability and plant rooting, thereby creating and maintaining micro-habitats for various organisms. Localised salination also occurs in association with wetland sites and soluble salt content increases downstream. Structure, productivity and spatial distribution of biotic communities are thus strongly affected by flow patterns in this ephemeral river ecosystem. Altering flow in these rivers has a negative affect on this fragile balance and reduces overall productivity. Although contributing nutrients, the fine grained alluvial soils deposited in the lower reaches of Namibia's westward-flowing rivers are highly sensitive to misuse (Jacobson et al., 1995) and are rapidly eroded when subjected to heavy livestock presence or tourist vehicle traffic.

Subsequent movements of water or wind over the disturbed surface will carry away large amounts of soil. These riverbed and riparian soils are also relatively poor and thin and have little potential for irrigated agriculture production. These same soils however, do support dense stands of trees and other woody vegetation that provide essential fodder for livestock and wildlife.

Flooding is another important element in the structure and maintenance of ephemeral river ecosystems. Jacobson (1994) vividly describes a flood in the Kuiseb River in western Namibia: 'The leading edge of the flood was nearly a meter high and looked more like lava than water as it rolled rapidly down the channel. The water was loaded with sediments and organic material, including seeds, sticks, logs, grasses and animals of various shapes and sizes. The water itself contained high amounts of nutrients and dissolved organic carbon. All of this material was carried downstream and deposited within the desert reach of the Kuiseb River'.

Floods in ephemeral rivers are usually produced by heavy downpours that leave little time for water to infiltrate the soil (Jacobson et al., 1995). These floods continue in the normally dry channel until water flow stops. The rate of water flow, or discharge, depends upon the amount and pattern of rainfall in the catchment, and where the discharge is measured. Discharge in ephemeral rivers increases to a point until the combined effect of evaporation and infiltration and seepage of rain causes a decrease in water level. Infiltration, the seepage of water into the channel bed, is the main factor contributing to downstream decline in discharge (Jacobson et al., 1995). Discharge in ephemeral rivers is highly variable and may be described as a flash flood, a single peak flood or a multiple peak flood. These differences are caused by different rainfall patterns in the upper catchment and different shaped catchments. These large variations in floods, coupled with a limited record of past floods, hinder understanding of the resource base in ephemeral rivers as well as their sustainable management.

The presence of fish in ephemeral rivers usually depends on the presence of perennial water somewhere along the course of the river. In the Kuiseb River, fish are washed out of farm dams and carried downstream. The fish are restricted to water holes and then disappear entirely as the water dries up. In the ephemeral wetlands of the Cuvelai system in north-central Namibia, fish are brought into the system from the perennial reaches of the upper river. This is one of the few types of ecological systems where it is sustainable to remove all fish. They would die as the river dried up, and recolonisation would occur from perennial river sections (Seely et al., 2003).

Streams in semi-arid regions have highly seasonal flow regimes with a marked pattern of low to zero flow during summer/winter and early spring/autumn (depending on when the wet seasons are). As a result, throughout the dry months, most rivers have long reaches that are dry with occasional pools. The biotic communities have evolved specific adaptive strategies to face those alternating lotic-lentic conditions, but when water resource development creates longer and/or more extreme dry seasons, the environmental stress can be lethal for important groups of the biota (Bernardo and Alves, 1999).

As the flow reduces and the level of the water decreases, some species, especially fish, move to deeper zones as an adaptive strategy, where the probability of water persistence is higher. The remaining pools become refugia for resident individuals, and the abundance and diversity of species in the pools seem to be related to its depth, area and degree of isolation. The declining volume and wetted area of these pools, together with the concomitant increases in temperature, changes in chemical characteristics, and the increased predation pressure, determine the success of populations occupying the pools, until recharge and reconnection occur during the following rain period. When the streams again start to flow, the surviving organisms recolonise the river system (Bernardo and Alves, 1999).

2.2.4 Geohydrology

Groundwater recharge is one of the most important functions of floods in ephemeral rivers. As a flood travels down an ephemeral river, water infiltrates into the sandy and gravel alluvial deposits of the channel beds. The amount of recharge depends on the intensity, volume and duration of a flood (Heyns et al., 1997). The recharge of alluvial aquifers ensures a water source during the dry season for plants, animals and people (Jacobson et al., 1995).

Communities in western Namibia, dig wells in the river bed after floods to obtain water for human and livestock consumption. The availability of boreholes and pumps makes water along ephemeral rivers accessible all year round. In some Namibian rivers, such as the Kuiseb and the Swakop, a gradual decline in the groundwater table is being observed, despite some good floods in recent years. This is one of the first signs of unsustainable water consumption. The permanent lowering of groundwater tables will have a detrimental effect on ephemeral systems, including the associated riparian vegetation (Seely et al., 2003).

The constant availability of groundwater in the ephemeral river channels allows for the presence and growth of woody riparian vegetation. In the west-flowing ephemeral rivers of Namibia dense stands of large woody trees (e.g., *Faidherbia albida, Acacia erioloba*) stand in contrast to the otherwise arid landscape. While constant groundwater availability plays a vital part in tree survival, the occurrence of irregular, extreme floods plays a vital part in aquifer recharge, morphological reshaping of the channel as well as the age structure and spatial distribution of riparian trees (Friedman and Lee, 2002). The riparian forests provide various different kinds of resources for people, such as wood for construction and fuel, medicines, fruit, essential fodder and shade for wildlife and livestock. Ephemeral rivers are frequently referred to as the linear oases of the Namib Desert because of the riparian forest and groundwater availability (Jacobson et al., 1995). Human groundwater use is in direct competition with the water needs of the riparian vegetation and therefore water consumption should be carefully weighed against the value of the riparian vegetation.

Furthermore groundwater-fed wetlands occur in Namibia’s western rivers where sub-surface flow is forced to the surface by bedrock. Such wetlands vary in flow rates, water chemistry and duration of flow. They provide water, food, shelter and a unique habitat for a great variety of plants and animals (Loutit, 1991; Christelis and Struckmeier, 2001).

2.2.5 Hydrology of Ephemeral rivers

Many contemporary ecosystem theories developed to explain how rivers function originated from research on temperate perennial streams. Recommendations for river management and restoration and water policies and legislation share similar origins. However, uncritical extrapolation of theories developed in permanent lotic ecosystems to intermittent and ephemeral streams can prove perilous and even misleading.

For example, extremes of flooding and drying (variable flows) largely structure stream assemblages and regulate ecosystem processes in most intermittent streams (Boulton et al., 2000). Conversely, biological interactions such as predation by fish, which is often excluded by a temporary flow regime, may be more important in perennial streams. Flooding occurs in perennial streams as well, but drying is rare except during severe drought when the fauna is devastated by desiccation (Boulton et al., 2000).

Rivers and streams naturally vary in flow although the temporal scale must be specified when the term, “variable”, is used. The most highly variable flow regimes usually occur in intermittent and ephemeral rivers, especially those in semi-arid and arid areas. Here, the coefficients of variation of annual flows are, on average, 467% greater than those from humid and temperate regions (Davies et al., 1994). The hydrological variability seems to be associated with increased habitat and food web complexity, although it is likely that the persistence of many species in dry-land rivers, rely on maintenance of intermittency. There is few scientific data to support this hypothesis because information about the ecological functioning of the river before regulation is often lacking. Such data are a fundamental requirement for managing these types of rivers and raises the question: how should one manage rivers with variable flow regimes when so little information is available?

Historically, water management practices in arid and semi-arid zones have been driven by human demand for water. River regulation and interbasin water transfer are imposed most extensively upon rivers with highly variable flow regimes (including natural intermittency) to sustain human agriculture. The issue is made more complex by a Western human perception that a “healthy” river flows all year round; many of the more ambitious river regulation projects have had technological and intellectual input from experts living in well-watered regions (Boulton et al., 2000).

There has been a growing awareness of the importance of both flow variability and the multivariate aspects of a rivers flow regime, and the use of this information to formulate management practices.

2.2.6 Water quality of Ephemeral rivers

A sound understanding of the adequacy of water quantity availability in a catchment is a prerequisite to the understanding of water quality issues and appropriate management responses to them. At the heart of certain water quality issues, lie inadequate or unreliable supplies of fresh water, needed for dilution, flushing, assimilative capacity, river channel maintenance, or as alternative supplies to existing supplies that have problematic quality (Department of Water Affairs and Tourism; DWAF, 2003a).

Consequently, an understanding of the discharge regime of a river is extremely important to the interpretation of water quality measurements, especially those including suspended sediment or intended to determine the flux of sediment or contaminants. The discharge of a river is related to the nature of its catchment, particularly the geological, geographical and climatological influences.

The levels of dissolved oxygen (DO) in non-impacted running water are usually close to saturation and thus increases in discharge have little effect. If discharge is reduced sufficiently, either due to natural or anthropogenic causes, pools of standing water may develop. Particularly during summer months when water temperatures are high, DO levels in such pools may reach critically low levels (Malan and Day, 2002).

Where shallow pools remain in a channel, diffusion of oxygen from the atmosphere is usually sufficient to maintain concentrations of oxygen above stress levels in temporary water bodies.

Declines in or depletion of dissolved oxygen may have a deleterious or lethal effect on the fauna, and are generally a result of:

- increases in either temperature or salinity (due to lack of flow and evaporation in pools);
- decomposition of benthic organic matter (e.g. leaves, algae, macrophytes);
- algal growth, which can cause oxygen depletion at night;
- inputs of eutrophic effluents or deoxygenated water from the bottom of a dam.

Increases in dissolved oxygen may result from:

- dense algal growth, which causes surges in oxygen saturation during the day.

When flow resumes in a dry river, a “pulse” of largely unprocessed litter is carried downstream, and decomposition of this litter may reduce or deplete oxygen in the water-column.

The concentration of suspended solids increases with the discharge of sediment washed into rivers due to rainfall and resuspension of deposited sediment. As flow decreases, the suspended solids settle out, the rate of which dependents on particle size and the hydrodynamics of the water body. In South Africa, all rivers, excluding some in the Natal foothills of the Drakensberg and in the south-western Cape, become highly turbid and laden with suspended solids during the rainy season (Dallas and Day, 2004). Rivers and streams are normally more turbid than still waters, and many are always markedly turbid.

The TSS (total suspended solids) concentration is a measure of the amount of material suspended in water. An important feature of many South African reservoirs is high turbidity caused by the presence of suspended silt (Dallas and Day, 2004). Wofsy (1983) concluded that suspended sediment concentration above about 50 mg/ℓ prevents significant algal blooms in all but the shallowest streams.

Under low- or zero-flow conditions, slow or zero current and (possibly) high water temperatures are conducive to the production of dense mats of filamentous algae, particularly in exposed areas. These mats provide a food source and cover, both of which may be vital for final instream insects attempting to emerge before water temperature drops or conditions become unsatisfactory.

With the onset of disconnectivity in a temporary river, large amounts of detritus are likely to accumulate in the channel and pools. With time and decomposition of plant matter, nutrient levels are raised. Most nutrients (except nitrites and ammonia ions) are not toxic to animal life and the major effect of increased nutrient levels is proliferation of fast-growing plants (e.g. algae, waterweeds) and animals, both of which may become pests, alter community structure, and/or cause water quality problems.

Algal growth results in high diurnal dissolved oxygen levels in pools, and significant decreases in oxygen saturation at night. With increased levels of photosynthesis, changes in pH can be dramatic. This may affect the transport of materials across animal membranes.

Deeper pools may also exhibit thermal stratification, whereby distinct layers are formed between the warm surface water in contact with the atmosphere and the cold bottom water. No mixing occurs between the water strata and therefore once oxygen is depleted in the lower water column, as a result of respiration by biota or due to chemical reactions, it is not replenished. Such anoxic conditions can persist until stratification is disrupted by mixing of the water layers once again at the end of summer or by the onset of a storm event (Malan and Day, 2002).

Unnatural changing water temperature may expose aquatic organisms to potentially lethal or sub-lethal conditions. An increase in water temperature decreases oxygen solubility and in turn may also increase the toxicity of certain chemicals, both which result in increased stress in the associated organisms (Dallas and Day, 2004).

Many small farm dams (<250 000 m^3) constructed on small tributaries do not have any water release control measures and potential temperature impacts on the biota may be significant, particularly since the dams are small they heat up rapidly and therefore do not undergo stratification. Stream temperatures may increase by 10 to 20 °C as a result of irrigation practices and the return of agricultural drainage (Dallas and Day, 2004).

Water samples for chemical analysis are usually taken only when the river is flowing. Thus, the impact of periods of flow cessation, or of times when the flow regime changes from perennial to seasonal, are usually not recorded. This is an important limitation, since these are the times when water quality changes may be most severe (King et al., 2000). During long dry periods however, groundwater accounts for almost all the flow in stream (Malan and Day, 2002). Thus, monitoring should be arranged so that it targets episodic events. For instance, seasonally-variable stream flows can cease for large parts of the year. In some streams and reservoirs, slow flowing or pooled water leads to thermal stratification, which together with autochthonous organic loading, results in naturally low and variable dissolved oxygen concentrations. Seasonal rainfall events often produce 'first-flush' loads of stressors that can cause rapid changes in stressor concentrations that may not be captured with routine monitoring programs (ANZECC, 2000).

If discharge in a river is reduced, instream concentrations of water quality variables, as well as values of physical variables, will change. A reduction in the surface water volume, together with high evaporation, usually results in an increased salinity in a temporary river. The trends of discharge on water quality have been summarised recently by Malan and Day (2002) and will, therefore, only be considered briefly (see Table 1). Responses of stream chemistry to discharge can be extremely complex and site-specific. Thus, predictions of stream chemistry in response to changes in discharge should be made with caution and require verification with field data.

Table 1 The general effect of an increase in discharge on the concentration of water quality constituents in rivers (modified from Malan and Day, 2002).

Total dissolved solids	Nitrogen	Phosphorus	Other	Comments
TDS ↓ or conductivity ↓ (Ca^{2+}, Mg^{2+}, Na^{+}) ↓ (Cl^{-} & SO_4^{2-}) ↓ Alkalinity (HCO_3^{-}) ↓	NO_3 & NO_2 ↑ Total N ↑ NH_4 ↑	TP ↑ PO_4 ↑ Particulate P ↑	TSS & turbidity↑ pH ↓ DO ↓ Chl-a, or (algal biomass) ↓ Hardness ↓	See description below

Summary of discharge-concentration trends (Malan and Day, 2002):

- Suspended sediments (SS) generally increase with discharge but the rate of increase may level off at high discharges as substratum becomes limiting. Storms occurring early during the wet season are likely to carry heavier loads of sediments compared to storms later on in the season. This once again is due to limitation in the supply of this material.
- Dissolved minerals derived from the underlying substratum are likely to decrease as discharge increases due to dilution by rainfall and surface run-off containing low solute loads.
- Due to the high degree of mobility in the soil, nitrate is likely to increase during storm events, or during the initial part of the rainy season. Depending on the nutrient status of the soils of the surrounding catchment, such a flushing effect may be sustained in urban areas, or in regions of intense agricultural activity. In nutrient-poor soils such as Fynbos, the flushing effect may be short-lived and followed by rapid assimilation of nitrates by aquatic organisms.
- pH is likely to decrease during storm events, especially in the South Western Cape. This variable is likely to decrease in Cape rivers in autumn but may increase during high flow events. It is also to be expected in other parts of South Africa although the effect may not be so pronounced.
- Particulate phosphate is likely to increase during spates due to enhanced sediment loads. In the absence of point sources of pollutants, dissolved

phosphate (ortho-phosphate) is likely to decrease or remain constant in nutrient poor areas in response to increased discharge. In urban areas, or regions of intense farming activity, however, this trend may well be reversed due to wash-off effects of pollutants or phosphate fertilisers. If point sources of phosphate are actively discharged the overall trend will depend on the proportional contributions from each source. Dissolved phosphate levels may well increase during low flow periods as the proportion of effluent to river water increases.

- The resultant effect of discharge increases on TDS (total dissolved soilds) is difficult to predict, reflecting as it does the sum of effects on pH, nitrates, phosphates as well as other chemical constituents. Due to the high rate of evaporation in SA, in non-impacted catchments, TDS is likely to be at a maximum during periods of low flow, and at a minimum during high flow. In urban, or polluted, areas however, or where surface wash-off of ions is likely to be substantial, such a response may be obscured.
- Seasonal variations of river water hardness often occur, reaching the highest values during low flow conditions and the lowest values during floods (Chapman, 1996).

2.2.7 Comparing perennial and intermittent streams

It is useful to address the differences in physical, chemical and biological features between perennial and intermittent streams. Many of the ecological features that typify a stream with a variable flow regime are not predictable by some of the conventional, deterministic models of river ecosystems and require modifications (Boulton et al., 2000).

Amplitudes in physical and chemical conditions in ephemeral rivers, particularly in drying pools, far exceed those in permanent streams. As rivers dry, conductivity tends to rise through evaporation. Water temperature also rises (>30°C) and dissolved oxygen saturation falls. In some receding pools, leaf leachate concentration increases and pH may fall to as low as 4.5, further exacerbating conditions for the aquatic biota. These range from intensifying competitive interactions for space and moisture to heavy predation by terrestrial and aquatic invertebrates and vertebrates (Boulton et al., 2000).

The numbers of species of water plants, invertebrates and fish are generally lower in intermittent streams compared with nearby permanent streams of the same size and geomorphology. For water plants that are usually submerged or floating, periodic drying poses a serious limitation unless they can produce desiccation-resistant propagules.

Invertebrates that either lack desiccation-tolerant stages or are poor recolonists will be eliminated from intermittent streams when they dry. Permanent streams will contain both species that are opportunistic and found in nearby intermittent streams as well as long-lived aquatic stages (> 1 year) and limited powers of dispersal. Similarly, most species of riverine fish cannot tolerate drying or the harsh physical and chemical conditions in receding pools, and are restricted to permanent streams. However, some can use intermittent channels for spawning.

The relative magnitude of ecosystem components may differ between intermittent and permanent streams. Compared with permanent rivers, subsurface flow in the hyporheic zone of many gravel and sand-bed intermittent streams represent a substantial proportion of the total discharge. Exchanges of water between the surface and subsurface zones influence ecosystem processes such as algal productivity, respiration, and nutrient cycling. Drying may sever these hydrological linkages, changing a range of ecosystem processes. The usual balance between upwelling (movement of hyporheic water to the surface) and downwelling (surface water infiltrating into the hyporheic zone) tips almost completely towards the latter flux during drying. Microbial respiration continues while sediments remain moist or saturated, consuming available carbon and oxygen, and potentially shifting hyporheic metabolism towards anaerobic processes. This has profound effects on nitrogen transformations, phosphorus availability, and the potential for the hyporheic zone to serve as a refuge, for surface dwelling organisms (Boulton et al., 2000).

2.2.8 The ecological significance of high flow variability

It may appear that variable flows and intermittency have largely negative effects, adversely affecting water quality during the drying phase and limiting the diversity of water plants, invertebrates and fish. Yet, the significance of the comparison is not that “permanent” is better, but that river systems with high variable flow regimes are different and call for a different approach to their management. Efforts to reduce this flow variability in order to increase biodiversity or to “restore” the river system to one that better fits a Western perception of a “healthy” river may not be the best ecological option (Boulton et al., 2000).

Drought is part of the natural climatic cycle experienced by the animals, plants and micro-organisms that live in arid and semi-arid regions. Natural low-flow and dry periods are as important for maintaining biodiversity and healthy rivers as natural high flows and floods in other kinds of rivers. The abilities of organisms to survive prolonged dry conditions and drought (their resistance) and recover from it (their resilience) are “hard-wired” into healthy aquatic ecosystems through eons of evolution (Jones, 2003).

Flow variability is important in a number of ways. Variable flows maintain the complexity of the in-stream environment in semi-arid river systems. The cross-sectional morphology of unregulated river was complex and characterised by a series of flat surfaces or “benches”. These “benches” provided aquatic habitats during high flow events and enabled the accumulation and temporary storage of organic matter. The more variable the flow regime (especially in terms of flood flows), the greater the number of benches present. This is not the case in steep sided valleys but on floodplain areas.

Ecologically, flow variability underpins rates of most ecosystem processes and transport of organisms, nutrients, organic carbon and other materials within rivers and on their floodplain.

Variable flows in rivers promote a diversity of physical and chemical conditions, and these in turn lead to habitat patchiness and increased biodiversity (Boulton et al., 2000).

2.2.9 Removing variability – impacts of regulation

One of the main aims of flow regulation is to provide a reliable and constant water supply. By definition, this entails preventing intermittency or artificially creating reliable and constant flow below a dam. Water must be harnessed from high flows and released during dry weather, meaning that most flood peaks are dampened or removed completely.

Regulation in arid and semi-arid areas often involves interbasin transfers, thus water storage, and groundwater abstraction. These practices can alter groundwater recharge patterns, leading to the cessation of permanent flow in some areas. Pressure to regulate river flow is greatest in arid and semi-arid areas where human populations are increasing, and the limiting resource is water.

A compromise is sought between maintenance of intermittency as an extreme of the allocation of environmental flows to mimic a natural regime and the demands placed by a thirsty human population enjoying the benefits of irrigation.

The perception that a flowing river is better than a dry one, results in water quality standards being relaxed because of the belief that it is better to have sustained, albeit low quality, water than a predominantly dry channel. For example, in the Selati River (flowing into Kruger National Park), flow during the dry season comprises mainly of effluent (Rossouw, personal observation).

The logic of effluent release is based on two assumptions:

- That ephemeral streams do not support viable aquatic communities, and
- The effluent dependent systems provide "net ecological benefits" such as habitat restoration and increased species diversity by maintaining permanent flow.

Clearly there are problems with this logic. In some regions, temporary streams and rivers have quite diverse assemblages and considerable faunal overlap with adjacent perennial sites. Alternatively, temporary streams may support biota that are "temporary stream specialists" or that use these sites for special purposes such as spawning. Further, the poorly diluted or undiluted effluent inevitably has deleterious effects upon the biota of these systems and in the downstream receiving waters, regardless of the tolerance of the organisms to intermittency.

2.2.10 Mismatch between accepted water quality criteria and natural conditions in intermittent rivers

Historically, water quality criteria have been based on chemical and physical characteristics but increasingly, the use of biological variables is becoming popular because of the perceived advantages of biomonitors. Furthermore, there is increasing recognition of the potential value of ecosystem measures as indicators of the "health" of a system. However, at certain stages of the flow regime, water quality of intermittent streams naturally deteriorates and the diversity of intolerant biota declines. Unless this is understood, uncritical application to intermittent rivers of water quality criteria and biological indicator species used for assessing the health of permanent rivers will prove misleading.

2.2.11 Environmental flow allocations for intermittent rivers

Environmental flow allocations are becoming accepted as a valid approach to returning water to over-allocated systems but attention must be paid to the quality as well as quantity of water. Unfortunately, there are few scientists experienced in the ecology of intermittent rivers and their advice may reflect their experience with permanent rivers, potentially with disastrous results.

A need for specialist knowledge on intermittent rivers

Specialist knowledge is needed by scientists and river managers to address (Boulton et al., 2000):

- The importance of the dry phase (of variable duration and timing) to intermittent rivers;
- The importance of irregularity, gauging the variability on the pre-regulated flow regime (if such data are adequate);
- The necessity to assess the first two policies based on flow regime not hydrograph;
- The need for integrated flow management that does not allocate flows based on a few, readily identified water users (e.g. fish, waterbirds) but takes the whole system into account;
- The relationship between water quality and quantity, recognising that cues to using the floodplain may rely on subtle changes in water temperature, etc. and that the water of "artificial floods" may differ from natural flood-water in important ecological characteristics (e.g. sediment; particulate organics);
- Maintenance of variability of flows to promote diversity of habitat types over large time and spatial scales;
- Explicit recognition of public perception of intermittency as a "problem", and educational programmes to remedy this concern.

2.3 Legislation and Policy

Globally, and in South Africa, the historical emphasis of water management strategies has been characterised by maximum development and exploitation of the available resource, largely for the benefit of formal agriculture, industry and other consumers.

The dual pressures of limited water resources and the need for economic growth, coupled with worldwide changes in attitude towards social, institutional and environmental issues, have resulted in a global shift in policy regarding the sustainable use of natural resources. This has led to the transformation of legislation dealing with their management.

2.3.1 Global Initiative

The *Rio Declaration* on *Environment and Development, Agenda 21* and the *Statement of Principles for the Sustainable Management of Forests* were adopted by more than 178 governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in 1992. Together they constitute a comprehensive plan of action to be taken globally, nationally and locally by organisations of the United Nations, governments, and major groups in each area that humans have an impact on the environment. More information about UNCED and Agenda 21 is available at the following website:http://www.un.org/esa/sustdev/agenda21.html (DWAF, 2003a).

2.3.2 National Initiative on Water Resources

Previous legislation dealing with water use, namely the Irrigation and Conservation of Waters Act (1912), and the Water Act (Act No 54 of 1956) made no allowance for the equitable, sustainable use of water resources. Instead it upheld a policy of private water use that was linked closely to land ownership through the concept of riparian water rights (DWAF, 2003a).

Adoption of the Constitution of the Republic of South Africa (Act No 108 of 1996) laid the foundations for a democratic and open society in which government is based on the will of the people. It also contains a promise by government to improve the quality of life for all citizens.

All laws are subject to the Constitution, which promotes equity, protects the rights of access to resources, and seeks to enhance opportunities for the poor and previously marginalised.

The Bill of Rights set the stage for the development of a White Paper on a National Water Policy for South Africa (April, 1997), and was in turn founded on and guided by the Water Law Principles accepted by the South African Cabinet in November 1996.

The principle objectives of the National Water Policy (and hence the National Water Act of 1998) are to achieve equity of access to, and sustainable use of water (DWAF, 2003a). In the National Water Policy, the government describes itself as the public trustee of South Africa's water resources and commits itself to carry out its obligations in a way which:

- guarantees access to sufficient water for basic domestic needs;
- makes sure that the requirements of the environment are met;
- takes into account the interconnected nature of the water cycle – a process on which the sustainability and renewability of the resource depends;
- makes provision for the transfer of water between catchments;
- respects South Africa's obligations to its neighbours, and
- fulfils its commitment as custodian of the nation's water.

The ideals outlined in the Policy were translated into legislation, namely the National Water Act (NWA; Act 36 of 1998). The promulgation of the 1998 NWA formalised South Africa's changed approach to the management and utilisation of water resources in South Africa (DWAF, 2003).

The NWA has been acknowledged as one of the most far-reaching and pro-active water acts in the world (Palmer et al., 2000). It is based upon the twin pillars of sustainability and equity. This is in line with Agenda 21 and South Africa's Constitution, and identifies water for basic human needs, and for the environment, as a right of law.

Legislation is implemented by means of strategies. Chapter 2 of the NWA requires the Minister of Water Affairs and Forestry, after consultation with society at large, to develop a national water resource strategy (NWRS) that will facilitate the proper management of water resources. The NWRS provides the framework for the protection, use, development, conservation, management and control of water resources for the country as a whole.

Some of the protective measures are designated Resource Directed Measures, because they are measures designed to be applied to the water resource as a system, i.e. at catchment levels.

The named Resource Directed Measures are:

- The establishment of the Reserve;
- The classification of the water resource, and
- The setting of Resource Quality Objectives (RQOs).

Other protective measures are designated Source-Directed Controls, because they are intended to control the abstraction of water and the disposal of effluents.
In addition to the development of strategies, implementation of the NWA requires the development of methodologies to carry out these protective measures, in order to ensure that the legislative requirements and the stated purpose of the Act are met.

Subjecting water resources to control, in order to promote the sustainable management thereof, requires the administration of water needs through the registration and licencing of water uses. Licences for use of a water resource can only be issued once the Reserve has been set.

2.3.3 The Reserve

The Reserve is defined as:

> *The quantity and quality of water required to satisfy the basic human needs, and to protect aquatic ecosystems, in order to secure ecologically sustainable development and use of the relevant water resource.* (NWA, Act No 36 of 1998, Chapter 3, Part 3).

The reserve therefore consists of two distinct parts, namely the basic Human Needs Reserve and the Ecological Reserve. The basic human needs reserve, provides for the essential needs of individuals served by the water resource and includes water for drinking, for food preparation, and for personal hygiene. Currently this amount is calculated as a minimum of 25 litres per person per day, and is thus relatively easy to determine (DWAF, 2003a).

The Ecological Reserve relates to the quantity, quality and variable flow of water required to protect the aquatic ecosystems of the water resource.

The four Principles in South Africa's Water Act of 1998, that relate to the Reserve.

Principle 7

The objective of managing the quantity, quality and reliability of the nation's water resources is to achieve optimum, long term, environmentally sustainable social and economic benefit for society from their use.

Principle 8

The water required to ensure that all people have access to sufficient water shall be reserved.

Principle 9

The quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that human use of water does not individually or cumulatively compromise the long-term sustainability of aquatic and associated ecosystems.

Principle 10

The water required to meet the basic human needs (Principle 8) and the needs of the environment (Principle 9) shall be identified as "the Reserve" and shall enjoy priority by right. The use of water for all other purposes shall be subject to authorisation.

Due to the complexity of the systems and processes involved within the catchment, this amount is relatively difficult to determine, requiring detailed studies to assess the current status quo of the resource, and the desired environmental objectives of the resource for the future.

The Ecological Reserve is not intended to protect the aquatic ecosystem at the expense of all development, but to ensure that water resources are afforded a level of protection that will support a sustainable level of development for the future.

The volume and temporal distribution of water needed as the Ecological Reserve will differ from system to system, depending on its sensitivity and ecological importance, and on the priorities for water use within each catchment.

The Resource Directed Measures (RDM) Directorate within DWAF is tasked with ascertaining the Ecological Reserve for every major watercourse in the country by:

- classifying each water resource to a Management Class;
- allocating an environmental water allocation appropriate for that Management Class and ecosystem;
- setting Resource Quality Objectives (RQOs) for the water course (i.e. the objectives to be measured in a monitoring programme).

The Resource Quality Objectives refer to the quality of all the aspects of a water resource including:

- the quantity, pattern, timing, water level, and assurance of instream flow;
- the water quality, including the physical, chemical, and the biological characteristics of the water;
- the character and condition of the instream and riparian habitat, and
- the characteristics, condition and distribution of the aquatic and riparian biota

The RQOs are numerical and narrative descriptors of conditions that need to be met in order to achieve the required management scenario.

2.3.4 The Classification System

One of the major challenges of RDM is to assess, as accurately as possible, how much exploitation a natural water resource can withstand before its ability to ensure sustainable use is reduced.

The classification and RQOs are the means by which RDM seeks to achieve the delicate balance between protection and development. Together they provide the tools to assess the current status, and plan for the desired condition of the water resources. They are a way of balancing protection and use of a water resource.

According to the NWA, the Minister is obliged to develop a system that will establish guidelines and procedures for the determination of different classes of water resources, and the determination of the Reserve.

Until a system for determining different classes of water resources has been prescribed by the Minister (Section12), all resource classes and Reserve determinations are deemed preliminary. This allows the interim implementation of the NWA to proceed whilst the necessary systems and methodologies are being finalised.

In South Africa, DWAF sets objectives according to different ecological management targets for the Reserve. There are four target classes, A to D (see Table 2). Two additional classes, E (Seriously modified; the Reserve has been seriously decreased and depletion regularly exceeds the amount of water required to maintain ecosystem functioning; the loss of natural habitat, biota and basic ecosystem functions is extensive) and F (Critically modified; the Reserve has been critically decreased and there is never enough water to maintain ecosystem functioning; modifications have reached a critical level and the resource has been modified completely with an almost total loss of natural habitat and biota; in the worst instances the basic ecosystem functions have been destroyed and the changes are irreversable) may describe present ecological status but not targets. Water resources currently in category E or F must have a target class of D or above (DWAF, 1999; O'Keeffe and Uys, 2000).

Table 2 The four Ecological Management Classes used for setting ecological management targets for the Reserve (DWAF, 1999).

Class	Description
A	Negligible modification from natural conditions. Negligible risk to sensitive species. The Reserve has not been decreased and the resource capability has not been exploited.
B	Slight modification from natural conditions. Slight risk to intolerant biota. The Reserve has been decreased to a small extent. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	Moderate modification from natural conditions. Especially intolerant biota may be reduced in number and extent. The Reserve has been decreased to a moderate extent. A change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	High degree of modification from natural. Intolerant biota unlikely to be present. The Reserve has been decreased to a large extent. Large changes in natural habitat, biota and basic ecosystem functions have occurred.

The application of this objective-based approach necessitates that the desired status of the river has first been set. It should then be possible to define threshold flows above or below which a change in status will be evident.

A number of methods have been developed internationally and within South Africa to define the flows (i.e. the environmental flows) required to maintain a river in whatever class (A to D) as selected as the target management class.

2.4 Environmental Flow Assessment: Methodologies

2.4.1 Introduction

More than 200 approaches to environmental flow assessments have been reported (Tharme, 2003), and they are now used in more than 50 countries as a water planning and management tool. Four main types of approaches have developed, more or less in chronological order since the mid 1900s, namely hydrological, hydraulic rating, habitat simulation and holistic (Tharme, 2003). Other reviewers (Loar et al., 1986; Gordon et al., 1992; Swales and Harris, 1995; Tharme, 1996; Jowett, 1997; Dunbar et al., 1998) have classified the methodologies slightly differently, but the overall pattern is much the same, and so the classification of Tharme (2003), which is felt to be the most comprehensive to date, is used here. The reader is referred to this document for a full review and bibliography. The four main types are briefly described below, followed by information on new developments in recent years.

2.4.2 Hydrological methods

These typically desktop approaches are the earliest, simplest and most rapid. They use one or more summary statistics gleaned from hydrological data sets, usually a percentile from the annual flow duration curve, to set what is often called a minimum flow for the river. Gordon et al. (1992), Stewardson and Gippel (1997), and Smakhtin (2001) review many of the established hydrological and regionalisation techniques used to derive relevant flow indices, such as the Q_{95} or, ${}_7Q_{10}$. The minimum flows, identified in overseas studies, are usually set for the dry season with the purpose, for instance, of ensuring adequate dilution of pollutants or sufficient habitat for fish. Usually the set flow is assumed rather than known to have ecological relevance, although the most widely used method, the Tennant Method (Tennant, 1976), is an exception in that it is based on extensive field observation of habitats used by fish. Tennant's approach could be used elsewhere in the world, but becomes 'rapid' only after it has been locally calibrated using the same extensive local field observations as done in its country of origin. A major drawback with all of these approaches is their lack of specificity – they do not take into account any features of the river other than its (usually monthly) flow data. The results are broad-brush guides to flows for ecological maintenance that are insensitive to the nature of individual rivers and mostly have little ecological relevance.

A more recent development within this kind of assessments is the Range of Variability (RVA) approach of Richter et al. (1997). The natural range of hydrological variation is described using 32 hydrological indices derived from long-term daily flow records. Indices reflect the magnitude of both high and low flows, the timing and frequency of different sized flows; and their duration indexed by moving averages. Each index is calculated on an annual basis for each year in the hydrological record, thus allowing assessment of inter-annual variability. An acceptable range of variation of the indices for maintaining the natural system is then set, for example + or - 1 standard deviation from the mean or between the 25th and 75th percentiles. This method is intended to define interim standards, which can be monitored and revised, but to date there has been insufficient research on the relationship between the flow statistics and specific elements of the ecosystem to allow revision.

2.4.3 Hydraulic rating methods

From the 1970s onwards, initially in North America, it became recognised that flows for river maintenance should be guided by field measurements of the river of concern. Pioneers of this approach included Collings et al. (1972, cited in Trihey and Stalnaker, 1985) and Waters (1976). Two groups of transect-based methodologies evolved from this foundation: hydraulic-rating (this section) and habitat-rating (next section).

Loar et al. (1986) coined the term ‘hydraulic rating’ methods (also known as habitat retention methods) for approaches using changes in simple hydraulic variables over a range of flows as a surrogate for ecological data on habitat. The variables are usually wetted perimeter, wetted width or depth and are measured at one or more cross-sections at representative sites along the river. The values are plotted against discharge, and break points sought where there is a change in the slope of the curve. The implicit assumption is that when flow falls below such a break point, there will be a sharp change in the quality of habitat and thus repercussions for the aquatic life and ecological integrity of the ecosystem. A major asset of these approaches is the use of river-specific data, which allow precise hydraulic relationships to be described, whilst their main drawback is the common assumption that arbitrarily chosen hydraulic break points have ecological significance. The generic Wetted Perimeter Method is the most widely applied of these approaches (Gippel and Stewardson, 1998).

2.4.4 Habitat-simulation methodologies

More complex habitat-rating approaches evolved from the hydraulic-rating methods in about the late 1970s and 1980s. These, for the first time, incorporated ecologically relevant data, often utilising a quantifiable relationship between the quality of an instream resource, such as fishery habitat, and discharge, to guide decisions on environmental flow allocations (e.g. Stalnaker and Arnette, 1976; Prewitt and Carlson, 1980). The methodologies link the hydraulic relationships of a river with extensive data on the habitat requirements of aquatic plants or animals in the same river. Hydraulic data such as water velocity, water depth and substratum particle size, collected at many cross-sections, are used to compile a description of representative river sites in terms of the hydraulic habitat they provide over a range of flows. The descriptions are linked to descriptions of hydraulic-habitat requirements of selected plant or animal species, using

the same variables. The output, usually in the form of graphs, illustrates how much habitat is provided for that species at any flow. These relationships can be used to identify what are perceived to be optimal flows for the species selected. Advantages of these approaches are their strong ecological links, and quantitative outputs that can be used in water negotiations. Early drawbacks included the focus on habitat without recognition of the wider environmental needs of species, on aquatic species whilst ignoring riparian species and on lower flows with no focus on floods. Some of these shortcomings have been addressed to varying extents within the last decade. The most widely used of these approaches is the Instream Flow Incremental Methodology (Stalnaker et al. 1995)
(Box 1), used extensively in the U.S.A., its country of origin, and many other countries (Tharme, 2003).

Concern over the simplicity of the habitat modelling in IFIM led to a proliferation in habitat modeling, such as 2D and 3D hydraulic models (Proceedings of the First to Fifth International Ecohydraulics Symposia, International Association for Hydraulic Research website). Likewise, new habitat models have included additional hydraulic variables and have been expanded to address community-level data and river processes. So far, none of these developments have produced a package that is the logical replacement of IFIM.

Box 1 The In-stream Flow Incremental Methodology (IFIM)

IFIM is a framework for addressing the impacts on river ecosystems of changing a river's flow regime. Developed by the U.S. and Wildlife Service, its use has become a legal requirement in some states of the U.S.A., especially for assessing the impacts of dams or abstractions. It has five main phases.

Phase 1. *Identifying problems*
The problems, broad issues and objectives are identified.

Phase 2. *Project planning and catchment characterisation*
The technical part of the project is planned in terms of characterising the broad-scale catchment processes, species present and their life-history strategies; identifying likely limiting factors for the species; and collecting baseline hydrological, physical and biological data.

Phase 3. *Developing models*
Models of the river are constructed and calibrated. IFIM distinguishes between microhabitat, at the scale of a study site and commonly modelled using the hydraulic-habitat model PHABSIM; and macro-habitat, which includes variables that are reasonably uniform over longer river lengths, such as water chemistry/quality, temperature, hydrology and geomorphology. A structure for specifying channel and floodplain maintenance flows is present, but there is little guidance on specific methods. Hydrological models of alternative scenarios, including a baseline of either naturalized or historical conditions, drive the habitat models. The models are integrated, using habitat as a common currency.

Phase 4. *Formulating and testing scenarios*
Alternative scenarios of dam releases or abstraction restrictions are formulated and tested using the models to determine the impact of different levels of flow alteration on individual species, communities or whole ecosystems.

Phase 5. *Providing inputs into negotiations*
The technical outputs are used in negotiations between different parties to resolve the issues set out in step one.

Advantages of IFIM include it being a comprehensive framework for considering both policy and technical issues, and its problem-orientated structure. Its integration of micro and macro-habitat variables is generally considered an advantage, whilst its scenario-based approach is favoured for negotiations between water users but may be less suitable for setting flow regimes to comply with ecological objectives.

Disadvantages of IFIM partly arise from its comprehensive nature. A full study takes a considerable time and, because of the wide range of issues included, provides numerous avenues for criticism. Furthermore, it is important to understand the limitations of the models used, what they include, omit or simplify, and any further issues arising from the linkages of models. Many IFIM studies have been criticised, but the problem has often been that the IFIM framework was not applied in its entirety. Emphasis has been placed on Step 3 - the modeling of micro-habitat with PHABSIM - at the expense of the other critical steps. IFIM studies have also been criticised for being too institutionalised, with the method being applied in an inflexible fashion. Finally, IFIM provides an incremental view of the relationship between flow and habitat and does not provide "the answer" – an attribute that has been seen as both a disadvantage and an advantage.

2.4.5 Holistic approaches

Holistic methodologies emerged from a common conceptual origin in South Africa and Australia (Arthington et al., 1992), to become recognised as the latest major advance in method development and the most rapidly growing category of methods globally today (Tharme, 1996; Dunbar et al., 1998; Arthington, 1998). Emerging in the early 1990s, they address all parts of the river ecosystem and all parts of the flow regime. The most advanced ones used in developing countries additionally address the impacts of changing rivers on subsistence users of river resources and can provide economic information on compensation for resources lost, for instance, downstream of dams. Holistic approaches are essentially structured data and information management tools that require and use hydrological, hydraulic, sedimentological, geomorphological, chemical, thermal, botanical (aquatic, marginal and riparian plants), zoological (fish, invertebrates, plankton, water birds, other wildlife), and microbiological data to compile an understanding of the river ecosystem and develop a consensus prediction of how it would change with flow changes. Where subsistence users also exist, anthropological, medical, socio-economic and resource economic data can be used to predict the implications for people of the changing river. The methodologies can use any relevant data, knowledge or local wisdom, and incorporate any individual discipline methods to derive the relationships needed for predictions. Their advantages are immense because of their wide scope, because they contribute toward national databases that enhance understanding of the rivers, and because ultimately they allow derivation of their own rapid versions based on past applications. Such rapid versions are becoming available and to date have been used in, for instance, South Africa and Zimbabwe (Section 7.6).

Their main drawback is the cost of large multi-disciplinary teams optimally working over at least one annual hydrological cycle to gather river-specific data.

In the following paragraphs, the three main South African holistic methodologies are introduced, followed by an outline of comparable methods developed in parallel in Australia.

The Building Block Methodology (BBM)

Perhaps the best-known holistic methodology, the BBM was developed in South Africa in the early 1990s (King and Louw, 1998; King et al., 2000). The basic premise of the BBM is that riverine species are reliant on basic elements (building blocks) of the flow regime, including low flows and floods that maintain the sediment dynamics and geomorphological structure of the river. An acceptable flow regime for ecosystem maintenance can thus be constructed by combining these building blocks. The BBM has a detailed manual for implementation, and is the basis of the two next methods now routinely used in South Africa to comply with the 1998 Water Act. It has also had trial applications in Australia (Arthington and Lloyd, 1998) and the United States.

Flow-stressor Response (FSR)

The FSR method was developed in South Africa in 2000 (O'Keeffe and Hughes, 2002) for predicting impacts caused by changes in the low-flow part of the flow regime. It is designed to convert lowflow-related ecological stresses to an index that relates to hydrological time series. Using it, hydrological time series are converted to stress time series. For any river site, the stress regime for any planned future flow regime can be analysed in terms of the magnitude, duration and frequency of stresses that would be faced compared to those experienced under the natural flow regime. One of the advantages of the method is that once the index of stresses has been calibrated for a river reach, any flow scenario can be analysed using the same ecological knowledge base. Current development is addressing inclusion of floods into the method.

Downstream Response to Imposed Flow Transformation (DRIFT)

DRIFT was developed in South Africa, with its first major applications being in the Palmiet River, Western Cape, and in the Lesotho Highlands Water Project (King et al., 2003). It is a scenario-based approach that provides a number of scenarios of a future flow regime together with predictions of how each of these will change river condition. It has a strong socio-economic module, which describes the predicted impacts of each scenario of river change on subsistence users of the resources of a river.

DRIFT has four modules:

- **Module 1.** *Biophysical.* Within the constraints of the project, scientific studies are conducted of all aspects of the river ecosystem: hydrology, hydraulics, geomorphology, water quality, riparian trees and aquatic and fringing plants, aquatic invertebrates, fish, semi-aquatic mammals, herpetofauna, water bird and microbiota. All studies are linked to flow, with the objective of being able to predict how any part of the ecosystem will change in response to specified flow changes.

- **Module 2.** *Socio-economic.* Social studies are carried out of all river resources used by common-property users for subsistence, and the river-related health profiles of these people and their livestock. The resources used are costed. All studies are linked to flow, with the objective being to be able to predict how the people will be affected by specified river changes (results from Module 1).
- **Module 3.** *Scenario-building.* For any future flow regime the client would like to consider, the predicted change in condition of the river ecosystem is described using the database created in Module 1. The predicted impact of each scenario on the common-property subsistence users is also described using the database created in Module 2.
- **Module 4.** *Economics.* The compensation costs of each scenario for common-property users are calculated.
- If there are no common-property subsistence users, modules 2 and 4 can be omitted.
- The DRIFT software SOLVER is a custom-built optimization package that creates the scenarios, and DRIFT CATEGORY (Brown and Joubert, 2003) allocates each scenario to an ecological condition class.

Although DRIFT is usually used to build scenarios, its database can equally be used to set flows for achieving specific ecological objectives. Two other activities should run outside DRIFT to provide additional information to the decision-maker:

- a macro-economic assessment of each scenario, to describe its wider regional implications in terms of industrial and agricultural development, cost of water to urban areas and so on;
- a public participation process, in which the wider body of stakeholders can voice its level of acceptability of each scenario.

DRIFT has also been applied to the Breede (Brown and Louw, 2001) and Olifants-Doring (In progress) Rivers in South Africa. Implementation of the chosen scenarios is already underway in the Palmiet system and Lesotho.

Because of their multidisciplinary nature, a comprehensive BBM, FSR or DRIFT application could cost up to one million rand for a large river system but, put into perspective, this is still probably less than one percent of the cost of the planned water-resource project.

Australian holistic methodologies

In Australia, the basic BBM concept is reflected in several holistic approaches, such as the Expert Panel Assessment Method (EPAM) (Swales and Harris, 1995), the Scientific Panel Assessment Method (SPAM) (Thoms et al., 2000), the Flow Restoration Method (FLOWRESM) (Arthington and Zalucki, 1998), the Benchmarking Methodology (Brizga et al., 2002) and the Flow Events Method (Stewardson and Gippel, 2003).

EPAM was the first of these, designed for use at the reconnaissance and planning phase of a project, and reliant on the professional judgement of a panel of scientific experts. The panel assesses the suitability of (usually dam-released) flows for maintenance of river plants and animals, and channel morphology, through visual assessment of the flows and in workshop discussions. SPAM is a more sophisticated version of EPAM and has been applied to regulated and unregulated but highly modified rivers. FLOWRESM is specific to river-restoration projects where flow restoration plays a part, describing flows that need to be built back into the flow regime to achieve a designated pre-regulation state. The Benchmarking Methodology assesses how much water can be removed from a river's flow regime before the ecosystem undergoes unacceptable change. It is used at the planning/reconnaissance level, and predicts how a river might change with flow manipulations by comparing it with similar rivers that have undergone varying levels of flow-regime change. The Flow Events Method appears to have many similar attributes to the others, using the natural flow regime as a template and knowledge of the influence of flow events on ecosystem processes to set environmental flows.

Methodologies for other ecosystems

In addition to these types of methodologies, a number are appearing that have diverged from an emphasis on the relationship between instream habitat and flow, to explore other information best suited to other kinds of aquatic ecosystems (Tharme, 2002). Recent reviews or discussion documents are available or in preparation for wetlands and lakes (McCosker, 1998; DWAF, 1999a), estuaries and the nearshore coastal environment (Bunn et al., 1998; DWAF, 1999b), water quality (Dortch and Martin, 1989; Tharme, 1996; Malan and Day, in press), geomorphology and sedimentology (Reiser et al., 1987, 1989; Stewardson and Gippel, 1997; Brizga, 1998), riparian vegetation (Tharme, 1996; McCosker, 1998), wildlife (Kadlec, 1976; Tharme, 1996), groundwater-dependent ecosystems (e.g., DWAF, 1999c; Parsons and MacKay, 2000), social dependence (e.g., Acreman et al., 2000; Pollard, 2000); and recreation, aesthetics and cultural amenity (e.g., Mosley, 1983; Whittaker et al., 1993 (taken from Tharme, 2002).

Recent developments

A number of new and innovative approaches for assessing environmental flows have evolved from the flurry of holistic method development in the 1990s. Two promising developments from the U.K. and two from South Africa are outlined below.

Lotic Invertebrate Index for Flow Evaluation (LIFE)

Recently developed in the U.K., LIFE is based on routine macro-invertebrate monitoring data (Extence et al., 1999). An index of perceived sensitivity to water velocity was developed by giving all recorded UK taxa a score between 1 and 6. For a sample, the score for each observed taxon is modified based on its abundance, and an aggregate score calculated. The system works with either species or family level data. For monitoring sites close to flow gauging stations, the relationship between LIFE score and preceding river flow may be analysed. Moving averages of preceding flow have shown good correlation with LIFE scores over a range of sites. Procedures for using this information in the management of river flows are still under development. Nevertheless, the principle is believed to be sound and LIFE has the major advantage of utilising the data collected by existing bio-monitoring programmes. Some disadvantages are:

- it is difficult or even impossible to derive biotic indices that are only sensitive to flow and not to other factors such as habitat structure and water quality; at the very least, biotic indices designed for water-quality monitoring should be used with extreme caution;
- lack of both hydrological and biological data is often a limiting factor, and sometimes routinely collected data may have been gathered for other purposes and not be suitable;
- time series of flows and ecological indices may well not be independent, which can violate assumptions of classical statistical techniques and require special care.

Catchment Abstraction Management Strategies (CAMS)

The U.K. Environment Agency is responsible in England and Wales for ensuring that the needs of the abstractor are met whilst safeguarding the environment. To implement this responsibility in a consistent manner, the Agency has developed CAMS (Dysan et al., 2003). The CAMS process includes participation of interested parties through catchment stakeholder groups and a Resource Assessment and Management (RAM) framework. RAM is intended as a default methodology in the absence of other more sophisticated techniques.

The first step is to calculate the environmental weighting that determines a river's sensitivity to a reduction in flow. Four elements of the ecosystem are assessed: physical characterisation; fisheries; macrophytes; and macro-invertebrates. Each element is given a RAM score from 1 - 5 (1 being least sensitive to reductions in flow, 5 being most sensitive). In terms of physical characterisation, rivers with steep gradients and/or wide shallow cross sections score 5, since small reductions in flow result in a relatively large reduction in wetted perimeter. At the other extreme, lowland river reaches that are narrow and deep are less sensitive to flow reduction and score 1. Photographs of typical river reaches in each class are provided to aid the scoring of physical character. Scoring for fisheries is determined either through modelling with a model such as PHABSIM, or by using expert opinion of Environment Agency fisheries staff. An example of the description and RAM score for each class is given in Table 3.

Table 3 Fisheries Scoring Scheme as part of the Environmental Weighting within the Resources Assessment and Management Framework (RAM).

RAM score	Description
5	Salmonid fish – spawning/nursery areas
4	Adult salmonid residents (wild) and/or rheophile coarse fish – barbell, graling
3	Salmonid fish passage (smolts and adults) and/or. Flowing water cyprinid fish - dace, chub, gudgeon, Bullhead, and/or shad spawning/rearing/passage
2	Slow/still water cyprinid fish - roach, bream, tench, carp
1	Minimal fish community e.g. eels and sticklebacks only, or no fish

Once a score for each of the four elements has been defined, the scores are combined to categorise the river into one of five Environmental Weighting Bands, where Band A is the most sensitive (average score of 5) and E is the least sensitive (average score of 1). In a separate part of the RAM framework a flow duration curve for natural flows is produced. The RAM framework then specifies allowable abstractions at different points of the curve for each weighting band. Table 4 details the percentage of natural Q_{95} flow that can be abstracted for each band.

Table 4 Percentages of natural Q95 flow that can be abstracted for different environmental weighting bands.

Environmental weighting band	% of Q_{95} that can be abstracted
A	0 - 5%
B	5 - 10%
C	10 - 15%
D	15 - 25%
E	25 - 30%
Others Special Treatment	

These percentages are not well supported by hydro-ecological studies and are only intended as a default method. Where environmental flows need to be defined more accurately, detailed methods such as habitat modelling are recommended. The RAM framework focuses on producing an ecologically acceptable flow duration curve. The flow duration curve retains many characteristics of the flow regime, such as the basic magnitude of droughts, low flows and floods. However, it does not retain other characteristics, including temporal sequencing, duration or timing of flows, which are important for river ecosystem functioning.

The South African Desktop Model

The holistic methods developed in South Africa take some months of work from a multi-disciplinary team to produce scenarios of the effects on the river of flow manipulations. The country's new Water Act stipulates that future water-resource developments should be ecologically sustainable with some proportion of the natural flow of the river retained for ecosystem maintenance. This requirement served as an impetus for development of a rapid, low-confidence environmental flow (EF) assessment process that could be used in planning and reconnaissance studies. The Desktop Model (Hughes and Hannart, 2003) was developed in 1999-2001 to meet this need, using results from the many EF assessments done within the country to that time. From these data for many rivers, a relationship was developed between the percentage of Mean Annual Runoff (MAR) defined as the EF for the river and the ecological management class (see Section 2.3.4) that this would place the river in. Further, for any one management class, a relationship was defined between the percent of MAR and a Hydrological Index (HI). The HI was derived from two other indices of the long-term flow data. These were the Base Flow Index, which indicates the proportion of total flow that is base flow, and the Coefficient of Variation (CV), which sums the average CV for the three driest months and that for the three wettest months as an indication of different flow-regime types across the country. Once the relationships had been developed, then for any one ecological management class the HI indicates how much of the MAR needs to be reserved for river maintenance.

The Desktop Model is now routinely used in South Africa to define the EF needs for perennial rivers. Already acknowledged as a rapid, low-confidence method, confidence in its outputs decreases markedly once the HI reaches values of 10 or above (D. Hughes, pers. comm.). Such values tend to be for rivers in more arid areas, thus making the method unsuitable for ephemeral rivers as it stands. Research is needed to reveal if it can be modified for use in arid rivers, or if another approach is needed.

Mini-DRIFT

The scenario-based approach of DRIFT requires population of a custom-built database with predictive flow-response couplets. This then becomes a rapid and highly flexible tool for creating scenarios but populating the database is time-consuming and requires quite detailed insights into the functioning of the river ecosystem. As such, it was seen as too complex for immediate use in countries with few research and other resources. A trial application of a reduced version of DRIFT was thus undertaken in Zimbabwe (King et al., 2003). A team of biophysical and social specialists, all of whom had no experience of EF assessments, undertook a short programme of workshops and field data collection in order to be able to respond to some pre-selected flow scenarios for three rivers with planned dams. They provided descriptions of how these would change the downstream rivers and impact their subsistence users. An analysis was also completed of which parts of the altered flow regimes would be causing the most degradation, so that mitigation through adjustment of flow releases could be considered. The results were discussed with the regional Catchment Councils, which ultimately have the responsibility for managing the catchments. The project took a few weeks compared to the months to years of comprehensive EF assessments, but did not produce a populated database and so could not be used for providing predictions of the consequences for any flows scenarios other than the pre-chosen ones.

2.4.6 Summary guide for using methods

Different kinds of EF assessment are more suited to different applications. Suggested applications of the four major types of methods are given in Table 5. In general, the earlier and simpler methods should be used only for coarse regional planning where conflicts over water are likely to be low. The more complex approaches should be used for rivers of high strategic or conservation importance, for those that have high subsistence use, and for those where conflicts over water are likely to be high.

Prior and post-determination monitoring

The scenarios of possible future flow changes and their implications, both for river condition and for subsistence users of the river, are predictions based on the best available scientific data and understanding. As such, monitoring of the situation after a scenario has been selected and implemented is vital. This should have several main objectives:

- to ensure the agreed on EF is being delivered to the river;
- to assess if it is achieving the predicted river condition class;
- to assess if the impacts on the riparian people are as predicted, and agreed compensation and mitigation actions are being carried out;
- to adjust management plans of either of the first three objectives is not being met;
- to allow the river and social specialists to assess the accuracy of their predictions and learn through unexpected outcomes.

Time and money spent on a well-designed monitoring programme will significantly enhance the confidence in the EF process as well as the predictive capacity of the specialists. This in turn supports acceptance by stakeholders and the general community, thus helping to ensure successful implementation. Both the initial data-collection research phases and the post-development monitoring phases are vital investments in improving the management of the nation’s aquatic resources. The greater the investment in the research phase, the higher the confidence in the predictions of change made by the specialists. The greater the investment in post-development monitoring, the greater the learning and the possibility of good communication and understanding among all stakeholders.

Table 5 Comparison of the four main kinds of environmental flow methodologies (After King et al. 1999).

Type	Ecosystem components addressed	Data needs	Expertise	Com-plexity	Resource intensity (time, cost, technical capacity)	Resolution of output (the EF)	Flexi-bility	Appropriate level of application
Hydrological	Non-specific	Low (primarily desktop): measured or simulated hydrological record	Manipulate hydrological date	Low	Low	Low	Low	Reconnaisance level planning
Hydraulic-rating	General aquatic habitat	Low-medium (desktop and limited field): measured or simulated hydrological record; one or a few hydraulic variables from a cross-section	Manipulate hydrological data; perhaps some hydraulic modelling	Low-medium	Low-medium	Low	Low	Low-conflict water-resource allocations
Habitat-simulation	Aquatic habitat for selected species	Medium-high (desktop and field): measured or simulated hydrological record; many hydraulic variables at many cross-sections; habitat data for selected species	Advanced hydrological and hydraulic modelling; specialist ecological expertise on habitat requirements of selected species	Medium-high	High	Medium-high	Medium	Water allocations for high conservation areas where in-channel habitat is main concern
Holistic	Whole aquatic and riparian ecosystem; can include groundwater, wetlands, floodplains, estuary, delta, and subsistence users	Medium-high (desktop and field): measured or simulated hydrological record; many hydraulic variables at many cross-sections; biological data on flow-related habitat requirements of wide range of species	High: advanced hydrological, hydraulic, and habitat modelling; chemical and thermal modelling if possible; specialist expertise on all ecosystem components; social and economic expertise as required	Medium-high	High	High	High	Developed and developing countries; Flow management in any size river, including ones of high strategic or conservation importance; dam de-commissioning and river rehabilitation

2.4.7 The South African Context

The Ecological Reserve is relatively difficult to determine because of the variability imparted by a range of Management Classes and types of ecosystem, and because of the poor historical investment in the knowledge base about the ecosystems and their water needs. Because of this difficulty and the need to move quickly to determine the Reserve nationwide, several levels of Reserve determination have been recognised.

The levels for Ecological Reserve Determinations

- The levels were initially described in terms of the time it took to carry out an assessment, from Rapid, which might take from eight days at four sites to two months for an Intermediate Reserve at four sites and up to eight months to two years for a Comprehensive Reserve determination. It was originally assumed that the degree of confidence in the results of an assessment would increase in direct proportion to the time and cost involved. In practice, this was not necessarily the case. Any Reserve determination that does not satisfactorily define the biophysical relationships between:
- the hydrological regime, and
- channel hydraulics,
- geomorphology,
- water quality, and
- ecological functioning

will return low-confidence information on the link between flow and ecosystem health, no matter how high its cost and how long it took. Hence at present, Rapid, Intermediate and Comprehensive refer to the method, whilst the terms low, medium or high refer to the level of confidence in the resulting Environmental Flow assessment.

The importance of the confidence level at which the Reserve is determined depends on a number of factors namely the:

- degree to which the catchment is already utilised;
- the ecological sensitivity and importance of the catchment;
- potential impact of the water use.

High-confidence determinations are required for:

- all compulsory licensing;
- large impacts in any catchment;
- important or sensitive catchments.

The South African EF methodologies described in Section 2.4.5 are the means by which the decision-makers receive information on the likely consequences of a water project and reach a decision on the Ecological Reserve for the ecosystem of concern.

The RDM requirement is that the methodologies:

- are legally defensible, since they serve as a basis for issuing legally valid water use licences;
- are scientifically defensible, and based on sound ecological principles in line with the integrated ecosystem approach to water resource management;
- match administrative requirements, meaning that the information that is provided to the licensing agencies should be in a format that can be used as a basis for drawing up water-use allocation plans and catchment management strategies, and for setting individual water use licence conditions;
- provide estimates of the water quantity and quality required to meet the Ecological Reserve, in order to prevent irreversible degradation of water resources;
- provide a variety of options to meet the projected demand for NWA implementation in the transitional period.

2.4.8 Environmental Water Requirements (EWR) for ephemeral systems

A country such as South Africa has a wide range of ephemeral aquatic systems, such as rivers, pans and floodplains. A question yet to be seriously addressed is whether these systems are more or less vulnerable than perennial ones. At the moment the general attitude of many seems to suggest that ephemeral systems already receive so little water, in such an unpredictable way, that a little less water should not make that much difference. Others feel that they already exist in such a marginal way that any further stress would have a massive (and largely unknown) effect on them.

Assessing EWRs for them will be difficult, because they are usually more remote from human settlements than perennial systems and so few data exist for them. In principle, the comprehensive holistic EF methodologies developed in South Africa should be amenable to revision to cater for ephemeral rivers and, in fact, a few such assessments have happened (DWAF, 1996a). The Rapid Desktop Method is not suitable in its present form, not least because average monthly flow figures cannot capture the variability in the quantity, quality, timing, and duration of available water, which is so different and so critical in these systems. Minimum or average flow allocations would not be useful for such ecosystems (Dysan et al., 2003).

The relationship between surface water and groundwater in such systems is complex. The slow movement of groundwater means that reducing abstraction when the surface or ground water falls to a critical level may be too late, since the impact of the abstraction may continue for many months. Possibly an assessment method needs to be sought that combines some aspects of the present methods (for times when the systems have surface water) with some consideration of groundwater and aquifer conditions (for times when there is no surface water).

The surface-water component could guide the Ecological Reserve for the wetter months whilst the groundwater component could limit abstractions based on the position of the water table.

3. METHODOLOGY

The revised Resource Directed Measures methodology as set out in Louw et al. (2004) (Figure 2) was followed as far as possible for this project

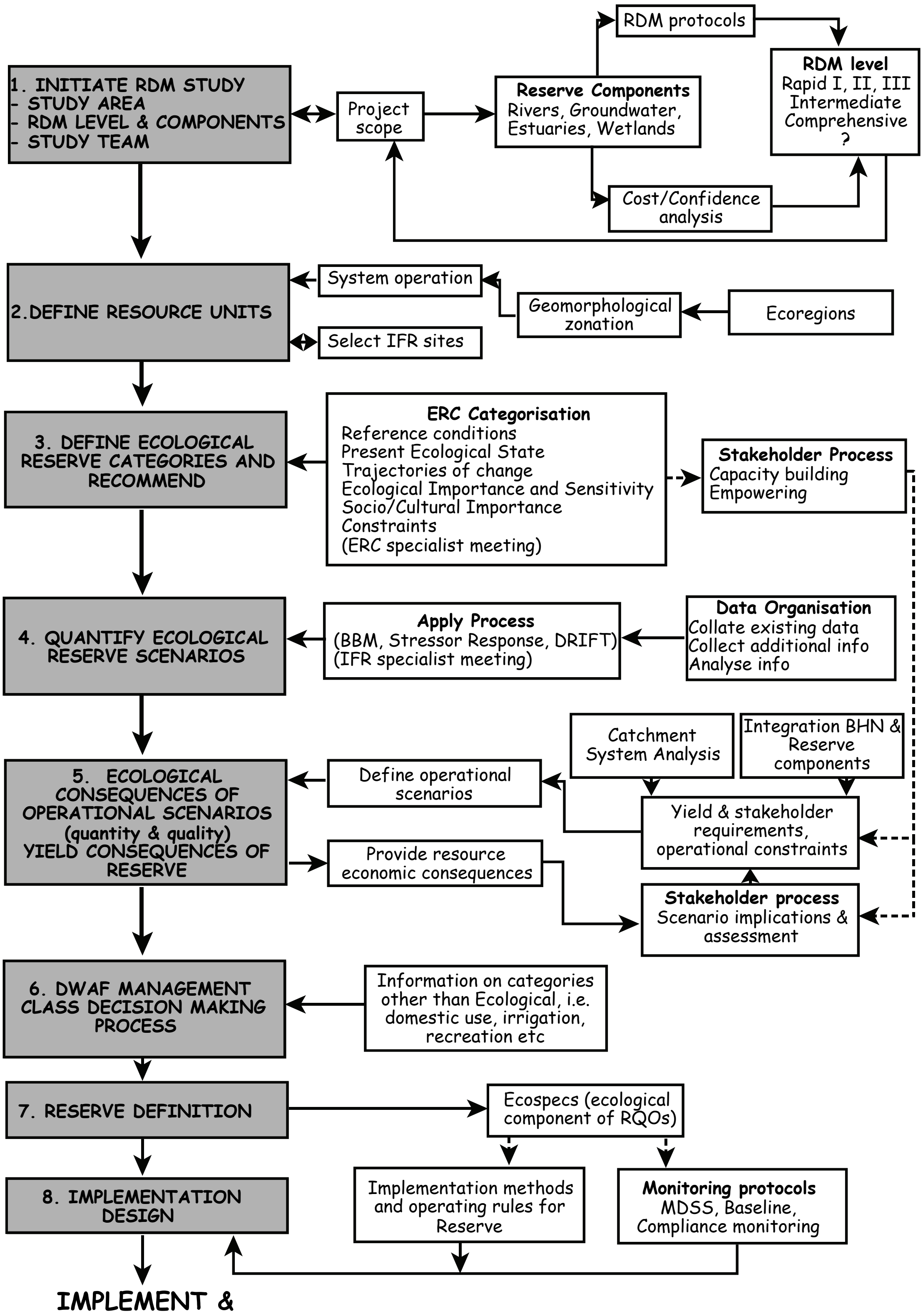

Figure 2 Revised Ecological Reserve Procedure (After Louw et al., 2004).

This methodology does however not make provision for a desktop reserve determination as set out in the terms of reference for this project and therefore only the first 3 steps were followed.

Terms of Reference of the current study:
An extract of the Terms of Reference that was set out in the proposal document required that the following steps should be followed:

ii. *Review environmental water requirements / Instream flow requirements (IFR) on non-perennial systems to date, on the systems that a rapid reserve determination has already been done (Mogalakwena, Matlabas, Shisa, Shingwedzi, Bushmans [E Cape] and Gonubie). So as to identify which areas need refinement of methods.*

iii. *Perform a **rapid** desktop reserve determination on each of the following data rich systems: - Kuiseb (Ephemeral), Limpopo (seasonal), Nylsvley (seasonal). Changed to **desktop** reserve determinations.*

iv. *Review available management tools and identify the knowledge gaps*

v. *Review ecosystem typing*

vi. *Review the linkages between drivers and responses*

vii. *Review people-ecosystem interactions*

- *Social cultural interactions*
- *Economics*

This project is preliminary to a larger, main programme. The intention is to provide the background and to define the needs for the programme. This preliminary study should be done largely at a desktop level, but involving experts from the appropriate disciplines.

As a **desktop reserve** determination was required, and no site visit therefore required, the team decided to use a combination of the revised Reserve Determination Methodology (Louw et al., 2004) and the desktop methodology as set out by Kleynhans (1999b).

The Desktop Model provides a low confidence estimate of the Instream Flow Requirements (IFRs) linked to the different Ecological Reserve Categories (ERCs) i.e. different ecological states (Louw et al., 2004)

Section C, of the Resource Directed Measures for Protection of Water Resources for River Systems, sets out the procedure to be followed during a desktop estimate of water quantity component of the ecological reserve (Kleynhans, 1999a).

The revised RDM methodology also sets out similar steps and a combination of these were followed during this study.

The steps followed, were namely:

Step 1: Initiate RDM study, define study area, select RDM level and establish study team.

The RDM study was initiated by WRC as part of the overall Environmental Water Requirements in Non-Perennial Systems study as mentioned in the terms of reference set out above.

The level of determination was also decided on by the project steering committee for this project namely a rapid/preliminary or desktop reserve determination.

The study team was selected from the expertise available at the Centre for Environmental Management as well as at the Universities of the Free State and Cape Town.

Step 2: Define resource units

The Nylsvley, Kuiseb and Limpopo River catchments were divided into resource units, by each of the specialists involved in the study, according to the occurrence of different ecoregions and/or large contributing tributaries within the catchment, as well as the availability of data for each of these resource units. These resource units were then discussed and geographic boundaries of each were determined. Consensus was then reached between specialists as to which resource units were the most meaningful for the scope of the study.

Ecotyping of non-perennial rivers was discussed at the workshop and the results are included in the report (see Chapter 5).

No IFR site selection was done, as this was a Desktop Determination, and no site visit was required.

Step 3: Define Ecological Reserve Categories and recommend

The following specialists were included to define the Ecological Reserve Categories (ERCs) of Nylsvley, Kuiseb and Limpopo Rivers:

IFR coordinator, Hydrologist, Geohydrologist, Geomorphologist, Riparian Vegetation specialist, Invertebrate specialist, Fish specialist, Water Quality and Algae specialist, and a Socio-Economic specialist.

The following steps were followed by each specialist:

1. Determine the Reference conditions

All (historical and present) data available on the river systems was collected and reference conditions (what the river looked like before) were determined for the hydrology, geohydrology, riparian vegetation, biota and water quality.

2. Determine the Present Ecological State (PES)

The PES is determined by the degree of negative change from natural (reference conditions).

The Present Ecological State (PES) of each of the resource units identified on Nylsvley, Kuiseb and Limpopo Rivers were determined by each of the specialists following the specific guidelines in their specialist fields.

Each resource unit was assessed individually by best expert judgement, data available and the specialists' knowledge and experience.

The PES was then scored and rated by each of the specialists using the guidelines set out in Kleynhans (1999a) as follows:

Extract from Kleynhans (1999a):

Scoring and Rating Guidelines

Table 6 provides scoring and rating guidelines for the estimation of the PESC. Each of the attributes is scored and the mean calculated. The mean is used to place the resource unit in the river in a particular present ecological status class (PESC). In cases where any of the attributes scores < 2 (i.e., it is considered to be seriously or critically modified) this score and not the mean is taken into consideration. The latter approach is based on the assumption that extensive degradation of any of the river attributes may determine the PES. However, as is the case with the estimation of the ecological importance and sensitivity, the mean on which the assessment of the PES is based, should be regarded as a guideline and should also be tested against the opinion of local experts. Biological integrity is not directly estimated through this approach and it is acknowledged that in some systems or parts of systems, information on biological integrity is available. In such cases, the information on biological integrity can be used as a check of the PES assessment. The mean (or default low rating due to individual scores of serious or critical modification) is used to relate the river resource units to a particular PES Class (Table 6).

The confidence with which the PES for each resource unit was determined was indicated by each specialist by following guidelines set out in Table 6.

3. Determine the Trajectory of Change

The degree to which each resource unit in the river is changing according to the different specialist fields was determined. The Trajectory of Change was indicated by either a 'O' for stable, '+' for improving or a '-' for degrading.

Table 6 Scoring and rating guidelines for present ecological status estimation (Adapted from Kleynhans, 1999b).

Scoring Guidelines Per Attribute*	Relative Confidence of Score of Attribute (Applicable to all Attributes)	Interpretation of Mean* of Scores for all Attributes: Rating of Present Ecological Status Category (PESC)
Natural, unmodified - score=5.	Very high confidence - score=4	Within general acceptable range
		CATEGORY A >4; Unmodified, or approximates natural condition.
Largely natural - score=4.	High confidence - score=3	CATEGORY B >3 and ≤4; Largely natural with few modifications, but with some loss of natural habitats.
Moderately modified- score=3.	Moderate confidence - score=2	CATEGORY C >2 and ≤3; moderately modified, but with some loss of natural habitats.
Largely modified - score=2.	Marginal/Low confidence - score=1	CATEGORY D ≤2; largely modified. A large loss of natural habitats and basic ecosystem functions has occurred.
		OUTSIDE GENERALLY ACCEPTABLE RANGE
Seriously modified - rating=1.		CATEGORY E >0 and <2; seriously modified. The losses of natural habitats and basic ecosystem functions are extensive.
Critically modified - rating=0.		CLASS F 0; critically modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat.

*: If any of the attributes are rated <2, then the lowest rating for the attribute should be taken as indicative of the PES category and not the mean.

4. Determine the Ecological Importance and Sensitivity (EIS) and Social Importance (SI)

The EIS was determined for each resource unit, following guidelines set out in Kleynhans (1999a).

The ecological sensitivity of a river system gives an indication of the system's ability to resist disturbance and its resilience (Milner, 1994 cited in Kleynhans, 1999b). In the determination of an ecological reserve, the ecological importance and sensitivity of a river section is considered, together with reference conditions, PES, trajectories of change, the socio-cultural importance and possible constraints, to define and recommend the ecological category for a river segment.

According to Kleynhans (1999a), the following ecological aspects should be considered as the basis for the estimation of EIS:

- The presence of rare and endangered species, unique species (i.e. endemic or isolated populations) and communities, intolerant species and species diversity;
- Habitat diversity;
- Biodiversity in its general form should be taken into account as far as the available information allows;
- The importance of the particular river or stretch of river in providing connectivity between different sections of the river;
- The presence of conservation or relatively natural areas along the river.
- The sensitivity of the system and its resilience (i.e. the ability to recover following disturbance) to environmental changes should also be considered.

For the present study the guidelines of Kleynhans (1999a) were used to determine the EIS for each river system. The following biotic and habitat determinants were considered and scored on a scale of "0" = low to "4" = very high:

BIOTA (RIPARIAN & INSTREAM)

- Rare & endangered species
- Unique (endemic, isolated, etc.) species
- Intolerant (flow & flow related water quality) species
- Species/taxon richness

RIPARIAN & INSTREAM HABITATS

- Diversity of types
- Refugia
- Sensitivity to flow changes
- Sensitivity to flow related water quality changes
- Migration route/corridor
- Importance of conservation & natural areas

The scores were then calculated to derive the ecological importance and sensitivity category (EISC).

The Social Importance (SI) was also determined and considered together with the EIS in the determination of the Ecological Reserve Category (ERC).

5. Define Ecological Reserve Categories (ERC) and recommend

The ERCs for each of the resource units was not determined but an Attainable Management Ecological Management Class (AEMC) was determined as follows:

The four EISC categories (EISC; A-D) were regarded as equivalent to the four Default Ecological Management Classes (DEMC; A-D) as set out in Kleynhans (1999a). The DEMC was then defined in terms of the Default Ecological Status Class (DESC) where the DEMC would be based on the EISC with the end point being the default status or condition of a class.

The Attainable Ecological Management Class (AEMC) of each resource unit was then determined keeping the following assumptions (taken from Kleynhans, 1999b) in mind.

Extract from Kleynhans (1999a):

> ***The PESC is compared with the DESC.***
>
> *1) If it falls in the same class as the DESC or is higher than the DESC, the PESC is taken as the attainable ecological management class (AEMC)*
> *2) If the PESC is lower than the DESC, the possibility of attaining the DESC has to be assessed. Gonzalez (1996) proposes a system of four categories indicating distance from the "default future condition". In the context of the current approach, categories are formulated in terms of the PESC and DESC (adapted from Gonzalez, 1996)*
>
> *(a) Close; PESC $\geq$ DESC*
> *(b) Moderate; PESC (for classes B-D) is 1 class lower than the DESC (for Classes A-C)*
> *(c) Far; PESC (for classes C to D) is 2 classes lower than the DESC (for Classes A-B)*
> *(d) Very far; PESC < class D when the acceptable range of the DESC can potentially vary from class A to class D (Figure 3).*
>
> *In general, it can be accepted, that the further the PESC is below the DESC, the more effort would be required to realise the DESC. However, the kind of change(s) that resulted in a particular PESC may vary in terms of the possibility*

of improving them in order to achieve restoration of the system up to the DESC. It follows that each of the attributes will have to be assessed in terms of the perceived possibility of restoring them to a condition where such an improvement will lead to an improvement of the PESC. Some changes may be practically irreversible within the limits of time and effort (including financial resources) required to achieve this. While five years is a commonly used time frame for many institutions and is considered a realistic period for attempting to estimate future conditions (Gonzalez, 1996), it is difficult to put limits to what can be regarded as realistic efforts. Nevertheless, if three broad categories of threat to ecosystems are considered, it is possible to obtain some perception of the effort required to restore ecosystems (adapted from Gonzalez, 1996):

- *Ecosystem degradation; occurs mainly through pollution, but could also be from selective removal of species (e.g., overfishing, overharvesting, etc.). Restoration potential is probably moderate to high.*

- *Ecosystem alteration; major physical changes (dredging, water diversion) and major removal of species (i.e., extinction). In terms of rivers, it is proposed that factors such as flow modification, and water abstraction (i.e., indicators of physical habitat modification), would also be included here. Restoration potential is probably low to moderate.*

- *Ecosystem removal; the highest level of alteration (e.g., destruction of wetlands due to urbanisation, etc.). In terms of rivers, modifications such as inundation, canalisation and concreting, destruction of the riparian zone and the macro-geomorphological features of the river and its catchment could conceivably be included here. Restoration potential is probably low.*

It must be emphasised that for the National Water Resources Situation Assessment, the desktop estimate is required in order to estimate the ecological flow requirements. This means that the assessment of the possibility of improving the ecological conditions must be approached in terms of the flow situation, i.e. degradation of the system that occurred because of purely non-flow related changes should not be included as part of the estimation of the restoration potential of a river (Kleynhans, 1999b).

The output of this process is the AEMC, which is used as an input into the hydrological model of Hughes and Münster (1999).

This means that regarding the AEMC, only classes A - D would be acceptable.

When the assessment of the improvement indicates that a class better than E or F is not attainable in 5 years, the AEMC will have to be taken as class D as an input to the hydrological model. However, it must be realised that a class of E or F may indicate a practically irreversible change of the ecosystem.

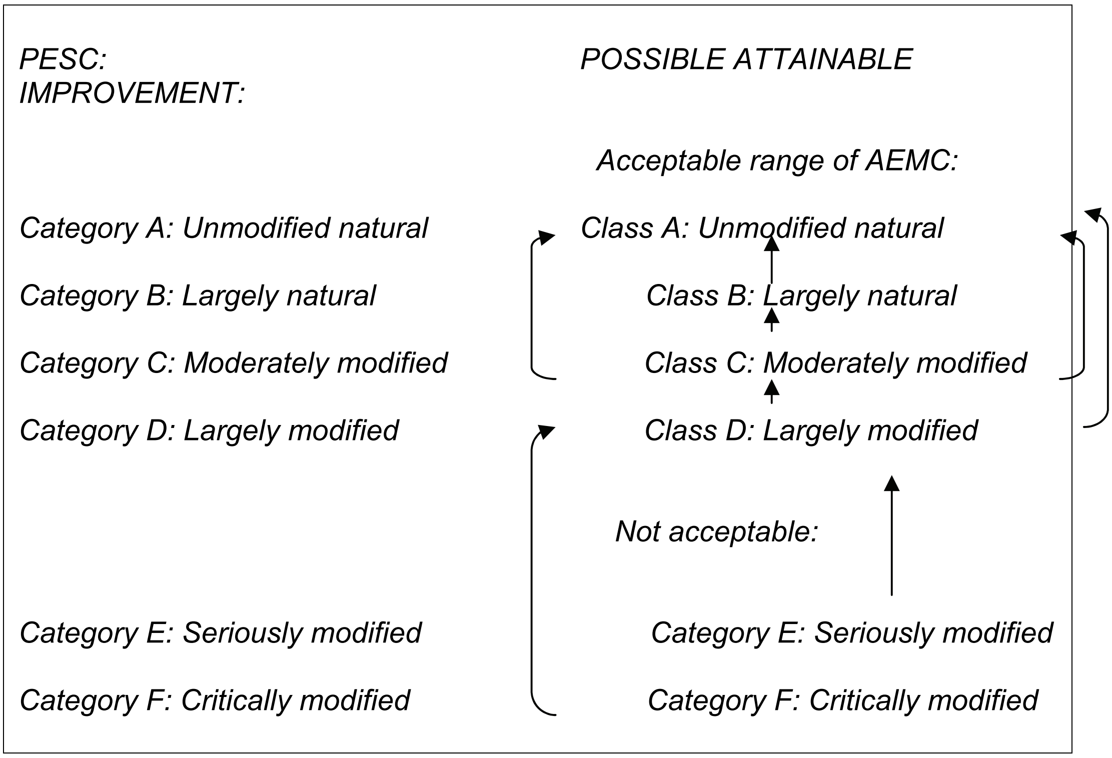

Figure 3 *Present ecological status categories and relationship with possible attainable class.*

The AEMCs, determined for the resource units in the Nyl and Limpopo Rivers, were used in Hughes & Münster (1999) Hydrological Model, and results are included in the report. The confidence level of this is, however, very low according to the high values given by the Hydrological Index (HI) for these rivers.

4. BACKGROUND ON SPECIALIST FIELDS AND INPUT REQUIREMENTS

4.1 Hydrology

The flow of water in a river channel and its physical structure are intimately related in a cycle of cause and effect, both spatially and temporally. Depending on the susceptibility of the channel to flow related change, channel morphology is determined by the geology as well as by the sediment and flow regimes, whilst local hydraulic conditions are determined by the geometry and flow resistance of the channel. Local hydraulics and channel morphology are the primary determinants of the availability of physical habitat that, in turn, controls ecosystem functioning. A quantitative understanding of the flow regime of a river, its physical structure, and its discharge-depth regime, derived jointly and severally from hydrological, geomorphological and hydraulic analyses, is therefore a prerequisite for deriving quantitative information about its ecological functioning.

Holistic methods for IFR determination (Tharme et al., 1996) quantify ecological flow requirements for the various biotic components of rivers in terms of parameters such as flow depth, flow velocity, wetted perimeter and water surface width, adding time as a parameter by referring to the frequency of occurrence (or level of assurance) of a particular flow rate, or the duration of inundation resulting from a particular flooding event.

The NWA of 1998 stipulates that future water resource developments should be environmentally sustainable and that a component of the natural flow of rivers should be reserved to ensure some level of ecological functioning.

Detailed methods for quantifying the environmental instream flow requirements of rivers have been available internationally and in South Africa for some time, but the implementation of the new act introduced a degree of urgency and pointed towards the need for rapid, low-confidence assessments that could be used for initial planning.

The principal output from the application of the Building Block Methodology (BBM) (King and Louw, 1998) for determining the instream flow requirement (IFR) of rivers is a table of monthly values for low and high flows for the so-called “maintenance” periods, and also for drought periods.

The Institute for Water Research (IWR) at Rhodes University has developed a method of extrapolating the outputs from previous IFR studies to provide initial, low-confidence “planning” estimates of the water quantity component of the Ecological Reserve for rivers. The mentioned Decision Support System (Hughes DSS) is applicable to any river within South Africa, at the scale of the quaternary catchment.

The method is based on the calculation of a hydrological index, which combines the variability and base flow characteristics of the natural flow regime of the river, and enables the estimation of the annual volume of water required for the Ecological Reserve, expressed as a percentage of the Mean Annual Runoff (MAR). The results are a series of non-linear relationships between percentage of MAR and the hydrological index for each of the four ecological management classes A to D currently in use in Reserve determinations. In addition, the method provides a means of estimating the monthly distribution of the so-called “maintenance” low and high flows and drought low flows, and also defines assurance rules to specify the frequency of occurrence of maintenance and drought flows.

Most of the data that are available for use in the Hughes DSS have been derived from studies in rivers that flow, in South African terms, relatively reliably, and in which the natural flow regime has a relatively high base flow component. No IFR studies have been carried out in the many seasonally flowing or ephemeral rivers of the country. Consequently the data used for extrapolation are from rivers with hydrological indices in the range 1 to 8, while about 38% of South Africa’s rivers have indices between 8 and 50. Although the existing extrapolation curves appear to be sensible from a hydrological point of view, they cannot be used with any confidence in rivers with a hydrological index greater than approximately 10.

Another method for determining IFR is the DRIFT development which is a scenario-based holistic approach to environmental flow assessment for rivers. DRIFT is a structured process for combining data and knowledge from all the disciplines to produce flow-related scenarios for water managers to consider. A more detailed description of the BBM, Desktop Model and DRIFT methodologies are presented in Appendix A.

Sustainable use of river ecosystems requires that they be managed holistically. DRIFT is used as a holistic methodology, for advising on environmental flows for rivers targeted for water-management activities. The underlying philosophy of DRIFT is that all major abiotic and biotic components constitute the ecosystem to be managed. Within that, the full spectrum of flows; and their temporal and spatial variability, constitutes the flows to be managed. The methodology employs experienced scientists from the following biophysical disciplines: hydrology, hydraulics, fluvial geomorphology, sedimentology, chemistry, botany and zoology. Where there are subsistence users of the river, the following socio-economic disciplines are also employed: sociology, anthropology, water supply, public health, livestock health and resource economics.

Although both approaches are completely valid in their own context, the application of the BBM (Building Block Methodology) requires an interface between them: this interface is found in the hydraulic analysis of flow in natural open channels. The results of hydraulic analyses and modeling therefore form the essential link between the way in which the hydrologist, engineer and water resource manager express the flow of water in the river, and the ways in which river ecologists express the water requirements of the river ecosystem itself.

It is important to note that there is, of necessity, great emphasis on the hydraulic characterization of low flows in the BBM. The difficulties connected with low hydraulics work, when compared with the analyses of high flows and floods, which are more familiar to engineering hydraulicians, are not to be underestimated.

Resource constraints, both financial and temporal, dictate that the Intermediate RDM determination is a scaled-down version of the CER (Comprehensive Ecological Reserves). The scale reduction of the IFR applies to all aspects and has important ramifications for the hydraulics component. Holistic methods for IFR determination are dependent on an acceptable degree of accuracy in the characterization of river hydraulics at the IFR sites. The means of achieving reasonable confidence in the hydraulics over a range of flows, and particularly at low flows, may be assessed by considering the influence of data requirements and site complexity on overall hydraulic confidence for Comprehensive and Intermediate type assessments.

As the principal purpose of an IFR determination is to determine the flow regime which will maintain an acceptable level of ecological functioning in the river, biotic considerations will dominate the selection of appropriate sites. Resource constraints will almost always dictate that the reach of river under investigation has to be characterized by a relatively small number of sites, and this in turn dictates that the limited number of sites used should illustrate a higher degree of habitat – and therefore biotic – diversity as possible. Consequently, thus far in the relatively brief history of IFR determination in South Africa, sites with riffles have been widely used. Such geomorphological features are hydraulically complex, especially at the low flows, which receive considerable attention in IFR determinations. Under these conditions depths of flow are usually the same order of size as the roughness elements (gravels, cobbles and boulders) which constitute the river bed, and which result in wide variations and non-uniformity of flow velocities. These factors complicate the hydraulic analysis.

Although it is important for the hydraulics specialist not to expect that hydraulic considerations will enjoy absolute pre-eminence in site selection, it is equally important for the hydraulician to influence the selection process to the extent that the sites chosen are not of such hydraulic complexity that reliable hydraulic analysis becomes impractical within the limits of available resources. Under these circumstances, a site which is difficult to analyse, will almost certainly produce hydraulic information which is of low confidence, with consequent negative implications for the IFR assessment process.

The hydraulic complexity of the sites selected for an IFR exercise has a profound influence on the ways in which hydraulic data are analysed, particularly in respect to the proportions of observed and modeled data required for the production of reliable relationships between flow rate and, for instance, depth and velocity. As a general rule: the more hydraulically complex the site, the greater the reliance on observed data for reliable results form the hydraulic analysis. Conversely, the hydraulic characterization of a simpler site may be achieved by using relatively sparse observed data, followed by the use of appropriate hydraulic modeling techniques.

This cannot be overemphasized for an IFR, where the ability to provide hydraulic information of reasonable accuracy, based on minimal observed data, is required. Sites selected for an IER should therefore ideally be characterized by prismatic, single active channels; uniform energy (water surface) gradients; conditions where flow resistance is not strongly influenced by stage or discharge; and the ability to accurately assess the discharge through the site.

A major difficulty with low-flow hydraulic analysis at many IFR sites (pools, for instance), is the estimation of the stage of zero discharge; that is, the water level at which the flow ceases. The most appropriate method for estimating the stage of zero discharge (in the absence of observed flow data) is to survey the longitudinal profile downstream of the cross-section within the deepest portion of the active channel to ascertain the level of the downstream bed which causes the upstream backup. Alternatively, extrapolation of the observed rating data to zero discharge may also provide a useful, albeit approximate, estimate of the stage of zero discharge. In many non-perennial rivers these pools are fed continuously from groundwater sources. In other words although IFR has stopped completely but there is still water flowing into the pools. In some cases the water level of these pools, continue to rise especially during the winter months. The calculation of groundwater flow should be included to determine IFR.

Hydraulic analysis and modeling must only be carried out by skilled practitioners who are familiar with low flow techniques and problems, as the errors inherent in the application of the more traditional approaches of analysis, more suited to high flows, resonate throughout the entire process. For instance, the values of the resistance parameter Manning's *n* which must be applied to low flows in a riffle are considerably higher than the range of values used in high flow analyses. Application of inappropriately low *n* values results in significant underestimation of flow depths, and concomitant overestimation of velocities, for specific flow rates. This in turn prompts over estimation of flow rates to achieve particular flow depths and velocities for, for instance, fish passage, and thereby inflates the instream flow requirement. In non-perennial river systems this values will be very difficult to calculate. The flow in these rivers will gradually become less and less until the flow stop completely. The surface water will be concentrated in large pools and these pools will also disappear in time. Groundwater will help to sustain these pools. To maintain water pools the availability of groundwater cannot be underestimated. Groundwater plays a major role in non-perennial river systems.

4.2 Geohydrology

4.2.1 Groundwater and surface water interaction

When groundwater and surface water interact, unique gradients develop, and the two realms can be considered as essentially one resource (Gardner, 1999). Surface water has the ability to enhance or detract from ground water quality, and vice versa. The groundwater/surface water interaction areas may be considered an ecotone between land and water environments and, in some cases, contain the hyporheic zone. These areas provide important ecological functions, support a high degree of biodiversity, and have the potential to affect water quality (Gardner, 1999). In the context of the surface water and groundwater transition zone, the term “ecotone” encompasses water flow, living and non-living components of surface water/groundwater interactions. In the ecotone concept, the hyporheic zone is contained within the land/water ecotone and is comprised of upwelling and downwelling ecotones. In literal terms, “Hyporheic” can be broken down into its Greek base words “hypo” and “rhe”, which mean below and flow, respectively. It is defined by the presence of groundwater that originated as surface water in the river. The hyporheic zone is functionally a composite of both riverine and groundwater ecosystems. This zone provides a number of ecologically important services, including thermal, temporal, and chemical buffering, “food service”, habitat, flow augmentation, and refugia (Gardner, 1999).

Surface water bodies recharge or discharge groundwater. The exchange rate of water is controlled by the difference in hydraulic heads (water levels) and resistance of the media between the groundwater and surface water bodies. According to water levels, a surface water body such as a river (river and stream are used as synonyms in this chapter) can be classified as one of the following (Figure 4):

Influent: The groundwater level is lower than the surface water level, therefore surface water is recharging groundwater. A losing river is usually ephemeral.

One of two conditions may exist (Vegter and Pitman, 1996):
a). Material between the streambed and piezometric surface is pervious – the stream is influent and the piezometric surface slopes downward away from the stream. The stream acts as a sink and recharges groundwater. Little or no work has been undertaken in South Africa to quantify stream recharge.

b) In many instances in the drier parts of South Africa, no or very little interaction takes place between surface and groundwater bodies. These rivers are referred to as *detached streams* (Vegter and Pitman, 1996), *remote streams* (Lerner, 1996), or *disconnected streams* (Winter et al., 1999) and are a special case of influent rivers. After very heavy rains, flow may occur in the river. During this time (usually only hours or days after the storm) water in the river will seep into the subsurface, resulting in the river attaining an influent character for a short period of time. However, as soon as flow ceases, the river reverts to its more dominant detached character and the riverbed is separated from the underlying groundwater body by a vadose zone. The Kuiseb River in Namibia is a good example of such a river.

In certain instances where the water table rises up to the base of the stream, the character of a river can range from a detached stream to an effluent stream. As the water table recedes, the stream could attain an influent character before reverting back to a detached stream. Many rivers in the Karoo display this sort of *intermittent* or *interacting* character

Effluent: The groundwater level is higher than the surface water level; therefore the groundwater is recharging surface water. A gaining river is usually a sign of a perennial river.

One of the following conditions may be encountered:
a) Groundwater reaches and emerges into the stream at all times. The piezometric surface at the stream is permanently above the stream stage and the material between it and the streambed is pervious – porous or fractured. The stream acts as a drain and is effluent and perennial.

b) Groundwater, from the catchment area, emerges into the stream at intervals, i.e. for a while after recharge episodes, the stream is intermittent. During dry periods groundwater storage is depleted by the effluent seepage or in combination with evapotranspiration from the stream banks and within the catchment. Groundwater may be replenished to a certain extent in the immediate vicinity of the stream by storm run-off. In the absence of rechargeable alluvial deposits and/or porous decomposed rock, replenishment from storm run-off would appear to be of minor importance compared to the volume of water recharged over the catchment area. Recharge from storm run-off is restricted in its lateral extent as well as volumetrically by low storage capacity.
c) Groundwater does not reach the stream, because it is permanently being dissipated along its flow path towards the stream by evapotranspiration - a famished stream (Vegter and Pitman's terminology, 1996).

Flow in rivers (and other surface water bodies) is not constant throughout the year. In addition to responding to short duration rain events, flow also responds to seasonal variations in the long-term relationship between stormflow and baseflow, determining the main flow characteristics of a river. This gives rise to perennial rivers, seasonal rivers and ephemeral rivers (Figure 5). While this classification may be useful, the three river types represent a continuum of flow conditions.

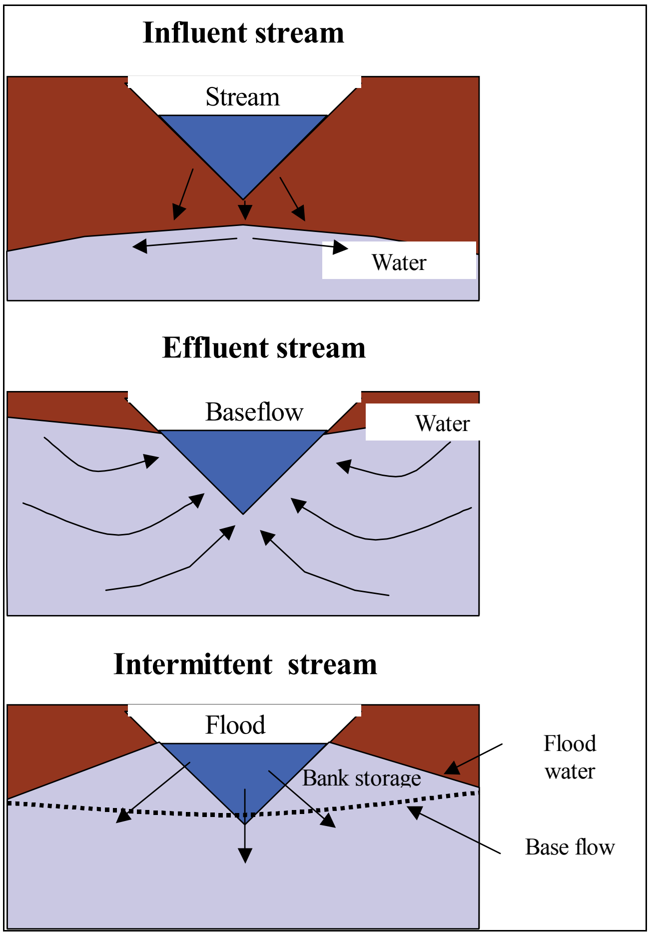

Figure 4 River classification based on water levels.

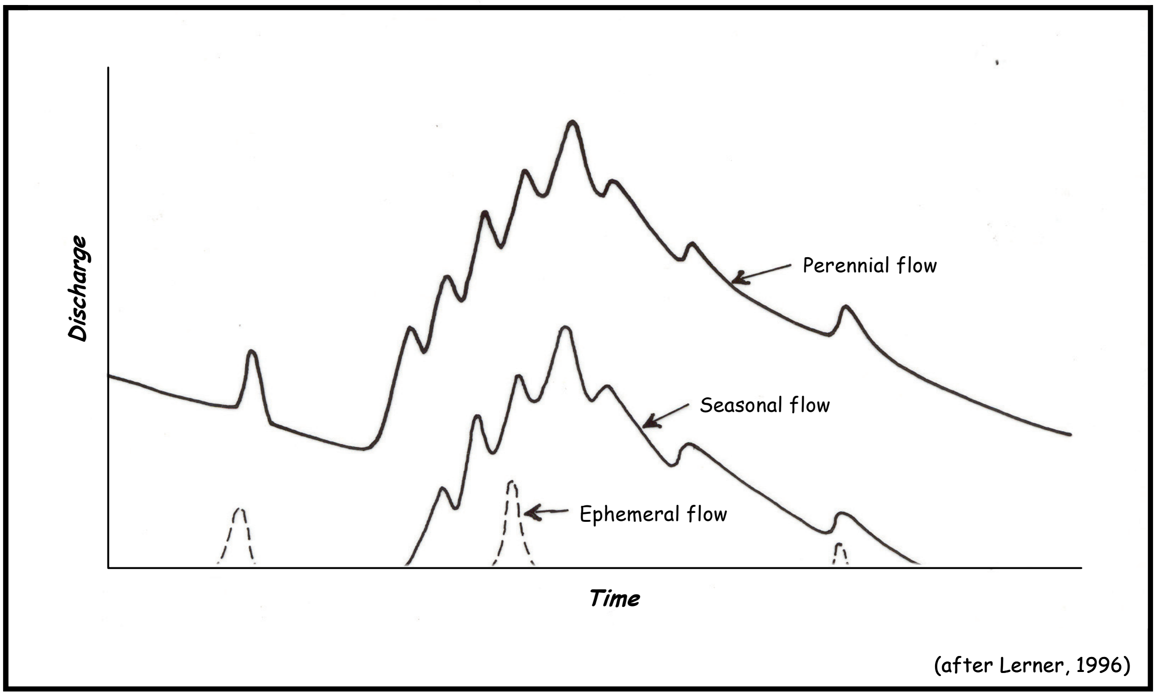

Figure 5 Types of rivers, based on seasonality of flow (After Lemer, 1996).

Examples of river types (taken directly from Vegter and Pitman, 1996)

Influent: Kuruman River downstream from at least Frylinckspan, Molopo River downstream from at least Tshidilamolomo, Phepane, Kgokgole, and other "laagtes" in the catchments of the Kuruman and Molopo River. Most rivers in the drier parts of the country, such as the Karoo and Kalahari, are ephemeral in nature. These rivers are generally event driven and flow occurs less than 20% of the time (Parsons, 2004). Typically, flow is a result of heavy or persistent rains and usually ceases within days of the rainfall event. Groundwater would contribute little in terms of flow, but may be crucial in sustaining pools and refugia. Examples include the Doring River in the Western Cape, the Kuiseb River in Namibia and the Matlabas River in the Northern Province.

Detached: Relatively steeply graded and dry, rocky stream beds particularly in the arid northwestern parts of the country

Effluent: Upper reaches of perennial rivers rising on the eastern escarpment, such as the Vaal, Olifants (TVL), Tugela, Blyde, Komati etc.

Intermittent: Streams in the Karoo such as the upper reaches of the Salt River (Beaufort West), the Kamdeboo, the Sundays, and the Brak (De Aar)

Famished: Rocky sections of the Limpopo River such as alluvium-free stretches between Stockpoort 1 LQ and Sannandale 9 LQ; and the steeper graded section between the junctions with the Lephalala and Motlouse Rivers. The bordering country, which is underlain by the granulite-gneiss of the Limpopo Mobile Belt, is very poorly endowed with groundwater

In-/effluent: Wide stretches of relatively unexploited alluvium along the Limpopo River between the confluence of the Marico and Crocodile Rivers and its junction with Mahalapswe River. Under conditions of heavy exploitation, as is presumably the case downstream along the Limpopo at Weipie and along the Crocodile River between Koedoeskop and Thabazimbi, the stream may change its dual character to influent only. The latter has been declared a Subterranean Water Control Area and has been the subject of a number of studies. Seasonal rainfall patterns drive seasonal rivers where flow occurs between 20 and 80 % of the time. In general these rivers do not originate in areas of high rainfall while contributions from tributaries and groundwater are variable. Examples of seasonal rivers include the Limpopo River, the Letaba River, the Fish River in the Eastern Cape, the Shingwedzi River in Mpumalanga, and the Mogalakwena River.

4.2.2 Baseflow

Groundwater contributes to river flow, particularly in wetter areas that experience high rainfall. The concept of baseflow does not enjoy a common understanding between surface water hydrologists and geohydrologists (Parsons, 2004).

- Surface water hydrologists usually define baseflow as those low flow events during dry periods of little or no precipitation (or snowmelt), i.e. low amplitude, high frequency flow events. They distinguish between stormflow and baseflow using well established, but arbitrary baseflow separation techniques, with no distinction between the origins of the water and the mechanisms and processes by which it arrived in the river. They usually include interflow (see Figure 6) as part of their meaning of baseflow (i.e. baseflow = interflow + groundwater reaching the stream, called the groundwater component of baseflow). [*Interflow* is the water that infiltrates the soil surface and moves laterally through the upper soil horizons until it is intercepted by a channel, or until it returns to the surface downslope of its point of infiltration. Wet weather seeps and springs are the result of interflow]. Interflow usually occurs in the headwater (upper catchment) part of steams, while groundwater baseflow occurs in the middle and lower parts of the catchment.

- Geohydrologists generally understand baseflow to have its origin from groundwater discharged into streams, and proposed estimates of baseflow provide an indication of minimum levels of recharge. Vegter and Pitman (1996), for example, used this approach.

It is thus very important that the person quoting baseflow values clearly indicates what he or she assumes its meaning to be.

Figure 7 shows the twenty-two primary drainage regions in South Africa and the base flow values for each of these regions. A value of the ecological component of the reserve is obtained by multiplying the specific base flow value of the drainage region with the size of smaller area of a resource management unit inside the drainage region. Table 7 and Figure 8 show the values for baseflow that Vegter and Pitman have estimated for each of the drainage regions. Figure 9 shows the probability map of groundwater reaching rivers.

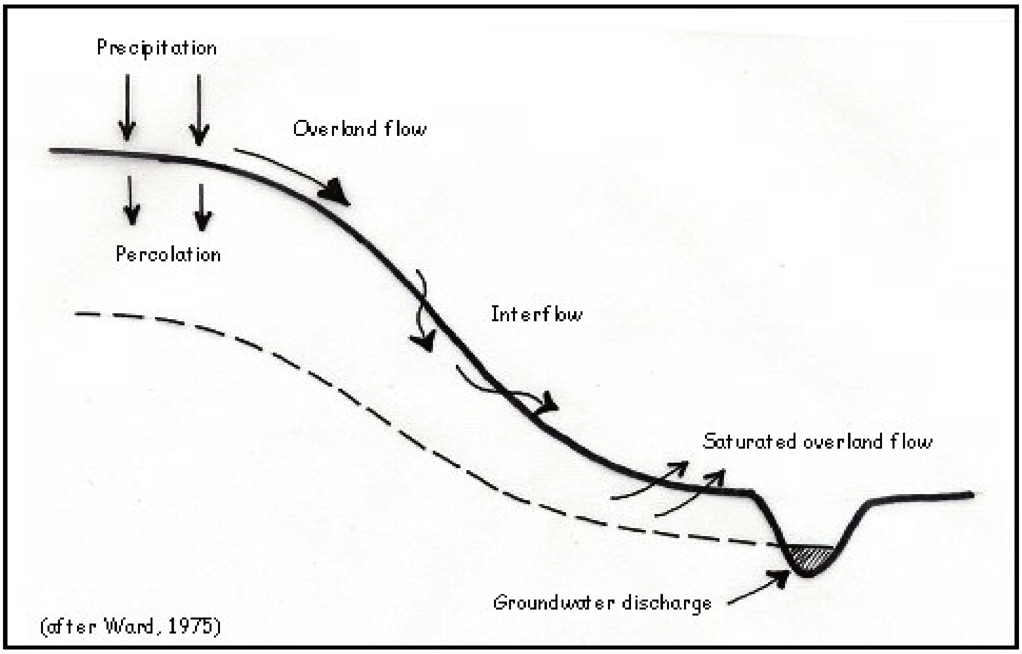

Figure 6 Interflow component of river baseflow.

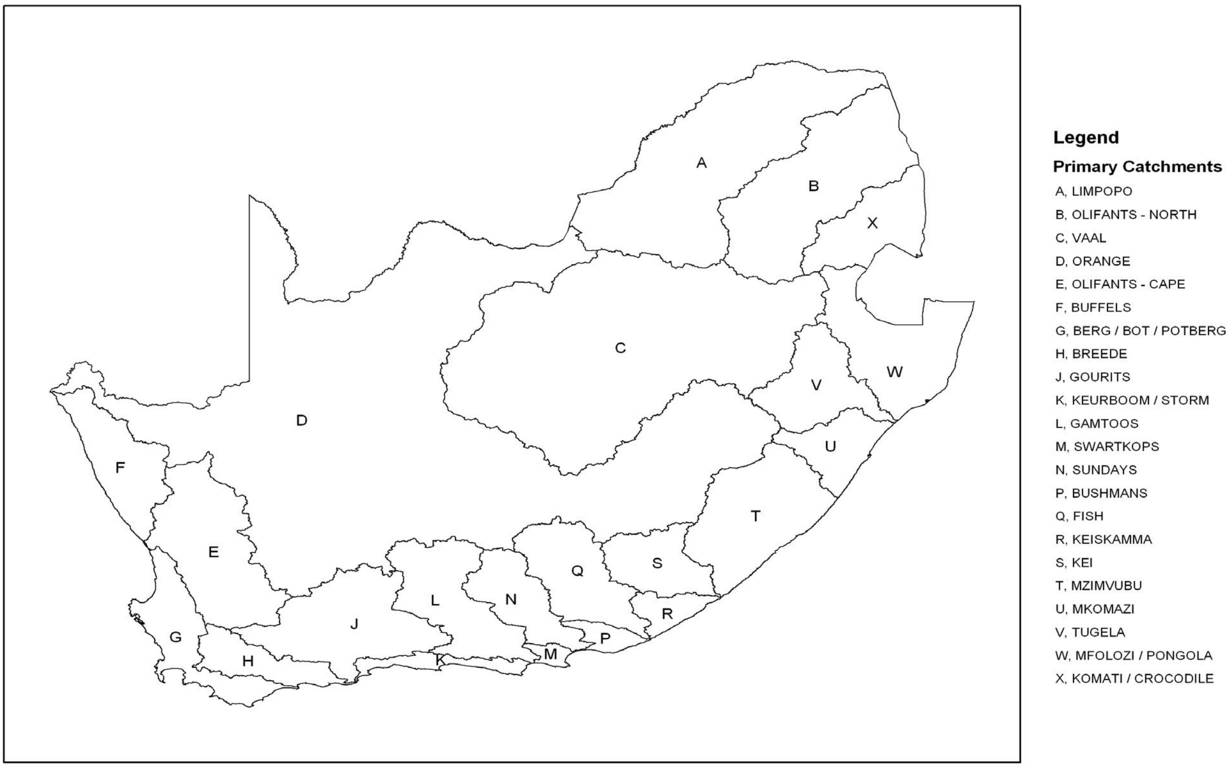

Figure 7 The 22 primary catchments in SA (according to name).

4.2.3 Groundwater dependent ecosystems

Australia has a diverse set of groundwater dependent ecosystems (Sinclair Knight Merz Pty. Ltd., 2001). Cave and aquifer ecosystems, particularly, are very specialised, and are characterised by high levels of endemism. Groundwater dependent ecosystems vary from being marginally or only episodically dependent on groundwater (e.g. some terrestrial vegetation) to being entirely groundwater dependent (e.g. mound springs and the aquatic ecosystems of caves and aquifers). Six major types have been identified:

- terrestrial vegetation – vegetation communities and dependent fauna that have a seasonal or episodic dependence on groundwater;
- river base flow systems – aquatic and riparian ecosystems that exist in or adjacent to streams that are fed by groundwater base flow;
- aquifer and cave ecosystems – aquatic ecosystems that occupy caves or aquifers; wetlands – aquatic communities and fringing vegetation dependent on groundwater fed lakes and wetlands;
- terrestrial fauna – native animals that directly use groundwater rather than rely on it for habitat;
- estuarine and near-shore marine ecosystems – coastal, estuarine and near-shore marine plant and animal communities whose ecological function has some dependence on the discharge of groundwater.

Table 7 Primary catchment baseflow values as obtained by Vegter and Pitman (1996).

Drainage region	Area (km^2)	MAP (mm)	MAR ($10^6 m^3$)	MAR (mm)	MAR (%MAP)	Baseflow ($10^6 m^3$)	Baseflow (mm/a)	Baseflow (%MAP)	Baseflow (%MAR)
A	109610	528	2176	19.9	3.8	690	6.3	1.2	31.7
B	73550	620	2651	36	5.8	758	10.3	1.7	28.6
C	196293	571	4298	21.9	3.8	606	3.1	0.5	14.1
D	409621	315	6987	17.1	5.4	947	2.3	0.7	13.6
E	49063	212	1008	20.5	9.7	102	2.1	1	10.1
F	28623	129	24	0.8	0.6	0	0	0	0
G	25312	476	1986	78.5	16.5	250	9.9	2.1	12.6
H	15530	545	2059	132.6	24.3	245	15.8	2.9	11.9
J	45134	260	662	14.7	5.6	50	1.1	0.4	7.6
K	7220	763	1307	181	23.7	298	41.3	5.4	22.8
I	34731	283	495	14.3	5	46	1.3	0.5	9.3
M	2630	555	151	57.4	10.3	10	6.6	1.2	6.6
N	21428	330	279	13	3.9	2	0.1	0.09	0.7
P	5322	560	174	32.7	5.8	4	0.8	0.1	2.3
Q	30243	410	519	17.2	4.2	29	1	0.2	5.6
R	7936	675	580	73.1	10.8	87	11	1.6	15
S	20485	610	1043	50.9	8.3	209	10.2	1.7	20
T	46684	860	7397	158.4	18.4	1526	32.7	3.8	20.6
U	18321	935	3128	170.7	18.3	868	47.4	5.1	27.7
V	29046	829	3994	137.5	16.6	770	26.5	3.2	19.3
W	59200	825	6533	110.4	13.4	2000	33.8	4.1	30.6
X	31157	715	3361	107.9	15.1	1370	44	6.1	40.8
Average	**57597**	**545**	**2309**	**66.6**	**10.4**	**493.9**	**13.98**	**1.98**	**15.97**

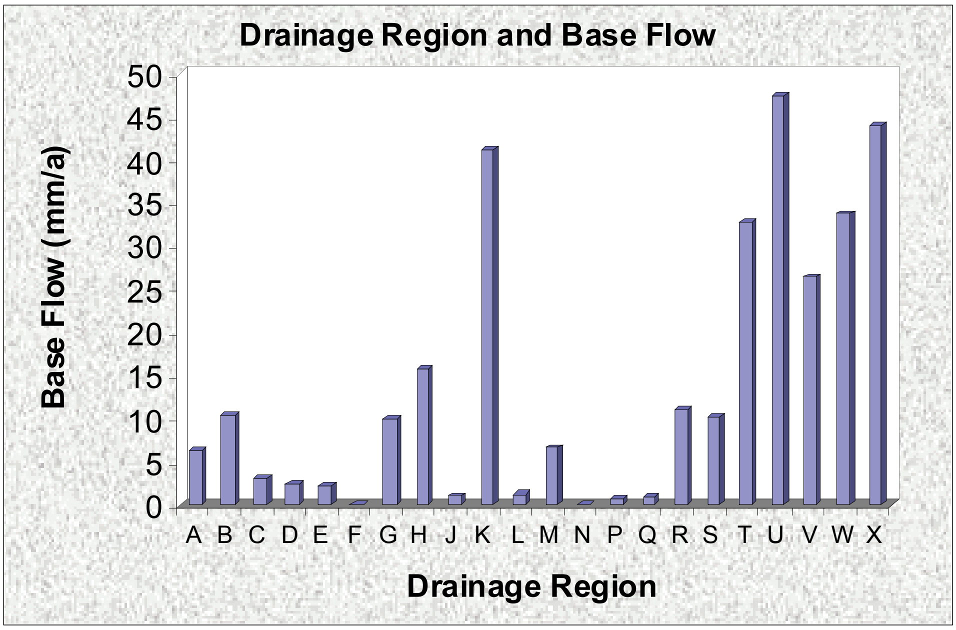

Figure 8 Baseflow values for the twenty-two drainage regions in SA.

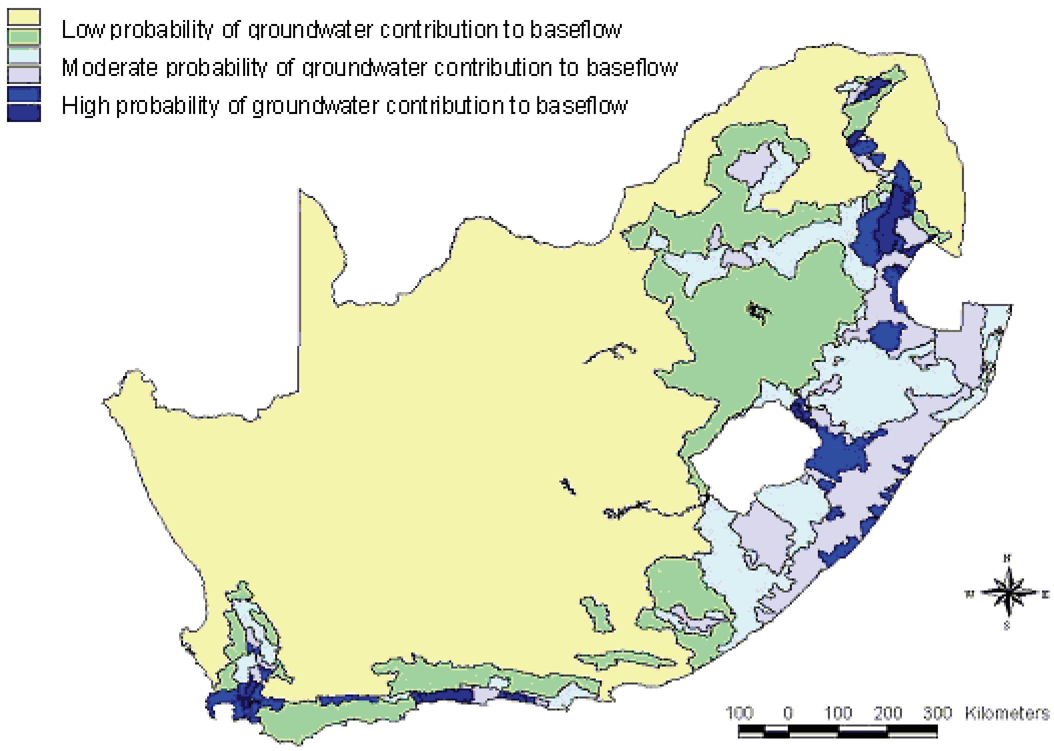

Figure 9 National scale map showing the relative probability of groundwater contributing to baseflow.

Ecological processes in these ecosystems depend on water regimes involving the:

- level or pressure of groundwater;
- discharge flux from an aquifer;
- quality of water.

Ecotone is a term used to describe the transition zone between different habitat types. In the context of surface/groundwater interaction, the land/water ecotone encompasses both water flow and living and non-living components in the interaction. The NWA (Act 36 of 1998) recognised the need to set aside water for aquatic ecosystems and basic human rights. It has been interpreted that groundwater generally falls outside the definition of aquatic ecosystems, except where groundwater discharges and sustains surface water bodies. However, groundwater provides a linkage between terrestrial ecosystems and aquatic ecosystems.

Springs are an expression of subsurface water discharging at surface. In addition to providing a groundwater contribution to river flow, these springs play a critical role in providing fauna and flora with a source of water. Unique ecosystems develop around springs in response to the permanency of available water.

The hyporheic zone is contained within the land/water ecotone and is functionally a composite between surface and groundwater ecosystems. It provides a number of ecologically important services, including: thermal, temporal and chemical buffering; habitat; flow augmentation and refugia. The zone may be significantly different from the overlying surface water body and the underlying aquifer system. Brown et al. (2003) noted that upwelling (or discharge) of groundwater creates patches of high productivity in the hyporheic zone and aquatic ecosystems, supporting greater animal densities and diversities when compared to non-upwelling situations.

Riparian zones, especially in arid and semi-arid areas, are important for maintaining biodiversity, offering refugia and habitat to a variety of organisms not able to survive in adjacent terrestrial and aquatic ecosystems (Brown et al., 2003). They create a buffer between terrestrial and aquatic ecosystems, protect rivers from the effects of activities in adjacent terrestrial environments, and stabilises river banks. These zones are typically sustained by a combination of surface and subsurface water, with the contribution of groundwater being critical during dry periods.

While it is important to recognise the dependence of ecosystems on groundwater, it is equally important to recognise that not all aquatic or terrestrial ecosystems are groundwater dependent. Furthermore, a demonstration of groundwater use does not necessarily equate to groundwater dependence, while groundwater abstraction will not necessarily affect the supply of groundwater to groundwater-dependent ecosystems.

Potential impact of groundwater abstraction on vegetation is a current topic of attention amongst environmental scientists. However, not all vegetation (or ecosystems) is groundwater dependent. While hydrophytes, mesophytes and phreatophytes may obtain some or all of their water from groundwater, xerophytes probably obtain most of their water from the unsaturated zone. Neither the role of water stored in soils and the unsaturated zone nor the independence of water in the saturated and unsaturated zones should be neglected.

To conclude, the following important points regarding non-perennial rivers are important:

- There is still a lot of research required (meaning real measurements in the field) to shed more light on the issue of groundwater/surface water interaction.
- The role that groundwater plays to sustain the pools in a non-perenial river must not be over looked.
- It is foreseen that chemical analyses of the water in the pools, will fingerprint the origin of the water.

4.3 Geomorphology

A river ecosystem is seen as all the components of the landscape and all life forms directly linked to a stream. It includes the source area, the channel from source to sea, riparian areas, the water in the channel and its physical and chemical nature, associated groundwater in channel and bank areas, wetlands either through surface or subsurface water, floodplains, the estuary, and any near-shore environment that is dependent on freshwater inputs (King et al., 1999). If this statement is analyzed, the pivotal concept immediately coming to the fore is the processes governing the development and functions of the landscape. A science concerned with these processes is Geomorphology.

Geomorphology could be defined as the scientific description and explanation, primarily of the origin, distribution and occurrence of landforms, and secondarily of the processes responsible for the development of landscapes and landforms on the earth's surface (Barker, 2002). This description and explanation are given in terms of time and space with humankind as a central theme.

If the processes involved in shaping the landscape are used to define different approaches to geomorphology, more detail could be added:

- Water: Fluvial geomorphology
- Wind: Aeolian geomorphology
- Ice: Glacial or peri-glacial geomorphology
- Ocean waves and coastal processes: Marine geomorphology and
- Plate tectonics: Structural geomorphology.

As water is the most important factor that sustains life on earth, it is also not surprising that fluvial processes dominated geomorphic research in the literature. Except for the coastal zone and extremely dry areas, fluvial processes are also the dominant agents in shaping the South African landscape (Le Roux, 1990).

In South Africa, the NWA (Act 36 of 1998) makes provision for an integrated process of catchment area management that, by implication, includes all aspects of the hydrology, as well as the physical landscape and associated processes (RSA, 1998). This policy direction reflects an attempt to manage the limited water resources of the country optimally — which was already established in the objectives of the Water Research Commission (WRC, 1996). It is stated, among others, that research in the field of water resource management, development and conservation, pollution, aquatic ecosystems, and the conservation of catchment areas, are of national importance. Geomorphology furthermore is relevant to environment management if the research results are used in the management process (Cooke and Doornkamp, 1990). This implies that both geomorphologists and environment managers ought to have a clear understanding of the function of the environment. Nir (1983) remarks that, although few, some sources in the literature mention the effect of man on the geomorphosphere. Since then, applied geomorphology has been gaining ground and a great number of publications have already been issued (cf., among others, Garland, 1990; Thorne et al., 1997; Knighton, 1998; Lane et al., 1998; and Ahnert, 1998).

4.3.1 Fluvial geomorphology

Schumm (2003) described a fluvial system as consisting of three main components, namely a production, a transfer and a deposition zone, and further identifies some of the following variables as crucial in the development of a landscape:

- Time,
- Initial relief,
- Climate,
- Geology,
- Vegetation,
- Relief (above base level),
- Hydrology,
- Drainage network morphology,
- Hill slope morphology,
- Channel and valley morphology,
- Depositional system morphology and
- Human interference

When all of these variables or components are seen as a whole, the drainage basin can be regarded as an excellent example of a natural system (Gregory and Walling, 1973).

4.3.2 Environmental Flow Assessment

Estimates in a 1986 publication by the then Department of Water Affairs (DWA) put the amount of water needed for the "managing of the environment" 2 958 Million $m^3\ a^{-1}$ for the year 2010 or 13% of the total water need. A detailed estimate for the different drainage regions of SA is given in Table 8 and Figure 7.

An Environmental Flow Assessment (EFA) is defined by King et al. (1999) as an assessment of how much of the original flow of a river or stream should continue to flow down the stream channel in order to maintain certain features of the river ecosystem. An EFA has two main areas of focus:

- The different flow regimes that would maintain a river ecosystem at various levels of health (condition) and
- The ways in which these different levels of river health will affect people.

Hughes and Münster (2000) further describes the flow components of EFR in streams as consisting of the following for each month of the year:

- Maintenance low flows expressed in $m^3\ s^{-1}$
- Maintenance high flow events defined as peak flows in $m^3\ s^{-1}$ and durations in days
- Drought low flows expressed in $m^3\ s^{-1}$
- Drought high flow events defined as peak flows in $m^3\ s^{-1}$ and durations in days

Table 8 Estimated environmental water need (million m^3 a^{-1}) (After DWA, 1986; DEAT, 2001).

Region	1980	1990	2000	2010	MAR
A	7	8	9	10	4 877.4
B	46	47	48	49	8 035.8
C	40	40	41	41	6 263.4
D	550	552	554	556	14 681.6
E	77	77	77	77	3464
F	1	1	1	1	29.4
G	143	143	143	143	9 837.3
H	149	149	149	149	12 373.9
J	40	40	40	40	1 608.4
K	70	70	70	70	7 542.5
L	37	37	37	37	1 142.5
M	19	19	19	19	444.9
N	17	17	17	20	472.1
P	20	20	20	20	539.1
Q	38	38	38	38	1 419.0
R	51	51	51	51	2 417.6
S	76	76	76	76	3 026.0
T	742	742	742	742	21 998.0
U	134	134	134	134	10 530.8
V	230	230	230	230	13 623.4
W	411	411	411	411	1 5101.1
X	47	47	47	47	1 5144.6
Total	2 946	2 949	2 954	2 958	154 572.9

4.3.3 Methods used for input to EWR

In an effort to describe the environmental water requirements for a regulated river, a holistic approach to EFA was developed in South Africa (King et al., 2000). A detailed description of the method is not necessary for the purpose of this report and further attention will be aimed at the geomorphology chapter (Rowntree, 2000). From literature it is apparent that a link exists between the channel pattern, or plan form of a reach of an alluvial river and the hydrodynamics of flow within the channel and the associated processes of sediment transfer and energy dissipation (Richards, 1982). Gregory and Walling (1973) described the relation between mean velocity (v), mean depth (d) and width (w) of the flowing water and discharge (Q) in power functions of the form:

$w = aQ^b$

$d = cQ^f$

$v = kQ^m$

where a, c, k, b, f, m, are numerical coefficients

As cross sectional area A = wd and wd v = Q then

$aQ^b . cQ^f . kQ^m = Q$ so that a c k = 1.0 and b+f+m = 1.0

This relations is graphically illustrated in Figure 10.

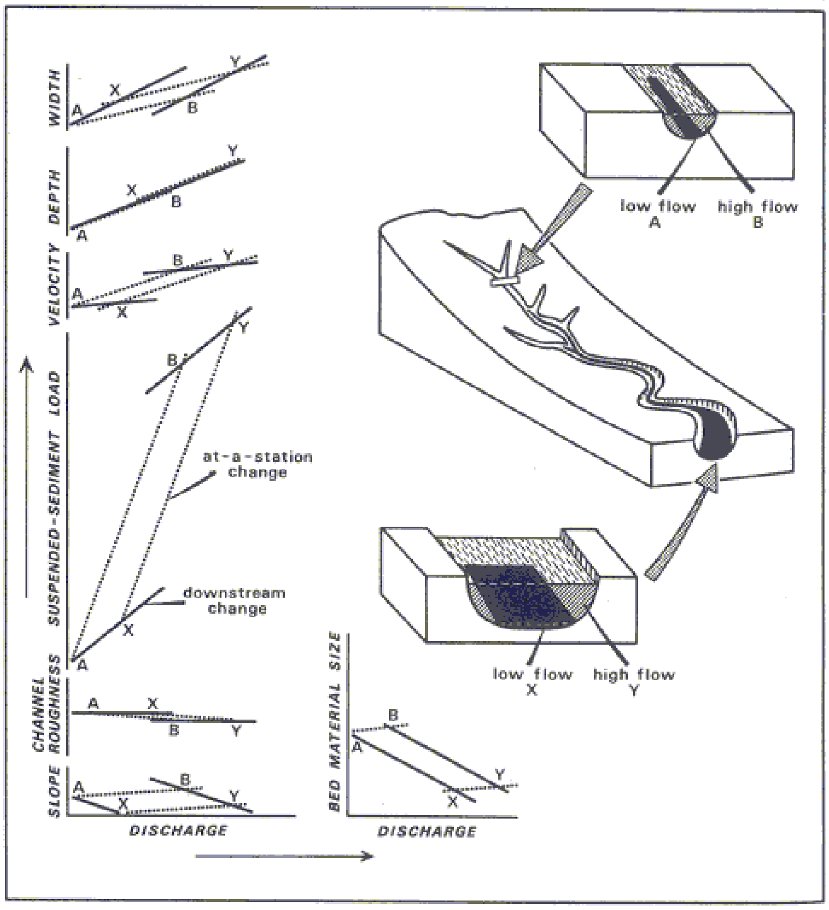

Figure 10 The relation between various hydraulic and geometrical variables (After Gregory and Walling, 1973).

Graff (1988) proposed a so-called rational method for the estimation of peak flow

$$Q_{pk} = 0.278CIA$$

Where

Q_{pk} = Peak runoff ($m^3 s^{-1}$)
C = Dimensionless coefficient determined by surface cover
I = Rainfall intensity ($mm\ h^{-1}$)
A = Drainage area (km^2)

Rowntree (2000) suggested a variety of variables to be included in the assessment of the geomorphology of a stream channel at different spatial and temporal scales (Table 9). She further proposed a hierarchy of spatial scales for the assessment of geomorphic issues in a catchment. Rossouw (2004) states that "*During the determination of IFR, the geomorphological information is used to predict what in-stream flows will be needed either to maintain the current patterns of sediment movement and distribution or to restore the patterns that will lead to geomorphological habitat meeting the necessary condition for the desired ecosystem health status…*", while Hughes and Münster (2000) expected the geomorphologist to determine requirements for EFR in terms of flow depths, widths and velocity.

Table 9 Information needs for the determination of the EFR for rivers (After Rowntree, 2000).

CRITERIA	TIME SCALE	SPATIAL SCALE	INFORMATION NEEDS
Spatial and temporal availability of physical habitat.	Short term (<1-5 years)	Hydraulic biotope and morphological unit (<1-10 m^2)	Distribution of hydraulic biotopes; channel cross-sections; substratum type; floodplain morphology.
Maintenance of substratum characteristics: Seasonal flushing of substratum. Modification to substratum.	Short term (<1-5 years) Medium term (2-20 years)	Morphological unit (10-100 m^2)	Particle size distribution; cross-section hydraulic geometry; channel gradient; rate of sediment supply from upstream.
Maintenance of channel form: Adjustment of channel plan and cross-section.	Long term (10-100 years)	Reach (100 m)	Channel cross-sections; channel gradients; bed and bank resistance to flow; sediment supply; natural flow regime.

The detailed methodology described by Rowntree (2000) in section 14.3.2 is unfortunately software specific but with the necessary background in GIS, a user should be able to do the analyses with other software.

The two geomorphology-related parts of the BBM Manual (King et al., 2000), Hydrology and Hydraulics (Chapters 12 and 13 respectively), both place emphasis on runoff and flow-data. This is an important component in reaching Rowntree's goal that further research is needed in channel forming processes in South African rivers – especially non-perennial streams.

Implications of floods to maintenance of channel morphology

King et al. (2000) in their underlying assumptions stated that inter alia "Rivers will recover from most perturbations". The statement is based on the so-called sensitivity concept in geomorphology. According to Brunsden (2001) "the landscape sensitivity concept concerns the likelihood that a given change in the controls of a system or the forces applied to the system will produce a sensible, recognisable, and persistent response". The landscape stability index is a function of the spatial and temporal distribution of "resisting and disturbing forces" (Brunsden, 2001). The geomorphic system might be described by using Chorley and Kennedy's (1971) concept of a metastable equilibrium (Barker, 2002), illustrated in Figure 11.

Within the pattern of environmental change, each geomorphological tectonic – climatic regime is characterised by a hierarchy of process events distributed in time and space and described by their frequency and magnitude distributions. Sensitivity is measured by the reaction of each part of the landscape to these events.

It is, however, common for environmental scientists to emphasise the effect of large, extreme, "catastrophic" or formative events on the system (Brunsden, 2001). In non-perennial systems it will be shown that these events play a major role in the development of the landscape. Zawada et al. (1996) produced an analysis of regional flood-peak regions in Southern Africa and their study into paleofloods of the region should prove helpful in understanding the hydrology of streams in specific regions.

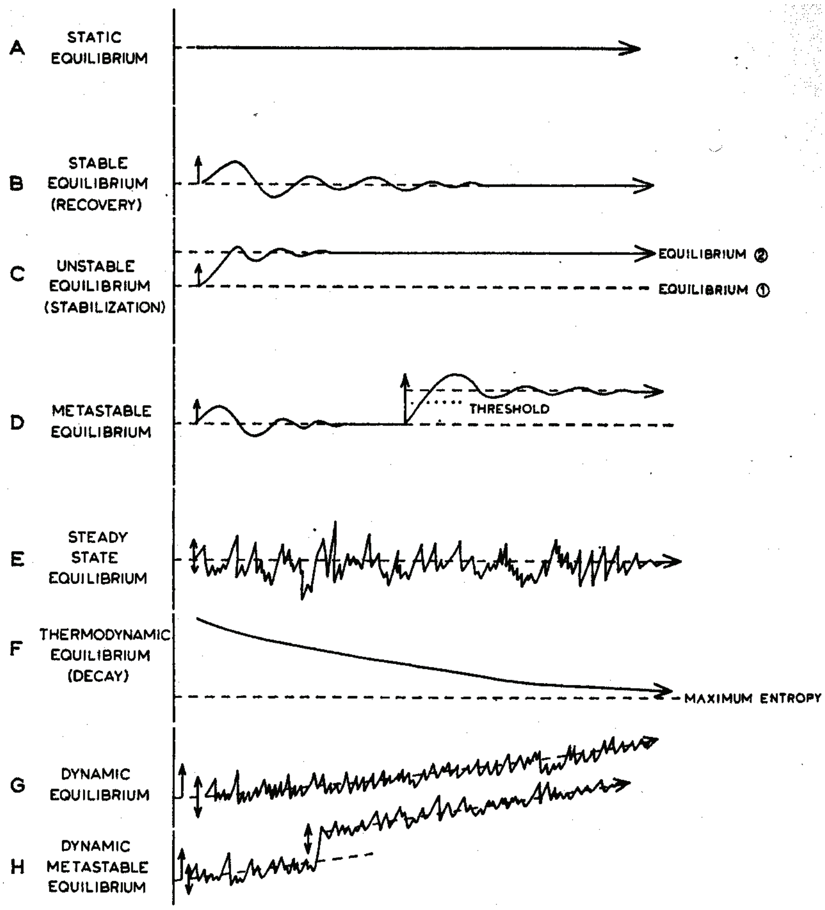

Figure 11 Possible equilibrium conditions in geomorphic systems (Taken from Chorley and Kennedy, 1971).

Channel characteristics of ephemeral rivers

Fluvial processes in drylands are driven by precipitation, so that an understanding of the temporal and spatial variability of precipitation is a prerequisite to understanding the variation of river behaviour (Graf, 1988).

Thornes (1994) states that flow in ephemeral channels is characterised by high sediment concentrations and large sediment yields and indicates a link between the large amount of geomorphic work that is done and the occurrence of extreme events. Therefore a vast difference exists between the magnitude and frequency relationships of dry land and temperate channels.

Figure 12 indicates a maximum yield at a mean annual temperature (indicating evaporation) of 15ºC (line E) at approximately 400 to 600 mm. (Also see Schulze, 1997 and Rooseboom, 1992).

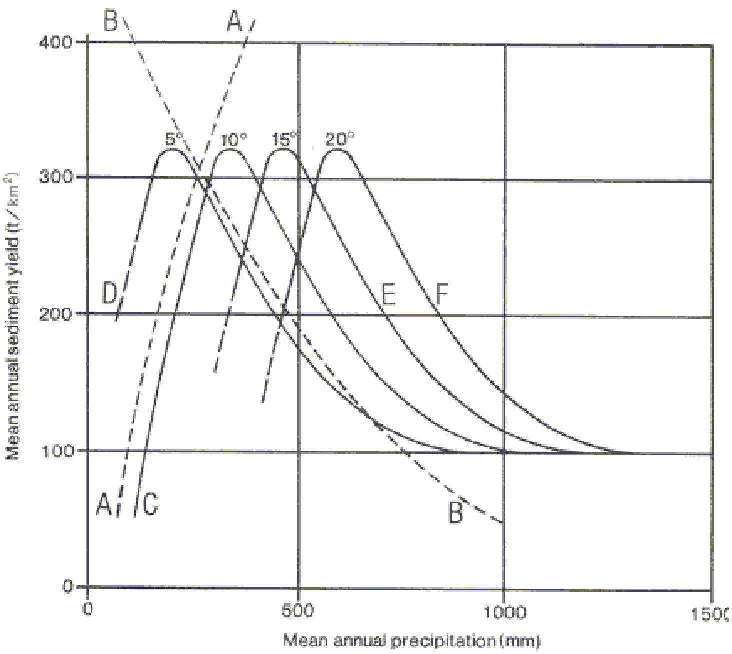

Figure 12 Climate and sediment yield (After Wilkinson, 1988).

4.3.4 Difference between perennial and non-perennial rivers: Geomorphological perspective

Definition of "non-perennial"

A non-perennial stream is by definition a stream that does not flow permanently. While a number of descriptions for different classes of non-perennial streams are available, (cf. Uys and O'Keeffe, 1997) a clear-cut definition is difficult to formulate. It would however be useful to note a few well known descriptions:

- Intermittent: Flow occurs seasonally when the water table is at its maximum. Drains semi-arid areas
- Ephemeral / episodic: A stream which is often one of the outer links of a drainage system and which contains flowing water only during and immediately after a fairly intense rainstorm.

It is also clear from the literature that this class of stream or river will mostly have its origin in semi-arid areas (Figure 13; also see Chapter 5, Figure 22) but does not include allogenic rivers such as the Orange or Okavango. Non-perennial streams can also be endorheic, which means that none of the runoff in the channel will leave the drainage basin. Some good examples can be found in the drainage systems of the Modder and Riet Rivers in the western Free State. Figure 14 illustrates the proposed scheme by Uys and O'Keeffe (1997).

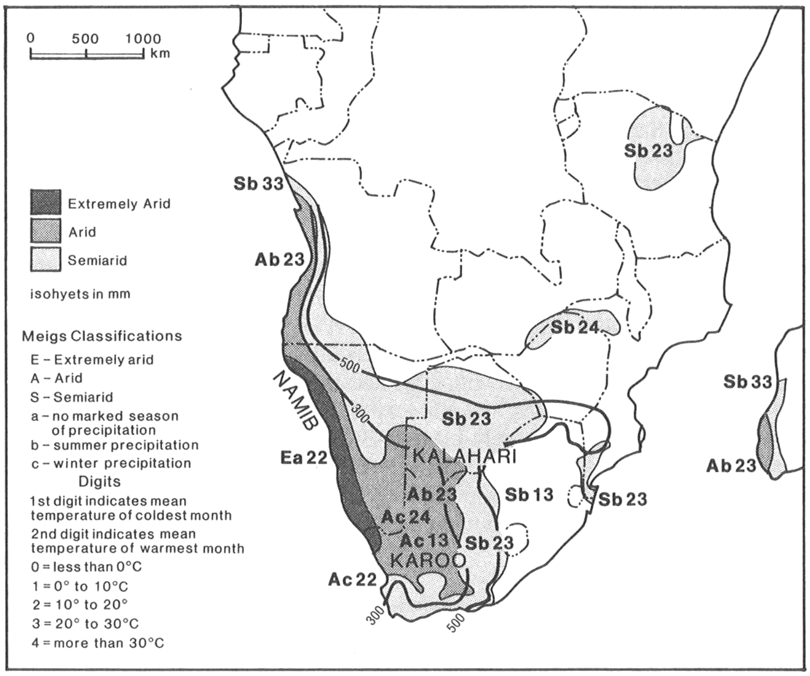

Figure 13 Zones of aridity in Southern Africa (After Wilkinson, 1988).

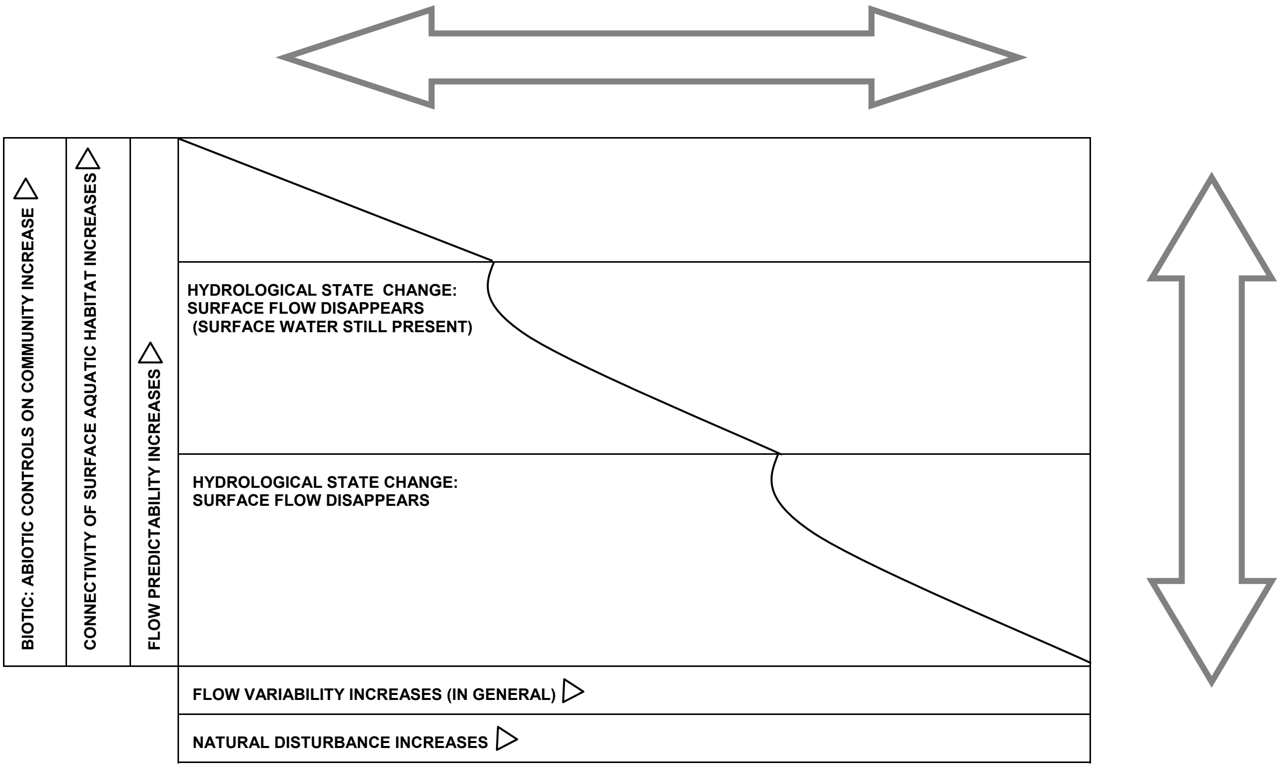

Figure 14 A conceptual illustration of stream types with an indication of the scope of this report (adapted from Uys and O'Keeffe, 1997).

A functional classification of the nature of flow can also be found on the 1:50 000 topographical maps of South Africa which show only "perennial" and "non-perennial" streams and open water. It might be useful to keep this in mind for modelling purposes, as the data is readily available.

4.4 Water Quality

Aquatic resources worldwide are currently being threatened at an unparalleled rate. South Africa's available freshwater resources are already almost fully utilised and under stress. At present many water resources are polluted by industrial effluents, domestic and commercial sewage, acid mine drainage, agricultural runoff and litter. Agriculture, deforestation, and urbanization have resulted in increasing eutrophication of rivers and lakes. Most of South Africa's rivers have an eutrophication problem. The demand for water in South Africa is projected to increase by 50 % in the next 30 years (DEAT, 1999).

The term "water quality" is used to describe the physical, chemical, biological and aesthetic properties of water, which determines its fitness for use and its ability to maintain the health of farmed aquatic organisms (DWAF, 1996b). Thus water quality expresses the suitability of water to sustain various uses or processes. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water; for example limits on the concentrations of toxic substances for drinking water use, or restrictions on temperature and pH ranges for water supporting invertebrate communities. Consequently, water quality can be defined by a range of variables which limit water use.

Water quality is only one aspect in maintaining a healthy ecosystem. Other factors can also be important, including flow regime, habitat quality, sediment quality and the condition of the riparian vegetation, barriers to fish migration, and connections between river and its catchment and floodplain (Figure 15). Ideally, all these factors should be considered when defining the water resource management program.

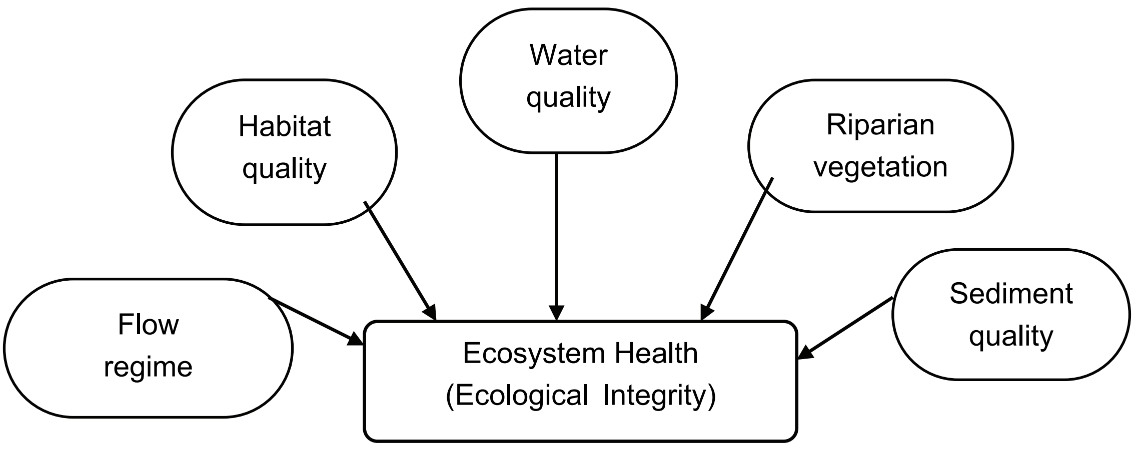

Figure 15 Key factors influencing ecosystem health (Adapted from Hart, 2002).

Water pollution and water quality

Human use of water for almost all purposes results in the deterioration of water quality and generally limits the further potential use of the water.

Aquatic populations and communities are often impacted by anthropogenic sources of pollution. The results of these impacts include a variety of alterations in the biological integrity of aquatic systems.

Types of physical and chemical stressors

Physical and chemical stressors can be classified broadly into two types (Figure 19) depending on whether they have direct or indirect effects on the ecosystem (ANZECC, 2000).

There are two types of physical and chemical stressors that can directly affect aquatic ecosystems. These two distinguishable stressors are directly toxic to biota, and those that, while not directly toxic, can result in adverse changes to the ecosystem (e.g. to its biological diversity or its usefulness to humans).

Excessive amounts of direct-effect stressors cause problems, but some of the elements and compounds covered here are essential at low concentrations for the effective functioning of the biota, e.g., nutrients such as phosphorus and nitrogen, and heavy metals such as copper and zinc, for example.

The major types of pollutants (stressors) and the extent of deterioration in freshwater quality at a global level are summarized in Figure 16.

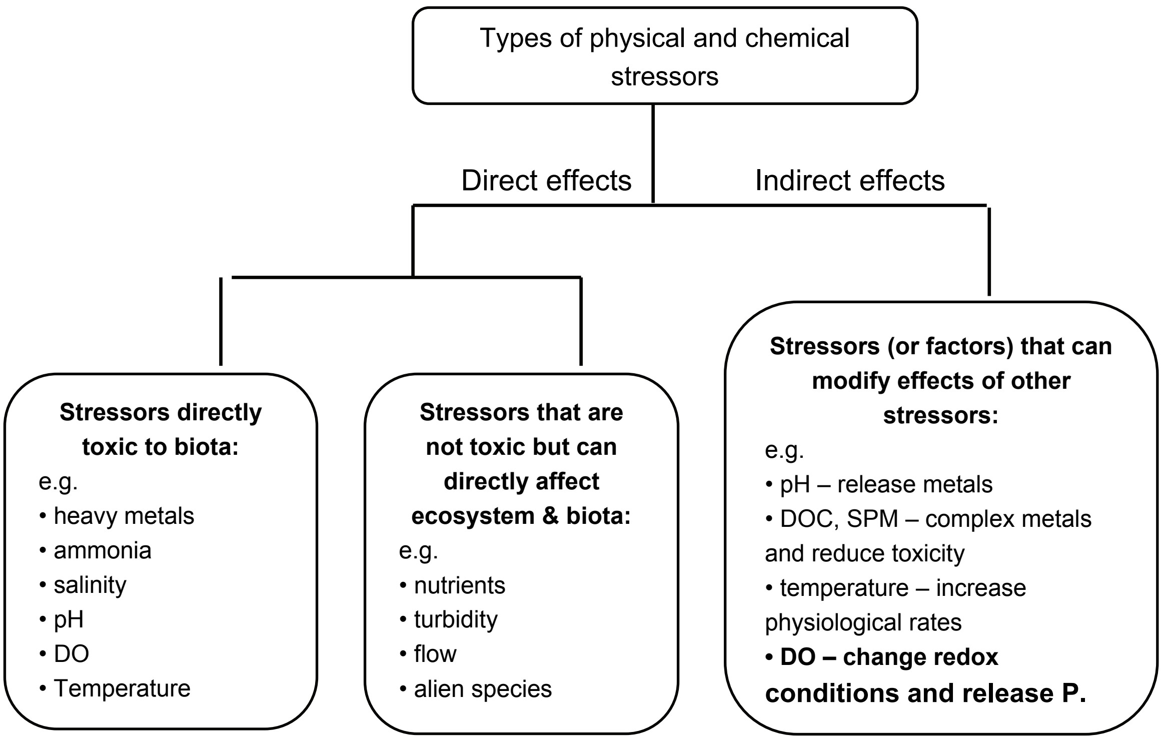

Figure 16 Types of physical and chemical stressors (Adapted from ANZECC, 2000).

Rapidly increasing water use for basic human and domestic needs, development and recreation is the reason why water resource management has a high priority in South Africa. Water use inevitably results in the discharge of water containing waste and return flows, and reduces assimilative capacity in stream flow. As river catchments become increasingly populated and developed, the effects of point and diffuse sources of pollution are likely to mask the natural cyclic patterns in aquatic ecosystems to an even greater extent. A summary of the leading sources, pollutants (stressors) and their effects on aquatic ecosystems are summarized in Table 10.

The probable key water quality issues or potential water quality problems in the study area are identified. The objective is to first identify the water quality concern. A water quality concern can be excessive algal blooms or corrosion of household appliances. The next step is to identify and understand the processes that affect or influence the concern and then to identify the most relevant water quality indicator (or constituent) that should be measured to assess the current status.

Water quality and time scales

Within any one water body, water quality can differ with time and with place. Differences due to time are of five types (Meybeck et al., 1996):

- Minute-to-minute and day-to-day differences resulting from water mixing and fluctuations in inputs, usually as a result of meteorological conditions. These differences are most evident in small water bodies.
- Diurnal (24-hour) variations resulting from biological cycles and daylight/darkness cycles, which cause changes, in, for example, dissolved oxygen and pH. Diurnal patterns also result from the cyclic nature of waste discharges from domestic and industrial sources.
- Irregular sources of pollution include fertilisers, pesticides and herbicides, present in the run-off from agricultural land, and wastes discharged from food processing plants. The resultant variations in water quality may be apparent over a matter of days or months.
- Seasonal biological and hydrological cycles.
- Year-to-year trends, usually as a result of increased human activities in the watershed.

Water quality differences may result from either internal or external processes. Internal processes are usually cyclic, with either daily or seasonal recurrence, and are not directly related to the size of the water body. External processes, such as the addition of pollutants, may be buffered by large water bodies (depending on flow regimes) and long water residence times.

As a result, the average composition of a very large lake probably changes little from one year to the next. Similarly, the differences in water quality at different times of the year will be much greater for a stream than for a large river.

This means that the sampling frequency necessary to allow average water quality to be described correctly is normally much greater for a stream than for a river; for lakes it is normally much lower than for rivers.

Water quality differences from place to place depend more on the homogeneity of the water body than on its size. The water in a round lake, e.g., may be adequately described by one sample taken from near the centre of the lake. Long, thin lakes and lakes with many bays and inlets will require more samples; the minimum is three while the optimum number could be ten or more.

The flow pattern, or regime, of any particular river will be the product of very specific conditions. Although similar to that of rivers in the surrounding geographical region, it will be extensively influenced by altitude, the extent to which the slope is exposed to by wind and variations in rainfall.

Water quality methods used for input to EFR

Environmental water quality guidelines

Water quality guidelines provide an objective means for judging the quality needed to maintain a particular environmental value. The South African guidelines for the protection of aquatic ecosystems (DWAF, 1996b) list recommended target ranges (i.e. TWQRs), Acute Effect Values (AEVs) and Chronic Effect Values (CEVs) for specific water quality variables. These can be used to assess the present condition of the system and the extent of its degradation.

The Target Water Quality Range (TWQR) proposed by the Department of Water Affairs and Forestry (DWAF, 1996b) is used to evaluate the water quality for the aquatic ecosystem. TWQR is not a water quality criterion, but is rather a management objective, which has been derived from quantitative and qualitative criteria. This is the range of concentrations or levels within which no measurable adverse effects are expected on the health of aquatic ecosystems, and should therefore ensure their protection. These ranges assure life-long exposure. As a matter of policy DWAF will strive to protect South Africa’s water resources by maintaining water quality within the TWQR.

The CEV is defined as “that concentration or level of a constituent at which there is expected to be a significant probability of measurable chronic effects to up to 5 % of the species in the aquatic community”. If such chronic effects persist for some time and/or occur frequently, they can lead to the eventual death of individuals and disappearance of sensitive species from aquatic ecosystems.

The AEV is defined as “that concentration or level of a constituent above which there is expected to be significant probability of acute toxic effects to up to 5 % of the species in the aquatic community”. This can have considerable negative consequences for the health of aquatic ecosystems, even over a short period.

Table 10 The leading sources, pollutants / stressors and their effects on perennial and non-perennial aquatic ecosystems (as proposed by this study).

<table>
<tr><th>Leading sources</th><th>Leading pollutants/ stressors</th><th>Major effects</th></tr>
<tr><td rowspan="11">**Agriculture:**
• Feedlots – manure
• Fertilizers application
• Land clearing, erosion
• Deforestation

Industrial:
• Pulp & Paper mills
• Wineries & Breweries
• Electrical power plants
• Leather & tannery
• Food-processing
• Petro-chemical
• Textile factories

Informal settlements:
• Untreated sewage
• Litter & coal fires

Municipal sources:
• Sewage treatment works
• Urban runoff
• Septic tank leachate
• Landfills

Forestry:
• Erosion & acidification
• Logging & clear cutting

Resource extraction:
• Agricultural (irrigation)
• Industrial
• Domestic

Mining:
• Coal, Gold & Uranium
• Mine dumps, tailings & chemicals
• Acid mine drainage

Engineering & construction:
• Road & dam
• canalization

Hydrologic modification:
• River regulation
• Inter-basin transfer

Aquaculture:
• Fish farming

Atmospheric deposition:
• SO_2 & $NO_2 \rightarrow$ acids
• Particulate matter</td>
<td>**Pathogens:**
• Bacteria, viruses
• Protozoa
• Parasitic worms</td><td>• Consumer health hazards – e.g.
• Cholera, typhoid fever, hepatitis, etc.
• Impair product quality
• Biofouling</td></tr>
<tr><td>**Nutrients enrichment:**
• Nitrogen (NO_3, NH_4)
• Phosphorus (PO_4)
• Silica</td><td>• Nuisance algal & plant growth
• Clogging – filters, pipes & canals
• Increased probability of fish kills
• Low ecological stability, biodiversity</td></tr>
<tr><td>**Conductivity & Salinity:**
• TDS
• Major ions
• Salinization</td><td>• Reduce crop yield
• Affect osmotic, ionic and water balance
• Change biotic composition
• Corrosion & Scaling</td></tr>
<tr><td>**Turbidity & suspended solids (TSS):**
• Siltation
• Dissolved matter</td><td>• Cloud water and reduce photosynthesis
• Smother and clog surfaces
• Disrupt aquatic food webs
• Adsorb nutrients, toxins, etc.</td></tr>
<tr><td>**Pesticides (Biocides):**
• Herbicides
• Fungicides
• Insecticides</td><td>• Toxicological effects
• Usually target specific groups thus alter community structure.
• Bioaccumulation</td></tr>
<tr><td>**Organic enrichment:**
• Oxygen-depleting substances
• Organic waste</td><td>• Reduces oxygen concentration
• Increases nutrient levels
• Increase in turbidity
• Fish kills</td></tr>
<tr><td>**pH & alkalinity:**
• Acids
• Alkalis
• Buffer capacity
• H^+ & OH^- ions
• HCO_3^- & CO_3^{2-} ions</td><td>• Acid rain, aquatic acidification
• Leaching of nutrients & toxic metals
• Aluminum toxicity – fish kills
• Affects chemical species & ionic balance
• Severe effects on the biota
• Affects gill functioning</td></tr>
<tr><td>**Habitat alterations:**
• Siltation</td><td>• Habitat loss & significant loss of wildlife
• Reducing in spawning habitat</td></tr>
<tr><td>**Thermal modifications:**
• Temperature change
• Thermal pollution</td><td>• Determine metabolic rates
• Influence availability of nutrients & toxins
• Provide cues for breeding, migration, etc.
• Lowers dissolved oxygen levels</td></tr>
<tr><td>**Heavy metals:**
• Fe, Mn, Cu, As
• Al, Cr, Ni, Cd, Hg
• Pb, Co, Se, Be, Sn</td><td>• Some mutagenic or carcinogenic
• Reduction in species richness & diversity
• Some metabolic inhibitors
• Harm fish and wildlife</td></tr>
<tr><td>**Flow alterations:**
• Dams & weirs
• Flow reduction
• Canals</td><td>• Barriers to fish migration
• Changes channel shape
• Change patterns of sedimentation
• Increase suspended matter settlement</td></tr>
</table>

Water quality in a catchment is closely dependent on the degree to which land-use and other physical developments have modified the condition of the land phase of the hydrological cycle. We now recognise that all aspects of the environment are interdependent. Environmental values (or uses), in particular, are interdependent, and cannot be considered in isolation. Nor can influences on the environment be considered in isolation e.g., changes in water temperature may lead to changes in the abundance, diversity and composition of aquatic communities.

Chemical parameters

Dissolved Oxygen

Oxygen is essential to all forms of aquatic life, including those organisms responsible for the self-purification processes in natural waters. Gaseous oxygen (O_2) from the atmosphere dissolves in water and is also produced during photosynthesis by aquatic plants and phytoplankton.

Changes or differences in dissolved oxygen (DO) concentration provide valuable information about the biological and biochemical reactions occurring in waters; it is a measure of important environmental factors affecting aquatic life, as well as of the capacity of water to receive matter without causing nuisance conditions.

In unpolluted surface waters, dissolved oxygen concentrations are usually close to saturation. The Target Water Quality Range (TWQR) for DO is between 80 and 120 % of saturation (DWAF, 1996b). Concentrations below 5 mg/ℓ may adversely affect the functioning and survival of biological communities and below 2 mg/ℓ may lead to the death of most fish.

Gross organic pollution leads to disturbance of the oxygen balance and is often accompanied by severe pathogenic contamination. Bottom-water O_2 depletion resulting from organic matter loading events can cause hypoxia (< 4 mg O_2/L). Hypoxia is physiologically stressful for fish and invertebrates.

Depletion of oxygen in lake bottom waters and the onset of anoxia, results in the re-mobilisation of phosphorus and other elements from lake sediments. In anoxic water, nitrogen is commonly found as NH_4^+. As with most reduced forms (Mn_2^+, Fe_2^+, H_2S, CH_4), the presence of NH_4^+ may severely impair the quality of the water for certain uses, particularly as a drinking water source (due to odour, taste, precipitation of metals upon re-aeration, etc.).

Assessing the present status for system variables: Dissolved oxygen concentration

The current methodologies are currently under revision, but were not yet available for use in this report.

The current methodologies were, therefore, used and reviewed.

- For the particular water quality reach, obtain all the dissolved oxygen data for the last three years of data.
- Convert the dissolved oxygen concentrations into percentage saturation taking account of the water temperature and elevation above mean sea level.
- Calculate the median dissolved oxygen saturation for each month, and assign the monthly water quality assessment category using Table 11.

Table 11 Present status assessment for dissolved oxygen (DWAF, 1999).

Assessment category	Dissolved oxygen concentration (%)
A	80 - 120 % of saturation
B	80 - 100% of saturation
C	60 - 80% of saturation
D	40 - 60% of saturation
E & F	< 40% of saturation

pH

The pH is an important variable in water quality assessment, as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment. The pH of most natural waters is between 6.0 and 8.5, although lower values can occur in dilute waters high (rich) in organic content, and higher values in eutrophic waters, and salt lakes.

Critical range: pH 6.0 – 5.0:

- critical pH level, when the ecology of the lake changes greatly
- the number and variety of species begin to change
- salmon, roach and minnow begin to become less diverse
- less diversity in algae, zooplankton, aquatic insects, insect larvae
- rainbow trout do not occur and molluscs become rare
- usually there is a high concentration of aluminum present
- the fungi and bacteria that are important in organic matter decomposition are not tolerant so the organic matter degrades more slowly and valuable nutrients are trapped at the bed and are not released back into the ecosystem
- most of the green algae and diatoms (siliceous phytoplankton) that are normally present disappear. The reduction in green plants allows light to penetrate further so acid lakes seem crystal clear and blue
- snails and phytoplankton disappear.

Assessing the present status for system variables: pH

- Extract the pH data for the past three years of data.
- Calculate the median pH value for each month (using the IWQS web site software).
- Assign a water quality assessment category for each month using Table 12.

Table 12 Rapid present status assessment for pH in rivers (DWAF, 1999).

Assessment category	Median monthly pH
A	6.5 – 7.5
B	6.0 – 6.5 or 7.5 – 8.0
C	5.5 – 6.0 or 8.0 – 8.5
D	5.0 – 5.5 or 8.5 – 9.0
E and F	<5.0 or >9.0

Total dissolved solids (TDS)

Total dissolved solids (TDS), is a measure of all the dissolved materials, organic as well as inorganic, in water. The TDS concentration is generally low in water in contact with granite, siliceous sand and well-leached soils, namely less than 30 mg/ℓ. Headwater streams rising in hard rock, mountainous regions of high precipitation yield weakly ionic, nutrient-poor waters in which the algal growth capacity may be severely limited (Reynolds, 1996). Most rivers exhibit decreasing TDS concentrations with increasing flow (Malan and Day, 2002; Roos and Pieterse, 1995).

Human activities have severely increased the TDS concentrations of inland waters worldwide, particularly in arid regions (Dallas and Day, 2004). But very little information is available of the tolerance of freshwater organisms to increased TDS. In general, it seems that many species are able to survive and even flourish at relatively high salinities. The recommended TDS concentration guideline for the protection of aquaculture species (freshwater) is <3 000 mg/ℓ (ANZECC, 2000).

However, in general, there seems to be a 'critical level' of salinity at about 5 000 – 8 000 mg/ℓ which marks the upper limit of survival of most salinity-tolerant freshwater animals. (Dallas and Day, 2004).

Assessing the present status for system variables: Total dissolved salts (TDS)

- For the water quality river reach, extract the TDS data for the last three years of data.
- Calculate the median value for each month (using the IWQS web site software).
- Assign a water quality assessment category for each month using Table 13.

Table 13 Rapid present status assessment categories for total dissolved salts (TDS) (DWAF, 1999) .

Assessment category	Median monthly TDS (mg/ℓ)
A	0 – 163
B	163 – 228
C	228 – 325
D	325 – 520
E and F	> 520

Exclusions: This method cannot be used rivers in the Eastern Cape and Western Cape with high baseline salinity values. In these cases, site-specific reference conditions will need to be determined, and the assessment categories must be adjusted accordingly.

Nutrients

Nutrient over-enrichment (eutrophication) has become one of the leading causes of water quality impairment of lakes and rivers worldwide. Blooms of noxious algae, excessive growths of aquatic macrophytes, episodes of anoxia, and a decrease in species diversity characterize eutrophication. One of the major consequences of eutrophication is the algal-related water purification and water quality problems associated with high algal concentrations in the raw water.

The excessive plant and algal growth can lead to a number of problems including:

- Toxic effects, particularly due to cyanobacteria in fresh and brackish waters;
- Reduction in dissolved oxygen concentrations when plants die and are decomposed;
- Reduction in recreational amenity (phytoplankton blooms and macrophytes in wetland, rivers and lakes);
- Recreational use of water is adversely affected.
- Blocking of waterways and standing waterbodies by macrophytes;
- Treatment of potable water may difficult and costly with unacceptable taste or odour; and
- A decrease in biodiversity.

Nitrogen

Inorganic nutrients provide the chemical constituents on which the entire food web is based. Nutrient cycling implies by definition that nutrients pass among different components of a cell, community, or ecosystem and can be cycled and reutilised by some of these components. Nutrient cycling occurs at many spatial and temporal scales.

Nitrate (NO_3^{2-}) is normally the most common form of combined inorganic nitrogen in lakes and streams. Natural concentrations, which seldom exceed 0.1 mg/ℓ NO_3-N, may be enhanced by municipal and industrial wastewaters, including leachates from disposal sites and sanitary landfills (Chapman, 1996).

Ammonium (NH_4)

Ammonia is a common pollutant and is one of the nutrients that contribute to eutrophication. Unpolluted waters contain small amounts of ammonia, usually well below 0.1 mg/ℓ as nitrogen (Chapman, 1996). In oligotrophic and mesotrophic lakes, ammonia in the epilimnion varies around a low value of about 0.005 mg/ℓ throughout spring and summer and any excess is taken up by phytoplankton (Horne and Goldman, 1994).

Ammonia in water is present primarily as NH_4^+ and the undissociated NH_4OH, the latter being highly toxic to many organisms, especially fish. The most significant factors that affect the proportion and toxicity of un-ionised ammonia in aquatic ecosystems are water temperature and pH. Potential toxic conditions when 3 conditions, namely high temperature, high pH and high ammonia, converge. The target water quality range of un-ionised ammonia is 0.0 – 25 µg/ℓ (DWAF, 1996b).

Assessing the present status for nutrients:

Ammonia

- For a particular water quality reach (downstream boundary), extract all the ammonium data for the last three years. If the number of data records is less than 60, use a longer period of data. Ideally, all nutrient classification must use the same period of data (it may not be valid to use ammonium data for the early 1980's with phosphate data for the late 1990's).
- Convert the ammonium values into un-ionised ammonia using information on water temperature and pH (page 24 in the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1997) for methods to convert ammonium data to un-ionised ammonia concentrations.
- Calculate the 90 percentile ammonia value. Where the ammonia concentration is at or near, the analytical detection limit, the river is allocated an A/B category.
- Assign the water quality assessment category for ammonia using Table 14.

Table 14 Present status assessment for nutrients using the un-ionised ammonia concentration (DWAF, 1999).

General categories for nutrient assessment	Assessment Categories	Ammonia (un-ionised) concentration (expressed as µg-N/l as NH_3)
Unimpacted	A	<7
Moderately impacted	B	<15
	C	<30
	D	<70
Highly impacted system	E	<100
	F	>100

Phosphorus compounds

Phosphorus is an essential nutrient for living organisms and occurs as both dissolved and particulate species in water bodies.

Phosphorus is generally the limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body. Artificial increases in concentrations due to human activities are the principal cause of eutrophication. High concentrations of phosphates can indicate the presence of pollution and are largely responsible for eutrophic conditions.

Phosphate (PO_4)

Phosphorus is rarely found in high concentrations in freshwaters as plants and algae actively take it up. As a result there can be a considerable seasonal fluctuation in concentrations in surface waters. In most natural surface waters, phosphorus ranges from 5 to 20 µg/ℓ PO_4-P (Chapman, 1996).

Assessing the present state for nutrients:

The ortho-phosphate to total phosphate ratio

- For a particular ecoregion, extract all the ortho-phosphate [(otherwise known as soluble reactive phoshate, (SRP)] and total phosphorus (TP) data for the past three years. Where there is no TP data then this method cannot be used.
- For each pair of SRP and TP values, determine the % ortho-phosphate content, given by:
- Ortho-phosphate content = [SP] / [TP]*100
- where [SP] is the soluble ortho-phosphate concentration (expressed in mg-P/ℓ), and [TP] is the total phosphorus concentration (expressed in mg-P/ℓ).

- In a river where the measured ortho-phosphate concentration is at or near, the analytical detection limit, the river is allocated an A/B assessment category.
- Calculate the median ratio value, and assign the water quality assessment category for ortho-phosphate using Table 15.

Table 15 Rapid present status assessment of nutrients based on ortho-phosphate as a percentage of the total phosphorus content (DWAF, 1999).

General category intervals for nutrient assessment	Assessment Category	Percentage ortho-phosphate content
Oligotrophic	A	< 10 percent
	B	< 20 percent
Mesotrophic	C	< 40 percent
	D	< 60 percent
Eutrophic	E	< 80 percent
	F	> 80 percent

N: P ratios

The N: P ratio is usually **high** in unpolluted and mountainous lakes and very **low** in eutrophic lakes (Downing and McCauley, 1992; Hessen et al., 1997). An analysis of the TN and TP data from 55 lakes by Harris (1986) revealed that the TN: TP ratio varied from over 200 in oligotrophic lakes to less than 15 in the eutrophic ones. Most of the polluted European and North American rivers also have N: P ratios <16 (Jarvie et al., 1998).

Assessing the present status for nutrients: Nitrogen to Phosphorus ratio

- For a particular water quality river reach, extract the phosphate (SRP), total phosphorus (TP), ammonium and nitrate data for the past three years. If the number of records is less than 60, use a longer period.
- Calculate the total inorganic nitrogen (TIN) concentration by summing the ammonium and nitrate values for each set of values.
- Calculate the N:P ratio using the TIN and TP values
- For the period of data, calculate the median N: P ratio, and the median SP concentration.
- Assign the assessment category using Table 16. Where the measured ortho-phosphate concentration is at or near, the analytical detection limit, the river is allocated an ortho-phosphate concentration of <0.01 mg-P/ℓ.
- If there is no TP data (and only SP), use the same calculations for nitrate and ammonia to derive the TIN concentration.

The N: P ratio is then derived from the TIN and SP values and the value assessed using Table 17.

Table 16 Rapid present status assessment of nutrients based on the N-P ratio (using TIN and TP) (DWAF, 1999).

		Total inorganic Nitrogen to Total Phosphorus Ratio			
		<5:1	**>5:1 & <10:1**	**>10:1 & <20:1**	**>20:1**
Ortho-phosphate concentration (expressed in mg-P/ℓ)	<0.01	C	B	A	A
	<0.05	D	C	B	A
	<0.07	E/F	D	C	B
	<0.10	F	E/F	D	C
	>0.10	F	F	E/F	D/E

Table 17 Rapid present status assessment of nutrients based on N-P ratio (using only ortho-phosphate data).

		Total inorganic Nitrogen to Soluble Phosphate Ratio			
		<10:1	**>10:1 & <20:1**	**>20:1 & <30:1**	**>30:1**
Ortho-phosphate concentration (expressed in mg-P/ℓ)	<0.01	C	B	A	A
	<0.05	D	C	B	A
	<0.07	E/F	D	C	B
	<0.10	F	E/F	D	C
	>0.10	F	F	E/F	D/E

4.5 Riparian Vegetation

Vegetation of floodplains, perennial streams and ephemeral rivers are directly related to the magnitude and duration of flooding and the retention of water in pans, pools and the subsoil (Rogers, 1980). Lateral, vertical and longitudinal gradients lead to vegetation changing with distance from the channel, elevation above the channel and distance downstream. The change in species composition of the riparian vegetation reflects these gradients (Higgens et al., 1996)

The frequency, duration and depth of flooding are likely to change markedly along each gradient, leading to concomitant changes in the biota. Upper reaches of rivers are subject to more frequent and intense discharge. Since the frequencies, duration and depth of flooding as well as sediment movement are driven by a variable run-off regime, these resource gradients are extremely dynamic in both space and time (Higgens et al., 1996).

According to Tinley (1976) two basic groups of communities could be recognised namely; the seasonally flooded communities which occur between the flood level and the low water level, and the aquatic communities which occur in areas such as pools and pans, where water accumulates and remain for longer periods of time.

Different plant communities could be recognised according to their relative periods of exposure and inundation. Floodplain communities differ in species composition from region to region although the habitat type remains more or less the same along the streams and rivers. Examples are the *Acacia xanthophloea – Dyschoriste depressa* community of the Pongola floodplains (Furness and Breen, 1980), the *Acacia karroo – Asparagus laricinus* community of the Highveld floodplains (Fuls and Bredenkamp, 1997), and the *Croton megalobotrys – Combretum microphyllum* Community of the Limpopo floodplains (Götze et al., in press).

Due to climatic conditions, geomorphology, and human impacts (impoundment of streams and abstraction of water from rivers and streams) many of South Africa's river's natural flow regimes have been modified to become ephemeral systems with an increase in sediment load. This phenomenon is giving rise to increased stress levels amongst the natural riverine biota (Van Coller and Rogers, 1996).

The maintenance of riparian ecosystems is dependent on the effective management of water supplies to rivers. Adequate water is needed to meet the consumptive (transpiration) and non-consumptive (habitat) requirements of the riparian vegetation. Riparian vegetation contributes to the habitat of other river biota such as invertebrates, amphibians, reptiles, fish, birds and mammals (Birkhead et al., 1996). Riparian vegetation also influences fluvial geomorphology by reducing energy gradients and enhancing sedimentation (Hicken, 1984; Jacobson et al., 1995).

According to Rogers and Biggs (1999) managing river health should not be confused with measuring it. It should be the means of achieving specific management goals. The integration of value systems, end points and indicators of an ecosystems' health or ecosystems' integrity, form the corner stone of a consultative management process for rivers.

The River Health Programme (RHP), is developed with the overall goal of expanding the ecological basis of information on aquatic resources, in order to support the rational management of rive systems (Roux, 1997).

Macrophytes and riparian vegetation in and along stream and rivers form an integral part of riparian ecosystems. Depending on each individual species' water requirement, it will position itself in narrow zones along the length of a stream or river. The result is longitudinal zones along a river representing plant communities that contain plant species that have similar water requirements.

According to Boucher (2002) different parts of the flow regime could be related fairly accurately to different lateral vegetation zones. The water requirements of the riparian vegetation in each lateral zone are used in the determination of the IFR and the Ecological Reserve.

4.5.1 Riparian vegetation methods used for input to EFR

According to Boucher (2002), in the IFR process a number of sites are selected in the river under study. The requirement here is that the banks are carrying reasonably complete natural vegetation.

Kemper and Boucher's method

Kemper and Boucher (2000) described a method determining the IFR for riparian vegetation. A number of transects (2 - 4) that cross the mainstream biotopes present (including at least a pool and a riffle) as well as passing through acceptable fringing vegetation are placed across the river at each side. Each transect is then examined visually for lateral zones on the basis of physiography (substratum types, areas of deposition and erosion) and floristic composition (observing species that reflect plant communities and particular the boundaries between communities). The cross-sectional topography is then formally surveyed and each lateral vegetation boundary is recorded along the cross-sectional profile of each transect.

Each zone occurring along the demarcated transect on each bank is treated as a separate sample plot, resulting in a minimum of seven plots per transect per bank if all zones are represented once and all support vegetation. The substratum types presented in each zone are recorded. Samples are taken of the finer deposits (coarse sand to clay). A cover-abundance score is assigned to each plant species in each zone (Braun-Blanquet method) (Werger, 1974). A flexible plot size approach is used for each zone because of the variation.

The size of the sample area is not only dictated by the characteristics of the river at the sample site but primarily by the area that can be observed at any time to obtain a reasonable comparable assessment of the relative contribution by each species to each zone (Kemper and Boucher, 2000).

Daily runoff sequences are used at each site by disaggregating monthly sequences, based on recorded daily flow data, which are extrapolated to the survey sites. Daily time series of base flows for both virgin and present-day conditions are produced. The return periods for the different flows are then computed (Brown & King, 2000). The low flows are subdivided into Summer and Winter baseflows. The daily volume of the annual mean maximum flood is computed (= class 4 flood) while lesser flood classes are determined by the successive halving of the volume of a class 4 flood event (class 3 – 1 floods). The inundation level of each flow-type is introduced onto the surveyed cross-section and the vegetation zones are compared to these levels (Boucher, 2002).

Riparian Vegetation Index (RVI) (Kemper, 2000)

The Riparian Vegatation Index (RVI) is a method to monitor the riparian vegetation along a river; which together with other aspects such as fish, aquatic invertebrates, geomorphology, hydrology and social usage; form part of the integrated biomonitoring programme in order to comprehensively reflect the full spectrum of changes which are likely to occur in such as system (Kemper, 2000).

The objectives of the RVI were to:

- Comply with the broad specifications provided by the river Health Programme
- Be developed and applied on the Crocodile, Sabie and Olifants River systems
- Be aimed at application on a national basis to a broad spectrum of rivers within South Africa
- Be usable by technical personnel of Provincial and other responsible organizations:
  - Be easily applied by a single assessor if necessary
  - Not require a high level of vegetation knowledge and experience, and
  - Be as qualitative as possible and avoid technical and quantitative considerations.

Formula for the Riparian Vegetation Index:

RVI = [(EVC) + ((SI x PCIRS) + (RIRS))]

Where:

EVC is extent of vegetation cover

SI is structural intactness

PCIRS is percentage cover of indigenous riparian species

RIRS is recruitment of indigenous riparian species

4.5.2 Difference between perennial and non-perennial rivers: riparian vegetation perspective

Boucher (2002) used a model of determining three lateral vegetation zones in perennial rivers (See Table 18). For non-perennial, ephemeral and episodic rivers only the Drybank zone of Boucher (2002) is applicable.

This zone is found along rivers because of the presence of an alluvial substrate, formed directly by river processes. Moisture is accessible to plants with deeper-rooted systems. Under natural conditions the lower dynamic subzone is maintained by, and inundated annually, on average, by the maximum levels of the Class 4 floods

.

Table 18 Lateral vegetation zones (after Boucher 2002).

Zone	Subzone
Aquatic zone	Permanent Aquatic Zone
	Rooted Aquatic Subzone
Wetbank zone	Lower Sedge or Moss Subzone
	Upper tree/shrub or Willow Subzone
Dry bank zone	Lower Dynamic Zone
	Tree/shrub Zone
	Back Dynamic Zone

The typical part of the Dry Bank Zone is termed tree/shrub subzone. The vegetation in this zone is generally long-lived in perennial systems. It is maintained by a ratio of 1:2 to approximately 1:20 year maximum flood levels (Boucher, 2002).

Large floods recurring on average at 20-100 year intervals maintain the Back Dynamic Subzone. The outer part of this zone is determined by the end of the riparian deposits or by a debris line where this is still present. As this is a transitional zone it contains a mixture of plants from the riparian and adjacent biome. The presence of plants associated with riparian environment is basic to the recognition of this subzone. The Drybank Zone is often absent in small, fast-flowing mountain streams, and because of the shape of the steep sided V-notch valleys, which are eroding and have not built up any lateral alluvial deposits (Boucher, 2002).

4.6 Invertebrates

4.6.1 Role of invertebrates in EWR determinations

Aquatic invertebrates are included in the Environmental Water Requirements (EWR) determinations as they play a major role in the functioning of a river where they are responsible for the retention and breakdown of organic material and recycling of minerals and nutrients. They also contribute to the energy processes in rivers at different trophic levels. The fact that invertebrates are relatively immobile and small makes them easy to collect.

Boulton and Lake (1992a) stated that the historical biological record of a non-perennial river has a greater influence on the community composition of the river than do the site and time specific abiotic differences.

Invertebrates are used in Ecological Reserve Determinations as indicators of conditions in the river at a particular site. They integrate the short term ecological condition present in the system, in particular the organic pollution level, habitat availability and the variability or permanence of flow.

Habitat availability and diversity have an impact on the presence of invertebrates and therefore invertebrates in conjunction with fish can be used as indicators for the types of habitats and hydraulic conditions (O'Keeffe, 1999).

Data collected on the invertebrates inhabiting a river system can also be used as an indicator of many flow-related conditions in the Ecological Reserve. Different invertebrates have different tolerances to no flow conditions, and some are able to survive dry conditions (O'Keeffe, 1999).

Invertebrate information is also used in conjunction with fish and riparian information to determine the Ecological Importance and Sensitivity (EISC) of each quaternary catchment in the specific study area. The presence or absence of rare and endangered taxa, unique taxa and intolerant taxa as well as the taxa richness on a Provincial, National or Local scale are considered when determining the EISC of a quaternary catchment.

4.6.2 Invertebrate methods used for input to EWR

Building Block Method (BBM)

In the BBM method (King et al., 2000) a series of steps for the invertebrate specialist to follow are set out. It must however be stressed that all these steps are not required for a desktop Ecological water requirement (EWR) determination:

1. Access relevant historical data available - to determine reference condition
2. Collect invertebrate data – *not included in desktop. Could however get present day data from biomonitoring data (River Health Programme), if available*
3. Analyse data
   - Calculate SASS (South African Scoring System) -*in desktop only if present day data is available*
   - Categorise the Present Ecological Status Class (PESC) and compare to reference condition (the condition determined from either historical data or an assessment of an undisturbed part of the system in the same ecoregion and river reach, which represents an A class in the DWAF classification system (King *et al.*, 2000). So as to determine level of change
   - Describe hydraulic conditions associated with each sensitive taxon.
4. The workshop:
   - Prepare a starter document
   - Define Ecological Management Class (EMC) according to classes A-D and objectives for the flow-related management of the river that will maintain the invertebrate fauna in that class
   - Recommend maintenance and drought flows for critical months in order to maintain invertebrates for the recommended EMC
5. Roles and responsibilities at the workshop:

Interpret each step of the process of recommending the EWR

- State the PESC with reasons and contribute to the determination of EISC and recommend an EMC. The EMC is a consensus of the PESC and the EISC as well as what change is possible.
- Discharge needed for the above is determined in terms of baseflows and higher flows for maintenance and drought conditions.
  Example
  - Baseflow objective for driest month in drought conditions might be to maintain minimal flow through riffles, to allow for survival of rheophilic spp. as well as hydropsychid larvae – determine the required depth, velocity and wetted perimeter needed
  - Higher flows might be necessary to scour Stones-in-current (SIC) clean. A written motivation must be provided. This should detail the reasons for required flow and explain why it cannot be lower.

6 Roles and responsibility after the workshop:

- Check flow recommendations in final report
- After the yield model has been run, various scenarios are possible, which should be evaluated, and then the best scenario must be chosen.

Resource Directed Measures

Section C, of the Resource Directed Measures for Protection of Water Resources for River Systems, sets out the procedure to be followed during a desktop estimate of water quantity component of the Ecological Reserve (Kleynhans, 1999a).

The following steps are followed namely:

1. Delineation of resource units and ecoregional typing
2. Ecological Importance and sensitivity (EISC) and Present Status Assessment (PESC)
3. Setting Ecological Management Class (EMC)
4. Estimation of the water quantity component of the Ecological Reserve.

The invertebrate assessment is included in step 2 namely Ecological Importance and Sensitivity and Present Status Assessment (See Kleynhans, 1999a).

The invertebrate specialist uses his expert knowledge of the river in question to determine the EISC and PESC in conjunction with the fish and riparian vegetation specialist.

The PESC for a desktop EWR is determined by rating several aspects of the habitat integrity (instream and riparian) such as flow, inundation, water quality, stream bed condition, introduced instream biota and riparian or stream bank condition for the resource unit (Kleynhans, 1999a).

If no reference condition can be determined, either due to lack of historical data or lack of reference site data, SASS4 score and average score per taxon (ASPT) values obtained from the present day data can be used to determine a PESC for the resource unit by referring to a table of SASS4 and ASPT values per ecoregion developed by Thirion (2003). If the study area does not fall in one of the ecoregions in the table developed by Thirion, then the SASS4 score and ASPT value can be placed in a PESC by referring to a table developed by Chutter (1998).

If historical or present day invertebrate data is available this can be assessed by using IRAI (Invertebrate Response Assessment Index) to determine the PESC of the invertebrates which can then be used in conjunction with fish and riparian habitat information to verify the PESC determined using the habitat integrity assessment.

Ecoclassification and Invertebrate Response Assessment Index (IRAI)

Louw et al. (2004) states that the ecoclassification process is a method used to create an understanding of the PESC and the ecological functioning of the river. Attainable ecological aims and objectives can then be set.

Information obtained during the process is used within a scenario-based approach and a range of ecological aims and states have to be considered. For each of these states, a flow scenario is developed.

The Invertebrate Response Assessment Index (IRAI) for macroinvertebrates developed by Thirion (2004) uses the SASS4 score as well as the abundance and presence data of invertebrates found in the system. It incorporates the flow, habitat and water quality preferences of invertebrates present. By comparing the invertebrates present in the system to what would be expected (either using historical data or professional opinion) and weighting the importance of habitat type, water quality and flow, a Present Ecological Status Class (PESC) is generated.

For the purpose of the desktop study only the area in the red block would be completed to determine the PESC of invertebrates for each resource unit identified (Figure 17). The Invertebrate specialist in conjunction with the other specialists at the workshop would be required to provide information to complete the steps to determine an acceptable Ecological Class and scenarios for the particular river resource unit (Figure 17).

4.6.3 Differences between perennial and non-perennial rivers: an invertebrate perspective

Introduction

The prediction of which species would occur in non-perennial rivers is however complex as their presence relies on various factors such as time of dry period, duration of dry period, proximity of refugia (either perennial tributaries or pools) and length of wet period. Studies on recolonisation by invertebrates are few but it appears that Chironomidae, Oligochaeta and Simuliidae are some of the early colonizers (Harrison, 1966).
A fairly comprehensive study on the ecology of temporary streams was done by Williams and Hynes (1977) where a summary of the survival strategies used by fauna in a temporary stream to survive is provided.

The result of a formerly perennial river changing into an intermittent (seasonal) river, probably due to overabstraction, is that the aquatic biota present would be restricted to species that either have drought resistant stages or which are able to recolonise the river before it dries out again. The change in landuse in the catchment as a result of a river becoming intermittent is usually an increase in soil erosion therefore leading to siltation of the river and an increase in turbidity. Siltation changes the river habitat for invertebrates by altering the bed of the river as sediment settle down on the stones-in-current biotope (Chutter, 1973).

Habitat available for invertebrates in non-perennial rivers

Non-perennial (seasonal, intermittent, ephemeral and episodic) rivers are systems which place extreme stress on biota occupying them by exhibiting highly variable chemical and physical attributes. The most important of these are the unpredictable and highly variable flow patterns. These flow patterns determine the habitat available for biota such as aquatic invertebrates.

Habitat available can be diverse during flow but a very low diversity could be available during dry periods. The reduction in flow causes major habitat types (eg. stones-in-current, marginal vegetation) to dry out and become unavailable to biota.

The habitat type mostly available in temporary rivers is pools, in which invertebrates can survive the dry period and from where they can recolonise the stream as flow returns.

Uys (1996) as well as Chutter and Heath (1993) have found that as the river dries out the mobile invertebrates move into pools. Some invertebrates move under stones, leaves or any substratum available despite their normal habitat preferences. Even blackfly larvae, which prefer high flows, can survive up to two weeks in no-flow conditions. Boulton and Lake (1992a) found more taxa in pools than individuals in riffles during a study on two intermittent streams in Australia. Williams and Hynes (1976) state that the extended pool stage in a temporary stream allowed certain species with a fairly long aquatic stage to successfully complete their life cycle.

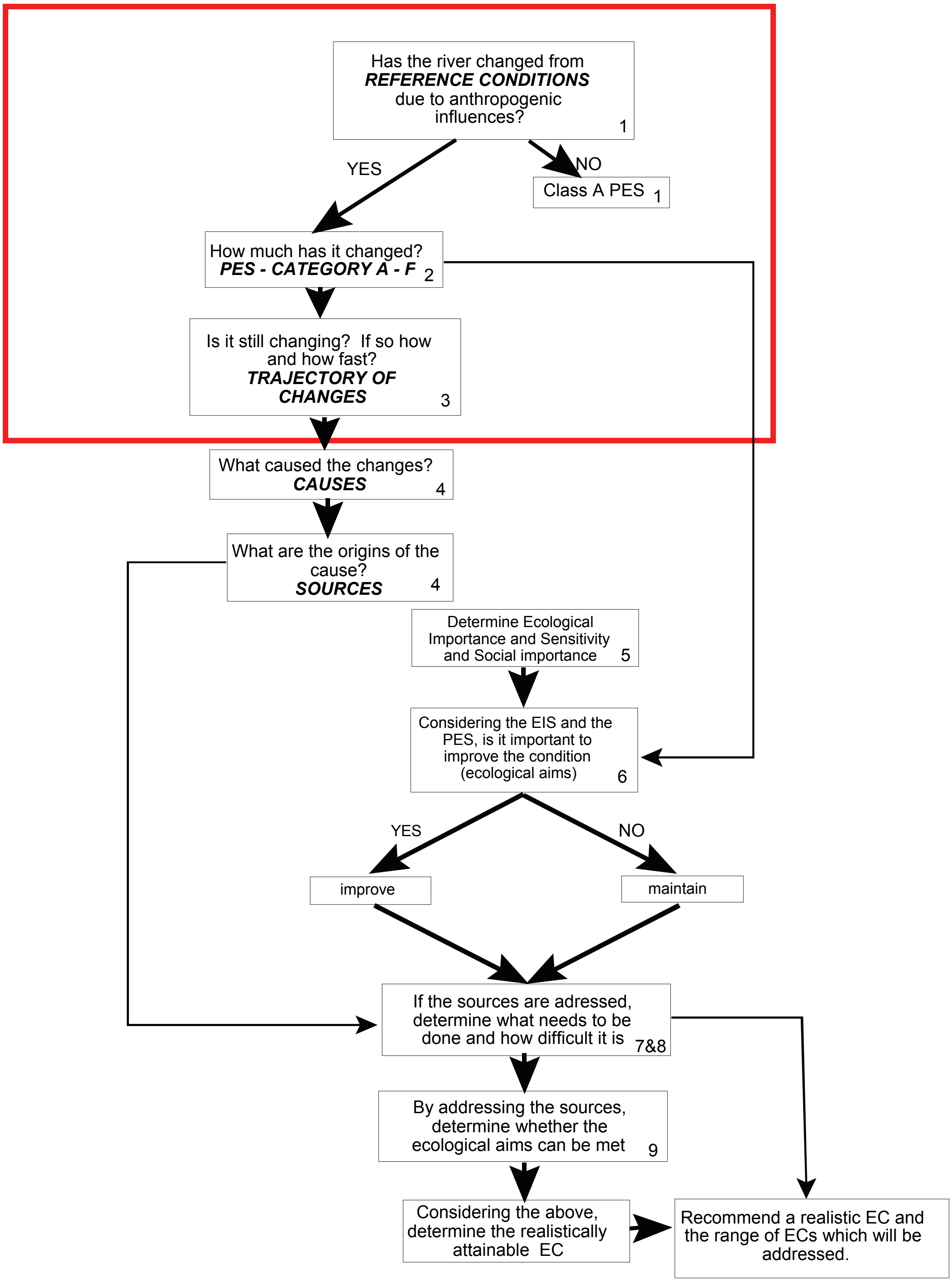

Figure 17 Flow diagram illustrating the information generated to determine the range of ECs for which EWRs will be determined (after Louw et al., 2004).

It is evident that marginal vegetation and pools are important biotopes in non-perennial rivers for invertebrates. Marginal vegetation is sometimes still available in pools and deeper sections even after the stones-in-current and stones-out-of-current biotope have dried up. The gravel/mud and sand habitat would also be available for longer than some of the other habitat types.

The presence of refugia near to the river – either tributaries or other streams in the vicinity is vital to survival of some species. Many of the invertebrates present in non-perennial rivers are the same as those found in temporary pools and pans in the area and these pans/pools also serve as refugia.

The dams and weirs built in non-perennial rivers also serve as refugia for invertebrates and fish, and the water quality in these structures would determine the population of invertebrates that survive the dry periods. These structures however also serve as migration barriers to biota.

Important to remember is that when pools are threatened by silting due to erosion or mismanagement of the catchment upstream it would mean that refugia for instream biota is removed and this could lead to the destruction of instream biota in other non-perennial rivers in the vicinity as well.

The recharging of the surface water by groundwater is also an important factor in these rivers as some invertebrates are found in this subsurface water and recolonise the surface water from there.

Stressors and habitat preferences in non-perennial rivers

Instream structure and substratum (formed as a result of the historical record of the non-perennial river) are regarded as dominant factors influencing distribution of invertebrate taxa (Harper et al., 1995 cited in Smith et al., 2003). Davies et al. (1993) suggest that in the arid and semi-arid Southern African Rivers the environmental stressors are extreme and organisms surviving in these systems are not stressed by the high flows as such but rather by competition for dwindling resources as the systems dry out.

Discharge variability and variation in water temperature are the major determinants of macroinvertebrate communities in springbrook rivers (Smith et al., 2003). The variability of discharge directly influences the instream habitat structure and therefore the macroinvertebrate community composition. Riparian vegetation and landuse also influence the organic material and content in the river and therefore also the macroinvertebrate community composition. Boulton and Lake (1992b) suggest that historical events (e.g. whether pools upstream dried completely during previous summer) influence the community composition in intermittent streams more than site specific abiotic differences.

Williams (1985) identified the following stressors namely

- **Dessication:** Drying out as a result of reduction in flow (either natural or due to abstraction)
- **Chemical:** Salinity can reach saturation point when water has nearly dried up. Williams (1985) and Dallas and Day (1993) found that salinity is not a major determinant but rather the rate of change of salinity is critical to invertebrates.
- **Temperature:** High temperatures do not last for long and rarely exceed 40 ºC. Invertebrates escape from high temperature by either burrowing into substratum or by migrating into deeper cooler water. Surface temperatures of up to 30-45 ºC are common in temporary water in semi-arid zones. Temperatures of small exposed streams tend to be influenced by atmospheric conditions. Tributaries may have higher summer temperatures than the main stream if they are smaller or more exposed. Some running waters exhibit considerable spatial thermal heterogeneity and lotic organisms by moving short distances may be exposed to different thermal regimes.
- **Oxygen:** Dilution from the atmosphere is usually sufficient for survival. Where pools are drying out, the concentration of organic material and salts and build-up of algae could lead to low oxygen concentration. Algal growth can lead to high diurnal dissolved oxygen levels and low oxygen concentration at night (Uys, 1996)
- **Light:** Water in non-perennial rivers is usually shallow and light penetration is at its maximum. Some waterbodies are, however, turbulent and therefore light does not penetrate as deeply as in clear pools.
- **Environmental instability**: Variability and unpredictable nature of precipitation.
- **Habitat isolation:** Fragmentation of habitat as a result of drying. Pools are isolated**.**
- **Fluctuating water levels** due to variability in rainfall and exacerbated by artificial flow manipulation

Various anthropogenic alterations can also add stressors to a system namely:

- **Stream Regulation**: Upstream regulation modifies thermal conditions depending on release depth, discharge pattern, retention time, stratification pattern and thermal gradients and the position of dam along the longitudinal profile. Diel thermal fluctuations are reduced by the upstream impoundment (Ward, 1985)
- **Forestry practices**: In arid regions, undisturbed streams have a narrow riparian corridor along the watercourse. The removal of this vegetation causes an alteration in thermal conditions, removal of overhanging vegetation causes higher summer and lower winter temperatures. Stream vegetation reduces bank erosion as well therefore influencing channel form, which indirectly influences temperature of water column. (Ward, 1985).
- **Agricultural practices**: Overgrazing causes soil erosion, which adds to the silt load of the stream. High silt loads characterize lotic waters in the southern hemisphere partly as a result of land use practices exacerbated by arid and semi

arid conditions (Chutter, 1970). Irrigation not only abstracts water from the system but also adds nutrients to the groundwater as well as to the surface water through leaching. These added nutrients can increase the likelihood of algal blooms or prolific growth of macrophytes in the water column. Algae cover the substratum in the river channel and clogs up the habitat where invertebrates could occur. An abnormal abundance of scrapers and filter feeders etc. could also be a result of algal blooms.

- **Urban influence**: Return flow from water purification works, sewage works as well as from storm water runoff, alter the habitat in the river by adding extra water (could change non-perennial streams to perennial streams) or by adding nutrients to the system.

Characteristics of invertebrates in non-perennial rivers

Wiggins *et al.* (1980) and Williams and Hynes (1976) have found that benthic communities within intermittent (non-perennial) aquatic systems usually differ from those in perennial systems.

King et al. (1987 a and b) add that for organisms to survive in these highly variable and unpredictable conditions they need to be widely tolerant particularly when critical phases of their life cycle occurs at the time when spates or droughts are most probable. The distance and condition of refugia are also imperative to the survival of invertebrates in these systems. The length of the inundation period influences the characteristics of the pools, as increases in temperature and changes in chemical characteristics occurs as pools dry out. These are factors which limit the survival of species in non-perennial rivers.

In arid regions where highly variable conditions occur, some streams have been extensively regulated. The general uniformity of environmental conditions (change from variable to constant flow) may not provide ideal conditions for indigenous biota or may at least place species adapted to the natural variable conditions at a competitive disadvantage (Ward, 1985).

Some riverine invertebrates may have narrower tolerances to flow changes (especially in different life stages) than many fish species (Weeks et al., 1996). O'Keeffe et al. (1996) added that when flow is permanently reduced, and the period of no flow during drought increases, many macroinvertebrate species would disappear, particularly the mayflies, caddis flies and simuliids, Hydropsychidae for instance are flow dependant and usually cannot survive in low flow <0.1 (Thirion, 2004).

Non-perennial aquatic habitats may be characterized by pioneer insect taxa that emerge from dessication-resistant eggs or those that are able to survive in small moist microhabitats such as riverbanks or within riverbed (Smith et al., 2003.).

Williams and Hynes (1977) identify three groups of invertebrates able to survive in non-perennial river systems namely:

- **Permanent river forms** with a wider tolerance range (not particularly adapted to life in temporary streams but able to survive short dry periods)
- **Facultative or opportunistic species** (occurring in lotic and lentic systems)
- **Highly adapted** and restricted to temporary waters

A summary of macroinvertebrates found in non-perennial (seasonal, episodic and temporary) waters in Namibia and South Africa is given in Table 19.

Life-history strategies

The temporal differences in the community composition of macroinvertebrates in streams are determined by the differences in life cycles. Seasonal differences in the distribution and abundance of macroinvertebrates reflect life-history characteristics of the individual biota (Dallas, 2002).

Adaptations

Abell (1956) proposed that invertebrates in non-perennial rivers used three methods of survival namely:

- Dormancy within habitat
- Transfer of activity to another environment
- Retreat to more favorable habitat to await resumption of flow

Williams and Hynes (1976) divided the mechanics by which species survive summer drought into 5 categories namely:

- Cyst (*Tubifex* etc.)
- Egg (Ephemeroptera, Chironomidae)
- Larvae or immature (Amphipoda, Ostracoda, Cyclopoida)
- Pupa (Tipulidae etc.)
- Adult (Hemiptera, Coleoptera, Gastropoda etc.)

Strategies

Absent from temporary fresh water are all animals which have no stage in their life cycle resistant to dessication or that cannot move away during periods of drying. (Williams, 1985).

Most of the invertebrates would have an r-selected life-history strategy (a combination of early maturity, many, small, young, short life and large reproductive effort) life-history strategy (Mac Arthur and Wilson, 1967). **NB: It must however be noted that no organism fits in this category completely but could have some of the following capabilities:**

- unstable habitat – need to be flow adapted
- high powers of dispersal
- high intrinsic rate of natural increase

- continuous opportunistic reproduction
- large number of eggs
- develop rapidly
- poor competitive ability
- opportunistic feeders
- tolerant of harsh conditions
- small body size
- short life span (Uys, 1996)
- capable of behavioral avoidance

Recolonisation

Uys (1996) identified two types of colonizers namely: Active (flight, crawling) and Passive (drift, wind) and the cues needed for colonisation as temperature, light and food availability.

Wissinger (1997) describes the colonisation and life-history strategies of taxa that occupy predictably and unpredictably disturbed ephemeral habitats. He suggests that unpredictably disturbed habitats have fugitive or colonizing taxa which usually use most of their energy in producing dormant or vagile propagules at the expense of parental survival.

Taxa that occupy predictable ephemeral habitats however respond to disturbance by escaping to permanent refugia where they then delay there reproduction effort until conditions becomes favourable and then recolonise the system. He names this process “cyclic colonisation” and the taxa involved “cyclic colonizers”.

Cyclic colonizers have different stages of life-history traits between generations. The “establishment generation” has small or no wings, individuals are sedentary, grow rapidly and reproduce at an early age. They also have high fecundity (**partly r-selected**). The “overwintering generation” (survivors during drought periods) have long wings, characteristics to enable flight and are reproductively immature (**partly k-selected** (a combination of late maturity, few, large young, a long life and small reproductive effort)). It therefore follows that cyclic colonizers **alternate between r- and k- selected strategies** during their lifetime.

Harrison (1966) in a study completed in the Munwahuku stream in Rhodesia (Zimbabwe) suggests that recolonisation occurs from three sources namely resting eggs, forms capable of aestivation and eggs laid by flying adults. He also found that recolonisation occurred rapidly after inundation – oligochaetes, small crustaceans and insect larvae appear within the first ten days after inundation. Species typical of permanent streams returned within one month of inundation in pools and within 4-6 weeks in streams**. (NB time needed to recolonise completely = 4-6 weeks).**

Table 19 A List of macroinvertebrate families found in non-perennial systems (seasonal, episodic and temporary – including rain pools in riverbeds) showing water quality, habitat and flow preferences (compiled from lists provided by Day (1990) and Curtis (1991), Uys (1996), and data from Thirion (2004).

Family present	SASS4 intolerance score	Water Quality preference	Habitat Preference	Flow Preference
Aeshnidae	8	Moderate quality preference	Cobbles	Any flow (not very slow)
Baetidae	4	No preference	All habitat types	Fast >0.6 m/s
Ceratopogonidae	5	Low quality preference	Cobbles	Fast >0.6 m/s
Chironomidae	2	No quality preference	Gravel, sand & mud	Slow 0.1-0.3m/s
Coelenterata (Hydridae)	1	No quality preference	Vegetation	Fast >0.6 m/s
Coenagrionidae	4	Low quality preference	Vegetation	Moderate 0.3-0.6 m/s
Corixidae	3	Moderate quality preference	Water Column	Slow 0.1-0.3m/s
Culicidae	1	No quality preference	Water Column	Very slow <0.1 m/s
Dryopidae	8	Moderate quality preference	Cobbles	Moderate 0.3-0.6 m/s
Dytiscidae	5	Low quality preference	Water Column	Very slow <0.1m/s
Ephydridae	3	No quality preference	Gravel, sand & mud	Very slow <0.1m/s
Empididae	6	Low quality preference	Cobbles	Fast >0.6 m/s
Gomphidae	6	Low quality preference	Gravel, sand & mud	Moderate 0.3-0.6 m/s
Gyrinidae	5	Low quality preference	Water Column	Fast >0.6 m/s
Heteroceridae				
Hirudinea (Glossiphoniidae)	3	No preference	Cobbles	Slow 0.1-0.3m/s
Hydracarina	8	Moderate quality preference	Vegetation/Gravel/Sand/Mud	Moderate 0.3-0.6 m/s
Hydraenidae	8	Moderate quality preference	Vegetation	Moderate 0.3-0.6 m/s
Hydrophilidae	5	Low quality preference	Vegetation	Slow 0.1-0.3m/s
Leptophlebiidae	9	Moderate quality preference	Cobbles	Very slow <0.1 m/s
Libellulidae	4	Low quality preference	Cobbles	Moderate 0.3-0.6 m/s
Naucoridae	7	Low quality preference	Water Column	Moderate 0.3-0.6 m/s
Nematoda (Monhysteridae)				
Notonectidae	3	No quality preference	Water Column	Very slow <0.1 m/s
Planorbidae (Bulininae)	3	No preference	Vegetation	Very slow <0.1 m/s
Psychodidae	1	No quality preference	Water Column (stagnant)	Very slow <0.1m/s
Simuliidae	5	Low quality preference	Cobbles	Fast >0.6 m/s
Tabanidae	5	Low quality preference	Gravel, sand & mud	Slow 0.1-0.3m/s
Tipulidae	5	Low quality preference	Gravel, sand & mud	Slow 0.1-0.3m/s
Turbellaria (Dalyellidae)	3	No quality preference	Cobbles	Fast >0.6 m/s

NB: Important to note is that all these taxa have SASS intolerance scores of 8 and below, except Leptophlebiidae (see discussion on applicability of SASS).

After a dry season from May to October the Munwahuku stream bed was dry and dusty and all aquatic animals would have been dead except those able to survive as resting eggs or escape to other available waterbodies. Seven days after inundation small nematodes, Oligochaeta (probably survived by burrowing into banks) and larvae of Chironomidae appeared. True running water forms such as Simuliidae had also appeared.

Up to six weeks later other permanent stream invertebrates appeared such as Baetidae and *Cheumatopsyche*. After nine weeks most invertebrate species had returned.

He also noted that there was a definite seasonal pattern in invertebrate communities, which was probably related to the different current speed. During slower flow Baetidae and some Trichoptera (*Cheumatopsyche*) disappeared.

Various authors cited in Uys (1996) described the process of colonization probable in a stream as follows:

Appearing first after few days, dependant on if there were pools in channel or outside river
(From eggs, drifted down from damp areas or found refuge in damp zones)
Mosquito larva, nematodes, springtails. Water mites, microcrustacea, oligochaetes, fly larvae (chironomids, ceratopogonids, tipulids, stratiomyids, ephydrids),

Other colonizers that can colonise quickly but that depend on specific temperature and oxygen available are: Beetles (dytiscids, gyrinids, hydraenids, hydrophilids)
Bugs (corixids, pleids, notonectids)
Mayflies (baetids and caenids)
Dragonflies (gomphids and cordulids)
Snails (planorbids, physids, lymnaeids)

After two weeks aerial colonists arrive:
Adult dragonflies, damselflies, beetles, bugs - depending on seasonal cues breeding will take place.

After one month of continuous flow:
Eggs laid will have hatched (mayflies, simuliids) and further colonization will have occurred. Species composition would resemble that of a perennial system with the exception of some mayflies and caddisflies. Williams and Hynes (1977) summarised the colonisation process as well as the methods used to survive dry periods in Figure 18.

The succession of taxa in an intermittent stream follows a general pattern of taxa increasing in the riffle biotope until just before flow ceases. Taxa then emigrate into pools or escape shortly after flow stops. The pools have maximum species richness shortly after flow has stopped.

The generalists are present for most of the year, scrapers increase when periphyton growth is increased usually late spring, early summer and predators increase steadily through the year with a maximum species abundance occurring just before flow stops. Floods early in the wet season generally reduce taxa richness but recovery occurs at least two weeks after floods (Williams and Hynes, 1977).

Vulnerability of invertebrates to flow change

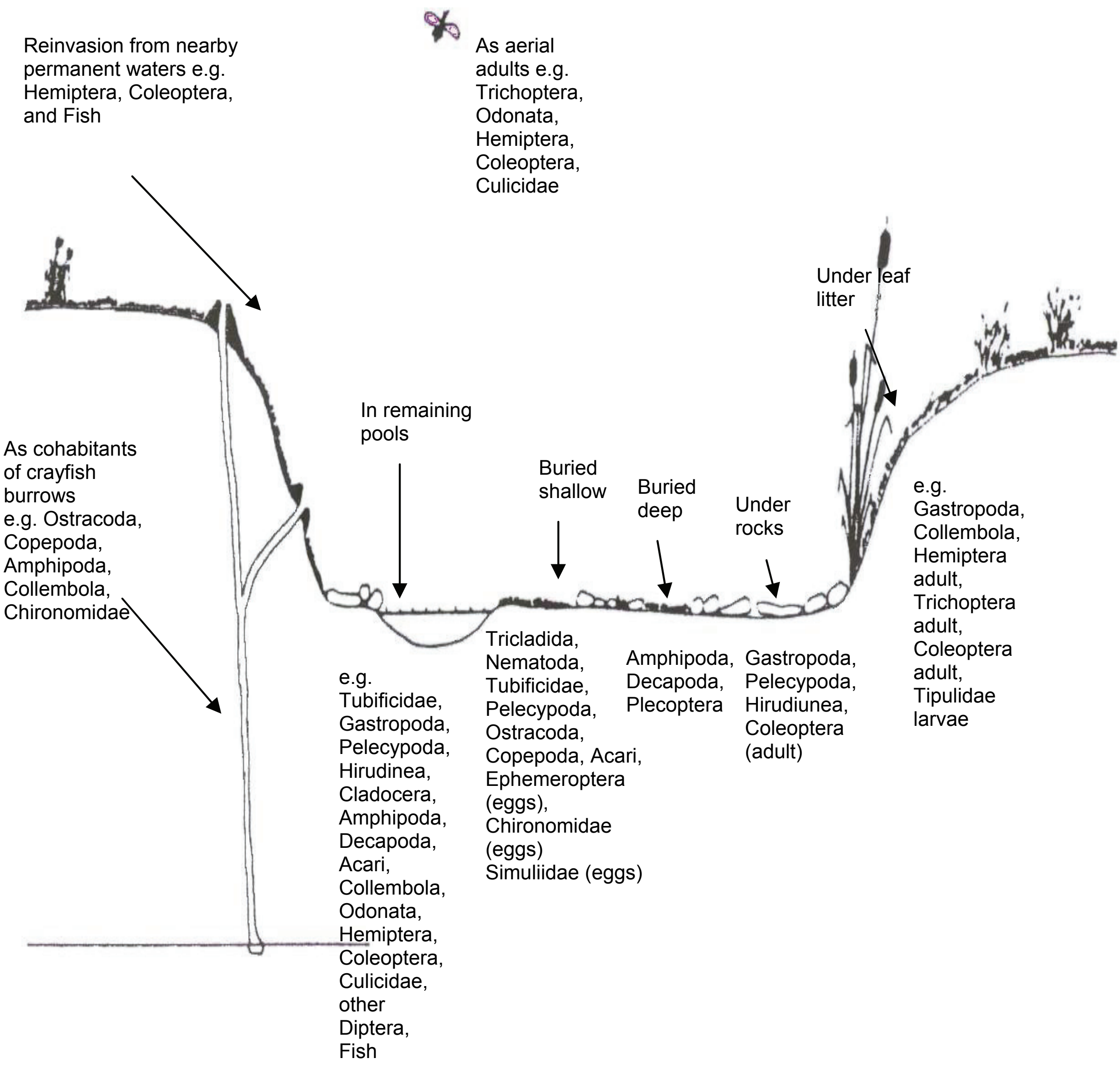

Figure 18 Summary of the colonisation and survival adaptation of invertebrates in temporary streams (after Williams and Hynes, 1977).

Flow needs of invertebrates in non–perennial systems:

- **Subsurface** flow in dry season must be in contact with pools (to make this habitat available and for recolonising of subsurface by sediment dwelling invertebrates). Also needed to maintain adequate water quality in pools.
- **Low flows in wet season as well as early in wet season** to provide connectivity between pools for recolonisation and to keep water quality adequate and reduce predation pressure. Should be linked to rain season and should last at least two months to allow for recolonisation (takes more or less six weeks for most invertebrates).
- **Some flash floods at natural sequence** to lift fine silt from alluvium and riffle areas. Also needed for dilution of accumulated salts and organics in pools.
- **Floods** to prevent pest species, which take advantage of altered system and weakened competition and predation from other spp., from proliferating and causing disease.
- **Flows late in wet season** to allow invertebrates to complete life cycle.
- **Large floods at start of wet season** to move pools and create new invertebrate habitat which is wetted long enough for invertebrates to colonise and complete life cycles.
- **Short periods of flow in drought –** to rejuvenate pools (Ractliffe, 1996)

Boulton (2003) discussed an important aspect of flow-related changes to the survival of macroinvertebrates in intermittent streams. He asks the question whether the biota of intermittent streams is less vulnerable than those of perennial streams, to species loss when artificial drought is imposed through human activities and he explains as follows.

Drought in non-perennial streams is considered as natural disturbance in these systems (drought occurs often in areas where rainfall is unpredictable and variable). The length and severity of the drought could however exceed the limits normally found in these systems. When flow in a stream or river ceases abruptly, changes such as abrupt loss of habitat, alteration of physicochemical conditions in pools downstream and the fragmentation of the river, result. Drought conditions in a river can eliminate populations such as atyid shrimps, stoneflies and free-living caddis flies that occur in intermittent streams.

Drought in an English chalk stream was buffered by the sustained groundwater discharge from the previous winter (Boulton, 2003). There are vertical linkages between groundwater and surface water habitats as well as lateral linkages with floodplains and riparian zones. These linkages can be disrupted during drought periods. The effect that drying of surface water has on the subsurface layer was recorded by Valett et al. (1992) cited in Boulton (2003) in a sandbed river in the Sonoran desert. They found that during drying, the community of invertebrates in the subsurface layer changed due to the decreased influx of water from the surface layer. During a dry period the duration, extent and frequency of the river floodplain linkages can be altered.

The variation in invertebrate assemblage composition in floodplain wetlands has been attributed to varying degrees of connectivity.

Drought causes habitat fragmentation and disruption of vertical and lateral linkages. The extent of this is determined by the resident catchment characteristics. Low flow causes increases in siltation, change of vegetation and alters the channel shape and water chemistry. As the dry period increases the critical threshold (defined as the thresholds of discharge or water level at which habitats become isolated or dry) is passed and aquatic macroinvertebrates need to either leave the system or escape by forming resistant eggs, or finding refuge in remaining pools or burrowing into substratum. After flow returns the invertebrates recolonise but this process relies on the life-history strategies, complexity of the physical habitat, the availability and distance of refugia, the degree of habitat fragmentation and the changes caused by low or no flow (Figure 19) (Boulton, 2003).

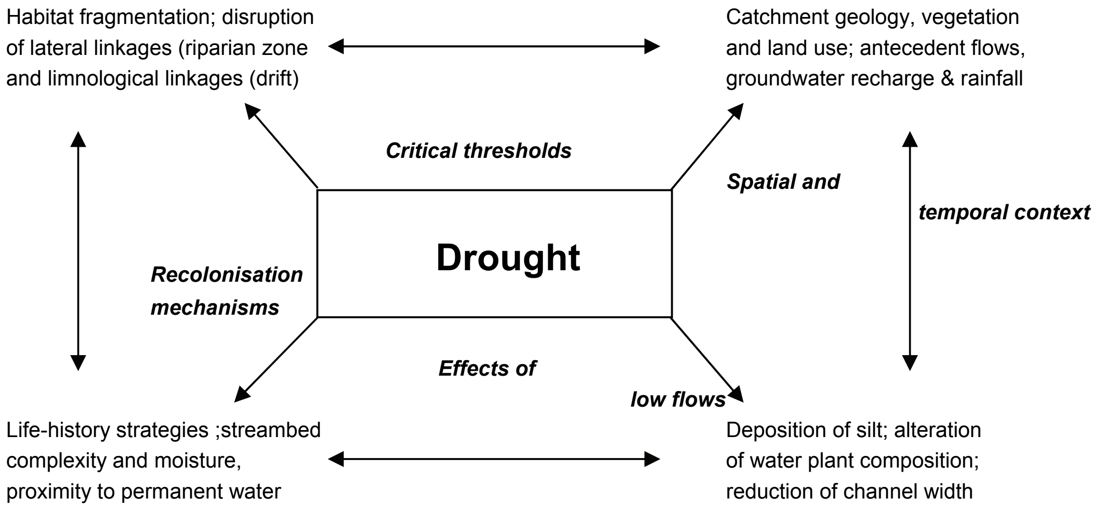

Figure 19 Relationship between low flows, critical thresholds, recolonisation mechanisms and spatio temporal context in drought dynamics of aquatic macroinvertebrates (After Boulton, 2003).

The trophic structure of rivers and streams that dry out undergoes change. When riffles are lost, due to drying, the periphyton available to grazers is reduced and the movement of detritus downstream is stopped. Filterers and grazers are reduced in abundance while collectors become more abundant in pools. As pools dry out and become stagnant, the accumulated detritus and deoxygenated water combined with a buildup of leachates causes many of the surviving fish and invertebrates to die. In deeper pools, which do not dry out as easily, predators, mainly Odonata nymphs, dytiscid beetles and hemipterans increase (Boulton and Lake, 1990, 1992a and; Canton et al*.,* 1984; Maamri et al*.,* 1997; Towns, 1985, 1991; Larimore et al*.,* 1959; Tarmer, 1977; Closs and Lake, 1995; Stanley et al*.,* 1994 and Matthews, 1998 cited in Lake, 2003).

Presence of pest organisms

Chutter (1967) found that the density of the simuliid, *Simulium chutteri* increased with reduction in flow variation as a result of regulation of flow for irrigation downstream of a weir. Large populations of simuliid persisted for up to 50 km downstream, of the weir. It was found that the simuliids invaded the newly flooded area and had gradually out competed their natural predators namely hydropshychids.

Curtis (1991) states that damming of a river creates new wetlands, which in turn could lead to the spread of unwanted species (pest species) within these new wetlands. As a result new predator free habitats are formed, which are utilized by these unwanted species. Furthermore pools in non-perennial systems could possibly become stagnant due to water abstraction upstream. This could lead to an outbreak of Culicidae and an increase in mosquito carried diseases.

Predictability – is the same community in the same pool every year? Is prediction of invertebrtes present in non-perennial rivers possible?

It is difficult to predict which invertebrates are present and where they would occur in a non-perennial river at a particular time, therefore making once-off sampling in a particular section (biotope) of the river is unreliable. Thus when using once-off sampling, in a rapid reserve determination, it is important that results obtained are accurate. Thus it is therefore not advised to use this once-off sampling methodology.

The species composition of invertebrates is difficult to predict in non-perennial systems as the time of sampling is critical. Variation and the number of invertebrate species present will depend largely on the time of year that the sampling is done. The following abiotic and biotic factors will further influence the variation and number of invertebrate species present:

- The last occurance and amount of rainfall
- The proximity of refugia
- The water quality of refugia
- Duration of inudated period for recolonization
- The rate of recolonization of various insects
- The various insects present in the biotope

Dallas (2002) notes that if a system is highly variable it may not be possible to define a reference condition (not be able to predict which taxa would be present) or it would be necessary to define several reference conditions for different types of rivers even when they are in a relatively discrete area.

Using data collected even from the same ecoregion and same reach type as non-perennial rivers is not always advisable as rivers in the same ecoregion could be perennial or non-perennial and have different invertebrate community structures. Dallas

(2002) notes that even in regionally distinct areas variability in the community composition of macroinvertebrates is evident. It then follows that the extent to which one can extrapolate macroinvertebrate data from one site in a river to another site in a river in the same area deserves to be investigated.

It would also be difficult to predict communities present in non-perennial systems as there are numerous cues needed for recolonisation to take place such as differences in temperature, oxygen content, water quality in general. All of these would determine if colonization would take place and when. Roux et al. (2002) discuss the evolution and succession of biota in a river system and note that the evolutionary processes acting on species inhabiting perennial systems is very different from those inhabiting non-perennial systems. The community composition of invertebrates in non–perennial systems is determined by colonizer and pioneering species on a “first come, first served” basis. Two adjacent pools in the same river may have entirely different occupying species due to the difference in succession of colonizer species in each pool.

The groundwater recharge in non-perennial systems is an important aspect in the prediction of which invertebrates should be present in a system at a particular time. The recharge from groundwater to the stream is reliant on how much recharge there was to the groundwater during the previous season, the depth of the water table as well as the type of substratum present in the river/streambed. This would then determine the amount of flow in the river as well as the degree of dampness of the substratum in the riverbed. The invertebrates reliant on these features would then recolonise or survive during dry periods. This is however difficult to predict at present as specialised geohydrological knowledge of the system is required which is often lacking in non-perennial rivers in South Africa.

4.7 Fish

4.7.1 Role of fish in EWR determinations

The introduction of the concept “restoring and maintaining ecological integrity” (as included in American legislation early in the second half of the previous century; see Karr and Dudley 1981; Karr et al. 1986) and the realization that the halting of chemical pollution alone will not suffice to assure and restore the ecological integrity of water resources, paved the way for a whole new way of thinking about the management of water resources. The realization that the ability of a water resource to sustain a balanced biological community best indicates it’s potential to provide ecological services to human society, finally lead to water biologists becoming involved in water management, creating a platform for cooperation between water engineering and ecology.

The need for determining environmental flows in rivers arose in the previous century in response to the growing deterioration of river conditions and aquatic habitat quality (King, 2000). One of the earliest attempts at environmental flow determination was by a fish biologist, Tennant, who linked the quality of fish habitat with flow. He realised a relationship between quality of fish habitat and percentage of the flow in the river, which developed into a desktop method that could be applied in other rivers that he had not visited (King, 2004) (see Tennant 1976 for further details). Tennant's method is still widely used across America (and some other parts of the world). A vast body of formal methodologies for prescribing environmental flows has since been developed (Tharme, 2000). Although some of the initial methods (hydraulic rating and habitat simulation methodologies) have been moulded around the environmental flow requirements (EFRs) of economically important fish species, recent methodologies (eg. holistic methods) tend to increasingly address the EFRs of other components of the riverine ecosystem as well (Tharme, 2000).

Environmental flow methodologies are mainly concerned with one component of the river ecosystem – its flow regime - thereby reflecting the regime's overwhelming importance in the sculpting of the ecosystem (O'Keeffe, 2000). The holistic approach, for example, identifies important and critical flow events in terms of criteria such as flow magnitude and timing for all components of the riverine ecosystem (Tharme, 2000).

Why must fish be included?

Biological communities reflect a combination of current and past catchment conditions because organisms are sensitive to changes across a wide array of environmental factors (Karr et al. 1986). Fish are useful as biological indicators because of the following reasons:

- Fish assemblages (usually) represent a wide variety of trophic levels and may therefore integrate the effect of detrimental environmental changes (Kleynhans, 2003).
- Fish are good indicators of long-term effects and broad habitat conditions due to their relative longevity and mobility (Kleynhans, 2003). Their greater mobility has the potential to integrate diverse aspects of relatively large-scale habitats and their longer life span includes a temporal dimension to the assessment of stream conditions (Karr et al. 1986).
- Fish use a wide range of habitats during their daily activities and different life-stages. These habitats may be seen as a function of base flow (Kleynhans and Engelbrecht, 1999).
- Fish represent less identification problems than do aquatic invertebrates. The conservation status and distribution patterns of most fish species have been determined (Skelton, 2001).
- The public at large tend to value fish and are usually more familiar with fish than with other forms of aquatic life (Karr et al. 1986).

With regards to environmental flow assessments (EFAs), fish are valued for the following reasons (Louw, 2003):

- They are often the critical indicator due to factors such as size and more critical flow requirements.
- In determining EFRs, fish are used as one of the key indicators of the biological integrity of the system.
- Fish are used to define the objectives for which flows must be quantified. Together with other components, they are used to quantify the Ecological Reserve.
- Fish are used to set resource quality objectives for biota and habitat and as a monitoring tool to measure compliance and whether objectives are being achieved.

By including ecological information on fish, an attempt is made to link the size, temporal and spatial distribution of flow or floods in a river to the ecological requirements of life-history stages of different fish species (Kleynhans and Engelbrecht, 1999).

The role of fish in the four levels of Reserve Determination

Four levels of reserve determination, Desktop, Rapid, Intermediate and Comprehensive, are indicated in the Resource Directed Measures (RDM; DWAF, 1999). The level of reserve determination used depends on factors such as the current and the desired ecological integrity of the river, and its ecological importance and sensitivity (Kleynhans and Engelbrecht, 1999). For the purpose of this study a desktop/rapid study (without field visits) was prescribed. The following discussion will, therefore, focus on the role of fish in desktop and rapid reserve determinations only.

Information on the fish assemblages of a river segment is principally used in the determination of the ecological importance and sensitivity (EIS) and the present ecological state (PES) of a particular river reach (Kleynhans and Engelbrecht, 1999). For the EIS, information on the presence of rare and endangered fish species, as well as unique and flow sensitive species (or life stages), are considered in combination with other ecological information. For the PES existing information on fish assemblages is used. No field surveys are undertaken in a desktop assessment, but existing information in the form of published information and professional knowledge is used. If information for a particular quaternary catchment is lacking, information from similar, better known, catchments or river sections, may be used. Understandably, confidence in the results of such desktop assessments is relatively low.

Rapid reserve determinations are distinguished from desktop studies in that they represent higher levels of confidence and include limited fish surveys in the field (Kleynhans and Engelbrecht, 1999). For rapid, intermediate and comprehensive reserve determinations a fish assessment document, which includes the following information, should be compiled (Kleynhans and Engelbrecht, 1999):

- List of species expected to be present in the different zones indicating conservation status.
- Habitat information on the resource units and sampling sites. The availability of biotopes, flow depth (slow deep; slow shallow; fast deep and fast shallow) and cover classes (overhanging vegetation; undercut river banks and tree wads; substratum and aquatic macrophytes) should be noted.
- Habitat (flow-depth and cover classes) preferences and requirements of fish species, also indicating intolerances (as prescribed by Kleynhans 2003 and 2004).
- The use of a fish index (e.g. Fish Assemblage Integrity Index, FAII) to determine the biological integrity of the river segment.
- Provide fish flow requirements (including life-history stage requirements and habitat needs), especially for sensitive and indicator species.
- Provide conclusions and explanations as to the current biological integrity class of the river as based on the fish assemblages.

4.7.2 Fish methods used for input to EWR

For desktop and rapid reserve determinations, information on the fish assemblages of a river segment is considered in the assessment of the ecological importance and sensitivity (EIS) and the present ecological state (PES) of a particular river reach (Kleynhans, 1999b). The PES of a river segment is taken into consideration when a decision has to be made on the attainable and desired Ecological Management Class (EMC). The tools or indices that are currently used to determine the biological integrity of a river segment, based on fish data, are discussed below.

According to Kleynhans (2003), for the purpose of reserve determination studies, fish indices should relate to the following general questions:

- To what extent has the integrity or condition of the fish population or assemblage in a river changed from the desired ecological category as specified in the resource quality objectives for that particular category?
- To what degree can such change be considered to reflect the overall integrity of the river as a whole?

Setting of reference conditions

The determination of the reference condition is a very important aspect of the overall reserve determination methodology as it describes the natural, unimpacted characteristics of a water resource (DWAF, 1999). The reference condition represents a baseline that is relevant to a particular resource, and it should be stable to ensure optimal future management of the resource. The natural, unimpacted condition is generally seen as the most stable baseline available and is therefore generally used as the reference condition (DWAF, 1999). However, as information on fish distribution during pre-development conditions is generally unavailable, alternative procedures have to be applied. The list of expected fish species for each river segment is usually based on available literature, expert judgement and local knowledge. The information used to draft the list of expected species for the three case studies in this report is indicated in each chapter.

Present Ecological Status (PES) based on fish

Three indices, the Fish Assemblage Integrity Index (FAII; Kleynhans, 1999c and 2003), a qualitative version of the FAII, and the Fish Response Assessment Index (FRAI; Kleynhans, 2004) were used to determine the present ecological status (PES) of the river segments under investigation.

Fish Assemblage Integrity Index (FAII)

The Fish Assemblage Integrity Index (FAII) is a multi-metric index based on a comparison between aspects of the expected and observed fish assemblages (Kleynhans, 1999a and 2003). The purpose of this approach was to develop an index that can use readily available and measurable fish assemblage attributes responsive to human-induced environmental changes (Kleynhans, 1999a). Kleynhans (2003) summarises the method as follows:

"A list of expected fish species for minimally impaired conditions for a fish habitat segment (a section of a river where the fish habitat is relatively homogenous) is compiled. A rating system is then applied to assess the degree of specialisation and intolerance of native fish species to environmental modifications. (Attributes include trophic specialisation, habitat specialisation, flow dependence and unmodified water quality). The frequency of occurrence and health of expected and observed fish species in the river segments are then assessed and rated".

A score is calculated using the following formula:

Expected situation: FAII (EXP) = ΣIT((F+H)/2)

Observed: FAII (EXP) = ΣIT((F+H)/2)
Where:
IT = Intolerance rating per species
F = Frequency of occurrence per species (per fish habitat segment)
H = Health/condition rating per species

A relative FAII score is calculated by comparing the expected and observed situations:
Relative FAII = FAII(OBS)/FAII(EXP) X 100

This relative FAII score is then interpreted according to generic FAII categories (from A-unmodified to F-critically modified).

Qualitative FAII

A qualitative version of the FAII was developed for use in reserve determination studies on rivers with very low species richness, lacking historical data (Dr. Pieter Kotze, RAUECON, pers. comm.). A set of seven attributes is rated by the fish expert, based on the results of the sampling survey and expert opinion. Attributes are scored between 0 (poor) and 5 (excellent) and include the following:

- Native species richness;
- Presence of native intolerant species;
- Abundance of native species;
- Frequency of occurrence of native species;
- Health/condition of native and introduced species;
- Presence of introduced species;
- In-stream habitat modification.

Fish Response Assessment Index (FRAI)

The Fish Response Assessment Index (FRAI) is part of the Habitat Flow Stressor Response (HFSR) -methodology (Louw et al., 2004) that is currently being developed. The HFSR-methodology is an Ecological Water Requirement method aimed at determining low or base flows and was devised to better comply with the method requirements of the Reserve (Louw, 2004). The method relates flow to species stress through an assessment of the habitat features resulting from a particular flow regime. The quantity and quality of available habitat are used as an indirect indication of the effect of stressors on individual fish and populations (Kleynhans, 2004). Fish are therefore viewed as one of the components acting as a response to drivers (geomorphology, hydrology and water quality) and are used as an indicator of the instream status of the river (Kleynhans, 2004).

With regards to the fish component, the HFSR approach requires certain actions (see Figure 20). However, due to the rapid nature of the current study and the lack of information, not all the steps could be completed.

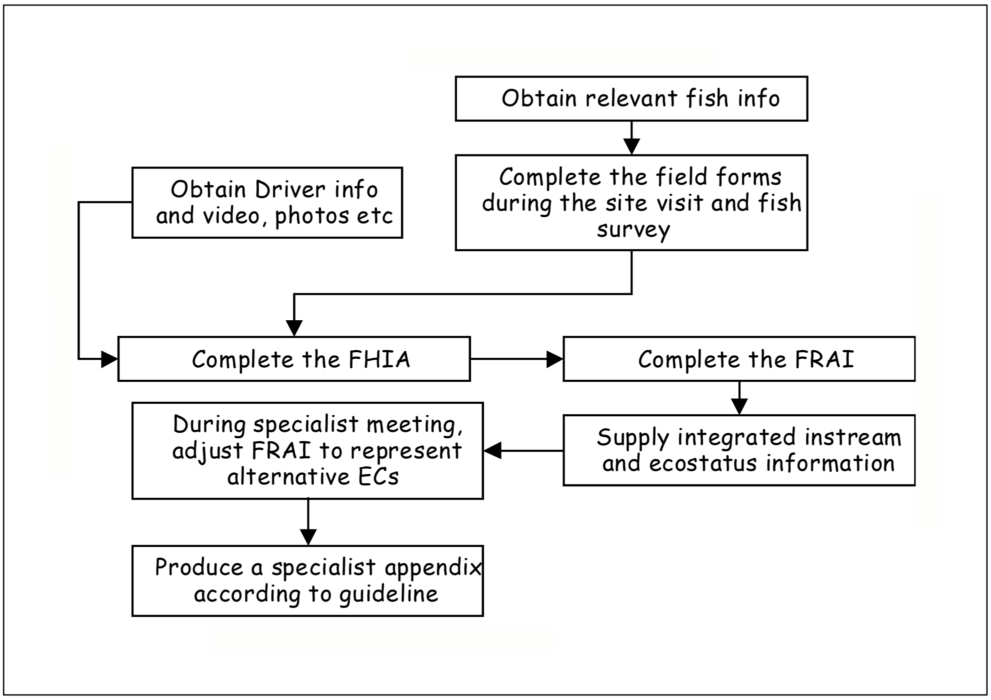

Figure 20 Actions required in the determination of the Present Ecological Status (PES) based as part of the Habitat Flow Stressor Response (HFSR) method (Kleynhans, 2004).

4.7.3 Difference between perennial and non-perennial rivers: Fish perspective

Introduction

Flow in dryland rivers (rivers in arid and semi-arid regions) is usually not only intermittent, but also highly variable (Boulton et al., 2000). These rivers are governed by stochastic events (disturbances) such as floods and droughts and often have low seasonal predictability (O'Keeffe, 1986). Under natural conditions, this used to be true for *c.* 40% of South Africa's total river length (Davies and Day, 1998). The variable nature of our rivers is confirmed by the high average coefficient of variation of annual river flow, compared to that of North American and European rivers (0,7 *vs*. 0,3 and 0,2 respectively – Braune, 1985). This variability in flow in semi-arid regions (such as South Africa) usually leads to massive river regulation and interbasin-transfers in an effort to supply water for domestic and industrial uses (Davies et al., 1993).

As the period of flow intermittence increases, variability of flow also increases. In their continuum classification system for rivers, based on differences in their hydrological regimes, Uys and O'Keeffe (1997) proposed an increase in flow intermittency and flow variability and a decrease in flow predictability when moving towards an episodic state. In moving towards episodic systems, community-structuring forces may switch from biotic to abiotic, natural disturbances may increase and the connectivity of surface water habitats may decrease (Uys and O'Keeffe, 1997).

Two hydrological state changes that may result in major biotic and abiotic changes in streams were indicated: the first when surface flow disappears but surface water is still present in the river, and secondly when surface water disappears from the majority of the river channel. The ecological consequences of the loss of flow of surface water in temporary systems may be the most influential environmental parameter affecting the aquatic biota (Boulton, 1989 cited in Uys and O'Keeffe, 1997).

For the purpose of this project, non-perennial or intermittent rivers were put into three categories based on the percentage of time of no flow: semi-permanent streams (no flow 1-15% of the time); ephemeral streams (intermittent for 26-75% of the time) and episodic streams (intermittent for more than 75% of the time).

Flow requirements of fish

Although tremendous diversity occurs in the specific life-history characteristics of the different fish species, water is needed for all fish to complete their life cycles (see Figure 21) making them vulnerable to flow changes. Instream flow is required to provide adequate usable habitat, expressed in terms of acceptable water quality and quantity for all life stages (Cambray et al., 1989). The major components of fish habitat, as recognised by Wesche (1985 cited in Chutter and Heath, 1993), are water quality, water quantity, food producing areas, spawning grounds, egg incubation areas and cover. All of these may be influenced by alterations to the natural flow regime. Physical habitats are arguably the vital link between hydrology and the distribution and abundance of organisms in rivers (O'Keeffe, 2000). The hydraulic habitats required by the different fish species or their life-history changes are usually defined by baseflow conditions, whilst a series of life stage cues or habitat requirements may rely on high flow events (Kleynhans and Engelbrecht, 2000).

Bunn and Arthington (2002) recognised four principles linking hydrology and aquatic biodiversity:

- Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition.
- Aquatic species have evolved life-history strategies primarily in direct response to their natural flow regimes.
- Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species.
- The invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

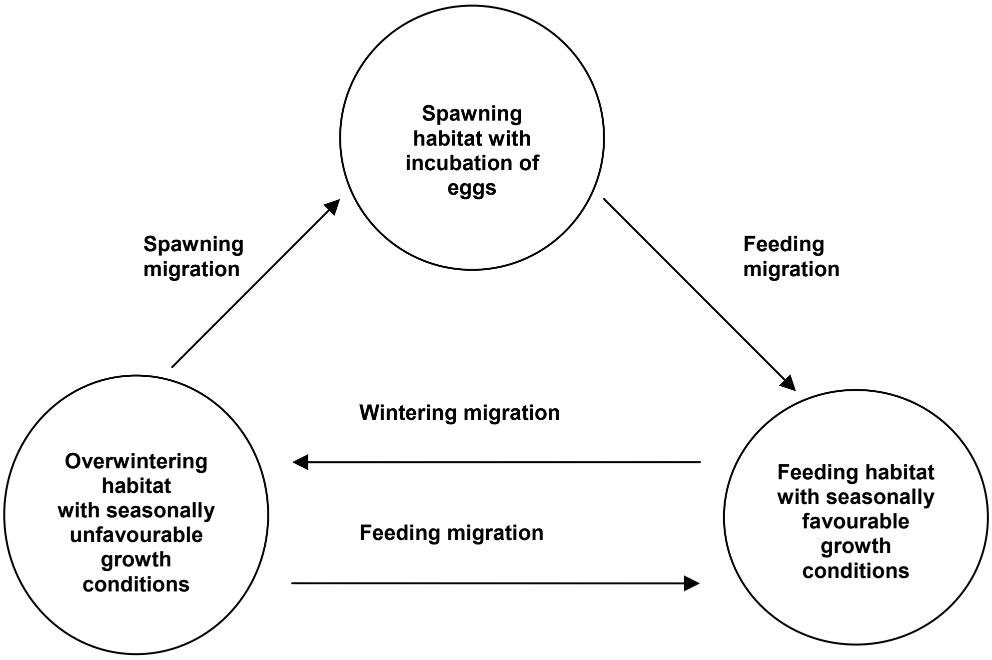

Figure 21 The basic life cycle of stream fishes with emphasis on habitat use and migration (taken from Schlosser, 1991).

The highly variable and unpredictable nature of the hydrological regimes of non-perennial rivers make these rivers a very harsh environment for their biota. It is expected that as the variability of stream flow increases (moving from semi-permanent to episodic), it becomes the key factor in the shaping of the community structure of fluvial systems (Jacobson, 1997). Aquatic biota in these systems have to negotiate not only variability in flow, but also habitat disconnectivity when surface flow disappears, disturbances like floods and droughts, and surviving low flow periods in pool refugia.

Factors shaping community structure

Disturbances, stressful environments and the ability of fish to cope with physico-chemical challenges, all affect local fish assemblage composition or dynamics (Matthews, 1998). Continually harsh conditions in a system may exclude, in ecological or evolutionary time, those species unable to withstand their impact, leaving only relatively hardy species in watersheds (Matthews, 1998). To survive in these hydrological variable systems, biota need to possess morphological, physiological and/or behavioural adaptations (Humphries and Baldwin, 2003). In South Africa's intermittent streams fish communities consist mainly of hardy opportunistic fish species (O'Keeffe 1986; Cambray et al., 1989).

Both biotic (e.g. competition, resource partitioning, predator-prey interactions, food availability, morphological adaptations) and abiotic (water temperature, pH, oxygen) factors may contribute to the shaping of fish assemblages (Matthews, 1998).

However, it is generally accepted that as physical conditions become increasingly harsh, community composition and species distribution are increasingly governed by abiotic rather than biotic factors (Uys and O'Keeffe, 1997). Even though physical harshness may act as a filter to assemblage composition in harsh places, this filter may not remove competition or predation as important variables in the success of an individual fish (Matthews, 1998). In fact, predation pressure and competition in deep pool refugia may be very severe for certain fish e.g. small species or size classes (Magoulick and Kobza, 2003).

Habitat connectivity

As surface flow diminishes, the availability of habitats decreases, with riffles and rapids being the most vulnerable biotopes. Connections between pools cease, and fish are subject to disturbance from their normal suite of biological or behavioural options (e.g. the ability to migrate between pools to escape predators, to forage, to reproduce etc.) (Matthews, 1998). The difference between no-flow and at least minimum flow can be critically important to stream fishes (Matthews, 1998). The critical issue in small or low-gradient streams subjected to summer intermittency is the length of time of no-flow, and therefore the length of time that fish are isolated in individual pools (Capone and Kushlan, 1991). In hot climates (with high evapotranspiration rates), the cessation of flow may also result in increased temperature and decreased oxygen concentrations to levels stressful to fish (Matthews, 1998). Magoulick and Kobza (2003) do not, however, consider the drying of an intermittent stream during the typical drying cycle as a disturbance, and the natural fauna seem to recover rapidly from drought conditions (Humphries and Baldwin, 2003). Where the focus of flow management in perennial streams would be to keep the river perennial and maintain habitat connectivity, the focus for non-perennial streams would be on maintaining pool refugia under low-flow or no-flow conditions. Retaining riffle habitat and connections between pools would only become a priority during the breeding season or high flow periods (Cambray et al., 1989).

Refugia

Droughts and floods are natural disturbances and can be major factors in structuring lotic communities (Magoulick and Kobza, 2003). For aquatic biota to persist under these circumstances, they must have refuge from the disturbance. According to Magoulick and Kobza (2003) refugia convey spatial and temporal resistance or resilience for biota in the face of disturbance. Refugia play, therefore, a central role in the structuring of aquatic communities and to reduce population losses.

Under drought conditions, surface area/volume of water bodies decrease and physical extremes increase (Magoulick and Kobza, 2003). As available habitats decrease, the spatial and temporal arrangement of refugia becomes very important for the survival of fish. Refugia exist at a range of spatial and temporal scales; from small (microhabitat) to large (drainage basin) and from short (hours) to long (millennia) (Lancaster and Belyea, 1997). Fausch et al. (2002) refer to the longitudinal nature of streams, putting the spatial nature of refugia on a continuum with fish potentially migrating throughout the continuum of habitat patches encompassed by refugia. However, resilience to disturbances may also be as a result of morphological, physiological or behavioural characteristics of fish species (Matthews, 1998). Matthews and Styron (1981) found evidence that fish species inhabiting intermittent streams are more stress-tolerant than species found in less extreme environments.

Conditions in these refugia may become increasingly harsh during a prolonged drought due to increases in extremes in abiotic conditions and increases in concentrations of organisms, which in turn can affect biotic interactions (Magoulick and Kobza, 2003). According to Magoulick and Kobza (2003), four water chemistry parameters arguably influence fish survivorship the most: oxygen, temperature, pH and nutrient content. Under such conditions, aquatic biota will therefore be more likely to experience (Department of Land and Water Conservation, 2002):

- Increased frequency and duration of high water temperature;
- Increased frequency and duration of periods with low dissolved oxygen;
- Increased frequency and duration of altered food resources;
- Decreased habitat availability; and
- Increased competition for food and space.
- Increased predation pressure;
- Decrease in fitness/ health and increase in parasites

Timing and intensity of drying, barriers to movement, and timing and extent of fish movement would be crucial in determining the distribution and abundance of fishes in refugia (Magoulick and Kobza, 2003).

With regards to the flow management of these refugia, Cambray et al. (1989) expressed the need for the top-up of pool refugia during drought years. Pools acting as refugia should be prevented from pumping dry. Cambray et al. (1989) further suggested that certain important pool refugia may be identified as “legislated pools” from which water abstraction should be prohibited below a certain level.

The role of fish in episodic rivers?

Lying at the one extreme of Uys and O’Keeffe’s (1997) continuum, intermittency and variability in flow is pronounced in episodic rivers. Flow in episodic rivers only occurs after a rainfall event. Floods occur whenever there is flow within the usually dry channel, and are characterised by their magnitude, duration, total flow volume, and number of discharge peaks during the flood (Jacobson, 1997). The flood ends when surface flow ends. Flash floods are associated with thunderstorms and could be described as stream flow increasing from zero to peak discharge within several minutes, generally lasting for less than a few hours (Jacobson et al., 1995). Single peak floods, lasting for several days to several weeks, depending on rainfall pattern and multiple peak floods which result from consecutive rainfall over many days can also occur.

The disappearance of surface water from the majority of the river channel has major ecological consequences for aquatic biota, especially fish. According to Puckridge et al. (undated) the most important hydrological measures for biological communities in arid zone rivers, are: duration of drying, frequency of drying, duration of connection between water bodies, as well as the duration of no flow and multi-annual variation in pulse magnitude in a river reach. These measures may, however, be different for macroinvertebrates and fish, and even between the different subsets and age-classes of the fish assemblage. Puckridge et al. (undated) found that fish species richness per water body is positively related to long-term water body permanence. In the Kuiseb River, this absence or discontinuity of surface water proved to be unsuitable for sustaining a natural fish community. The transient nature of the pools, disconnectivity between pools, absence of refugia for surviving droughts, absence of aquatic macrophytes and other cover, all contributed to unsuitable conditions for the development and support of a natural fish fauna. In such river systems, the assessment of flow requirements for fish is not relevant and should rather focus on macroinvertebrates, riparian vegetation or other vertebrates like frogs, birds or small mammals.

4.8 People-ecosystem interactions

4.8.1 Role of people-ecosystem interactions in EWR determinations

Over the past few decades, fresh water ecosystems have come under increasing pressure from human influences. The UNEP (2002) emphasises the effects of human actions on fresh water ecosystems as follows: *"Water development projects during the 20th century have had significant impacts on freshwater ecosystems…, by removing water for other uses, altering flows, and contaminating water... In many rivers and lakes, ecosystem functions have been lost or impaired."* The social dynamics in communities often change as a result of, for instance, reduced access to freshwater systems. Changes in freshwater flow systems, particularly conditions associated with drought and water scarcity have become a major contributing factor to social transformation. In fact, human beings have been forced into migration by drought and water scarcity since the earliest times in an attempt to sustain themselves in the face of varying environmental conditions.

Rivers have also not escaped the onslaught of humankind. River modification and management are firmly rooted in society's view of rivers both as natural hazards to overcome and resources to be utilised. Through the ages, people have modified rivers by constructing dams, building levees, and widening, straightening and deepening channels. Some 60% of the world's 227 largest rivers are fragmented by dams, diversions or other infrastructure. The extent of human involvement is so pervasive that

Postel and Richter (2003), remark that many rivers in industrialised *regions "are now controlled more by humanity's hand than by nature".* The impact of humankind on rivers has also led the United Nations World Water Assessment Programme to state that information from around the world suggests that rivers have become *'significantly degraded'* (UNESCO, 2003). Deteriorating quality of rivers also impacts on other aspects of ecosystems dependent on rivers and, thus, on river health. Human interference in river ecosystems through damming, abstraction, diversion and pollution, are, inter alia, preventing rivers from performing the ecological functions performed in their natural state, such as purifying water, moderating floods and droughts, and maintaining habitat for fisheries, birds and wildlife (Postel and Richter, 2003). If river ecosystems are unable to fulfil these functions, these ecosystems may eventually collapse and affect the social and economic existence of human communities relying on these ecosystems for various functions.

In many developing nations people directly depend on the productivity of natural or semi-natural ecosystems for their livelihoods. The intensity of human interaction with these systems is particularly great in extensive floodplain wetlands, such as those that are used for agriculture, fishing, hunting, grazing and plant gathering. In most tropical floodplains[1], both rivers and floodplains provide economic resources of crucial importance to both local and regional –and in some cases, national – economies. River floodplains have long been valued for the fertility of their soils, and these floodplains often made agriculture in river ecosystems possible and highly productive, while also delivering other services to the people dependent on them. But floodplains can only remain fertile if they are connected to a healthily functioning river. In an unspoilt river system, the seasonal flow of the river floods the floodplain with water, bringing with it nutrients and flushing away pollutants. Societies such as the ancient Egyptians relied on the seasonal flooding of the Nile Valley to grow crops on the floodplains.

Rural people in developing nations still often rely on the biological productivity of floodplains. The floodplains provide food and sources of income to people who use them for grazing animals, growing crops, collecting fuel wood and for fishing. In many developing regions the increasing threat of existing and proposed dams and irrigation streams are threatening the ecological functioning of floodplains. By the late 1980s, the Niger Delta, for example, already sustained more than 500 000 people – amongst them 80 000 fishermen - and in the dry season provided grazing for more than 1.5 million cattle, 2 million sheep and goats (Adams, 2001). These economic activities may overlap in time and space, and different communities may become involved in various ways during the course of a year. Hunting, grazing, fishing and gathering are closely linked to the seasonal cycle of river discharge. The seasonal grazing resources of the Niger Inland Delta, for example, are based on the perennial aquatic grass, that yields up to 25 tonnes per hectare of forage, and is accessible to livestock once seasonal floodwaters have retreated.

[1] A floodplain refers to that area of valley floor adjacent to rivers that is seasonally inundated with water (McCully, 1998).

The consumption of water from rivers and the use of river ecosystems are not only affected by the number of people relying on the services provided, but also relates to their consumption patterns. Consumption patterns are determined in large part by the wealth of the social group or society utilising these resources. Wealth influences demand for goods and it also impacts on people's ability to use water and ecosystem goods and services. Secondly, socio-cultural norms and values dictate the interaction between people and the ecosystem. This also influences the consumption patterns of people. The impact of people on their natural environment is, therefore, not only equated to the number of people making use of these resources, but environmental impact is rather a product of the consumption patterns, the ability to use resources and the number of people.

Large dams are arguably the most dramatic examples of the human capacity to transform rivers and nature in the name of development. Projects such as dams and irrigation schemes can trigger a range of serious and complex socio-economic and environmental impacts. Dams have been playing a major role in the interaction between freshwater systems and human populations for at least 5000 years. Initially, the first dams were constructed to control floods and to supply water for domestic and agricultural purposes. In modern times, dams are most often constructed for hydroelectricity, but they are also used for purposes of irrigation, domestic water supplies, and flood control[2]. Worldwide there are more than 40 000 "large dams", i.e. dams with walls higher than 15 meters. Most of these have been built since 1950, and have resulted in the displacement of an estimated 30 to 60 million people (PRB, 1996).

Although dams contribute to increased agricultural production and economic growth, they often also have a detrimental impact upon fisheries and aquatic ecosystems (e.g. rivers, deltas, floodplains and mangroves). Dams and extraction from rivers often alter the pattern of flows, resulting in poor water quality and negatively impacting upon conservation and other amenity values. Downstream physical changes in dammed rivers can cause disruptions in aquatic ecosystems, for example to fish and thus inevitably to communities who depend on the resource. Disruptions in natural flood cycles sometimes disproportionately affect the rural poor, who often depend for their livelihoods on fisheries, wetlands and flood-dependent agricultural practices. In the case of the Sabie River, for instance, Pollard (2002) points to the importance of annual floods ("brown" water) for fish species such as tiger fish, mormyrids and the large-scale yellowfish. In the case of yellow fish, the communities who fish the river regard floods as critical for spawning and precipitated upstream movement into tributaries, while rapids are considered essential for the survival of the large-scale yellowfish. Fish represent an

[2] A decade ago, it was estimated that around 19% of the world's electricity and 6% of primary power (power used directly for heating and transport) was provided by hydropower. Some twenty-four countries, including Ghana, Zambia, Brazil, depend on hydropower for over 90% of their electricity supply (McCully 1998).

important economic and health-related resource, particularly in poorer families where it is potentially the only source of protein.

Finding ways to understand and capture peoples' perceptions regarding the relationship between environmental flow and resources, as well as historical changes in resource availability, have become key issues in a holistic, ecosystem-based approach to river management (Pollard, 2002). This entails, amongst others, an understanding of the importance of riverine resources for people's livelihoods and it involves the identification of the population at risk, the quantification of resources used, and the economic value of such resources, as well as a knowledge of river-related health risks. As part of a more inclusive and comprehensive understanding of the factors that influence peoples' interaction with environmental flow systems, researchers have an obligation to provide an accurate and integrated picture of the linkages between people and the riverine resources that sustain them

4.8.2 Social methods used for input to EWR

The purpose of social assessment as part of a holistic river management approach is to provide information on the use of riverine resources by rural communities in order to determine the importance of the resource, from a community perspective, for sustaining their livelihoods. This entails amongst others the following:

- An identification and description of all the resources used, as well as their ecological identities and relevance for riverine ecosystem functioning;
- the quantification of resource usage;
- understanding and capturing peoples' perceptions regarding the relationship between flow systems and resources;
- determining historical changes in resource availability;
- developing a monitoring programme for tracking social implications of flow changes in terms of three key issues, i.e. health-related impacts, economic impacts and changes in the social dynamics of communities brought about by changes in access to resources.

The development of an applicable methodology for the above approach is still in its early stages and will need to be modified through further application and experience. An interactive, participatory approach is essential to allow for a proper explanation and exploration of new and complex issues. Standard participatory techniques such as Participatory Rural Appraisal (PRA) supplemented with in-depth interviews of key informants have been recommended in the past. Additional approaches include triangulation, focus groups and workshop sessions at the host villages, thus, in general, a qualitative approach to data gathering and analysis. Throughout the planning, data gathering and analysis stages of the process, close collaboration between the social scientists and the biophysical specialists is essential, as the flow regime will be designed, in part, to maintain valued river resources.

4.8.3 Difference between perennial and non-perennial Rivers: Socio-economic perspective

Literature dealing with the interaction between people and freshwater flow systems often does not clearly distinguish between perennial and non-perennial rivers for purposes of the social uses of such ecosystems. This lack of exact differentiation is no doubt complicated by the fact that many - what used to be - perennial rivers have been altered by human intervention in such a way that they have in effect become non-perennial systems. Increased demand for fresh water has led to the overdrawing of available and accessible fresh water resources to the extent that many large (and perennial) rivers, such as the Colorado, the Indus and the Yellow, no longer even reach the sea, their water being used up for domestic, industrial and agricultural purposes along the way. As a result of population pressure, the Yellow River now fails to reach the sea for more than half the year. This river first ran dry in 1972 and, since 1985, has run dry for a part of every year. In 1997 the Yellow River failed to reach the sea for 226 days (Brown and Halweil, 1999). The Ganges in India is just one of many other telling examples of the impact of growing population numbers on water resources. During the dry season this river is practically dry before reaching the Bay of Bengal. With India’s population of more than one billion, most of the river’s water is used up by the people of India, leaving the farmers of Bangladesh with too little water for their needs.

Groundwater sources are being tapped to the extent that some of the world’s largest aquifers are being depleted much faster than their recharge rate. This has severe consequences for the economic and social sectors dependent on the water from these sources. The ecosystems of natural lakes are also becoming severely degraded due to overuse and pollution and this, in turn, results in economic and social decline in the human communities relying on these water sources. The fisheries collapse along the Aral Sea, for example, as a result of pollution, and the depletion of this water source has left ghost towns where there once were productive communities.

People benefit from food supplied directly from the river, but also from its surrounding areas. Fish, clams, mussels and other freshwater species provide food sources for people and wildlife, and people again benefit from wildlife as a food source. Freshwater ecosystems, for example, contribute around 12% of the fish consumed by humans. In rural-based populations along rivers, fish is a very important source of food and contributes significantly to the subsistence of these populations. In the Thukela River Basin in KwaZulu Natal, 26% of households within 5 km of the river catch fish from the river. On average, households in the Thukela Basin consume between two and four kg of fish per month (Mander et al., 2004). Freshwater fish populations are increasingly jeopardised by over-consumption of aquatic species by people and by the effects of river alterations and obstructions on these species’ ability to reproduce. As a result of damming, many rivers that previously sustained not only economically lucrative fisheries, but also humans and other species, are now unable to do so.

European rivers such as the Volga, the Don and the Dnieper have been reduced to *"…string[s] of shallow, stagnant, polluted reservoirs".* Once extremely lucrative commercial fisheries in these rivers and their estuaries have been wiped out by the extensive damming of these rivers (McCully, 1998). Similarly, the people who used to rely on the fish yields of the Colorado Delta have suffered as a result of the impact of human alterations of this river. Damming and diversions of the Colorado River resulted in the once-productive Delta becoming practically dry and non-existent. The indigenous people of the Delta, the Cucapa, once sustained themselves by fishing, farming and hunting in the Delta, but apart from the fact that their population was reduced from 1200 a century ago to between 40 and 50 families in the mid-1990s, they now subsist on far less healthy food such as beans and junk food (McCully, 1998).

The critical role of riverine resources in sustaining rural communities has arguably nowhere been better demonstrated than in the loss of floodplain soils and fisheries resources to peoples downstream of the Aswan High Dam in Egypt. The natural discharge of the Nile is subject to wide seasonal fluctuations with 80% of the annual total discharge being received during the flood season (August to October). The Aswan High Dam allows management of the flow of the Nile's discharge, thereby evening out the annual flow below the dam and acting as protection against floods and droughts. Navigation and tourism also benefit from management of the Nile's flow, particularly from the stability in the river's course and navigation channels. Irrigation water for cropland is also provided by the dam's reservoir storage, which has allowed 400 000 ha of cropland to be converted from seasonal to perennial irrigation, as well as the expansion of agriculture onto 490 000 ha of new land (Middleton, 1995). This is particularly important in the context of Egypt being largely a hyper-arid country with only 3% of its land suitable for cultivation. Since the construction of the Aswan Dam in the 1950s, the dam has imposed a traumatic alteration on the Nile and the people who depend on it. The construction of the High Dam ended the annual flooding of the Nile that watered and renewed the land. Today, Egypt - largely self-sufficient before the construction of the High Dam – imports 70% of its food. The dam represents a massive and unique intervention in physical, biological and human interactions with flow systems, and *"has aroused more controversy than any other resource development project"* (Hughes, 2002). It further bears testimony to the principle that dams are not just engineering works, but also social institutions.

The abstraction of water from rivers also impacts on the sustainability of aquifers, an important source of water and another area in which people's interaction with rivers is impacting on other elements in the ecological system. When too much water is drawn out of the aquifer catchment area, too little water is often available to replenish aquifers. The decreased availability of water in the catchment area, coupled with water taken out at rates much faster than the aquifer is able to recharge, is compromising the natural ecological process for replenishing the water. Aquifers are often integral parts of river ecosystems, feeding rivers with water in seasons when rainfall is scarce. When aquifers are overdrawn, the rivers connected to them are also affected. The San Pedro River along the Mexico-United States border is a case in point. This river is one of the most intact rivers in the area, with no dams or alterations interrupting its flow. It is a biologically rich and ecologically wealthy river system, contributing to economic prosperity through the recreational tourist activities provided by the rich birdlife. The river's health is however, threatened by rising water demands in the basin. An aquifer beneath the valley floor mediates the river flows by soaking the floodplain soils, by feeding the river and by keeping it flowing during dry periods. The flow of the river is critical for the survival of the biodiversity of the ecosystem. However, the aquifer is also used as a water source for irrigation farmers, ranchers, for household and commercial water, and as a water supply for a military base. With economic expansion and population increases, groundwater pumping escalated twelve-fold between 1940 and 1997. This has drawn much needed water away from the natural ecosystem of the San Pedro to the extent that the river is expected to dry up for parts of the year and thus negatively impacting on aquatic wildlife, riparian vegetation and species of bird and wildlife dependent on the river habitat.

Although the above discussion does not clearly differentiate between perennial and non-perennial systems with regard to the human interaction with such systems, it does suggest two observations. Firstly, the degree of human dependence on non-perennial systems seemingly involves a greater multiplicity of activities directly related to the river. Secondly, human settlements alongside perennial systems appear to be more vulnerable when such systems become dry, than in the case of those who are compelled to interact consistently with non-perennial systems.

5. ECOTYPING

The task of this chapter is:

- A discussion of the concept of Ecotyping in South African river systems, within which non-perennial systems will fit
- Scenesetting: Definitions of non-perennial systems and levels or non-perenniality

5.1 Ecotyping

According to the National Water Act (No. 36 of 1998), the ecosystem is the water resource, which includes the physical or structural aquatic habitats, the water, the aquatic biota, and the physical, chemical and ecological processes that link water, habitats and biota. In terms of the Act, Resource Quality Objectives (RQO's), set in terms of a national classification system, will be used to define the desired protection status of water resources in South Africa. Resource quality is defined in the Act as:

- The quantity, pattern, timing, water level and assurance of instream flow;
- The water quality, including the physical, chemical and biological characteristics of the water;
- The characteristics and condition of the instream and riparian habitat; and
- The character, condition and distribution of the aquatic biota.

The present and historical condition of a water resource, its sensitivity and importance and its potential for restoration are all factors that need to be taken into account in deriving the future management class and related Resource Quality Objectives.

The Act also makes provision for a "Reserve": a particular water quality and quantity to be set aside to protect the ecological functioning of aquatic ecosystems before water uses such as industry or agriculture can be authorised (http://www.ngo.grida.no/soesa/nsoer/resource/wetland/reserve.htm).

5.2 Basic definitions

River ecotyping essentially reflects the range of ecological integrity of a specific ecosystem type. So it refers to many characteristics, which, for practical purposes, we must reduce to categories of key characteristics.

Definitions may however have different nuances. For instance, a New Zealand definition of ecotype in respect of rivers suggests that:

> "Ecotype means a group of streams with similar ecological characteristics, whose ecosystem health can be assessed using a common set of environmental indicators and criteria" (http://www.trc.govt.nz/PDFS/Freshwater%20Plan/).

According to Neels Kleynhans at the TOR workshop:

> "apart from hydrological, ecological typing refers to the biophysical (i.e. biological) characteristics of rivers"

5.3 Non-perennial ecosystems

Geographically, non-perennial systems occur in the "dry west" of southern Africa. This is very broad and needs much closer definition.

Factors which would be expected to define the area where non-perennial systems are found, are the following (these are our own views and no particular authors are referred to):

- variability of rainfall, e.g. Coefficient of Variance (CV). The greater the CV among years and among months, the more likely it is that non-perennial systems will occur.
- exceptional conditions, i.e. floods and droughts, are related to the high variability of rainfall.
- seasonality of rainfall and flow, i.e. winter, summer, equinoctial rains will promote the occurrence of non-perennial systems, while all-year rainfall will create perenniality.
- interannual (long-term) periodicity or cycles, e.g. 18-year cycle prevalent in the summer rainfall highveld area of South Africa, will cause non-periannial conditions to increase or decrease in harmony with the cycle.
- natural transferal of conditions from one rainfall region to another, as a result of the linearity and conductance characteristic of rivers will cause rivers in a dry area to be perennial if the "wet" catchment supplies water perennially.
- artificiality of the river as a result of man-induced flow-modification will cause a river to become more or less perennial:
  - damming
    - weirs (less than 5 m high, less than 1 ha surface area) tend to smooth flow patterns, but don't affect seasonality.
    - small dams (5 to 10 m high, 1 to 10 ha surface area) modify flow significantly, but don't affect seasonality greatly.
    - medium-sized dams (10 to 20 m high, 10 to 100 ha surface area) restrict flow, and affect seasonality
    - large state dams (more than 20 m high, more than 100 ha surface area) control flow and can be used to manipulate flow pattern
  - addition of water, as by interbasin transfer would make the system more perennial, and it can be highly disruptive to the ecosystem unless a clear operating rule is followed:
    - continuous inflow negates seasonality
    - seasonal inflow is best when it occurs in the normally wet season

    - random inflow is most disruptive, e.g. the flow from the Lesotho Highland water Scheme into the As River.
- removal of water, will have related effects, making the system more non-perennial:
    - continuous removal might turn a perennial system into a non-perennial one
    - seasonal removal would be least damaging if it occurs in the normally wetter season
    - random inflow would be most disruptive.
- alteration of seasonality would occur when the inflow pattern negates the natural one, in which case the river would tend to become a mere conduit rather than a river.

Simply stated, the conditions for creating non-perennial rivers are cumulative, and the contribution of the different conditions differs with region and with system. It is not simply a matter of low seasonal rainfall. Low slopes contribute to poor drainage, high temperatures lead to high evaporation; sparse vegetation reflects low rainfall.

According to Roux et al. (2002), "River ecosystems are essentially a manifestation of the landscapes that they drain. Catchment geology, climate, vegetation types, and landscape change dictate the character of freshwater ecosystems in terms of flow pattern, channel morphology, temperature and nutrient regimes, and substratum. These variables in turn control the biological attitudes of rivers and streams (Stanford, 1998). Stream biota are therefore considered to be protected by conserving habitat heterogeneity or pattern."

Level I and II Ecoregions have been developed for Southern Africa by the Department of Water Affairs and Forestry, based on the contributions of numerous experts in and outside of the Department. The descriptions rely on a number of factors. At Level I, (Figure 22) catchment vegetation or biome played a strong role, and at Level II, terrain morphology, covering complete catchments or subcatchments, but these are very broad categories and there is a lot of variation within catchments.

Omernik's (1987) approach, which has influenced the above view, brings ecoregion and ecotype together as follows: Ecoregion Level I is based on the attributes of physiography, climate, soils, potential natural vegetation and hydrology; while Ecoregion Level II has more detail (terrain morphology, relief, rainfall, temperature, lithology, soils, vegetation type, runoff), but explores the same attributes. Below Level II are, in order of refinement, stream classification, geomorphological segment, longitudinal zone and biological segment (for fish, invertebrates and riparian vegetation). Within these categories, there is a further distinction between extent (size, breadth) and grain (fineness, detail). Dollar et al. (2004) are presently exploring an interdisciplinary understanding of pattern and process in river systems, which should help us to understand the relationships between scale and the biophysical categories which have tended to be studied separately.

But what is the condition of non-perenniality, which is the subject of this project? Positively viewed, perenniality is dependent on two cumulative factors, namely seasonality of flow and variability of flow.

Perenniality and flow-volume are correlated, but are not totally dependent on each other. Inasmuch as these conditions are related, they might also conceivably not be related, i.e. one could have high variability, aseasonality and perenniality; or low variability, distinct seasonality and non-perenniality. Obviously, the less water available, the greater the chance of non-perenniality.

Uys and O'Keeffe (1997) highlight the following factors as contributing to the continuum between perennial and non-perennial. At one extreme are biotic/abiotic controls, connectivity of surface habitat and flow predictability, and at the other, natural disturbance and flow variability. Predictability and variability are juxtaposed. Between the two extremes there are conditions of surface flow, grading into the mere presence of surface water and, eventually, the absence of surface water. The questions arising then are:

- Does flow stop?
- How long does surface water persist?
- What is the connectivity of the system?

Boulton et al. (2000) have a very useful classification of stream classification as related to flow:

- Ephemeral streams – flow briefly (<1 month) with irregular timing and usually only after unpredictable rain has fallen;
- Intermittent or temporary streams – flow for longer periods (>1 – 3 months), regularly have an annual dry period coinciding with prolonged dry weather;
- Semi-permanent streams – flow most of the year but cease flow during dry weather (<3 months), drying to pools. During wetter years, flow may continue all year round;
- Permanent streams – perennial flow. Only cease flow during rare extreme droughts.

Roux et al. (2002) suggest:

- Ephemeral, for rivers that are short-lived, flow briefly and rarely and return to dry conditions.
- Episodic (periodic or intermittent), for rivers that flow for an extended period but are not predictable or seasonal.
- Seasonal, for rivers that flow predictably during the annual wet season but may be dry for several months each year.
- Perennial, for rivers that have surface flow throughout the year and do not cease to flow even during droughts.

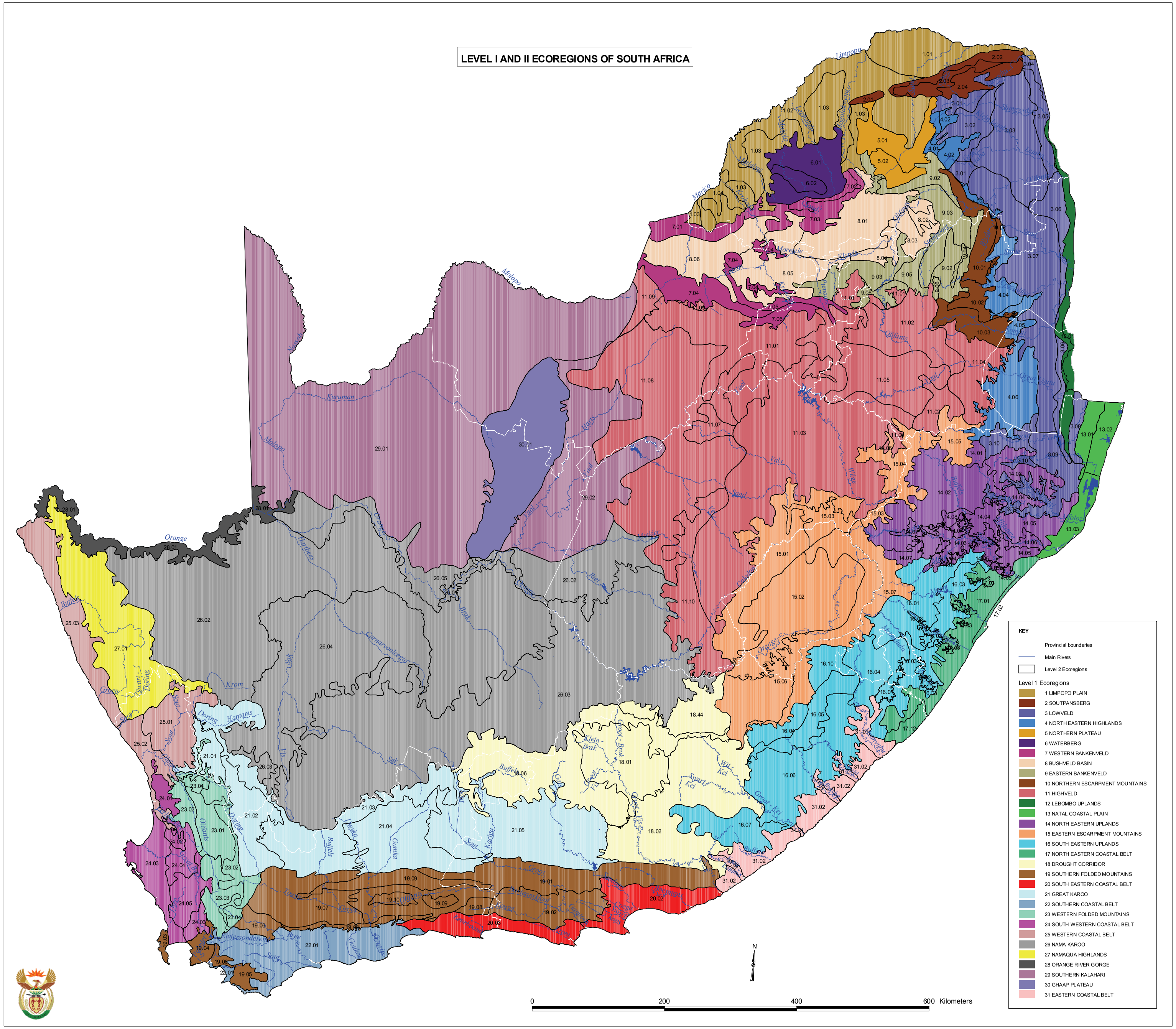
LEVEL I AND II ECOREGIONS OF SOUTH AFRICA
KEY
Provincial boundaries
Main Rivers
Level 2 Ecoregions
Level 1 Ecoregions
1 LIMPOPO PLAIN
2 SOUTPANSBERG
3 LOWVELD
4 NORTH EASTERN HIGHLANDS
5 NORTHERN PLATEAU
6 WATERBERG
7 WESTERN BANKENVELD
8 BUSHVELD BASIN
9 EASTERN BANKENVELD
10 NORTHERN ESCARPMENT MOUNTAINS
11 HIGHVELD
12 LEBOMBO UPLANDS
13 NATAL COASTAL PLAIN
14 NORTH EASTERN UPLANDS
15 EASTERN ESCARPMENT MOUNTAINS
16 SOUTH EASTERN UPLANDS
17 NORTH EASTERN COASTAL BELT
18 DROUGHT CORRIDOR
19 SOUTHERN FOLDED MOUNTAINS
20 SOUTH EASTERN COASTAL BELT
21 GREAT KAROO
22 SOUTHERN COASTAL BELT
23 WESTERN FOLDED MOUNTAINS
24 SOUTH WESTERN COASTAL BELT
25 WESTERN COASTAL BELT
26 NAMA KAROO
27 NAMAQUA HIGHLANDS
28 ORANGE RIVER GORGE
29 SOUTHERN KALAHARI
30 GHAAP PLATEAU
31 EASTERN COASTAL BELT
0 200 400 600 Kilometers
N

Figure 22 Level I and II ecoregions as developed by the Department of Water Affairs and Forestry (Kleynhans, et al. 2004).

Clearly, there is much gut-feeling or expert knowledge involved, with a bit of a problem with nomenclature (maybe the names ephemeral and episodic should be swapped), but the real issue lies in quantification.

During the present project's workshop, a scale (Table 20) was adopted, supported by a map (Figure 23), which divided the country into areas of perenniality of rivers.

Table 20 Categories of perenniality as developed by the present project.

Perennial	**Non-perennial**				
	Semi-permanent	**Ephemeral**		**Episodic**	
May cease flowing in extreme drought	No flow 1%-25 % of the time	No flow 26%-75% of the time		No flow at least 76% of the time	
	Flow for at least 9 months			Flow briefly only after flood	
		Seasonal	Non-seasonal	Seasonal	Non-seasonal
	e.g. Modder(F.State), Doring (W.Cape), Mogalakwena, 1st order Table Mt. stream	e.g. Shisa?		e.g. Kuiseb	

This set of categories contrasts with the others in the literature, in nomenclature as well as in degree. After extensive discussion, aided by interactive GIS technology, it was decided that the periodicity of inundation of quarters of the year was most appropriate, i.e. inundation for less than
one quarter of the year on average resulted in an episodic rver, for more than three quarters of the year on average a semi-permanent river, and the category inbetween, namely between one quarter of the year and three quarters of the year on average, an ephemeral river. The map of the location of each, divides the country into four main areas, with the perennial rivers mostly in the southwest and east. It divides the rest of the country among the non-perennial rivers, namely the semi-permanent rivers in a narrow band to the interior of the perennial rivers, with their greatest concentration in the southeastern midlands, the ephemeral rivers covering most of the central and northern areas, and the episodic rivers in the northwestern arid areas of Namaqualand and the Kalahari.

At the greatest extreme of variability, a non-perennial system simply becomes an episodic system, where flows occur in a broad season but each episode, associated with a single rainfall event, is separate, with distinct dry periods between, and with some years when there is no flow at all. At a lesser extreme, there is a wet season and a dry season, making this an ephemeral system. The next step is semi-permanent, followed by perennial.

Human interference can change a non-perennial river into a perennial one (e.g. the Fish River in the Eastern Cape Province) or a perennial one into a non-perennial one, or a semi-permanent one into an episodic one, by the building of dams in the catchment.

Temporary pans, which lie in palaeo-flowlines, are extreme examples of non-perennial rivers, while vleis are perennial systems. By this argument, Nylsvley is a neither a pan, a temporary water, nor a vlei, because it lies in a semi-permanent flowline.

5.4 Sensitivity

As opposed to the situation in perennial systems, where relative predictability (low variation) of habitat prevails, one can expect non-perennial systems to be characterised by low-predictability (high variation). The resultant tough conditions would be expected to lead to a low degree of speciation within the system associated with an increased importance of refugia from which recolonisation by generalists would occur (e.g. the Orange River). In extreme non-perenniality (episodic systems), where refugia would be absent, there would be an increased importance of aestivation strategies by adversity specialists and recolonisation strategies by opportunists (cf. Williams, 1985).

Semi-permanent rivers are those populated by generalists, for whom refugia are important. The Orange River is a good example, there being only about a dozen fish species, nearly all generalists, in the entire catchment (Skelton, 2001), and essentially the same invertebrate species from source to mouth (Chutter, pers.comm.).

Non-perennial systems favour generalists because conditions are so unpredictable, so it is unlikely that there will be rare species present. Rare species would be found in exceptional habitats or conditions that have a predictability that would favour that species. Great variability as found in non-perennial systems is not conducive to the evolution or presence of rare species.

5.5 Summary

The task of this chapter is:

- A discussion of the concept of Ecotyping in South African river systems, within which non-perennial systems will fit
- Scenesetting: Definitions of non-perennial systems and levels or non-perenniality

River ecotyping essentially reflects the range of ecological integrity of a specific ecosystem type. So it refers to many characteristics, which, for practical purposes, we must reduce to categories of key characteristics According to Neels Kleynhans at the TOR workshop: “apart from hydrological, ecological typing refers to the biophysical (i.e. biological) characteristics of rivers”.

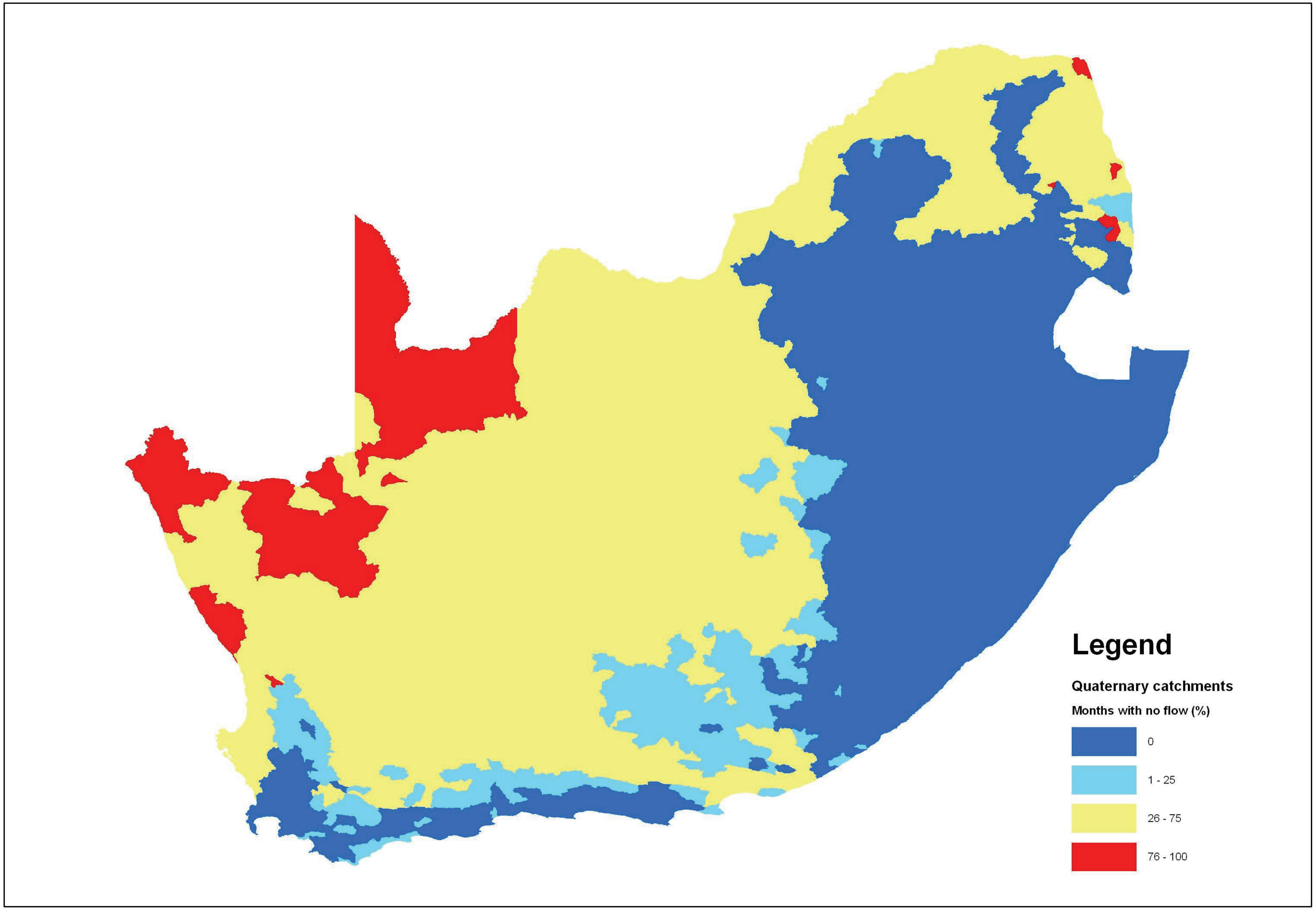

Figure 23 South African quartenary catchments categorized according to relative period of flow during each year. See Table 20 for the categories.

At Level I of Ecoregions, catchment vegetation or biome played a strong role, and at Level II, terrain morphology, covering complete catchments or subcatchments, but these are very broad categories and there is a lot of variation within catchments.

But what is the condition of non-perenniality, which is the subject of this project? Positively viewed, perenniality is dependent on two cumulative factors, namely seasonality of flow and variability of flow.

Simply stated, the conditions for creating non-perennial rivers are cumulative, and the contribution of the different conditions differs with region and with system. It is not simply a matter of low seasonal rainfall. Low slopes contribute to poor drainage, high temperatures lead to high evaporation; sparse vegetation reflects low rainfall.

During the present project's workshop, a scale was adopted, supported by a map, which divided the country into areas of perenniality of rivers. This set of categories contrasts with the others in the literature, in nomenclature as well as in degree. After extensive discussion, using GIS technology, it was decided that the periodicity of inundation of quarters of the year was most appropriate, i.e. inundation for less than one quarter of the year on average resulted in an episodic rver, for more than three quarters of the year on average, a semi-permanent river, and the category inbetween, namely between one quarter of the year and three quarters of the year on average, an ephemeral river. The map of the location of each, divides the country into four main areas, with the perennial rivers mostly in the southwest and east. It divides the rest of the country among the non-perennial rivers, namely the semi-permanent rivers in a narrow band to the interior of the perennial rivers, with their greatest concentration in the southeastern midlands, the ephemeral rivers covering most of the central and northern areas, and the episodic rivers in the northwestern arid areas of Namaqualand and the Kalahari.

At the greatest extreme of variability, a non-perennial system simply becomes an episodic system, where flows occur in a broad season but each episode, associated with a single rainfall event, is separate, with distinct dry periods between, and with some years when there is no flow at all. At a lesser extreme, there is a wet season and a dry season, making this an ephemeral system. The next step is semi-permanent, followed by perennial.

6. NYLSVLEY

6.1 Introduction

A Desktop reserve determination, following the methodology as set out in Chapter 3, was performed on the Nylsvley study area, as prescribed in the Terms of Reference. Due to the nature of this study, no field visit or sampling was done. The respective experts involved in the study were, therefore, dependent on existing data sources. Accordingly, the confidence in the results produced by the determination is low.

The study area was divided into two resource units (RUs): RU1, from the origin of Groot Nyl and Klein Nyl Rivers to their confluence with Nyl River (quarternary catchments A61A to the start of A61B), and RU2 from downstream of the confluence of the Groot Nyl/Klein Nyl and Nyl Rivers to Moorddrift (quaternary catchments A61B to A61E).

A summary by each specialist regarding reference conditions, availability and quality of data used to determine the PESC for each resource unit, follows.

The EISC was also determined through the input of the various specialists. A summary of the PESC, EISC and AEMC for the Nyl River, is provided at the end of the chapter.

6.2 Hydrology and Geohydrology

There is always an interaction between a river and the adjacent aquifer. Water is either flowing from the aquifer to the river (in the perennial rivers of South Africa this is usually the case and also for many non perennial rivers), or water is flowing from the river to the aquifer (this is usually the case in the very dry areas of South Africa). For this reason the hydrology and geohydrology are discussed under one section in this report.

In the Mogalakwena River Dam feasibility study, IFR estimations were done at five locations in the Nyl and Mogalakwena Rivers. To link up with their estimates, it was decided to describe the hydrology/geohydrology in terms of these five IFR positions (Table 21).

Du Toit (1996) gave a summary of the occurrence of groundwater in the Nyl River at IFR sites 1 to 5 (see Table 21):

Figure 24 shows the difference between virgin and current flow (the different results from Aden).

Table 21 Summary of geology/geohydrology for IFR sites 1 to 5 in the Nyl and Mogalakwena Rivers (After Du Toit, 1996).

	IFR 1	IFR 2	IFR 3	IFR 4	IFR 5
Longitude Latitude	**S 23°58'322 E 28°41'656**	**S 23°42'798 E 28°41'656**	**S 23°29'566 E 28°39'316**	**S 23°03'068 E 28°41'603**	**S 22°45'953 E 28°46'749**
Geology	Granite + alluvium along river	Sandstone + alluvium along river	Sandstone + alluvium along river	Gneis + alluvium along river	Orthogneis + alluvium along river
Geohydrology	Granite a poor resource of water. Only good yields in alluvial.	Only alluvium is good aquifer	Only alluvium is good aquifer	Only alluvium is good aquifer	At this IFR site the alluvium is the thickest (7 m)
SW/Ground-water interaction	River is receiving water from groundwater	River is receiving water from groundwater	River is receiving water from groundwater	River is receiving water from groundwater	River is receiving water from groundwater
GW abstraction	Very small	Very small	Very small	Very small	Irrigation from GW takes place

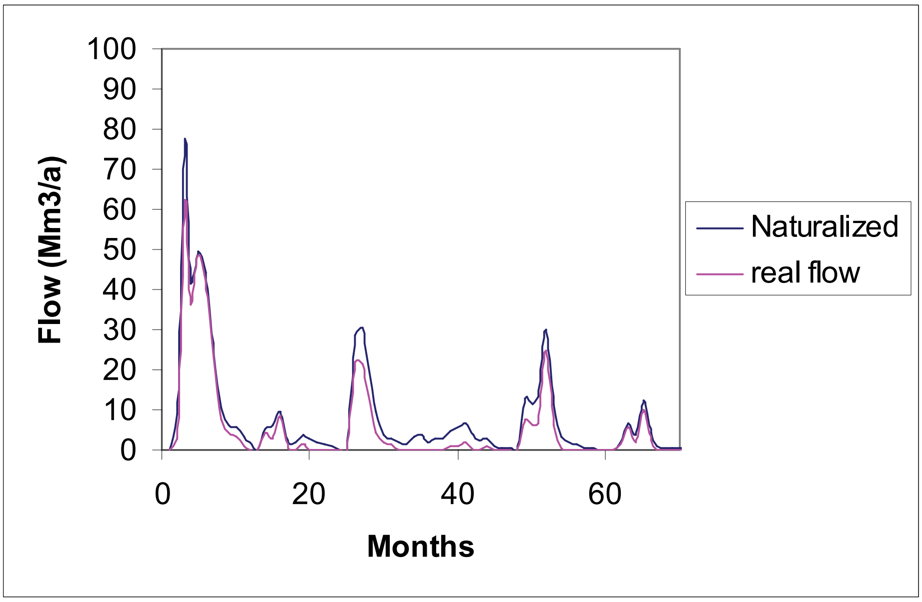

Figure 24 Difference between virgin and current flow in the Mogalakwena River (flow gauge A6H006, quaternary catchment A63B). Month 1 = October 1960.

The average annual difference between virgin and real flow = 57Mm^3 (change from 160Mm^3 to 103 Mm^3 annually), which implies a 57 Mm^3/a reduction of flow in the river (Glen Alpine Dam). Table 22 shows the real flows at gauge A6H006.

Table 22 Measured flows at gauge A6H006 (quaternary catchment A63B).

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1969	0	0.05	0.99	0.11	0.51	0.15	0	0	0	0	0	0
1970	0	0	0.13	2.28	4.3	1.04	1.94	1.26	0.94	0.67	0.51	0.27
1971	0.05	0.56	0.47	3.46	1.35	1.78	2.82	1.62	0.45	0.39	0.29	0.22
1972	0.13	0.14	0.02	0.02	0.14	0	0.45	0.08	0.05	0.03	0.01	0.04
1973	0.28	0.25	2.84	2.01	3.31	1.23	1.08	0.48	0.42	0.38	0.15	0.11
1974	0.03	0.46	0.69	3.86	7.15	3.18	4.53	1.45	0.99	0.75	0.48	0.22
1975	0.04	0.15	1.46	2.99	10	2.31	1.77	1.1	0.71	0.51	0.89	0.54
1976	0.02	0.52	0.33	0.18	0.38	1.48	0.47	0.09	0.07	0.03	0.02	0.02
1977	0.02	0.02	0.02	4.55	3.84	2.81	0.85	0.49	0.31	0.29	0.08	0.07
1978	0.06	0.03	0.13	0.04	0.08	0.24	0.07	0.01	0	0	0	0
1979	0.02	0.35	0.28	0.78	1.38	0.56	0.29	0.04	0.05	0.05	0.02	0.05
1980	0	0.02	0.72	0.56	0.52	0.36	0.07	0.07	0.05	0.05	0.06	0.02
1981	0	0	0.01	0.13	0	0	0.12	0.09	0.02	0	0	0.06
1982	0	0	0	0.02	0	0	0	0	0	0	0	0
1983	0	0.07	0.03	0	0	0.01	0	0	0	0	0	0
1984	0	0	0.05	0	0	0.1	0	0	0	0	0	0
1985	0.06	0.05	0.08	0.15	0.1	0.13	0.05	0.07	0.07	0.04	0.03	0.91
1986	0	0	0	0.28	0.07	0.04	0	0	0	0	0	0
1987	0	0.07	0.88	0.63	0.52	0.94	0.75	0.39	0.27	0.34	0.16	0.23
1988	0.22	0.1	0.1	0.43	0.93	0.81	0.39	0.5	0.42	0.17	0.13	0.04

From Table 22 it is clear that, in 60 of the 240 months, no flow occurs in the river (i.e. 25 % of the time).

In the Mogalakwena River Dam feasibility study, a maintenance low flow of 0.02 m^3/s for the months of December, January and February, or 0.19 Mm^3/a, which represents 3.5% of virgin MAR (for the gauged catchment area) - which equals 189 Mm^3, was estimated. **No values were set for the other months**.

The DSS program gives a value of 0.54 Mm^3/a for October and a total IFR of 29% of virgin MAR (for a class B). But for more than 30% of the time, the flow in October is equal to zero, as is evident from Table 23.

It is clear that in about 25% of the months, no flow occurs in the river and that pools are the major water source for aquatic life. It is expected that groundwater plays a very important role in sustaining the water level in these pools. To manage the water levels in these pools, a constraint on the groundwater gradient towards the river must be specified.

Table 23 Exceeding probability table for current flow [Mm3/a].

	90%	80%	70%	60%	50%	30%
Oct	0	0	0	0.328	0.42	1.117
Nov	0.007	0.478	1.286	1.662	2.23	3.842
Dec	0.624	1.482	2.995	3.638	5.035	12.574
Jan	0.654	1.756	2.194	4.344	11.15	24.736
Feb	0.328	1.076	1.615	4.412	7.135	27.139
Mar	0.208	0.538	1.876	2.824	4.99	27.29
Apr	0	0.286	0.655	0.864	1.455	9.288
May	0	0.008	0.222	0.632	1.375	3.959
June	0	0	0.017	0.206	0.375	1.89
July	0	0	0	0.166	0.365	1.328
Aug	0	0	0.027	0.39	0.515	0.78
Sept	0	0	0	0.184	0.41	0.65
Annual total	**1.821**	**5.624**	**10.887**	**19.65**	**35.455**	**114.593**

6.3 Geomorphology

The geomorphological characteristics of the study area are summarised in a set of maps (Figures 25 to 28). The maps were compiled from various sources and comprise the physical terrain (a DTM), geology, a terrain description and landcover of the Nyl River catchment. All maps are overlain by the quaternary catchments for easy reference.

Resource Unit 1

Resource Unit 1 has been defined as from the Groot Nyl River to the Nylsvley Nature Reserve (NR). This roughly consists of Quaternary catchments A61A, A61B, and A61C.

Data available and assessment of quality of data

The environmental potential atlas of South Africa (ENPAT) (DEAT, 2001) was used for most of the data represented in this report. Land cover data were obtained from the CSIR (SAC, 1999). Digital terrain models were constructed from Shuttle Radar Topography Mission (SRTM) data (USGS, 2004). ENPAT data were digitised from 1:250 000 scale maps and can be used at this and smaller scales. SRTM data are available in 3 arc second grids and are accurate within acceptable standards (JPL, 2004).

Present Ecological State and Motivation

PES: 3 Confidence level: 1

Motivation: The unit is located in a high laying mountainous region, sedimentation low, low human intervention

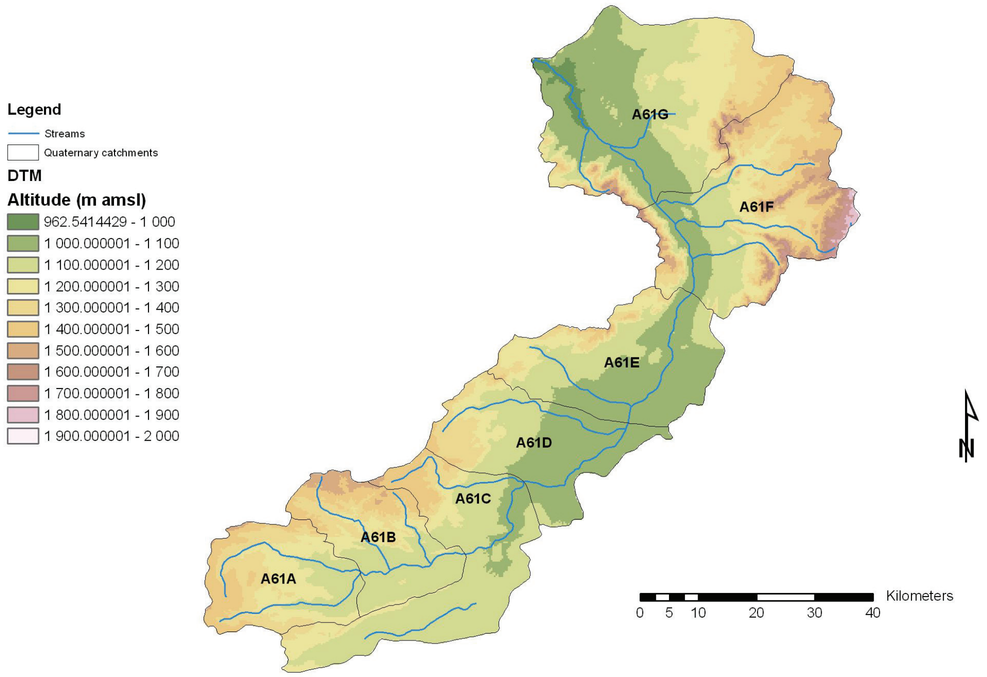

Figure 25 Quaternary catchments of the Nyl River catchment.

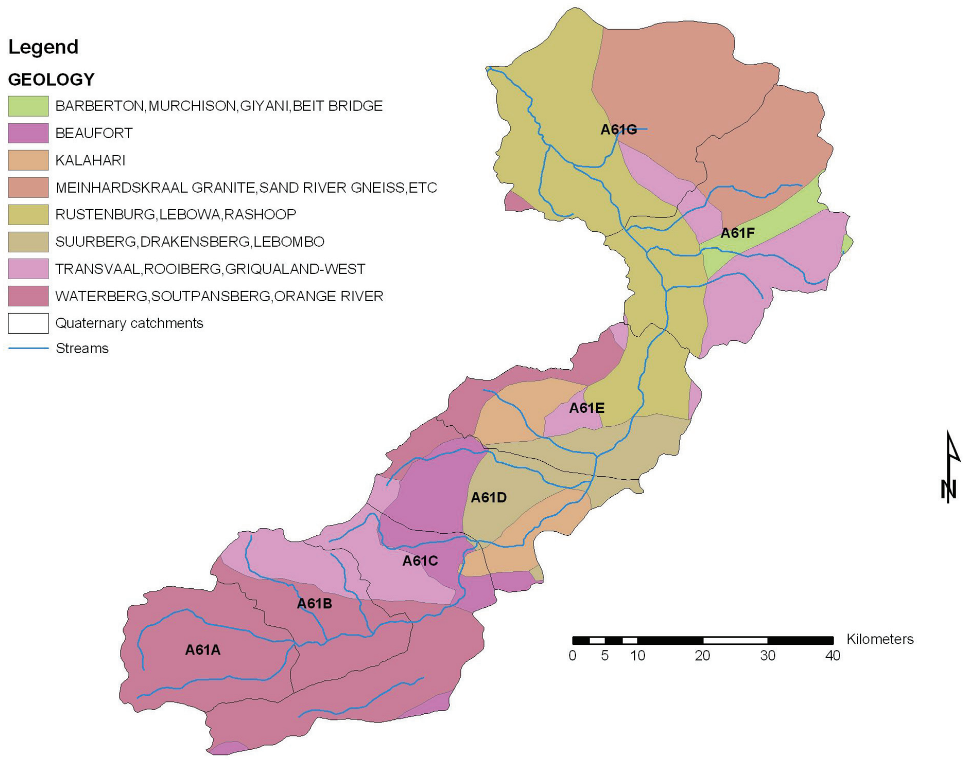

Figure 26 Geology of the Nyl River catchment.

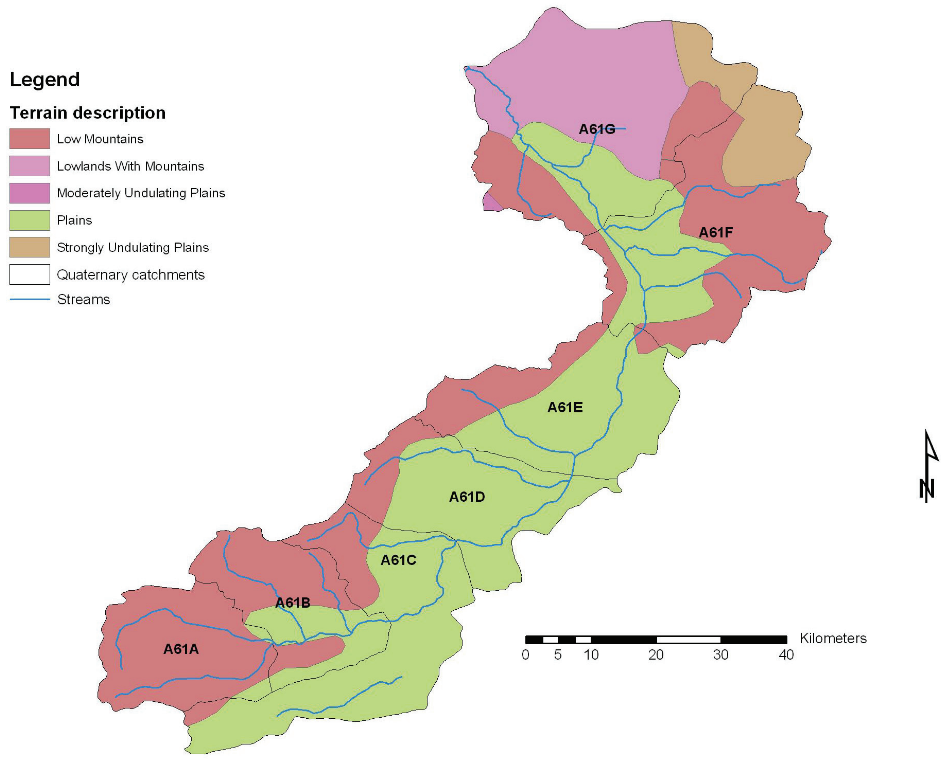

Figure 27 A terrain description of the Nyl River catchment.

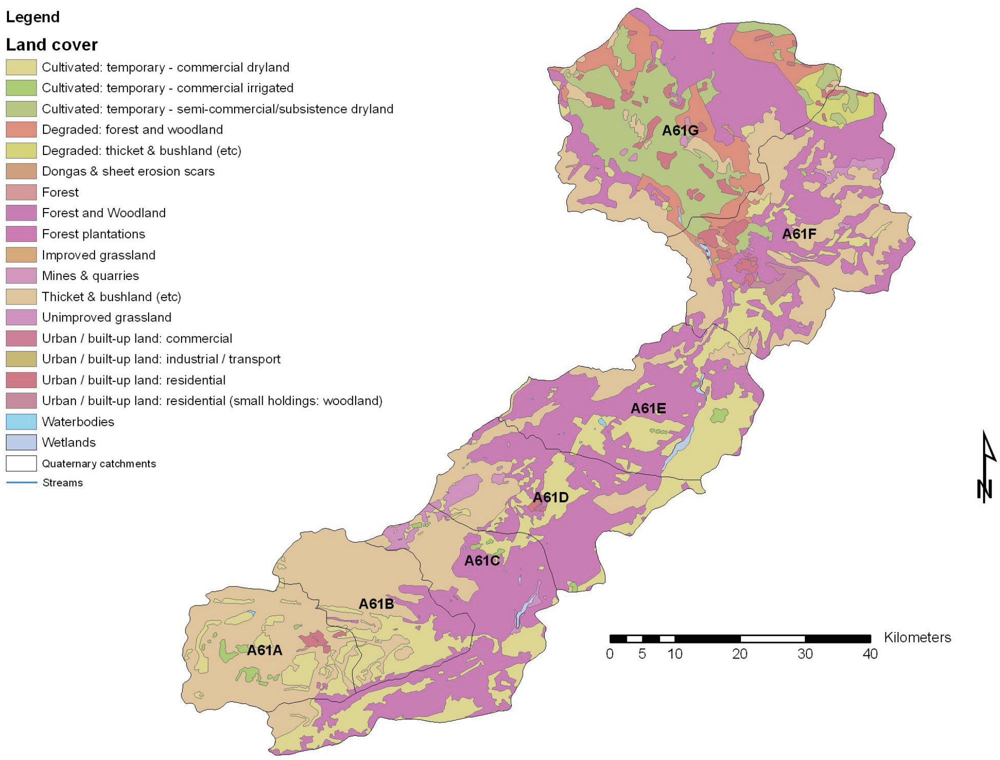

Figure 28 Landcover of the Nyl River catchment.

Resource Unit 2

Nylsvley NR to Moorddrift (A61D, A61E)

Data available and assessment of quality of data

The environmental potential atlas of South Africa (ENPAT) (DEAT, 2001) was used for most of the data represented in this report. Land cover data were obtained from the CSIR (SAC, 1999). Digital terrain models were constructed from Shuttle Radar Topography Mission (SRTM) data (USGS, 2004). ENPAT data were digitised from 1:250 000 scale maps and can be used at this and smaller scales. SRTM data are available in 3 arc second grids and are accurate within acceptable standards (JPL, 2004).

Present Ecological State and Motivation

PES: 2 Confidence level: 1

A larger amount of human intervention is present in these catchments, which will have a negative impact on the geomorphological processes.

6.4 Water Quality

Resource Unit 1

Data available and assessment of quality of data

Period of data: 1976 to 2000 (CSIR Environmentek, 1999), 330 data points (Table 24).

Table 24 Rapid status assessment of Great Nyl River at Modderpoort (A6H011).

Variable	Concentration or range	Assessment category
Total dissolved salts (TDS)	Median monthly: (min = 30; max = 40mg/ℓ)	**A** (0 – 163)
PH	Median monthly: (Min = 6.6; max = 7.0)	**A** (6.5 – 7.5)
Ammonia (un-ionised)	90 % percentile ~ 6 µg/L	**A** (< 7)
F	Max = 0.86 (mean = 0.109 mg/ℓ)	TWQR < 0.75
SP	Average summer SP = 12 µg/L	**B** (Mesotrophic; 5 – 25)
TIN	Average summer TIN = 0.13 mg/ℓ	**A** (Oligotrophic, <0.5)
TIN:SP	10.4 (Median TIN = 0.135; SP = 0.013)	**C** (SP <0.05; TIN:SP >10:1)
SP/TP (%)	No TP Data	–
TIN:TP	No TP data	–
Dissolved Oxygen	No data	–

TIN = total inorganic nitrogen (ammonium + nitrate); TP = Total phosphorus; SP = soluble phosphate (PO_4-P)

No data on: Bacteriological, DO, Temp, Algae (Chl-a), TP, TN, TSS, and Toxicants (Heavy metals),

Summary of data

The Nyl River is characterized by low salinity, low pH, and soft water. The median hardness is about 25 mg/ℓ $CaCO_3$, while the mean alkalinity is about the same. The low pH and hardness of the water means that aquatic life in this area will be more susceptible to the toxic effect of trace metals.

Present Ecological State and Motivation

PES = 4, A/B system; largely natural (see Table 6 in Chapter 3).

The upper part of the catchment is largely natural with few modifications. The water quality indicates that the basic ecosystem functions are essentially unchanged.

However, the low salinity water of the upper reaches is sensitive to changes in water quality due to effluent discharges and diffuse sources.

Resource Unit 2

Data available and assessment of quality of data

Period of data: 1983-11-30 to 1991-09-16; only 43 data points (Table 25).

Table 25 Rapid status assessment of Nyl River at Deelkraal (A6H002); {24:40:57S; 28:37:44E}.

Variable	Concentration or range	Assessment category
Total dissolved salts (TDS)	Median monthly: min = 52; max = 97 mg/ℓ	A (0 – 163)
PH	Median monthly: Min = 6.6; max = 7.45	A (6.5 – 7.5)
Ammonia (un-ionised)	90 % percentile ~ 12 µg/L	B (<15
F	Mean = 0.18 mg/ℓ	TWQR < 0.75
SP	Average summer SP = 22 µg/L	B (mesotrophic; 5 – 25)
TIN	Average summer TIN = 0.08 mg/ℓ	A (Oligotrophic, <0.5)
SP/TP (%)	No TP Data	–
TIN:TP	No TP data	–
TIN:SP	3.6 (Median TIN = 0.08; SP = 0.022)	D (SP <0.05; TIN:SP <10:1)
Dissolved Oxygen	No data	–

TIN = total inorganic nitrogen (ammonium + nitrate); TP = Total phosphorus; SP = soluble phosphate (PO_4-P)

Summary of data
Unfortunately the available water quality records are incomplete.

The water plants and algal growth are probably nitrogen limited because of the low TIN in the river.

The phosphate concentration at this sampling point, although still low, is higher than in Resource Unit 1. This is possibly due to the effluent from the Nylstroom wastewater treatment works.

Present Ecological State and Motivation
PES: **A/B system**

Good, but the upper part of the catchment is relatively densely populated, and this is expected to increase even further. Coupled with an increase in the per capita demand, not only will the demand increase significantly, but also will the return flow. The return flow represents a valuable resource, and it can reasonably be expected that this will eventually be discharged into the river. Thus, eutrophication will probably be a problem over the long-term.

6.5 Riparian Vegetation

Resource Unit 1

Data available and assessment of quality of data No quantitative data was available.

Summary of data No quantitative data was available.

Present Ecological State and Motivation
The present ecological status is considered to be moderately modified (score = 3). The reasons are the construction of weirs, the collection of firewood, the lack of veldfires, or on the other hand, the high frequency of veldfires.

Resource Unit 2
Data available and assessment of quality of data
No quantitative data was available.

Summary of data
The Nylsvlei wetland is situated in the Savanna biome (Rutherford and Westfall, 1986).

The savanna vegetation of the Nylsvlei nature reserve has been thoroughly investigated (Scholes and Walker, 1993; Teague and Smit, 1992). Several studies on the Nylsvlei wetland and associated communities have been conducted (Noble and Hemens, 1978;

Frost, 1987; Tarbotton, 1987; Marnewick, 1990; Coetzee and Rogers, 1991; Rowlston, 1991; Tarbotton, 1991; Rogers and Higgens, 1993; Higgens and Rogers, 1993; Higgins et al., 1996, to name a few) and some are in progress (Marnewick, pers. comm.).

In seasons of above-average rainfall, particularly when there has been a carry-over of water in the Nyl River from the previous wet season, some 9 000 to 16 000 ha of the Nyl Valley become inundated. These floodwaters may persist for some months into the dry season and even occasionally into the following wet season; though more frequently the water gradually recede until only the deeper parts of the main channel retain water (Frost, 1987).

The functioning of the Nyl River's floodplain is tightly linked to the hydrological regime.

Dominant types of riparian vegetation:

The Nylsvlei floodplain is characterized by periodically inundated reed beds and grasslands.

Macrophyte communities

The channel is the most frequently inundated landscape unit to depths of at least 0.5m for much of the growing seasons. It acts as a refuge for obligatory aquatic plant and animal species. The vegetation of the channel is dominated by floating-leaved (*Nymphaea lotus, Cratophyllum demersum* and *Potamogeton thunbergii*) and submerged aquatic species (*Ludwigia schinzii*). The reed *Phragmites australis* form dense localized patches.

Riparian tree communities

Levee development is the result of the deposition of coarser sediments close to the channel rim. Levees provide well-drained habitats in which riparian trees and shrubs such as *Spirostachys africana, Maytenus heterophylla, Rhus pyroides, Combretum erythrophyllum, Carissa bispinosa* and *Acacia karroo* dominates.

Higrophyllous grass communities of the floodplains

These communities are restricted to the frequently inundated floodplains. These floodplain surfaces are a composite of mosaic of overlaying bands of different textured sediments. The plant communities of the floodplain landscape unit are the most temporally and spatially dynamic of the Nyl River system. Temporal variation in the plant community's species composition and production are evident through the flooding and drawdown periods. Spatial pattern is observed across the elevation gradient of the floodplain unit.

Dominant plant species are the grasses: *Oryza longistaminata, Panicum schinzii, Paspalidium obtusiflorum,* and *Leersia hexandra*.

Grass communities of the back-flooded areas

These areas are less frequently flooded than floodplain grasslands. The flooding occurs when there is overflow from the active floodplain. Cattle and indigenous ungulates extensively utilize these areas.

Dominant plant species are the grasses: *Setaria sphacelata* and *Botriochloa insculpta*.

Vegetation of sodic islands

The accumulation of sodium salts in certain sites forms a unique habitat for distinctive plant communities. The upward movement of groundwater and surface salt accumulation is driven by transpiration of woody trees and by evaporation – induced capillary rise. The resultant gradient of groundwater conductivity facilitates the sub-surface precipitation of calcium and magnesium compounds. The differential precipitation produces a gradient of soil conditions, which result in the distinct zonation of vegetation communities.

The sodic islands provide two distinct sub-habitats, namely a woody community (*Acacia tortilis*, *Euclea undulata, Pappea capensis, Ziziphus mucronata, Carissa bipinosa*, *Spirostachys africana* and *Acacia karroo*) of the raised island periphery and the grass community of the island interior, which is dominated by *Sporobolus ioclados* and *Chloris virgata*. After heavy rains these shallow depressions are inundated for weeks supporting aquatic plants such as *Nympaea lotus* and *Cyperus fastigiatus*.

Hydromorphic grasslands

These grasslands represent an ecotone between the floodplain and the terrestrial savanna. The soils of the habitat are subjected to seasonal waterlogging from lateral water run-off from the surrounding landscape. The frequent waterlogging prevents the establishment of terrestrial woody species, resulting in a landscape unit dominated by perennial grasses such as *Setaria sphacelata, Dichanthium papillosum, Aristida bipartita* and *Themeda triandra* as well as the sedge *Scirpus dregeanus.*

Alien vegetation:

Species present are *Sesbania punicea, Lantana camara, Verbena bonariensis, V. brazilliensis, Ricinus communis, Cirsium vulgare, Chenopodium album,* etc.

Flow impacts:

The flow of the Nyl River is ephemeral. The flood regime affects vegetation patterns by creating areas for recolonisation and by forming resource gradients on which plants showing varying tolerances to water flows and sediment movement can establish.

According to Higgens et al. (1996) three categories of flood events, on the Nyl River system could be identified. These flood events are based on their frequency, spatial extent and duration. These flood events are the hydromorphic zone flood, the floodplain zone flood and the channel zone flood. Ranging from most extensive to the least extensive. The variation in flood events cause shifts in the spatial distribution of certain plants species.

The construction of dams in the catchment will further reduce the run-off onto the floodplain.

Groundwater influence:
Depending on the frequency, spatial extent and duration of flooding the water table fluctuates. Regular hydromorphic floods for extended periods of time results in the die-off of trees species. This prevents the encroachment of terrestrial savanna trees into the backflooded and hydromorphic grasslands. More terrestrial species in the se areas could lead to the increase of sodic islands by increasing the evapo-transpiration relative to groundwater leaching. This could further impact upon the topsoil conservation and also grass production.

Present Ecological State and Motivation
The present ecological state of RU 2 is moderately modified (score = 3). The reasons are the low flow, abstraction from dams, agriculture, cultivated lands.

6.6 Invertebrates

A review of current information on the Nyl floodplain by Higgins et al. (1996) states that the systems biota would be negatively impacted on if the runoff to the system is reduced. They suggest that a comprehensive study of the functioning of the floodplain be considered to enhance understanding. A study is currently being carried out by University of the North. Richard Greenfield (University of the North) is also currently busy with a PhD study on the water quality and invertebrates in the system which should be completed by the end of 2004 (Richard Greenfield, pers. comm.). Data from a preliminary report (Vlok et al., 2005) was used to determine the PESC of the Nyl River.

Two resource units were identified in the Nyl River from its origin (Groot Nyl and Klein Nyl) to Moorddrift upstream of the Mogalakwena/Nyl River confluence.

Resource Unit 1

From the origin of Groot Nyl and Klein Nyl to confluence with Nyl River (A61A to beginning of A61B). The channel is clearly defined and has a high sinuosity in this section of the river (Higgins et al., 1996).

Data available and assessment of quality of data
Unpublished data collected by Vlok et al. (2005) in 2001 and 2002 was used in the assessment of the PESC for this resource unit.

Quality of the data used

Unpublished data collected in 2001 and 2002 by Vlok et al. (2005) was used and is therefore not present day data.

The SASS5 method, used during sampling, was developed to be used in a flowing habitat rich system (especially stones-in-current habitat; SIC). The naturally low diversity of habitat available (SIC etc.) could have a negative impact on the SASS5 scores. The SASS5 score is therefore not necessarily a true reflection of the present ecological state of the resource unit.

The absence of historical data made it difficult to determine the reference condition of the resource unit and to determine the natural diversity of invertebrates expected in the system.

The data used to determine the PESC for this resource unit is therefore of low confidence value and should be interpreted with caution.

Summary of data

Two sites namely Abba (situated near Klein Nyl River origin) and Donker (situated downstream of Donkerpoort Dam) were sampled on the Klein Nyl River and one site namely Dladla at the confluence of the Groot Nyl, Klein Nyl and Nyl Rivers was sampled by a research team from the University of the North.

Samples were collected using the SASS5 method (Dickens and Graham, 2002) from three different biotopes/habitats namely Stones-in-current (riffles/bedrock runs), marginal vegetation and sediments (mud, sand and gravel), if available.

No list of invertebrate taxa present was available and only the SASS5 scores for each site and sample was given. The IRAI method could therefore not be used to determine the PESC for this resource unit. No historical data was available and therefore no reference condition could be determined.

SASS results for Resource Unit 1 are summarized in Table 26.

Table 26 Unpublished SASS5 data for three sites sampled in Resource Unit 1 (Vlok et al., 2005).

	Donker				**Dladla**				**Abba**	
Date	March 2001	August 2001	April 2002	July 2002	March 2001	August 2001	April 2002	July 2002	April 2002	July 2002
SIC	54	74	57	74						
MV	22	76	91	76	90	29	72	37	65	61
GSM	8	49		49		45	33	37	1	
No. of Families	13	22	19	22	15	17	14	11	16	11
Combined ASPT	5.6	5.4	5.5	5.4	6.0	4.2	5.5	5.1	4.1	5.6
Combined SASS5	**72**	**118**	**105**	**118**	**90**	**71**	**77**	**56**	**66**	**61**
Class	**D(2)**	**C(3)**	**C (3)**	**C (3)**	**D (2)**	**D(2)**	**D (2)**	**E (1)**	**D (2)**	**D (2)**

The Combined SASS5 scores were used to determine the class (Table 26) at each site by referring to Table 27 developed by Thirion (2003) for the Bushveld Basin ecoregion. SASS5 scores should be converted to SASS4 scores before Table 27 can be used to determine the class. However no data on invertebrate families was available and it is therefore assumed for this study that the SASS5 scores were equal to the SASS4 scores. This therefore implies that the results obtained are of low confidence value.

Table 27 SASS4 and ASPT values per Ecoregion as an indication of biotic condition (Adapted from Thirion, 2003).

	SASS4	**ASPT**	**Condition**	**Class**
BUSHVELD BASIN	>180	>6	EXCELLENT	A (5)
	141-180	6-7	VERY GOOD	B (4)
	91-140	5-6.5	GOOD	C (3)
	61-90	<6	FAIR	D (2)
	30-60	VARIABLE	POOR	E (1)
	<30	VARIABLE	VERY POOR	F (0)

Present Ecological State and Motivation

The overall PESC for Resource Unit 1 was determined by adding the class (Table 26) for each site and sample and determining the mean.

PESC= (2+3+3+3+2+2+2+1+2+2/10)

PESC = 2.2 (C)

The PESC of >2 may possibly relate to a class C following the scoring and rating guidelines provided by Kleynhans (1999b).

PESC for invertebrates in Resource Unit 1 = C Moderately modified

It is possible that the PESC for invertebrates would remain the same in future if there are no additional impacts on Resource Unit 1 of the Nyl River.

The moderately modified PESC for Resource Unit 1 could be ascribed to the fact that the Donker site is situated downstream of Donkerpoort Dam which would have a negative impact on invertebrates present. The abstraction of water upstream also reduces habitat diversity downstream and negatively impacts on invertebrates.

The fact that the method (SASS5) used was developed to be used in a habitat rich system (especially SIC habitat) and the absence of historical and present day data make it difficult to determine an accurate PESC.

Resource Unit 2

From downstream of Groot Nyl/Klein Nyl and Nyl River confluence to Moorddrift (A61B to A61E). The upstream section of this unit consists of a channel (up to Nysvley Reserve) and the rest of the resource unit consists mostly of a floodplain. The surface of the floodplain is a complex mosaic of overlying bands of sediment of different textures (Higgins et al., 1996).

Data available and assessment of quality of data
Unpublished data by Vlok et al. (2005) was used in the assessment of the PESC for this resource unit.

Quality of the data used
Unpublished data collected in 2001 and 2002 by Vlok et al. (2005) was used and is therefore not present day data.

The SASS5 method used was not developed to be used in wetlands (floodplain) and no mention is made in the preliminary report if any flow was present during sampling. The natural low diversity of habitat available (SIC) could have a negative impact on the SASS5 scores. The SASS5 score is therefore not necessarily a true reflection of the present ecological state of the resource unit.

The absence of historical data made it difficult to determine the reference condition of the resource unit and to determine the natural diversity of invertebrates expected in the system.

The data used to determine the PESC for this resource unit is therefore of low confidence value and should be interpreted with caution.

Summary of data

Five sites namely Jasper (situated in the Nyl River downstream of Sewage works), Olifants (situated in tributary entering Nyl River downstream of Jasper site), Nylsvley (situated in the Nylsvley Nature Reserve), Haakdoring (in Nyl River downstream of Mosdene) and Moorddrift (situated in the Nyl River downstream of Haakdoring) were sampled by a research team from the University of the North in 2001 and 2002. Three sites namely Nylsvley, Haakdoring and Moorddrift are situated in the floodplain section of the Nyl River.

Samples were collected using the SASS5 method (Dickens and Graham, 2002) from three different biotopes/habitats namely Stones-in-current (SIC) (riffles/bedrock runs), marginal vegetation (MV) and sediments (GSM) (mud, sand and gravel) if available. No list of invertebrate taxa present was available and only the SASS5 scores for each site and sample were given. The IRAI method could therefore not be used to determine the PESC for this resource unit. No historical data was available and therefore no reference condition could be determined. SASS results for Resource Unit 2 are summarised in Table 28.

The Combined SASS5 scores were used to determine the Class (Table 28) at each site by referring to Table 27 developed by Thirion (2003) for the Bushveld Basin ecoregion.

Present Ecological State and Motivation

The overall PESC for Resource Unit 2 was determined by adding the class (Table 28) for each site and sample and determining the mean.

PESC = (1+0+1+1+3+3+3+3+2+1+1+3+2+3+2+1+1+2+2/19)

PESC = 1.8 (E)

The PESC of <2 may possibly relate to a class E following the scoring and rating guidelines provided by Kleynhans (1999).

The SASS5 method used in the wetland area could have had a major impact on the SASS5 score and the fact that SIC and GSM habitat were absent from most of the sites in the wetland would exacerbate the underestimation of the present ecological status of Resource Unit 2.

The absence of flow at some of the sites (in the floodplain) would limit the diversity of invertebrate families naturally present at the site but this would not be reflected by the SASS5 score.

The fact that the water quality, riparian vegetation and fish all fall in the moderately modified class would also indicate that the present state of the invertebrates would not be seriously modified.

The PESC is therefore lifted from an E to a C class due to specialist opinion but it must be emphasized that this is with a low confidence rating as no historical data was available and no reference condition could be determined.

PESC for invertebrates in Resource Unit 2 = C Moderately modified

It is possible that the PESC for invertebrates would remain the same in future if there are no additional impacts on Resource Unit 2 of the Nyl River.

The moderately modified PESC for Resource Unit 2 could be a result of moderately modified water quality in this resource unit. The abstraction of water and the impact on the hydrology of the resource unit also reduces habitat diversity downstream and negatively impacts on invertebrates.

The fact that the method used (SASS5) was not developed to be used in a wetland system and the absence of historical and present day data make it difficult to determine an accurate PESC.

6.7 Fish

For the purpose of the fish assessment, the study area was initially divided into two resource units (RUs). The first comprised the upper section section of the Nyl River, stretching from the confluence of the Klein en Groot Nyl Rivers to where the river channel starts to widen and the floodplain starts to dominate (on Nylsvley Nature Reserve). The second resource unit included the floodplain itself (from the Nylsvley Nature Reserve downstream to Moorddrift).

At the specialist meeting, however, it was decided to divide the study area into the following two resource units:

Resource Unit 1

Groot Nyl River up to its confluence with the Klein Nyl River.

Data available and assessment of quality of data
The list of fish species expected to occur in this resource unit is based on an unpublished report by Kleynhans (1991) on the fish community of the Nyl floodplain, incorporating sampling data from 1962 to 1990. More recent sampling data was obtained from a study done by Vlok et al., (2005). For this study, fish sampling was done quarterly at eight sampling sites from April 2001 to July 2002.

Table 28 Unpublished SASS5 data for five sites sampled in Resource Unit 2 (Vlok et al., 2005).

	Jasper				**Olifants**				**Nylsvley**				**Haakdoring**				**Moorddrif**			
Date	03/01	08/01	04/02	07/02	03/01	08/01	04/02	07/02	03/01	08/01	04/02	07/02	03/01	08/01	04/02	07/02	03/01	08/01	04/02	07/02
SIC	21	17	21		78	91	78	83												
MV	37	15	37	20	46	80	46	54	72		42	51	93	85	93	65	39	39	78	69
GSM	15	8	15	29		36					14	6								
No. of Families	12	9	12	9	18	22	18	22	15		11	12	20	16	20	15	11	8	16	14
Combined ASPT	3.8	3.2	3.8	4.7	6.5	5.5	6.5	6.1	4.8		4.7	4.3	4.7	5.3	4.7	4.3	3.6	4.9	4.9	4.9
Combined SASS5	**46**	**29**	**46**	**42**	**117**	**121**	**117**	**134**	**72**		**52**	**51**	**93**	**85**	**93**	**65**	**39**	**39**	**78**	**69**
Class	E(1)	F(0)	E(1)	E(1)	C(3)	C(3)	C(3)	C(3)	**D(2)**		**E(1)**	**E(1)**	**C(3)**	**D(2)**	**C(3)**	**D(2)**	**E(1)**	**E(1)**	**D(2)**	**D(2)**

The data from the following sites was used to calculate the present ecological status (PES), based on fish, for Resource Unit 1: Donkerpoort (below the Donkerpoort Dam on the Klein Nyl River) and a site on the Groot Nyl River. No information on fish abundance, fish health/condition, or the instream habitat integrity was available.

The following sources were consulted for information on the ecological requirements of fish species: Gaigher (1969, 1973), Kleynhans (1984, 1991, 1996b, 2003, 2004), Russell (1997), Schulz and Schoonbee (1999) and Weeks et al. (1996).

Constraints in the application of the fish indices
Three fish indices were applied on the available data. Specific constraints with regards to each method are discussed below:

Fish Assemblage Integrity Index (FAII)
The application of this index was problematic for the following reasons:

The method was developed for specific use in the River Health Programme, and may, therefore, not be ideally suited for use in the determination of environmental water requirements.

The method should be applied on data from relatively homogenous river segments with regards to physical habitat. To include both the Groot and Klein Nyl Rivers into one river segment is not ideal. The index was, however, applied on the combined data from the two rivers and compared with the FAII scores calculated for each river separately.

For both rivers, sampling data was only available for one site. Where only one site was sampled in a river segment, the frequency of occurrence should not be considered.

Due to the lack of information on the health of the fish species present, this particular metric could not be considered.

Qualitative FAII
Three of the seven metrics ("the abundance of native species", "health/condition of native and introduced species" and "in-stream habitat modification") were not considered due to the lack of information. The results obtained are therefore considered to be of low confidence.

Fish Response Assemblage Index (FRAI)
Due to the lack of information on the health/condition of the fish species, no deviances from the reference conditions were indicated for this particular metric.

Summary of data
Eighteen fish species are expected to occur naturally in Resource Unit 1: fifteen fish species in the Klein Nyl River and sixteen species in the Groot Nyl River (see Table 29).

Table 29 Expected and observed fish species for the Groot and Klein Nyl Rivers (After Kleynhans 1991; Vlok et al., 2005).

Species	Klein Nyl		Groot Nyl		Resource Unit 1	
Species	**Klein Nyl**		**Groot Nyl**		**Resource Unit 1**	
	Expected	**Donker-poort**	**Expected**	**Groot Nyl**	**Expected**	**Observed**
Amphiliidae						
Amphilius uranoscopus			X		X	
Mormyridae						
Marcusenius macrolepidotus	X	X	X	X	X	X
Cyprinidae						
B. bifrenatus	X	X	X	X	X	X
B. brevipinnis	X		X	X	X	X
B. paludinosus	X		X	X	X	X
B. trimaculatus	X	X	X		X	X
Barbus unitaeniatus	X		X		X	
Labeobarbus marequensis	X	X	X	X	X	X
Labeo molybdinus	X				X	
Mesobola brevianalis	X		X		X	
Clariidae						
Clarias gariepinus	X	X	X		X	X
C. theodorae	X				X	
Poeciliidae						
Aplocheilichthys johnstoni		X	X	X	X	X
A. katangae			X		X	
Cichlidae						
Oreochromis mossambicus	X	X	X		X	X
*Tilapia rendalli**	X	X		X		X
T. sparrmanii	X	X	X	X	X	X
Pseudocrenilabrus philander	X	X	X	X	X	X
Chetia flaviventris	X	X	X	X	X	X
EXOTIC						
Cyprinus carpio	X		X			
Micropterus salmoides	X		X			
Total no of species	**15**	**10**	**16**	**9**	**18**	**12**
Introduced species	**3**	**1**	**2**	**1**	**0**	**1**

Ecological requirements of expected fish species

Four of the fish species expected to occur in RU1 are sensitive to no-flow conditions, namely *Barbus brevipinnis, Amphilius uranoscopus, Labeo molybdinus* and *Labeobarbus marequensis.* The rest of the expected fish assemblage is moderately tolerant to tolerant to no-flow conditions and prefer slow deep and slow shallow habitats. Overhanging vegetation is the preferred cover type for most of the species.

Five species, *Barbus brevipinnis, Amphilius uranoscopus, Labeo molybdinus, Marcusenius macrolepidotus and Aplocheilichthys johnstoni,* are sensitive to modified water quality. *B. brevipinnis* is IUCN listed as "vulnerable" (Skelton, 2001) mainly as a result of habitat destruction and the introduction of predaceous species like *Oncorhynchus mykiss* (Schulz and Schoonbee, 1999). *A. uranoscopus* is a highly sensitive species (average intolerance rating of 4.8) preferring clear, flowing water in rocky habitats. *L. molybdinus* and *L. marequensis* are migratory species that also need flow for breeding.

Three introduced fish species have previously been recorded in the Klein and the Groot Nyl Rivers, namely *Tilapia rendalli*, *Cyprinus carpio* and *Micropterus salmoides*.

Present Ecological State and Motivation

Results

According to the FAII, the PES for the Klein Nyl and the Groot Nyl Rivers are moderately modified (Class C). The PES of the two rivers combined was also calculated to be moderately modified. This was confirmed by the results of the Qualitative FAII and FRAI (see Table 30).

The Present Ecological Status of Resource Unit 1, based on the fish assemblages, was therefore concluded to be moderately modified and was categorised as Class C. The confidence in this result is, however, low.

Table 30 Results for the different fish indices applied to calculate the PES for Resource Unit 1, based on fish.

Fish Index	River segment	Fish PES Class	Description
FAII	Klein Nyl	C	Moderately modified
	Groot Nyl	C	Moderately modified
	RU1 (combined)	C	Moderately modified
Qualitative FAII	Klein Nyl	C	Moderately modified
	Groot Nyl	C	Moderately modified
	RU1 (combined)	C	Moderately modified
FRAI	RU1	C	Moderately modified
Decision	**RU1**	**C**	**Moderately modified**

Motivation

The following could have contributed to the deviation from natural conditions as indicated by the fish indices:

- Loss of sensitive species – only 2 of the 4 expected sensitive fish species were observed.
- Moderate loss of flow sensitive species.

- Two of the 3 species with a very high preference for substratum, *A. uranoscopus* and *L. molybdinus*, were not recorded.
- One introduced species, *Tilapia rendalli*, was recorded at the time of sampling.

Resource Unit 2

From the confluence of the Klein and Groot Nyl Rivers to Moorddrift.

Data available and assessment of quality of data

The list of fish species expected to occur in this resource unit is based on an unpublished report by Kleynhans (1991) on the fish community of the Nyl floodplain, incorporating sampling data from 1962 to 1990. Recent sampling data was obtained from Vlok et al. (2005). Vlok et al. (2005) sampled quarterly at eight sampling sites from April 2001 to July 2002. Data data from the following sites was used to calculate the present ecological status (PES), based on fish, for Resource Unit 2: Jasper, on the Nyl River downstream of Modimolle, and Nylsvley, Haakdoorn and Moorddrift on the floodplain. No information on fish abundance, fish health/condition, or the instream habitat integrity was available.

The following sources were consulted for information on the ecological requirements of fish species: Gaigher (1969, 1973), Kleynhans (1984, 1991, 1996b, 2003, 2004), Russell (1997), Schulz and Schoonbee (1999) and Weeks et al. (1996).

Constraints in the application of the fish indices

Three fish indices were applied on the available data. Specific constraints with regards to each method are discussed below:

Fish Assemblage Integrity Index (FAII)

The application of this index was problematic for the following reasons:

The FAII was developed for specific use in the River Health Programme (RHP), and may, therefore, not be ideally suited for use in EWR studies.

The method should be applied on data from relatively homogenous river segments with regards to physical habitat. It would have been preferred to determine the PES for the Nyl River (river channel pronounced) and the floodplain separately. The index was, however, applied on the combined data for the Nyl River and the floodplain.

Due to the lack of information on the health of the fish species present, this particular metric has not been considered.

Qualitative FAII

Three of the seven metrics ("the abundance of native species", "health/condition of native and introduced species" and "in-stream habitat modification") were not considered due to the lack of information. The results obtained are therefore considered to be of low confidence.

Fish Response Assemblage Index (FRAI)

Due to the lack of information on the health/condition of the fish species, no deviances from the reference conditions were indicated for this particular metric. The absence of information on the instream habitat made interpretation of the results very difficult and impeded the identification of possible causes that could have contributed to a decrease in biological integrity.

Summary of data

Of the twelve fish species expected to occur in the Nyl River, only 10 species are expected on the floodplain (Kleynhans, 1991). Of these, 7 species seem to be present over the length of the floodplain, while the other 3, *M. macrolepidotus*, *Barbus bifrenatus* and *B. brevipinnis (*IUCN listed as "vulnerable", Skelton, 2001), only occur in the upper part of the floodplain (Table 31). Two introduced fish species were previously recorded in the Nyl River system, *C. carpio* and *M. salmoides*.

Historical records showed *B. unitaeniatus*, *L. marequensis* and *L. cylindricus* to be present in the Nyl River but not on the floodplain (Kleynhans, 1991). Of these, only *L. cylindricus* could be expected to utilise the floodplain as the species does occur on the Pongolo floodplain (Kok 1980 cited in Kleynhans, 1991). *B. bifrenatus* and *M. macrolepidotus,* recorded in the upper section of the floodplain, are known to utilise floodplains and should be able to extend their range if the inundation of the floodplain persists for a relatively long time (Kleynhans, 1991). Two other species recorded in some of the tributaries, *Clarias theodorae* and *A. katangae*, are known to occur on floodplains (Bell-Cross and Minshull, 1988 cited in Kleynhans, 1991), but appears to be too isolated from the floodplain to make use of it.

Ecological requirements of the expected fish species

All of the species expected to be present on the floodplain have a high preference for slow shallow habitat. The majority of these species (90%) are moderately tolerant to tolerant of conditions of no-flow. Two of the riverine species, *L. cylindricus* and *L. marequensis,* prefer fast deep and fast shallow habitats but are moderately tolerant to conditions of no-flow. *B. brevipinnis* is the only expected species considered to be intolerant to conditions of no-flow. This Red Data species is also intolerant of modified water quality and prefers well oxygenated waters low in dissolved solids (Schulz and Schoonbee, 1999).

Table 31 Expected and observed fish species for the Nyl River and the Nyl River floodplain (After Kleynhans, 1991; Vlok et al., 2005).

Species	Nyl River		Nyl River Floodplain				Resource Unit 2	
	Expected	Jasper	Expected	Nylvley	Haakdoorn	Haakdoorn	Expected	Observed
Mormyridae								
Marcusenius macrolepidotus			X(u)				X	
Cyprinidae								
B. bifrenatus	X	X	X(u)				X	X
B. brevipinnis	X		X(u)				X	
B. paludinosus	X	X	X	X	X	X	X	X
B. trimaculatus	X		X	X	X	X	X	X
Barbus unitaeniatus	X						X	
Labeobarbus marequensis	X						X	
L. cylindricus	X						X	
Labeo molybdinus								
Mesobola brevianalis								
Clariidae								
Clarias gariepinus	X	X	X	X	X	X	X	X
C. theodorae								
Poeciliidae								
Aplocheilichthys johnstoni	X	X	X	X			X	X
A. katangae								
Cichlidae								
Oreochromis mossambicus	X		X		X	X	X	X
*Tilapia rendalli**								X
T. sparrmanii	X	X	X				X	X
Pseudocrenilabrus philander	X	X	X	X	X	X	X	X
Chetia flaviventris								
EXOTIC								
Cyprinus carpio (EXOTIC)								
Micropterus salmoides (EXOTIC)								
Total no of species	**12**	**6**	**10**	**5**	**5**	**5**	**13**	**8**
Introduced species	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**

(u) Upper section of floodplain only.

Overhanging vegetation and undercut river banks are the preferred cover for the majority of floodplain fish species. *C. gariepinus*, *B. paludinosus*, *B. trimaculatus*, *O. mossambicus*, *Pseudocrenilabrus philander* and *Tilapia sparrmanii* are good colonizers (r-selected species), and are able to exploit the new aquatic conditions that arise when the floodplain is inundated (Kleynhans, 1991). These species have a wide habitat preference and could be considered opportunistic.

Three species, *M. macrolepidotus*, *B. paludinosus* and *A. johnstoni* are moderately intolerant to modified water quality. *A. johnstoni* prefers densely vegetated shallow waters (Steenkamp et al., 2001). The species feeds on neustonic organisms and therefore mainly utilize the upper 10 cm of the water to feed. Accordingly, the species is extremely vulnerable to the spraying of insecticides (especially those aimed at killing mosquito larvae) and other pollutants (Kleynhans, 1986).

Present Ecological State and Motivation

Results

The results produced by the three fish indices ranged from PES classes C (moderately modified) to E (seriously modified) (Table 32). FRAI seemed to be the most applicable method under the circumstances, but a score of 31,07% (Class E) presumably underestimates the biological integrity of RU2, most probably as a result of problems experienced with fish sampling techniques (see Vlok et al., 2005). A PES classification of **Class D,** or **largely modified,** is more realistic. Confidence in this result is low.

Table 32 Results for the different fish indices applied to calculate the PES for Resource Unit 2 as based on fish.

Fish Index	River segment	Fish PES Class	Description
FAII	RU2	D (50.17%	Largely modified
Qualitative FAII	RU2	C (68.6%)	Moderately modified
FRAI	RU2	E (31.07%)	Seriously modified
Decision	**RU2**	**D**	**Largely modified**

Motivation

The following could have contributed to the deviation from natural conditions as indicated by the fish indices:

- Eight of the 13 expected fish species were recorded.
- The loss of 2 sensitive fish species, *Barbus brevipinnis*, (IUCN Red listed as "vulnerable"; Skelton, 2001) and *M. macrolepidotus.*
- Complete loss of fish that are sensitive to conditions of no-flow.
- The loss of 3 species that are considered to be sensitive to modified water quality. (The 6 tolerant species were all present at the time of sampling).
- Complete loss of species with a very high preference for slow shallow and slow deep habitat.
- Complete loss of species preferring substratum cover.
- Problems experienced with sampling techniques.

The low scores of the fish assessments could, therefore, be as a result of the absence of species sensitive to changes in flow, modified water quality and substratum cover.

6.8 People-ecosystem interactions

No social data or references to socio-economic studies conducted on the Nyl River system could be found during the literature search for the compilation of this document.

6.9 Summary

For the purpose of this study, the Nyl River was divided into two resource units (see Table 33), namely:

RU 1

From the origin of Groot Nyl and Klein Nyl Rivers to their confluence with Nyl River (quarternary catchments A61A to the beginning of A61B).

RU 2

Downstream of the confluence of the Groot Nyl/Klein Nyl and Nyl Rivers to Moorddrift (quarternary catchments A61B to A61E).

Table 33 Identification of the Nylsvley study area and river segments (= resource units).

Specialist	**Study area**	**River segments**			
		1	**2**	**3**	**4**
Hydrology		Klein Nyl H6H006	Middelfontein spruit H6H020	Bad se loop spruit H6010	
Geohydrology	Whole catchment	Groot Nyl – Nylsvley NT	Nylvley NR		Moorddrift
Geomorphology		Groot Nyl – Nylsvley Nat Res	Nylsvley NR – Moorddrift		
Water quality	Groot Nyl - Moorddrif	Groot Nyl A6H011 – Klein Nyl Confluence	Klein Nyl		Moorddrift
Riparian veg		A61A Groot Nyl	A61B Middelfontein spruit		A61G Moorddrift
Invertebrates		Groot Nyl – Nylsvley NR	Nylsvley		Moorddrift
Fish		Groot Nyl – Klein Nyl Confluence	Nylsvley NR – Bad se loop	Bad se loop - Moorddrift	
Socio-economic		Western Bekenveld 7.03 A61A	8.01 A61BCDE Bushveld Basin		
Decision		Groot Nyl up to Klein Nyl Confluence Mountains	Klein Nyl & Groot Nyl Confluence to Moorddrift A61E Floodplain		

Resource Unit 1
The Present Ecological Status of this river section, based on the means of the individual scores of the specialists (exclusing the socio-economic attribute; see Table 34), was largely natural, with few modifications. A PES Category B was assigned. Confidence in this result was, however, moderately low. Half of the specialists indicated that river conditions in RU1 are degrading.

The EIS for RU1 was determined to be "moderate" (score of 2), possibly relating to an EIS Category C (Table 35). Based on biodiversity, this river section is, therefore, considered to be ecologically important or unique at a provincial or local scale. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

An AEM Category B was assigned to RU1, based on the fact that the PESC (B) was higher than the DESC (C). The AEMC was then used as an input into the hydrological model of Hughes and Münster (1999) and also used in DRIFT as a comparison. According to the Hughes DSS, 30.64% of the MAR should be left in the river, compared to the more than 50 – 58% indicated by the DRIFT model (Table 35).

Resource unit 2
The mean score of the respective attributes considered for the PESC, was 2.6 (Table 34), putting RU2 in a PES Category C. Resource Unit 2 is, therefore, considered to be moderately modified, mainly as a result of the loss of natural habitats. Confidence in this result was moderately low. The majority of specialists indicated a degrading tendency in river conditions.

Resource Unit 2 was considered to of high ecological importance and sensitivity (possibly a category B; see Table 35). Based on the biota and habitat availability, this section of the Nyl River may be sensitive to flow modifications. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

As the PESC for RU2 was lower than the DESC, the possibility of attaining the DESC had to be assessed. Based on Gonzalez (1996), the chances of attaining the DESC, are moderately good. An AEMC B was accordingly assigned, and then used as an input into the updated hydrological model of Hughes and Münster (1999).

Table 34 Identification of the present ecological status category (PESC) for the Nyl River.

Specialist fields	PES (0 – 5)*		Confidence (1 – 4)#		Motivation		TRAI of change -/0/+◊		Attainable improvement (0 – 5)		Confidence (1 – 4)#	
	RU1	RU2	RU1	RU2	RU1	RU2	RU1	RU2	RU1	RU2	RU1	RU2
Hydrology	4	1	3	3	Probably no dams or change, high up in catchment	Change from perennial to non-perennial	-	-	4	2	4	2
Geohydrology	5	4	3	3	Low stress from recharge or abstraction, can put no boreholes in catchment	Not lot of abstraction from boreholes	0	0	5	4	3	3
Geomorphology	3	2	1	1	High lining, sedimentation low, low human intervention	Larger amount of human intervention	0	-	4	3	3	3
Water quality	4	3	3	2	Upper catchment, limited human impact but still sewage from squattercamps	Higher human pressure, agriculture, etc.	-	-	4	3	3	3
Riparian veg	3	3	3	3	Weirs, collection of fire wood, fieldfires (lack and high frequency) road construction, alien vegetation	Low flow, abstraction from dam, agriculture, cultivated lands in floodplains, gracing, roads, bush encroachment	-	-	4	3	3	3
Invertebrates	3	3	1	1	Wrong methodology used, invertebrates in good conditions (assumption)	Water quality and abstraction, flow is low	0	0	3	3	2	2
Fish	3	2	1	1	Loss of sensitive species; loss of species with high preference for substrate cover	Complete loss of species sensitive to conditions of no-flow; loss of species with high preference for slow flowing habitat and substrate cover	-	-	4	3	2	2
Socio-economic (not included in mean PES score)	2	2	2	2	Population pressure, high levels of consumption, influx through informal settlement or urbanisation	Population pressure, high levels of consumption, influx through informal settlement or urbanisation	-	-	2	2	2	2
Mean score	3.6	2.6	2.1	2.0					3.8	2.9	2.8	2.5

* (0=critically modified; 1=seriously modified; 2=largely modified; 3=moderately modified; 4=largely natural; and 5=natural/unmodified)
# (1=marginal/low confidence; 2=moderate confidence; 3=high confidence; and 4=high confidence)
◊ (“-“=negative change; “0”=no change; and “+”=positive change)

Table 35 Identification of the Attainable Management Class and EWR for the Nyl River.

System	EISC	PESC	AEMC	HI	Hughes (2002)	DRIFT
Nyl RU 1	2 (Possibly C)	3.6 B	B	9.1	30.64 %	> 50 – 58% MAR
Nyl RU 2	3 (Possibly B)	2.6 C	B	13.2	29.16 %	

The model indicated that 29.16% of the MAR should be left in the river (Table 35). The large discrepancy between the outputs of the two hydrological models, confirms the uncertainty surrounding the use of existing models on non-perennial rivers.

7. LIMPOPO RIVER

7.1 Introduction

A Desktop reserve determination, following the methodology as set out in Chapter 3, was performed on the Limpopo River, as prescribed in the Terms of Reference. Due to the nature of this study, no field visit or sampling was done. The respective experts involved in the study were, therefore, dependent on existing data sources. Accordingly, the confidence in the results produced by the determination is low.

The study area was divided into three resource units (RUs): the first stretching from the confluence of the Marico and Crocodile Rivers downstream to the Limpopo-Mokolo confluence, the second from below the Limpopo-Mokolo confluence to the confluence with the Sashe River and the third RU stretches from below the Sashe-confluence to where the Luvuvhu River joins the Limpopo.

A summary by each specialist regarding reference conditions, availability and quality of data used to determine the PESC for each resource unit, follows.

The EISC was also determined through the input of the various specialists. A summary of the PESC, EISC and AEMC for the Limpopo River, is provided at the end of the chapter.

7.2 Hydrology and Geohydrology

The study area was divided into two sections (using geomorphology), namely from Quaternary A41D to A50J (split at Mogalakwena River confluence to the Limpopo River) and from A63C to A80J (border).

From a geological point of view, four aquifer types exist: the intergranular aquifer system, the sedimentary aquifer system, the crystalline system and the alluvium aquifer along the Limpopo River. From a geohydrological viewpoint, the alluvium aquifer is the most important regarding groundwater abstraction. A large area is irrigated from boreholes drilled into this alluvium aquifer.

Flows measured at Beitbrug (gauge A7H004) from 1956 to 1980 (Table 36) show that, in 70 of the 300 months, no flow occurs at this gauge (i.e. 23% of the time).

A comparison between the time of no flows in the Limpopo and the Mogalakwena Rivers, show that they are very similar (23 versus 25%).

It is also expected that in the case of the Limpopo River, groundwater plays a very important role in sustaining the water pools during times of no flow in the river.

Table 36 Monthly flows in the Limpopo River at Beit Bridge.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1956	16	12	97	388	164	519	232	84	52	28	12	8
1957	11	23	112	156	40	1388	102	32	15	63	43	27
1958	97	33	9	1383	404	211	20	11	0	0	0	0
1959	0	0	502	1697	297	284	39	2	0	0	0	0
1960	0	0	75	22	25	17	0	0	0	0	0	0
1961	0	181	304	295	505	488	303	78	29	17	3	0
1962	1	0	0	116	9	1	46	4	0	0	0	0
1963	0	436	148	157	11	38	137	1	1	2	1	0
1964	0	0	26	6	1	0	0	0	0	0	0	0
1965	22	67	283	4	8	4	0	0	0	0	0	0
1966	0	20	15	464	1500	29	0	0	0	0	0	11
1967	0	114	66	1488	3588	403	835	242	67	41	19	12
1968	2	0	0	0	57	10	6	4	0	0	0	0
1969	0	0	49	8	82	279	56	3	0	0	0	0
1970	151	15	205	29	152	5	2	1	0	0	0	0
1971	0	35	69	1031	187	136	122	44	13	1	0	0
1972	0	79	149	982	675	279	180	30	16	7	2	0
1973	0	8	0	0	39	16	1	0	0	0	0	1
1974	0	15	707	991	783	617	149	63	16	5	2	0
1975	0	55	371	218	1356	797	634	250	99	51	29	11
1976	2	0	84	309	767	887	849	413	149	86	52	19
1977	65	85	33	24	876	1114	312	120	55	37	25	17
1978	25	15	315	1605	1745	1339	367	175	93	57	30	16
1979	25	79	26	40	11	243	3	0	0	0	0	0
1980	9	3	76	181	335	422	53	11	2	0	0	0

7.3 Geomorphology

A set of maps (Figures 29 to 33) provide a summary of the geomorphology of the study area. The maps were compiled from various sources and comprise the physical terrain (a DTM), geology, a terrain description and land-use of the Limpopo River catchment (South African part). All maps are overlain by the secondary catchments for easy reference.

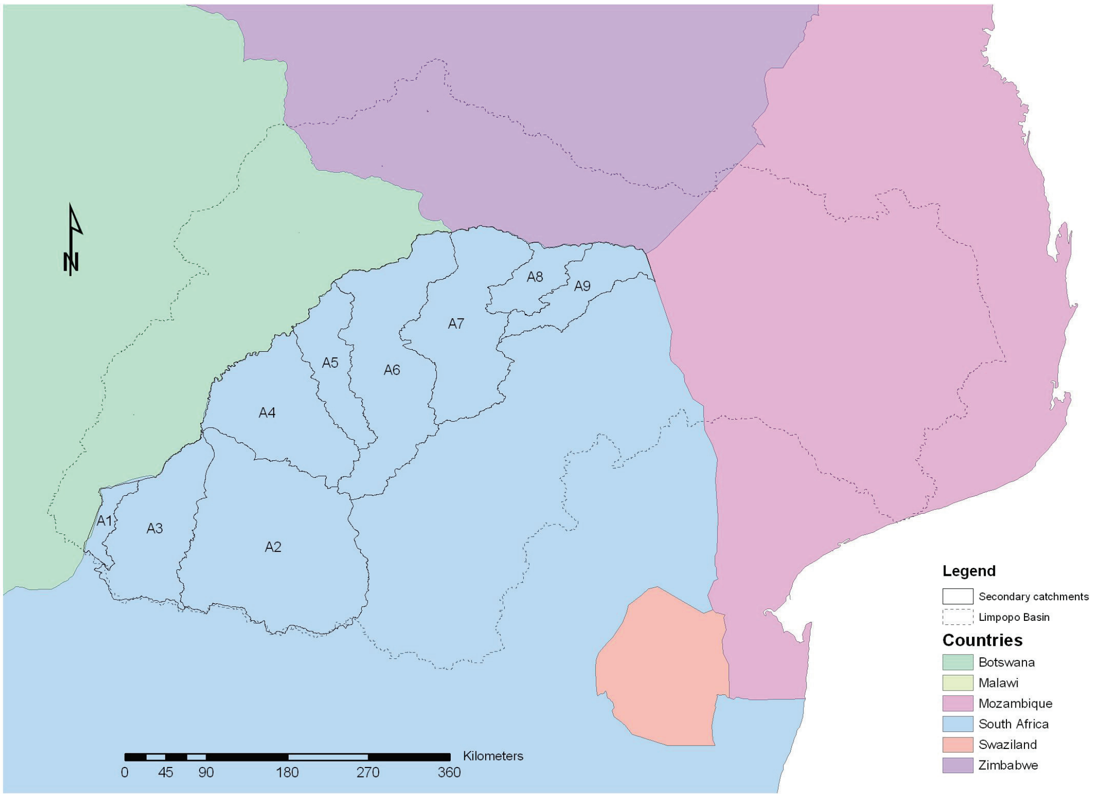

Figure 29 Quaternary catchments of the Limpopo River catchment.

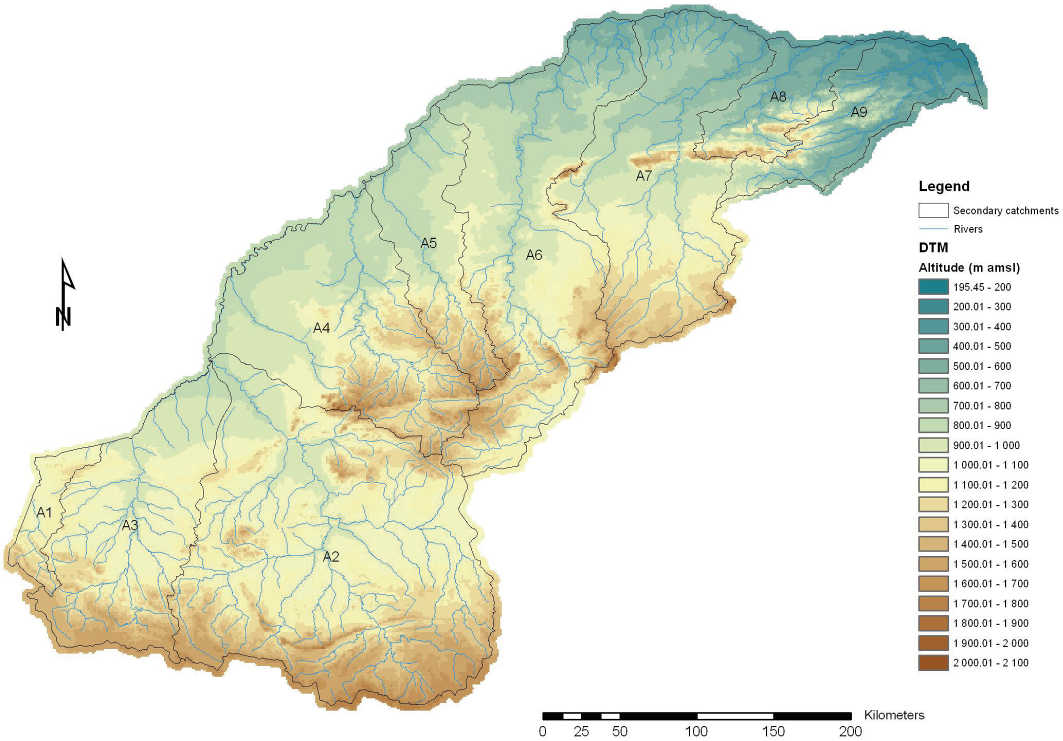

Figure 30 Altitudes in the Limpopo River catchment.

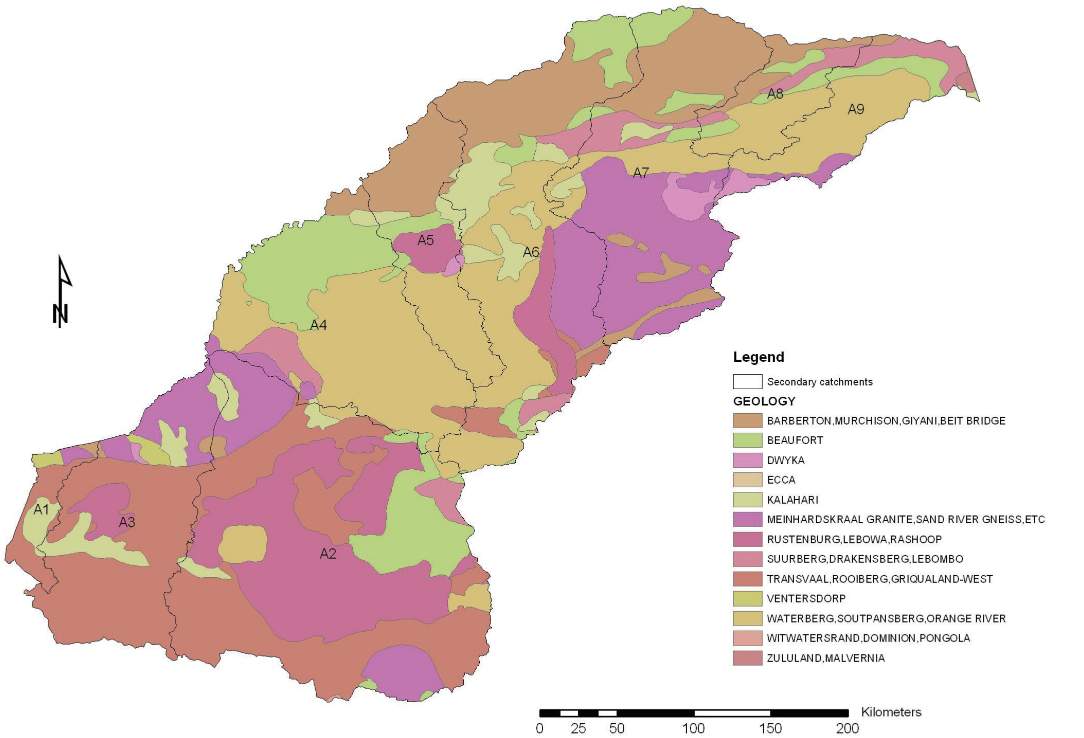

Figure 31 Geology of the Limpopo River catchment.

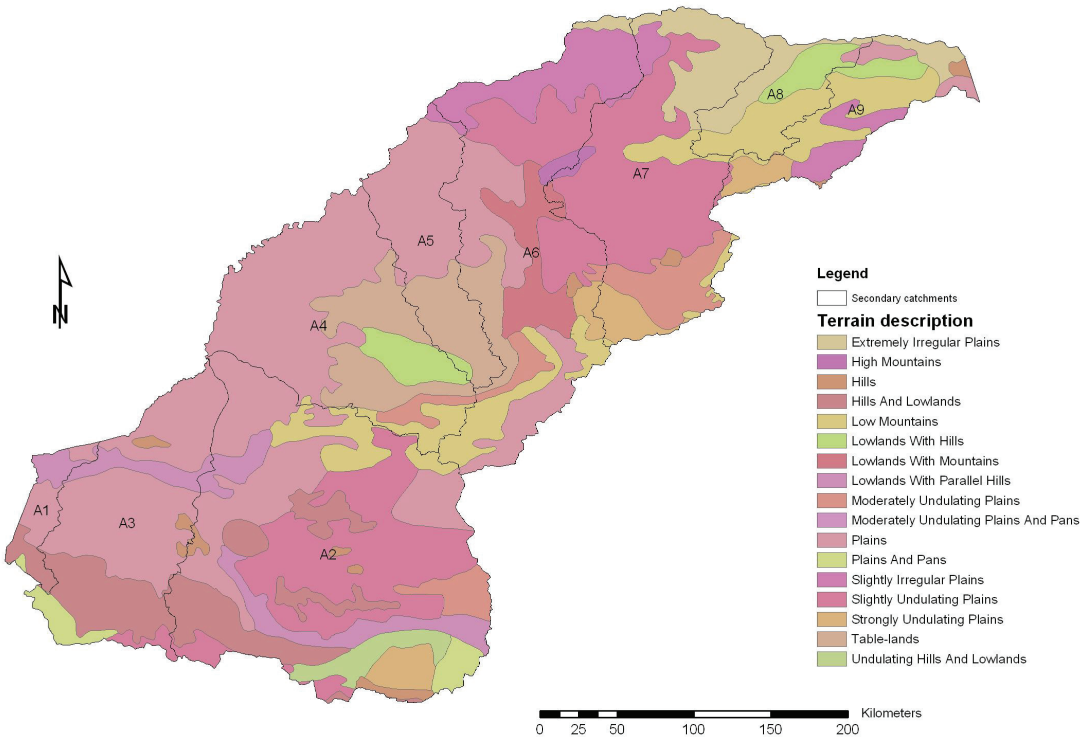

Figure 32 A terrain description of the Limpopo River catchment.

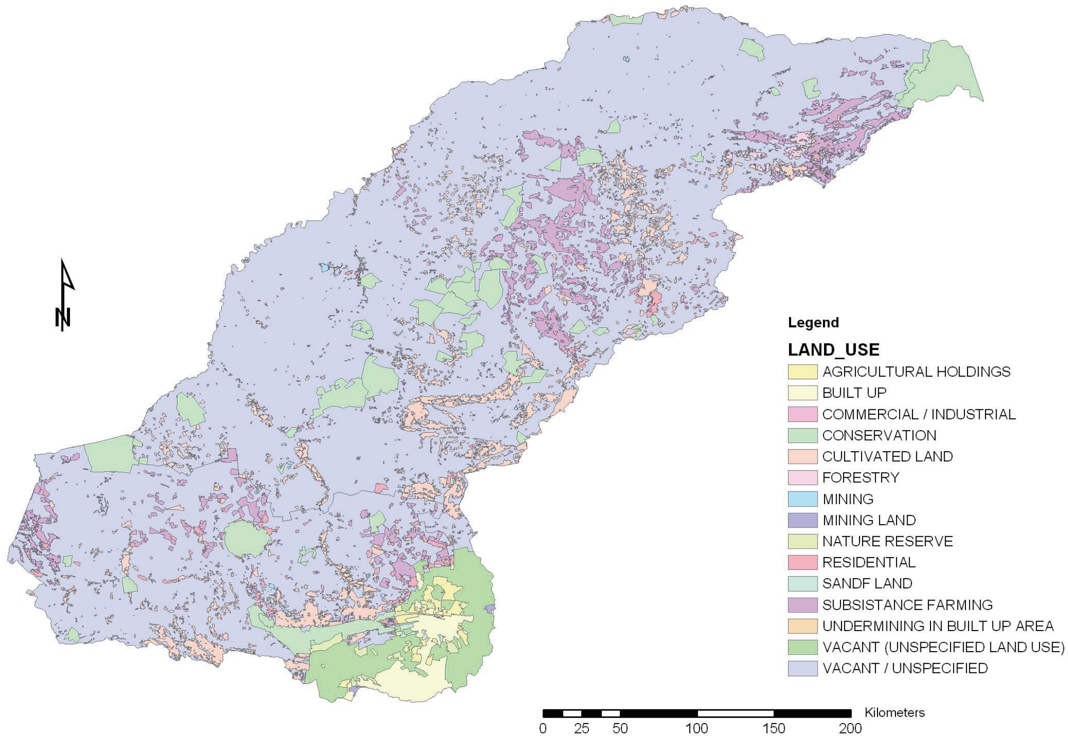

Figure 33 Land use in the Limpopo River catchment.

Resource Unit 1

Secondary catchments A1 – A3

Data available and assessment of quality of data

The environmental potential atlas of South Africa (ENPAT) (DEAT 2001) was used for most of the data represented in this report. Land cover data were obtained from the CSIR (SAC, 1999). Digital terrain models were constructed from Shuttle Radar Topography Mission (SRTM) data (USGS, 2004). ENPAT data were digitised from 1:250 000 scale maps and can be used at this and smaller scales. SRTM data are available in 3 arc second grids and are accurate within acceptable standards (JPL, 2004).

Present Ecological State and Motivation

PES: 3, Confidence: 2

Dams, bridges and human activity will impact negatively on the processes in the river.

Resource Unit 2

Secondary catchments A4 – A6

Data available and assessment of quality of data

The environmental potential atlas of South Africa (ENPAT) (DEAT, 2001) was used for most of the data represented in this report. Land cover data were obtained from the CSIR (SAC, 1999). Digital terrain models were constructed from Shuttle Radar Topography Mission (SRTM) data (USGS, 2004). ENPAT data were digitised from 1:250 000 scale maps and can be used at this and smaller scales. SRTM data are available in 3 arc second grids and are accurate within acceptable standards (JPL, 2004).

Present Ecological State and Motivation

PES: 3, Confidence: 2

Dams, bridges and other human activity will have a negative impact on the geomorphic processes in the river

Resource Unit 3

Secondary catchments A7 – A9

Data available and assessment of quality of data

The environmental potential atlas of South Africa (ENPAT) (DEAT, 2001) was used for most of the data represented in this report. Land cover data were obtained from the CSIR (SAC, 1999). Digital terrain models were constructed from Shuttle Radar Topography Mission (SRTM) data (USGS, 2004). ENPAT data were digitised from 1:250 000 scale maps and can be used at this and smaller scales. SRTM data are available in 3 arc second grids and are accurate within acceptable standards (JPL, 2004).

Present Ecological State and Motivation

PES: 2 Confidence: 2

High human impacts such as irrigation have a negative impact on the river.

7.3 Water Quality

Resource Unit 1

Data available and assessment of quality of data

Fairly good data. Period of data for A5H006: 1980 – 2002 (153 data points) (Table 37).

Summary of data

From the data available (see table 38), no major water quality problems were evident.

Present Ecological State and Motivation

PES: A/B category.

Table 37 Sampling sites in the Limpopo River catchment.

Station code	Location	Flow data*	Period of Data	Chem data	Period of Data	No. of Data Points
A4H012	Limpopo @ Olifants-hoek/Buffelsdrif	No	–	Yes	2000-10-09	1
A5H003	Limpopo @ Botswana	Yes	1994-10-01 2002-04-16	?		
A5H006	Limpopo @ Botswana Sterkloop (22:56:6S; 28:0:15E)	Yes	1971-03-12 2003-03-04	Yes	1980-02-11 2002-06-11	153
A5H007	Limpopo @ Sterkloop	ND	–	–	–	–
A5H009	Limpopo @ Villa	No	–	?		
A6H034	Limpopo @ Pont Drift (-22.2144; 29.13944)	No	–	Yes	1994-01-18 1994-03-14	5
A7H004	Limpopo @ Beit Bridge (-22.2239; 29.98722)	Yes	1955-1980 1980- 1992	Yes	1980-01-10 1993-12-14	44
A7H008	Limpopo @ Beit Bridge (Downstream) 22:13:32S; 29.59:26E)	Yes	1992-07-28 2002-06-13	Yes	1993-02-16 2004-04-20	66

* Monthly averages   ND = Not on DWAF database system

Table 38 Rapid status assessment of Limpopo River at Botswana Sterkloop (A5H006).

Variable	Concentration or range	Assessment category
Total dissolved salts (TDS)	Median monthly: min = 110; max = 185 mg/ℓ	**A / B** (0 – 163); (163 – 228)
PH	Median monthly: Min = 6.7; max = 7.6	**A** (6.5 – 7.5)
Ammonia (un-ionised)	~ 5 µg/L	**A** (<7)
F	Max = 0.86; Mean = 0.28 mg/ℓ	TWQR < 0.75
SP	Average summer SP =18 µg/L	**B** (mesotrophic; 5 – 25)
TIN	Average summer TIN = 0.11 mg/ℓ	**A** (Oligotrophic, <0.5)
TIN:SP	6.5 (Median TIN = 0.11; SP = 0.017)	**D** (SP <0.05; TIN:SP <10:1)
SP/TP (%)	No TP Data	–
TIN:TP	No TP data	–
Dissolved Oxygen	No data	–

TIN = total inorganic nitrogen (ammonium + nitrate); TP = Total phosphorus; SP = soluble phosphate (PO_4-P)

Resource Unit 2

Data available and assessment of quality of data

Period of data for A7H008: 1993-02-16 to 2004-04-20, number of data points, 66 (Table 39). The availability of data proved to be a problem, as only 66 data points were available over a 10 year period.

Summary of data

See Table 39 for a summary of the available data.

Table 39 Rapid status assessment of Limpopo River at Beit Bridge - downstream (A7H008).

Variable	Concentration or range	Assessment category
Total dissolved salts (TDS)	Median monthly: min = 150; max = 540 mg/ℓ	**C / D** (228 – 325); (325-520)
PH	Median monthly: Min = 7.55; max = 8.5	**B / C** (7.5 – 8.0); (8.0 – 8.5)
Ammonia (un-ionised)	~ 10 µg/L	**B** (<15)
F	Max = 0.64; Mean = 0.324 mg/ℓ	TWQR < 0.75
SP	Average summer SP = 25 µg/L	**B** (mesotrophic; 5 – 25)
TIN	Average summer TIN = 0.07 mg/ℓ	**A** (Oligotrophic, <0.5)
TIN:SP	2.7 (Median TIN = 0.068; SP = 0.025)	**D** (SP <0.05; TIN:SP <10:1)
SP/TP (%)	No TP Data	–
TIN:TP	No TP data	–
Dissolved Oxygen	No data	–

TIN = total inorganic nitrogen (ammonium + nitrate); TP = Total phosphorus; SP = soluble phosphate (PO_4-P)

Present Ecological State and Motivation

PESC: B/C.

7.4 Riparian Vegetation

Resource Unit 1

Data available and assessment of quality of data

No quantitative data available.

Present Ecological State and Motivation

The present ecological state is a 3. The reasons are the grazing and trampling of the riparian vegetation.

Resource Unit 2

Data available and assessment of quality of data
No quantitative data available.

Summary of data
The Limpopo River is situated in the Savanna biome (Rutherford and Westfall, 1986). The main vegetation types drained by the Limpopo River and its tributaries are the Mopane Bushveld, Soutpansberg Arid Mountain Bushveld, Waterberg Moist Mountain Bushveld, Clay Thorn Bushveld, Sweet Bushveld, Mixed Bushveld (Van Rooyen and Bredenkamp, 1996). The upper reaches of the tributaries also drain the Rocky Highveld Grassland of the Grassland Biome.

Götze et al. (in press) described the riparian vegetation of a section of the Limpopo River.

Dominant types of riparian vegetation:
According to Götze et al. (in press) the riparian vegetation along the Limpopo River in the Vhembe-Dongola National Park seems to be the most disturbed vegetation of the National Park. This is due to the extensiveness of the linear landscape, high fertility of the soils and the consequent establishment of irrigation lands on the flood plains. Furthermore the destruction is caused by over utilization by small and large livestock and by migratory Tuli elephants from neighbouring Botswana.

The riparian vegetation according to Götze et al. (in press) can be classified into the following communities and sub-communities, namely:

A. The *Salvadora australis* – *Cucumis zeyheri* Community. This community can be subdivided into three sub-communities namely the:
   a) *Colophospermum mopane* – *Eragrostis trichophora* Sub-community (<u>Habitat</u>: very outskirts of the floodplain).
   b) *Indigastrum costatum* – *Setaria verticillata* Sub-community (<u>Habitat</u>: Level areas of the floodplain that get trampled to a fine dust),
   c) *Combretum imberbe* – *Abutilon ramosum* Sub-community (<u>Habitat</u>: Situated in the riverine forest, usually on heavy clayey soils)

B. The *Hyphaene petersiana* – *Acacia tortilis* Community. This community can be subdivided into two sub-communities namely the:
   a) *Ximenia americana* – *Flueggea virosa* sub-community (<u>Habitat</u>: Soils with a high silt content)
   b) *Cordia monoica* Sub-community (<u>Habitat</u>: Slightly drier habitat than the previous sub-community)

C. The *Croton megalobotrys – Combretum microphyllum* Community. This community can be subdivided into two sub-communities namely the:

a) *Cenchrus ciliaris – Faidherbia albida* sub-community (Habitat: Occurs on riverbanks that get regularly flooded. Flood debris and alluvial sandbanks usually cover the soil surface). Reedbeds (*Phragmites australis* clumps also occur in this sub-community)

b) *Acacia schweinfurthii – Maytenus senegalensis* Sub-community (Habitat: Occurs in somewhat drier habitats as the previous sub-community. These areas are less frequently flooded).

4. The *Diplachne fusca – Acacia xanthophloea* Community (Habitat: This community occurs on heavy, clayey duplex soils in non perennial pans and wetlands). These communities are restricted to sites where groundwater is forced to the surface by shallow bedrock or depressions such as pans where water accumulates after rains. Most of the species are typically plants capable of rooting in saturated soils.

Alien vegetation:

Alien plants along the Limpopo River are almost present in every sub-community forming dense stands in places. Prominent exotics are *Amaranthus* spp. *Datura* sp. *Flaveria bidentis, Chloris virgata,* and *Chenopodium album* (Götze et al., in press).

Flow impacts:

Riparian forests are well adapted to the natural variability in flow regimes. Average floods maintain the forests by providing essential nutrients and water. Long spells of drought could cause the water table to drop and older trees may die, opening up spaces for younger trees to fill (Jacobson et al., 1995).

In comparison to the Kuiseb River the Limpopo River drains a higher rainfall area. Regular rains in the form of thunderstorms supply the floodplain communities of water. The riparian vegetation is not so sensitive to change in the runoff from upstream regions caused by climatic change and dam building.

Episodic floods in the Limpopo also have the most long-lasting impacts on the structure of riparian forests. These floods demolish whole forest reaches, create new channels within the floodplain, and recharge groundwater (Jacobson et al., 1995)

Groundwater influence:

Groundwater stored in the river channel under the sand supports the riparian vegetation during dry periods after floods. The depth of the groundwater table beneath the alluvial soils plays an important role in structuring the vegetation communities and sub-communities.

Most of the wetland and pan systems drain towards the Limpopo River. The abstraction of groundwater from the areas in the catchment, construction of dams and the clearing of the vegetation for cultivation purposed contribute to the degradation of the especially the The *Diplachne fusca* – *Acacia xanthophloea* Community (Götze et al., in press).

Present Ecological State and Motivation
The present ecological state is a 3. The reasons are the grazing and trampling of the riparian vegetation.

Resource Unit 3

Data available and assessment of quality of data
No quantitative data available.

Present Ecological State and Motivation
The present ecological state is a 3. The reasons are the grazing and trampling of the riparian vegetation.

7.5 Invertebrates

Three resource units were chosen in the Limpopo River for the macroinvertebrate analysis. The influences of the tributaries (Crocodile, Marico, Mokolo and Shashe Rivers) were taken into account as well as the geomorphological zonation of the river.

Resource Unit 1

From Crocodile/Marico/Limpopo Confluence to Mokolo/Limpopo Confluence.
Ecoregion 1: Limpopo Plains. Ecoregion Level II : 1.04 &1.02 (Kleynhans et al., 2004).
Geomorphological Zone: Lowland River (Low gradient alluvial sand bed channel. Increased silt content in bed and banks) Slope = 0.0003 (Kleynhans & Moolman, 2004)
Tributaries include Crocodile, Marico, and Matlabas Rivers.
Invertebrate data from the Crocodile & Marico Rivers was used to determine the PESC for this Resource Unit.

Data available and assessment of quality of data

Habitat in Limpopo River in Resource Unit 1
The Limpopo River in this resource unit is narrow with a deep channel of 30-50m wide with tall trees, shrubs and grass lining the banks. Riverbed is mainly sand and mud (Jacobsen & Kleynhans, 1993). Various biotopes are therefore available for invertebrates in this resource unit namely marginal vegetation (grass), sand, mud and pools (water column).

NB: Invertebrates which prefer GSM, water column and vegetation would therefore be more abundant in this resource unit.

Data available

Data obtained from Angliss (2004b) on the Crocodile & Marico Rivers was used in this report. Only sites located in the same ecoregion, namely Limpopo Plains, were used in this analysis. Data from four sites in the Crocodile River and one site in the Marico River sampled in May 2004 was used (See Table 5.1). For details on the sites and SASS data please refer to Angliss (2004b).

Quality of data

An Invertebrate analysis of the Limpopo River is difficult due to the lack of data on the main stream of the river itself. Macroinvertebrate studies have been done by Angliss (2002, 2004a&b), Newenham & Chavalala (2003) and Palmer & O'Keefe (1994) in most of the South African tributaries of the Limpopo River namely the Crocodile, Marico, Mokolo (Mogol), Nzhelele and Luvuvhu Rivers. Data from these tributaries were used to predict the expected macroinvertebrate fauna in the Limpopo River.

Due to fact that the tributaries and pools in the Limpopo River serve as refugia for the invertebrates during dry periods it is relatively safe to assume that the invertebrates present in these tributaries would be found in the Limpopo River during periods of flow if the habitat preferred by these invertebrates are present.

It is however very difficult to predict which macroinvertebrates would be present during different seasons as this would rely on rainfall timing, area of wetted surface in river (are marginal vegetation and riffles biotopes etc available for invertebrates), distance of refugia (time it would take for invertebrates to recolonise river from refugia), length of dry period and length of wet period (at least a month of flow is required for macroinvertebrates to complete their life cycles). The difference in habitat diversity in the tributaries and the main stem of the Limpopo River also makes extrapolation of data difficult.

Summary of data

A summary of the invertebrates present in the Crocodile and Marico Rivers is presented in Table 40. Thirty of the 59 expected taxa were sampled in Crocodile and Marico Rivers. Only one sensitive family namely Philopotamidae, which prefers moderate water quality, fast flow and cobbles, was present.

Present Ecological State and Motivation

The Invertebrate Response Assessment Index (IRAI) (see Thirion, 2004) was followed to determine the PESC for Resource Unit 1. No SASS scores were used in the analysis as no reference condition could be determined due to lack of historical data and no reference site data in the main stream of the Limpopo River. No comparison of present SASS data and reference data could therefore be made. The confidence level of the PESC determination is therefore also low.

According to the IRAI method the PESC for invertebrates based on data for Crocodile and Marico Rivers falls in a Class C.

The majority of taxa expected preferring different flow, water quality and habitat types were present in the Crocodile and Marico Rivers.

Habitat diversity followed by flow modification was regarded as the major drivers in resource unit 1.

Resource Unit 2

From Mokolo/Limpopo confluence to Shashe/Limpopo confluence
Ecoregion: Limpopo Plains. Ecoregion Level II: 1.02 & 1.01 (Kleynhans et al., 2004)
Geomorphological Zone: Rejuvenated Foothills (steepened section within middle reaches of the river caused by uplift. Characteristics similar to foothills (gravel/cobble beds with pool-riffle/pool-rapid morphology). Slope 0.0017 (Kleynhans & Moolman, 2004)
Tributaries include Mokolo, Lephalala, Mogalakwena, Motloutse Rivers
Invertebrate data from Mokolo tributary was used to determine PESC for this resource unit.

Data available and assessment of quality of data

Habitat in Limpopo River in Resource Unit 2
The Limpopo Rivers widens (40-60m) downstream, especially after its confluence with the Mokolo River up to Motloutse River. Well vegetated islands occur along river with an extensive sand bed. Riverbed consists mainly of sand with some faults and dykes which form natural pools (bedrock). Riparian vegetation consists mainly of tall trees, grass, shrubs and small patches of reeds (Jacobsen & Kleynhans, 1993). Upstream of Shashe some weirs are found which are used for abstraction and some irrigation. Pools formed by these weirs could serve as refugia for invertebrates. From the Motloutse/Limpopo confluence to Shashe/Limpopo confluence, the Limpopo River widens (60-80 m) and pools occur sporadically.

NB: Invertebrates which prefer GSM, water column and vegetation would therefore be more abundant in this resource unit. Some invertebrates preferring bedrock or hard substratum habitat types could also occur in regions where faults and dykes cross the river.

Data Available
Data from twelve sites in Mokolo River and tributaries sampled from May to September 2002 by Mike Angliss was used in this report (for details on the sites and SASS data refer to Angliss, 2002). Only sites located in the same ecoregion, namely Limpopo Plains, were used in this analysis.

Quality of data

The Mokolo River is a tributary of the Limpopo River and extrapolating data from a tributary to a main stream should be done with caution. The habitat in the Mokolo River is also more diverse than in the Limpopo River. (See notes on quality of data in resource unit 1).

Summary of data

A summary of the invertebrates present in the Mokolo River is presented in Table 41.

Forty-nine of the 62 expected taxa were sampled in the Mokolo River. Four sensitive taxa namely Perlidae, Heptageniidae, Philopotamidae and Athericidae which all prefer high quality water, high to moderate flow and cobbles were present.

Present Ecological State and Motivation

The Invertebrate Response Assessment Index (IRAI) (see Thirion, 2004) was followed to determine the PESC for Resource Unit 2. No SASS scores were used in the analysis as no reference condition could be determined due to lack of historical data and no reference site data in the main stream of the Limpopo River. No comparison of present SASS data and reference data could therefore be made. The confidence level of the PESC determination is therefore also low.

According to the IRAI method the PESC for invertebrates in Resource Unit 2 falls in a Class B, based on data from the Mokolo River.

Only a few of the expected taxa preferring different flow, water quality and habitat types were absent in the Mokolo River.

The invertebrates in the Mokolo River are in a good condition and this could infer that the invertebrates in Resource Unit 2 of the Limpopo River would also be in a good condition as the Mokolo River has an influence on this section of the Limpopo River.

Angliss (2002) mentions that a number of sensitive invertebrate taxa were absent or only found in low numbers namely cased caddis, stoneflies and the diversity of mayflies was low.

Flow modification followed by habitat diversity was regarded as the major drivers in resource unit 2.

Table 40 Limpopo plains analysis of macroinvertebrates present in the Crocodile and Marico Rivers with water quality, habitat and flow preferences indicated
(After Angliss, 2004b and Thirion, 2004).
* = presence at sites sampled, Veg = Marginal & Aquatic vegetation,
GSM = Gravel, sand and mud, Wc = water Column, Cob = Cobbles

LIMPOPO RIVER RESOURCE UNIT 1		**Preferences for water quality, flow and habitat**	**Resource Unit 1**			
FAMILY	**SASS4 tolerance score**	**Water Quality**	**Habitat**	**Flow**	**Crocodile (4 Sites)**	**Marico (1 site)**
ANNELIDA						
Oligochaeta	1	No	Gsm	0.1-0.3	**	*
CRUSTACEA						
Potamonautidae	3	No	Cob	0.3-0.6	*	*
Atyidae	8	Mod	Veg	?	*	*
HYDRACARINA	**8**	Mod	Veg/gsm	medium	*	
EPHEMEROPTERA						
Baetidae sp	4-12	No	All	>0.6?	****	*
Caenidae	6	Low	Gsm	<0.1?		*
Leptophlebiidae	9	Mod	Cob	<0.1	**	
ODONATA						
Coenagrionidae	4	Low	Veg	0.3-0.6	****	*
Aeshnidae	8	Mod	Cob	Slow-fast	*	*
Corduliidae	8	Mod	Gsm	0.1-0.3	**	
Gomphidae	6	Low	Gsm	0.3-0.6	****	*
Libellulidae	4	Low	Cob	0.3-0.6	***	
HEMIPTERA						
Belostomatidae	3	No	Veg	<0.1	****	*
Corixidae	3	Mod	Wc	0.1-0.3		*
Gerridae	5	Mod	Wc	<0.1	**	*
Hydrometridae	6	Mod	Wc	<0.1	*	
Naucoridae	7	Low	Wc	0.3-0.6	****	
Nepidae	3	No	Veg	<0.1		*
Notonectidae	7	No	Wc	<0.1	*	*
Pleidae*	4	Low	Veg	<0.1		
Veliidae/M…veliidae	5	Mod	Wc	<0.1	****	*
TRICHOPTERA						
Hydropsychidae 1 sp	4	Low	Cob	>0.6	***	
Philopotamidae	10	Mod	Cob	>0.6	*	
Leptoceridae	6	Low	Veg	0.3-0.6	***	
COLEOPTERA						
Dytiscidae	5	Low	Wc	<0.1	***	*
Gyrinidae	5	Low	Wc	>0.6	****	*
Hydrophilidae	5	Low	Veg	Slow?	*	
DIPTERA						
Ceratopogonidae	5	Low	Cob	>0.6	*	*
Chironomidae	2	No	Gsm?	0.1-0.3	****	*
Simuliidae	5	Low	Cob	>0.6	****	
GASTROPODA						
Lymnaeidae*	3	No	Veg	<0.1		*
Thiaridae*	3	No	Veg	<0.1		*
PELECYPODA						
Corbiculidae (rings)	5	Low	Gsm	0.1-0.3	*	

Table 41 Limpopo plains analysis of macroinvertebrates present in the Mokolo River with water quality, habitat and flow preferences indicated
(After Angliss, 2002 and Thirion, 2004). (* = presence at sites sampled, Veg = Marginal & Aquatic vegetation, Gsm = Gravel, sand and mud, Wc = water Column, Cob = Cobbles).

LIMPOPO RIVER RESOURCE UNIT 2		**Preferences for water quality, flow and habitat**			**Resource Unit 2**
FAMILY	**SASS4 tolerance score**	**Water Quality**	**Habitat**	**Flow**	**Mokolo) (12 Sites)**
TURBELLARIA	3	No	Cob	>0.6	****
ANNELIDA					
Oligochaeta	1	No	Gsm	0.1-0.3	*****
Leeches	3	No	Cob	0.1-0.3	***
CRUSTACEA					
Potamonautidae	3	No	Cob	0.3-0.6	**********
Atyidae	8	Mod	Veg	?	*********
HYDRACARINA	8	Mod	Veg/gsm	medium	******
PLECOPTERA					
Perlidae	12	High	Cob	>0.6	********
EPHEMEROPTERA					
Baetidae sp	4-12	No	All	>0.6?	************
Caenidae	6	Low	Gsm	<0.1?	***
Heptageniidae	13	High	Cob	0.3-0.6	********
Leptophlebiidae	9	Mod	Cob	<0.1	********
ODONATA					
Chlorocyphidae	10	Mod	Cob	0.1-0.3	******
Chlorolestidae	8	Mod	Veg	<0.1	
Coenagrionidae	4	Low	Veg	0.3-0.6	**********
Lestidae	8	Mod	Veg	<0.1	****
Aeshnidae	8	Mod	Cob	Slow-fast	****
Corduliidae	8	Mod	Gsm	0.1-0.3	**
Gomphidae	6	Low	Gsm	0.3-0.6	************
Libellulidae	4	Low	Cob	0.3-0.6	********
HEMIPTERA					
Belostomatidae	3	No	Veg	<0.1	****
Corixidae	3	Mod	Wc	0.1-0.3	***
Gerridae	5	Mod	Wc	<0.1	***
Hydrometridae	6	Mod	Wc	<0.1	***
Naucoridae	7	Low	Wc	0.3-0.6	******
Nepidae	3	No	Veg	<0.1	***
Notonectidae	7	No	Wc	<0.1	**8
Veliidae/M…veliidae	5	Mod	Wc	<0.1	************
TRICHOPTERA					
Ecnomidae	8	Mod	Cob	0.1-0.3	*
Hydropsychidae 1 sp	4	Low	Cob	>0.6	*********
Philopotamidae	10	Mod	Cob	>0.6	*
Lepidostomatidae	10	Mod		0.1-0.3	*
Leptoceridae	6	Low	Veg	0.3-0.6	*********
COLEOPTERA					
Dytiscidae	5	Low	Wc	<0.1	********
Elmidae/Dryopidae	8	Mod	Cob	0.3-0.6	********
Gyrinidae	5	Low	Wc	>0.6	********
Hydrophilidae	5	Low	Veg	Slow?	*

Table 421 (Continued) Limpopo plains analysis of macroinvertebrates present in the Mokolo River with water quality, habitat and flow preferences indicated (After Angliss, 2002 and Thirion, 2004).

LIMPOPO RIVER RESOURCE UNIT 2		**Preferences for water quality, flow and habitat**			**Resource Unit 2**
FAMILY	**SASS4 tolerance score**	**Water Quality**	**Habitat**	**Flow**	**Mokolo) (12 Sites)**
DIPTERA					
Athericidae	10	Mod	Cob	>0.6	**
Ceratopogonidae	5	Low	Cob	>0.6	*****
Chironomidae	2	No	Gsm?	0.1-0.3	***********
Culicidae	1	No	Wc	<0.1	**
Dixidae	10	Mod	Wc	<0.1	*
Simuliidae	5	Low	Cob	>0.6	***********
Tabanidae	5	Low	Gsm	0.1-0.3	*********
Tipulidae	5	Low	Gsm	0.1-0.3	
GASTROPODA					
Ancylidae	6	Low	`bed	all	*
Lymnaeidae*	3	No	Veg	<0.1	***
Planorbinae*	3	No	Veg	<0.1	***
Thiaridae*	3	No	Veg	<0.1	**
PELECYPODA					
Corbiculidae (rings)	5	Low	Gsm	0.1-0.3	******
Sphaeriidae	3	No	Gsm	0.1-0.3	*
Unionidae	6	Low	Gsm	0.1-0.3	*

Resource Unit 3

From Shashe/Limpopo confluence to Luvuvhu/Limpopo Confluence
Ecoregion: Limpopo Plains Ecoregion Level II: 1.01 (Kleynhans et al*.,* 2004)
Geomorphological Zone: Rejuvenated Foothills Slope 0.0014 (Kleynhans & Moolman, 2004)
Tributaries include Shashe, Sand, Umzingwane, Nzhelele, Nwanedzi and Luvuvhu Rivers.
Invertebrate data from Nzhelele and Luvuvhu Rivers was used to determine the PESC for this Resource Unit.

Data available and assessment of quality of data

Habitat in Limpopo River in Resource Unit 3
Downstream of the Shashe River the Limpopo River changes with a width of 600m at places. An extensive sandbed is present which can be up to 20m deep. Large densely vegetated islands occur. Some eroded rock pools and bedrock pools occur in this area. Trees and some small reed patches are found. A few weirs are found downstream of Shashe and these are almost completely filled with sand (Jacobsen & Kleynhans, 1993).

Some floodplain areas are present where backflows from tributaries occur. The flow from the tributaries sustains the subterranean water on which the riparian vegetation is dependant (Kleynhans & Moolman, 2004).

NB: Invertebrates which prefer GSM, water column and vegetation would therefore be more abundant in this resource unit. Some invertebrates preferring bedrock or hard substratum habitat types could also occur in regions where faults and dykes cross the river.

Data available

Data obtained from Angliss (2004a) on the Nzhelele River was used in this report.
Only sites located in the same ecoregion, namely Limpopo Plains, were used. Data from four sites in Nzhelele River, sampled in July 2002, June, September & November 2003 and March & July 2004, was used (for details on the sites and SASS data refer to Angliss, 2004a)

Data from two sites in the Luvuvhu River in the Limpopo Plains ecoregion was used in this report. Both sites are situated in the rejuvenated foothills zone. The data used was collected by Newenham & Chavalala from 1999 to 2000 and published in a Water Research Commission Report in 2003 (Newenham and Chavalala, 2003).

Summary of data

A summary of the invertebrates present in the Nzhelele and Luvuvhu Rivers is presented in Table 42.

Fifty-seven of the 65 expected taxa were sampled in the Nzhelele and Luvuvhu Rivers.

Four sensitive taxa namely Palaemonidae, Heptageniidae, Oligoneuridae and Athericidae which all prefer high to moderate water quality, high to moderate flow and cobbles were present.

Present Ecological State and Reasons

The Invertebrate Response Assessment Index (IRAI) (see Thirion, 2004) was followed to determine the PESC for Resource Unit 3. No SASS scores were used in the analysis as no reference condition could be determined due to lack of historical data and no reference site data in the main stream of the Limpopo River. No comparison of present SASS data and reference data could therefore be made. The confidence level of the PESC determination is therefore also low.

According to the IRAI method the PESC for invertebrates in Resource Unit 3, based on data for Nzhelele and Luvuvhu Rivers, falls in Class C.

Table 432 Limpopo plains analysis of macroinvertebrates present in the Nzhelele & Luvuvhu Rivers with water quality, habitat and flow preferences indicated (After Angliss, 2004a; Newenham & Chavalala, 2003 and Thirion, 2004). (* = presence at sites sampled, Veg = Marginal & Aquatic vegetation, Gsm = Gravel, sand and mud, Wc = water Column, Cob = Cobbles).

LIMPOPO RIVER RESOURCE UNIT 3		**Preferences for water quality, flow and habitat**			**Resource Unit 3**	
FAMILY	**SASS4 tolerance score**	**Water Quality**	**Habitat**	**Flow**	**Levuvhu (2 sites)**	**Nzhelele (4 sites)**
TURBELLARIA	**3**	No	Cob	>0.6	*	
ANNELIDA						
Oligochaeta	1	No	Gsm	0.1-0.3	**	****
Leeches	3	No	Cob	0.1-0.3	**	**
CRUSTACEA						
Potamonautidae	3	No	Cob	0.3-0.6	**	****
Atyidae	8	Mod	Veg	?	**	**
Palaemonidae	10	Mod	Cob	>0.6		***
HYDRACARINA	**8**	Mod	Veg/gsm	medium	**	*
PLECOPTERA						
Perlidae	12	High	Cob	>0.6	**	
EPHEMEROPTERA						
Baetidae sp	4-12	No	All	>0.6?	**	****
Caenidae	6	Low	Gsm	<0.1?	**	****,
Heptageniidae	13	High	Cob	0.3-0.6	**	*
Leptophlebiidae	9	Mod	Cob	<0.1	**	****
Oligoneuridae	15	High	Cob	>0.6	*	
Tricorythidae	9	Mod	Cob	>0.6	*	**
ODONATA						
Chlorocyphidae	10	Mod	Cob	0.1-0.3	**	*
Chlorolestidae	8	Mod	Veg	<0.1		*
Coenagrionidae	4	Low	Veg	0.3-0.6	**	****
Lestidae	8	Mod	Veg	<0.1		**
Zygoptera juvs.	6				*	
Aeshnidae	8	Mod	Cob	Slow-fast	*	***
Corduliidae	8	Mod	Gsm	0.1-0.3	**	**
Gomphidae	6	Low	Gsm	0.3-0.6	**	****
Libellulidae	4	Low	Cob	0.3-0.6	**	****
HEMIPTERA						
Belostomatidae	3	No	Veg	<0.1	*	****
Corixidae	3	Mod	Wc	0.1-0.3	**	****
Gerridae	5	Mod	Wc	<0.1	**	****
Hydrometridae	6	Mod	Wc	<0.1		*

Table 442 (Continued) Limpopo plains analysis of macroinvertebrates present in the Nzhelele & Luvuvhu Rivers with water quality, habitat and flow preferences indicated (After Angliss, 2004a; Newenham & Chavalala, 2003 and Thirion, 2004).

LIMPOPO RIVER RESOURCE UNIT 3		**Preferences for water quality, flow and habitat**			**Resource Unit 3**	
FAMILY	**SASS4 tolerance score**	**Water Quality**	**Habitat**	**Flow**	**Levuvhu (2 sites)**	**Nzhelele (4 sites)**
HEMIPTERA (Cont.)						
Naucoridae	7	Low	Wc	0.3-0.6	**	****
Nepidae	3	No	Veg	<0.1	**	*
Notonectidae	7	No	Wc	<0.1	**	****
Pleidae*	4	Low	Veg	<0.1	**	
Veliidae/M…veliidae	5	Mod	Wc	<0.1	**	****
TRICHOPTERA						
Ecnomidae	8	Mod	Cob	0.1-0.3		**
Hydropsychidae 1 sp	4	Low	Cob	>0.6	**	****
Hydroptilidae	6	Low	Cob	0.1-0.3	*	
Leptoceridae	6	Low	Veg	0.3-0.6	**	***
COLEOPTERA						
Dytiscidae	5	Low	Wc	<0.1	**	****
Elmidae/Dryopidae	8	Mod	Cob	0.3-0.6	**	***
Gyrinidae	5	Low	Wc	>0.6	**	****
Haliplidae	5	Low				**
Helodidae	12	High	Veg			*
Hydrophilidae	5	Low	Veg	Slow?	*	**
DIPTERA						
Athericidae	10	Mod	Cob	>0.6	**	
Ceratopogonidae	5	Low	Cob	>0.6	**	****
Chironomidae	2	No	Gsm?	0.1-0.3	**	****
Culicidae	1	No	Wc	<0.1	**	****
Dixidae	10	Mod	Wc	<0.1	**	
Muscidae	1	No	Wc	>0.6		**
Simuliidae	5	Low	Cob	>0.6	**	****
Tabanidae	5	Low	Gsm	0.1-0.3	**	****
Tipulidae	5	Low	Gsm	0.1-0.3	**	
GASTROPODA						
Ancylidae	6	Low	`bed	all	*	*
Lymnaeidae*	3	No	Veg	<0.1	**	***
Planorbinae*	3	No	Veg	<0.1	**	
Thiaridae*	3	No	Veg	<0.1		****
PELECYPODA						
Corbiculidae (rings)	5	Low	Gsm	0.1-0.3		**
Sphaeriidae	3	No	Gsm	0.1-0.3	**	

The majority of expected taxa preferring different flow, water quality and habitat types were present in the Nzhelele & Luvuvhu River. According to Davies et al. (1993) the Luvuvhu River was naturally perennial but is now seasonal, flowing for only a few weeks annually due to over-abstraction of water for irrigation and potable water supply beyond the western boundaries of the Kruger National Park. The river has been reduced to a stagnant trickle for approximately ten months of every year.
Flow modification followed by habitat diversity was regarded as the major drivers in resource unit 3.

7.6 Fish

Based on the geomorphological zonation (Rowntree and Wadeson, 1999) and the preliminary Level II ecoregions (C.J. Kleynhans and C. Thirion, pers. comm.), the study area was divided into three resource units (RU's). The upper Limpopo basin was divided into 2 RU's: the first stretching from the confluence of the Marico and Crocodile Rivers downstream to the Limpopo-Mokolo confluence, and the second from below the Limpopo-Mokolo confluence to the confluence with the Sashe River. The third RU stretches from below the Sashe-confluence to where the Luvuvhu River joins the Limpopo.

Resource Unit 1

Marico-Crocodile confluence, downstream to the Limpopo-Mokolo confluence;

Data available and assessment of quality of data
The list of expected fish species is based on surveys done on the lower sections of the Crocodile and Matlabas Rivers (Kleynhans, 1980), as well as on work done by Gaigher (1969, 1973) on the perennial upper sections of the Crocodile River and two sites on the Limpopo itself. No recent data for the Limpopo is available, and data from the lower Crocodile River (Angliss, 2004a) was used to compile a list of observed fish species. Only data from sampling sites occurring in the same Level II ecoregions as the Limpopo was considered.

Kleynhans (1984, 1996b, 2003, 2004), Russell (1997), Weeks et al. (1996) and Gaigher (1969, 1973) were consulted for information on the ecological requirements of the expected fish species.

Constraints in the application of the fish indices
Based on the data available, a PES could only be calculated for the lower Crocodile River. The list of expected species was adapted accordingly. Three fish indices were applied on the available data. Specific constraints with regards to each method are discussed below:

Fish Assemblage Integrity Index (FAII)

The FAII was developed for specific use in the River Health Programme, and may, therefore, not be ideally suited for use in EWR studies. Due to the lack of information on the health of the fish species present, this particular metric could not be considered.

Qualitative FAII

Two of the seven metrics ("the health/condition of native and introduced species" and "the in-stream habitat modification") could not be considered due to the lack of information. Results obtained from this index are therefore of low confidence.

Fish Response Assemblage Index (FRAI)

Due to the lack of information on the health/condition of the fish species, no deviances from the reference conditions were indicated. The absence of information on the instream habitat made interpretation of the results very difficult and impeded the identification of possible causes that could have contributed to a decrease in biological integrity.

Summary of data

Approximately 23 fish species are expected to occur in this resource unit. Of these, 16 indigenous species have been sampled in the lower Crocodile River (ecoregions 1.03 and 1.04, only) (Table 43).

Ecological requirements of the expected fish species

None of the expected fish species in this section of the river are Red Data listed (Skelton, 2001). Three of the species are, however, considered to be sensitive: *M. macrolepidotus*, *Barbus paludinosus* and *Chiloglanis paratus* (Kleynhans, 2003).

None of the expected fish species are intolerant to conditions of no-flow and the majority of expected fish species prefer slow deep and slow shallow habitats. Fast flowing habitats are, however, preferred by *C. paratus*, *L. marequensis* and *L. cylindricus* and *L. molybdinus.* Several of the species are, also, dependent on conditions of high flow for breeding purposes. None of the expected species have a high level of habitat specialisation. Overhanging vegetation, substratum cover and water column are the preferred cover types. Substratum for spawning is of high importance for the large cyprinids, as well as for *C. paratus*, which lays its eggs between rocks and gravel. Despite an affinity for rocky riffles and rapids, *C. paratus* may be found in rocky pools of intermittent streams during low water conditions (Skelton, 2001).

Although none of the expected species are intolerant of modified water quality, four species are sensitive for changes in water quality. *Micralestes acutidens*, has a low tolerance for low oxygen and high turbidity. *Barbus annectens*, *Labeo rosae*, *Labeo ruddi* and *Schilbe intermedius* have narrow temperature ranges, which could be of importance when water levels in the permanent pools decrease.

Table 453 Comparison of fish species sampled in RU1 (ecoregion 1.04 and 1.02) (After Gaigher 1969; Kleynhans, 1980; and Angliss, 2004a).

Fish species	**Lower Crocodile River**			**Matlabas**	**Expected fish species for Lower Crocodile R.**	**Expected fish species for RU1**
	Gaigher 1969	**Kleyn-hans 1980**	**Angliss 2004**	**Kleyn-hans 1980**		
Mormyridae						
Marcusenius macrolepidotus		X		X	**X**	**X**
Characidae						
Micralestes acutidens		X			**X**	**X**
Cyprinidae						
Barbus unitaeniatus	X	X		X[+]	**X**	**X**
B. trimaculatus	X	X	X	X[+]	**X**	**X**
B. viviparous				X		**X**
B. bifrenatus						**X**
B. annectens				X		**X**
B. paludinosus			X		**X**	**X**
Labeobarbus marequensis		X	X	X[+]	**X**	**X**
Labeo molybdinus		X	X		**X**	**X**
L. cylindricus				X		**X**
L. rosae		X		X[+]	**X**	**X**
L. ruddi	X *	X			**X**	**X**
Mesobola brevianalis	X *	X		X[+]	**X**	**X**
Cyprinus carpio (EXOTIC)		X				
Clariidae						
Clarias gariepinus		X	X	X	**X**	**X**
Schilbeidae						
Schilbe intermedius		X		X	**X**	**X**
Mockokidae						
Chiloglanis pretoriae	X					
Chiloglanis paratus		X			**X**	**X**
Synodontis zambezensis		Angler's report		Angler's report		**X**
Anguillidae						
Anguilla mossambica		Angler's report		Angler's report		**X**
Poeciliidae						
Aplocheilichthys johnstoni						
Cichlidae						
Oreochromis mossambicus	X	X	X	X[+]	**X**	**X**
Tilapia sparrmanii			X	X[+]	**X**	**X**
Pseudocrenilabrus philander	X	X		X[+]	**X**	**X**
Chetia flaviventris		Angler's report				**X**
Total	7	18	7	14	**16**	**23**

* Sampled at confluence of Marico and Crocodile Rivers.
+ Sampled at Matlabas-Limpopo confluence.

More than half of the fish species expected in this river section are invertivores. Two piscivores are expected, namely *S. intermedius*, and *Clarias gariepinus*.

Two exotic species, *Cyprinus carpio* and *Micropterus salmoides* are known to be present in the catchment (Kleynhans, 1980).

Present Ecological State and Motivation

Results

Based on the fish community, the biological integrity of RU1 seems to be largely modified and a Class D was assigned. The results ranged from a PES Class C to D (Table 44). The highest and the lowest score were discarded. Confidence in this result is low.

Table 464 Results for the three fish indices used to calculate PES for RU1, based on the fish community.

Fish Index	River segment	Fish PES Class	Description
FAII	RU1	E (31.22%	Seriously modified
Qualitative FAII	RU1	C (60.0%)	Moderately modified
FRAI	RU1	D (53.34%)	Largely modified
Decision	**RU1**	**D**	**Largely modified**

Motivation

Seven of the 16 fish species expected have been recorded by Angliss (2004). Of the 3 sensitive species expected, only one, *B. paludinosus*, was recorded. Losses of species were observed for the following metrics:

- More than half of the species preferring slow shallow and slow deep habitats were lost.
- More than half of the species that are moderately tolerant and tolerant to conditions of no-flow were lost.
- Large losses were observed among species preferring all cover types except aquatic macrophytes.
- Seven of the fish species sensitive to changes in water quality were lost.

Resource Unit 2

Mokolo-Limpopo confluence to the Sashe-Limpopo confluence.

Data available and assessment of quality of data

The list of expected species is based on published information by Kleynhans (1983, 1996b), Gaigher (1973, 1969), Van der Waal (1997) and Van der Waal and Bills (2000) on the Mokolo, Lephalale, Mogalakwena and Motloutse Rivers. Skelton (2001) was also consulted. With the exception of the Motloutse River (Van der Waal, 1997) where data from the whole river was used, only data from sampling sites occurring in the same Level II ecoregions as the Limpopo was considered.

No recent sampling data could be obtained for this resource unit. The published data of Van der Waal and Bills (2000) for the lower part of this resource unit (quarternary catchment: A63E) was then used to calculate the PES.

Kleynhans (1984, 1996b, 2003, 2004), Russell (1997), Weeks et al. (1996) and Gaigher (1969, 1973) were consulted for information on the ecological requirements of the expected fish species.

Constraints in the application of the fish indices

Three fish indices were applied on the available data. Specific constraints with regards to the fish data and each index are discussed below:

Data

Although the study of Van der Waal and Bills (2000) was primarily an investigation into the distribution of the exotic *Oreochromis niloticus*, information on species composition and abundances were given for 5 sampling sites, 4 of which fell in this resource unit. Sampling sites were, therefore, possibly selected to include the preferred habitat types of this and related species. The results are of very low confidence and should serve as a broad guideline only.

Fish Assemblage Integrity Index (FAII)

The FAII was developed for specific use in the River Health Programme, and may, therefore, not be ideally suited for use in EWR studies.

Due to the lack of information on the health of the fish species present, this particular metric could not be considered.

Qualitative FAII

Two of the seven metrics ("the health/condition of native and introduced species" and "in-stream habitat modification") could not be considered due to the lack of information. The results obtained may be an overestimation of biological integrity and are of low confidence.

Fish Response Assemblage Index (FRAI)

Due to the lack of information on the health/condition of the fish species, no deviances from the reference conditions were indicated.

Summary of data

Thirty-four fish species are expected to occur in this resource unit (Table 45). *Labeo rubromaculatus*, *A. mossambica, Glossogobius callidus* and *Brycinus imberi* were added to the list of previous recorded species.

Table 475 Expected and observed fish species for RU2 (After Van der Waal and Bills, 2000; Kleynhans, 1996; Kleynhans, 1983; Potgieter, 1974; and Gaigher, 1969).

Fish species	Mokolo	Lephalale	Mogala-kwena	Motloutse	Limpopo	Expected fish species for RU2
	Kleynhans 1983 & Gaigher 1969	**Kleynhans, 1983, Gaigher, 1969 & Potgieter, 1974**	**Kleynhans 1996**	**Van der Waal 1997#**	**Van der Waal & Bills 2000**	
Mormyridae						
Marcusenius macrolepidotus	X*					X
Petrocephalus catostoma	X	X				X
Characidae						
Micralestes acutidens	X*	X*	X			X
Brycinus imberi						X
Cyprinidae						X
Barbus unitaeniatus	X	X*	X			X
B. trimaculatus	X		X	X		X
B. viviparous	X	X				X
B. annectens	X*		X			X
B. afrohamiltoni	X	X*				X
B. bifrenatus	X*					X
B. paludinosus	X*		X	X	X	X
B. radiatus	X	X*	X			X
B. mattozi	X		X			X
B. toppini						
B. brevipinnis						
Labeobarbus marequensis		X*	X			X
Labeo molybdinus	X	X	X			X
L. cylindricus	X	X	X			X
L. rosae	X	X	X	X		X
L. congoro			X			X
L. ruddi	X	X	X			X
L.rubromaculatus						X
Mesobola brevianalis		X	X		X	X
Cyprinus carpio (EXOTIC)			X		X	
Clariidae						
Clarias gariepinus	X	X	X	X	X	X
Schilbeidae						
Schilbe intermedius	X	X	X		X	X
Mockokidae						
Chiloglanis paratus		X*	X			X
Synodontis zambezensis	X					X

Table 45 (Continued) Expected and observed fish species for RU2 (After Van der Waal and Bills, 2000; Kleynhans, 1996; Kleynhans, 1983; Potgieter, 1974; and Gaigher, 1969).

	Mokolo	Lephalale	Mogala-kwena	Motloutse	Limpopo	Expected fish species for RU2
Fish species	**Kleynhans 1983 & Gaigher 1969**	**Kleynhans, 1983, Gaigher, 1969 & Potgieter, 1974**	**Kleynhans 1996**	**Van der Waal 1997#**	**Van der Waal & Bills 2000**	
Gobiidae						
Glossogobius callidus						X
Anguillidae						
Anguilla mossambica						X
A. marmorata			X			X
Poeciliidae						
Aplocheilichthys johnstoni	X*	X*				X
Cichlidae						
Oreochromis mossambicus	X*	X*	X	X	X	X
O. macrochir (EXOTIC)						
O. niloticus (EXOTIC)					X	
Tilapia rendalli	X*	X	X			X
T. sparrmanii	X*	X				X
Pseudocrenilabrus philander	X*	X*	X			X
Chetia flaviventris	X*	X	X			X
TOTAL	**23**	**21**	**23**	**5**	**7**	**34**

*Sampled at locality closest to confluence.
Fish data recorded by Van der Waal (1997) are for the whole Motloutse River as the Level II ecoregions for this river are not yet available.

Ecological requirements of the expected fish species

The majority of fish species expected to occur in this RU prefer slow deep and slow shallow habitat. Although none of the expected species are intolerant to no-flow conditions, several species like the large cyprinids (*Labeobarbus marequensis, Labeo congoro, L. molybdinus* and *L. ruddi*), the sawfin rock catlet (*Chiloglanis paratus)* and the catadromous *Anguilla mossambica* prefer fast flowing habitats. For several species, high flow is also needed for spawning and breeding.

None of the expected species are considered to be intolerant to modified water quality. Ten species, among which, *M. acutidens* that is known to be sensitive for low oxygen concentrations, is moderately intolerant to modified water quality. During prolonged periods of droughts, oxygen levels in the refuge pools may decrease, and temperatures increase, creating very harsh conditions for aquatic biota.

Only one species is considered to have a degree of habitat specialisation, namely *Aplocheilichthys johnstoni.* This species prefers shallow, densely vegetated habitats (Steenkamp et al*.,* 2001). They primarily utilise the upper 10 cm of the water column where they feed on insect larvae, daphnia and other small invertebrates. Their eggs are not drought resistant and excessive water extraction poses a threat to the survival of the species (Kleynhans, 1986). The presence and absence of the species may be used an environmental health indicator when assessing the conservation status of river systems. Overhanging vegetation and substratum are the preferred cover type for most of the expected fish species. The majority of the expected fish species are invertivores.

Three exotic species are reported to be present in this river section. *Cyprinus carpio* (Kleynhans, 1983), *Micropterus salmoides* (in the upper reaches of the Mokolo River) (Angliss, 2002) and *Oreochromis niloticus* (Moralee et al*.,* 2000; Van der Waal and Bills, 2000).

Present Ecological State and Motivation

Two indices, the Qualitative FAII and FRAI, were applied to determine the Present Ecological State for RU2.

Results

The biological integrity of RU2 (A63E) seems to be largely modified and the PESC was determined to be a Class D (Table 46). Due to the unsuitability of the data used, it was decided to discard the lower FRAI score. Confidence in this result is very low.

Table 46 Results for the two fish indices used to calculate PES for RU2, based on the fish community.

Fish Index	River segment	Fish PES Class	Description
Qualitative FAII	RU2	D (54.3%)	Largely modified
FRAI	RU2	E (21.4%)	Seriously modified
Decision	**RU2**	**D**	**Largely modified**

Motivation

Only 12 fish species, including two exotic fish species, were recorded in the lower section of this RU (Van der Waal and Bills, 2000). The poor biological integrity measured could be as a result of the following:

- Only 1 of 7 species considered to be sensitive being sampled;
- An extreme loss of species preferring fast flowing habitats;
- An extreme loss of species preferring substratum cover;
- The absence of migratory and catadromous species;
- The presence of exotic species; and
- Bias in data collection.

The constraints and bias of the data used, could however, be the main reason why certain species were not found. The biological integrity is therefore most certainly underestimated.

Resource Unit 3

Sashe-confluence, downstream to where the Luvuvhu joins the Limpopo River.

Data available and assessment of quality of data

The list of expected fish species is based on surveys done by Angliss (2004b), Newenham and Chavalala (2003), Deacon (2000; cited in Newenham and Chavalala, 2000), Van der Waal and Bills (2000) and Kleynhans and Hoffman (1992a) in the Sashe, Nzhelele, Luvuvhu and Limpopo Rivers. Again, only data from sampling sites occurring in the same Level II ecoregions as the Limpopo was considered. With regards to the study of Newenham and Chavalala (2003), only data from IFR Site 2, situated in the Kruger National Park was used. Although the site falls just outside ecoregion 1.01, it is part of Bioregion 1: Limpopo (Brown et al., 1996), and was considered in this study.

The data of Angliss (2004) on the Nzhelele and Newenham and Chavalala (2003) on the lower Luvhuvu River were used to determine the biological integrity of this resource unit.

For information on the ecological requirements of fish species, Kleynhans (1984, 1996b), Russell (1997), Weeks et al. (1996) and Gaigher (1969, 1973) were consulted. The intolerance ratings, flow-depth and cover preference ratings for South African fish species (Kleynhans 2003, 2004) were also considered.

Constraints in the application of the fish indices

The fish indices were applied on the data for the Nzhelele and lower Luvhuvu Rivers separately, as well as on the combined data for the two rivers. Two indices, the Qualitative FAII and FRAI, were used to determine the Present Ecological State for RU3.

Qualitative FAII

Two of the seven metrics ("the health/condition of native and introduced species" and "in-stream habitat modification") could not be considered due to the lack of information. The results obtained may be an overestimation of biological integrity and are considered to be of low confidence.

Fish Response Assemblage Index (FRAI)

Due to the lack of information on the health/condition of the fish species, no deviances from the reference conditions were indicated.

Summary of data

Thirty-three species could be expected to occur in this river section (Table 47). Of these, 12 fish species are considered to be sensitive: *A. uranoscopus*, *M. macrolepidotus*, *Petrocephalus catostoma*, *Micralestes acutidens*, *Hydrocynus vittatus*, *Barbus afrohamiltoni*, *B. paludinosus*, *B. mattozi*, *L. cylindricus*, *L. congoro*, *Chiloglanis pretoriae* and *C. paratus*. None of the expected fish species are IUCN Red Data listed (Skelton, 2001).

Table 47 Checklist of fish species sampled in the Sashe River (Ecoregion 1.01), Limpopo System (After Angliss, 2004; Newenham and Chavalala, 2003; Deacon, 2000; Van der Waal 2000; Kleynhans and Hoffman, 1992a).

	Limpopo below Sashe	**Sashe-Limpopo confluence**	**Nzhelele+**	**Luvuvhu**		**Expected**
Species	**Kleynhans & Hoffman 1992**	**Van der Waal & Bills 2000**	**Angliss 2004**	**Deacon 2000**	**Newenham & Chavalala 2003**	
Amphiliidae						
Amphilius uranoscopus				X	X	
Mormyridae						
Marcusenius macrolepidotus	X			X		X
Petrocephalus catostoma					X	X
Characidae						
Micralestes acutidens	X	X		X	X	X
Brycinus imberi	X	X		X	X	X
Hydrocynus vittatus				X		X
Cyprinidae						
Barbus unitaeniatus	X	X				X
B. trimaculatus	X	X	X		X	X
B. viviparous				X	X	X
B. annectens	X				X	X
B. afrohamiltoni	X	X				X
B. bifrenatus				X	X	X
B. paludinosus	X		X			X
B. radiatus	X			X	X	X
B. mattozi	X					X
B. toppini	X					X
Labeobarbus marequensis	X		X	X	X	X
Labeo molybdinus			X	X	X	X
L. cylindricus	X			X	X	X
L. rosae	X			X	X	X
L. congoro	X			X	X	X
L. ruddi	X			X		X
L. rubromaculatus						X
Mesobola brevianalis				X	X	X
Clariidae						
Clarias gariepinus	X	X		X	X	X
Schilbeidae						
Schilbe intermedius	X			X		X

Table 47 (Continued) Checklist of fish species sampled in the Sashe River (Ecoregion 1.01), Limpopo System (After Angliss, 2004; Newenham and Chavalala, 2003; Deacon, 2000; Van der Waal, 2000; Kleynhans and Hoffman, 1992a).

Mockokidae						
Chiloglanis pretoriae				X	X	
Chiloglanis paratus	X[#]			X	X	X
Synodontis zambezensis	X					X
Gobiidae						
Glossogobius callidus					X	X
G. giuris				X		X
Anguillidae						
Anguilla mossambica	X			X	X	X
A. marmorata	X			X		X
Cichlidae						
Oreochromis mossambicus	X	X	X			X
O. macrochir (EXOTIC)	X					
O. niloticus (EXOTIC)		X	X			
Tilapia rendalli			X			X
T. sparrmanii						
Pseudocrenilabrus philander						
Chetia flaviventris						
Total	**24**	**8**	**7**	**22**	**20**	**33**

[#] Also recorded by Engelbrecht and Mulder (2000) at Sashe-Limpopo confluence.

Ecological requirements of the fish

Similarly to the first two resource units, the majority of expected fish species prefer slow deep and slow shallow waters. Three species, *H. vittatus*, *Barbus Toppini* and *Glossogobius giuris* are dependent on flow for survival. Nearly 80% of the expected fish species, the bulk of which are cyprinids, are dependent on high flows for breeding. A number of migratory species are present, needing high flows mainly during summer. Two catadromous species are also expected to be present in this resource unit.

Most of the expected fish species are moderately intolerant to moderately tolerant to changes in water quality. *M. acutidens* has a low tolerance for low oxygen levels, and six species are sensitive to temperature changes. Five species have a narrow tolerance range for high turbidity. The presence and abundance of *C. paratus* could point to relatively good water quality as the species are seen as useful indicator species of pollution (Skelton, 2001).

Substratum, overhanging vegetation and water column are the cover types preferred by most species.

Only four species (*Synodontis zambezensis*, *M. macrolepidotus, P. catostoma* and *A. mossambica*) have a very high preference for undercut banks. However, none of the species present is considered to be habitat specialists.

Three introduced species, *Cyprinus carpio*, *Oreochromis niloticus* (Van der Waal and Bills, 2000) and *O. macrochir* (Kleynhans and Hoffman, 1992a) have been recorded in this resource unit. The genetic integrity of *O. massambicus* in the Limpopo system is threatened by the presence of *O. macrochir* and *O. niloticus*, as interbreeding may occur (De Moor and Bruton, 1988). *O. mossambicus/O. niloticus* hybrids have been recorded in the system (Van der Waal, 2004; Van der Waal and Bills, 2000). A further threat to the indigenous fish assemblage of this RU is the presence of several exotic species in the Sashe Dam. Although none of these have been recorded in the Limpopo yet, *O. andersoni* may also interbreed with *O. massambicus*, while the impact of the predaceous *Serranochromis* sp. could be highly detrimental for feeding relationships in the Limpopo River and its tributaries (Kleynhans and Hoffman, 1992a).

Present Ecological State and Motivation

Results

The PES of the Nzhelele and Luvhuvu Rivers was determined to be moderately modified, and PESC classes C and B/C were assigned respectively (see Table 48). The same result was obtained by applying FRAI on the combined data. A PES Class C was therefore assigned to RU3. Confidence in this result is low.

Table 48 Results for the two fish indices used to calculate PES for RU3, based on the fish community.

Fish Index	River segment	Fish PES Class	Description
Qualitative FAII	Nzhelele	C	Moderately modified
FRAI	Lower Luvhuvu	C (78.37%)	Moderately modified
FRAI	RU3	C (63.80%)	Moderately modified
Decision	**RU3**	**C**	**Moderately modified**

Motivation

Twenty-three of the 33 expected fish species were observed (Angliss, 2004b; Newenham and Chavalala, 2003). The decrease in biological integrity measured could be as a result of the following:

- The loss of 4 sensitive species;
- A moderate loss of species preferring slow flowing habitats;
- A moderate loss of species considered to be moderately tolerant to tolerant to conditions of no-flow;
- A small loss of species preferring overhanging vegetation and substratum cover;
- A large loss of species moderately intolerant to modified water quality.
- The loss of one catadromous species, *A. marmorata*;
- The presence of exotic species.

From the results it became evident that sampling was possibly done under conditions of fast flow. This may account for the absence of species preferring slow flowing habitats. Flow modification in this resource unit, especially water abstraction, seems to have a serious impact on aquatic biota (Kleynhans, 1996a).

7.7 People-ecosystem interactions

The Limpopo water management area (WMA) is bordered by three other WMAs within South African borders, namely the Crocodile (West) and Marico, the Olifants and the Luvuvhu and Letaba. The following main rivers and their tributaries flow northward into the Limpopo: Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele.

Population patterns

The Limpopo WMA is home to 3.5% of the South African population. Over 80% of the population is rural, living in some 2000 informal rural villages and settlements scattered throughout the area. There is little economic activity to support current population concentrations. High population densities are found in the south eastern half of the area, with sparse population densities in the northern and western parts. The impact of HIV/AIDS and increasing urbanisation is expected to result in little growth in rural populations after 2025. In terms of rural water requirements, therefore, the situation will largely remain as is.

Economic activities

The government sector is responsible for 24.2% of GDP generated in the area, followed by electricity (17.7%). This is attributed to the presence of Matimba Power Station at Lephalale. Agriculture contributes 9% to the region's GDP. Cotton, grain sorghum and tobacco are the main crops being grown and 21% of the population are involved in agriculture. A large part of the population depends on subsistence agriculture. Mining contributes 7.5 % of the regional GDP and platinum and platinum group metals are the primary minerals mined. Future economic growth in the WMA is largely dependent on new mining developments as land and water resources available for agriculture are already highly developed. Other economic activities contributing to the GDP include trade (14.9%) and financial services (8.3%). Approximately 43% of the population in the WMA is unemployed, 46% are active in formal employed and 11% are involved in the informal economy (1994).

Water demands

Rain fed cultivation is practised in the central and southern parts of the WMA with cotton and grain being the main crops grown. The WMA is characterised by irrigation developments at various locations, with water supplied by farm dams and groundwater. Irrigation accounted for nearly 75% of the total water requirements in 2000, of which 9% are used for rural domestic supply and stock watering. In terms of water requirements, a total of 238 million m³/a out of 322 million m³/a is required for irrigation (Table 49). In the higher rainfall areas of the Soutpansberg, small commercial forests occur. However, most of WMA is still under natural vegetation. Livestock and game farming as well as cattle herding are main activities. Overgrazing occurs in many areas as a result of cattle herding and livestock farming.

Table 49 Limpopo 2025 projection: water requirements for selected sectors (million m³/a; Adapted from Basson and Rossouw, 2003a).

Total water requirements	2000	2025 Base scenario	2025 High scenario
Total local requirements	322	28	378
Rural	346	33	33
Urban	34	33	65
Irrigation	238	238	238

Rural domestic water requirements are met in large part through groundwater, while groundwater is also used for irrigation and stock watering. The total water requirements are presented in Table 50.

Table 50 Total Rural Water requirements for the Limpopo Water Management Area for 2000 (After Basson and Rossouw, 2003a).

	Rural population	Domestic	Stock Watering	Total	Rural human per capita
		Million m³/a			l/c/d
Total water requirements	1 298 024	22.3	6.5	28.8	47

Luvuvhu and Letaba

The Luvuvhu and Letaba WMA is home to Ndebele people and the area is dominated by presence of the Kruger National Park and the legacy of the decentralisation and homeland policies of the past.

Population patterns

Around 3.5% of the South African population resides in this area. More than 90% of the population of this area is classified as rural and there are a large number of rural villages scattered throughout the area. Little growth in the population is expected after 2025 as a result of the impacts of urbanisation and HIV/AIDS

Economic activities

Most developments are agriculture based with irrigated agriculture and afforestation being the strongest contributors to agricultural developments. Livestock farming is practiced in areas under natural vegetation resulting in serious overgrazing. Most of the rainfed agriculture and cattle herding are practiced on communal lands as subsistence farming.

Water demands

Irrigation is the main water user with 75% of the total requirements for water allocated to irrigation, while 13% is represented by the impact of afforestation and 9% goes to rural domestic supplies and for stock/game watering. The remaining 3% is allocated to urban, industrial and mining use. The water requirements per sector strongly reflect the rural and agricultural nature of the area.

Groundwater is an important source of water for rural domestic and stock watering requirements. Cultivation practices and overgrazing have severe impacts on surface runoff, sediment loads and infiltration to groundwater. Surface water is also subject to bacteriological pollution as a result of wash-off from rural villages and dense settlements without proper sanitation infrastructure and services in place.

Crocodile (West) and Marico

In relation to the Limpopo and the Luvuvhu and Letaba WMAs, this WMA is characterised by larger urban and industrial and mining developments.

Population patterns

The Johannesburg-Pretoria metropol partially falls into this WMA and about 85% of the population in the WMA are concentrated in this metropol and surrounding areas. In the rest of the WMA the population density varies from moderate to scarce.

Economic activities

Approximately one quarter of South Africa's GDP is generated in this WMA with manufacturing, government, finance and transport being the largest economic sectors. Agriculture constitutes the smallest economic sector in the area but is particularly important in sustaining a large proportion of the rural population in the area.

Water demands

In terms of water requirements, 60% of total water requirements in the area are for urban, industrial and mining use, 35% for irrigation and the remaining 5% for power generation and rural water supply.

7.8 Summary

The Limpopo River was divided into three resource units (see Table 51), namely:
RU 1 : From the Crocodile/Marico confluence to the Mokolo/Limpopo confluence
RU 2 : From Mokolo/Limpopo confluence to Shashe/Limpopo confluence
RU3 : From Shashe/Limpopo confluence to Luvuvhu/Limpopo Confluence.

Table 51 Identification of the Limpopo River study area and river segments (= resource units).

Specialist fields	Study area	River segments			
		RU1	**RU2**	**RU3**	**RU4**
Hydrology		A41D – A50J split at Mogalakwena	A63C – A80J (border)		
Geohydrology		A41D – A50J split at Mogalakwena	A63C – A80J (border)		
Geomorphology	Whole system including Botswana, Mozambique and Zimbabwe	Secondary catchments A1A – A3	A4 – A6	A7 – A9	Part of Mozam-bique coastal plain
Water quality		A41D – A63E source to Sashe	A71L – A80J Sashe to border		
Riparian veg		Crocodile/ Marico Confluence to Mokolo/Limpopo confluence	Mokolo to Sashe/ Limpopo confluence	Sashe to Luvuvhu/ Limpopo confluence	
Invertebrates		Crocodile/ Marico Confluence to Mokolo/Limpopo confluence	Mokolo to Sashe/ Limpopo confluence	Sashe to Luvuvhu/ Limpopo confluence	
Fish		Crocodile/ Marico Confluence to Mokolo/Limpopo confluence	Mokolo to Sashe/Limpopo confluence	Sashe to Luvuvhu/ Limpopo confluence	
Socio-economic	(Only one segment)				
Decision		Crocodile/ Marico Confluence to Mokolo/Limpopo confluence	Mokolo to Sashe/Limpopo confluence	Sashe to Luvuvhu/ Limpopo confluence	

Table 52 Identification of the present ecological status category (PESC) for the Limpopo River.

Specialist fields	PES (0 – 5)*			Confidence (1 – 4)#			Motivation			TRAI of change -/0/+◊			Attainable improvement (0 – 5)			Confidence (1 – 4)#		
	RU 1	RU 2	RU 3	RU 1	RU 2	RU 3	RU1	RU2	RU3	RU1	RU2	RU3	RU1	RU2	RU3	RU1	RU2	RU3
Hydrology	3	3	3	2	3	2	Lack of data	Know subcatchment flows, data available	Little available data	-	-	-	2	3	3	2	2	2
Geohydrology	3	3	3	2	3	3	Lot of abstraction	Lot of abstraction	Lot of abstraction	-	-	-	3	3	3	2	3	3
Geomorphology	3	3	2	2	2	2	Dams & bridges impact river	Dams & bridges impact river	High human impacts	0	0	-	3	3	3	4	3	2
Water quality	3	4	3	2	3	3	Lack of data	Data available	Data available	-	-	-	3	3	3	2	3	3
Riparian veg	3	3	3	3	3	3	Grazing and trampling	Grazing and trampling	Grazing and trampling	-	-	-	4	4	4	3	3	3
Invertebrates	3	4	3	2	2	2	Flow related habitat changes	Good condition of Mokolo	Flow related habitat changes	-	0	-	3	4	3	2	2	2
Fish	2	2	3	2	1	2	Flow related habitat changes; loss of species sensitive to changes in water quality	Flow related habitat changes; complete loss of species with high preference for flow; exotic species present	Better data available	-	-	-	3	3	3	2	1	2
Socio-economic (not included in the mean PES score)	2			2			Subsistence based (Only 1 segment)			-			4			2		
Mean score	2.4	3.0	2.9	2.1	2.4	2.4							3.1	3.3	3.1	2.4	2.4	2.4

* (0=critically modified; 1=seriously modified; 2=largely modified; 3=moderately modified; 4=largely natural; and 5=natural/unmodified)
# (1=marginal/low confidence; 2=moderate confidence; 3=high confidence; and 4=high confidence)
◊ (“-“=negative change; “0”=no change; and “+”=positive change)

Table 53 Identification of the Attainable Management Class and EWR for the Limpopo River.

System	EISC	PESC	AEMC	HI	Hughes (2002)
Limpopo RU 1	2 (Possibly C)	2.4 C	C	76.6	A41E 16.01 %
Limpopo RU 2	2 (Possibly C)	3.0 B	B	18.4 76.4 91.2 78.5	A50H 18.91 % A50J 17.19 % A63C 16.96 % A63E 17.00 %
Limpopo RU 3	2 (Possibly C)	2.9 C	C	13.4	A80J 19.57 %

Resource Unit 1

The Present Ecological Status of this river section, based on the means of the individual scores of the specialists (excluding the socio-economic attribute; see Table 52), was considered to be moderately modified, with some loss of natural habitats. A PES Category C was assigned. Confidence in this result was, however, moderately low. Seven of the eight specialists indicated that river conditions in RU1 are degrading.

The EIS for RU1 was determined to be “moderate” (score of 2), possibly relating to an EIS Category C (Table 53). Based on biodiversity, this river section is, therefore, considered to be ecologically important or unique at a provincial or local scale. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

An AEM Category C was assigned to RU1, based on the fact that the PESC (C) fell into the same class as the DESC (C). The AEMC was then used as an input into the hydrological model of Hughes and Münster (1999). According to the Hughes DSS, 16.01% of the MAR should be left in the river (Table 53). Due to the very high HI score of 76.6 for this river section, this result is most possibly an underestimation. According to Hughes (IWR Environmental, 2000), a hydrological index score of 10 or more is considered to be beyond the acceptable range of accuracy (10 or less).

Resource unit 2

The mean score of the respective attributes (excluding the socio-economic attribute) considered for the PESC, was 3.0 (Table 52), putting RU2 in a PES Category C. Resource Unit 2 is, therefore, considered to be moderately modified and some loss of natural habitats have occurred. Confidence in this result was moderately low. The majority of specialists indicated a degrading tendency in river conditions.

Resource Unit 2 was considered to be of moderate ecological importance and sensitivity (possibly a category C; see Table 53).

Based on the biota and habitat availability, this section of the Limpopo River may be sensitive to flow modifications. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

Because the PESC (B) was one category higher than the DESC (C), the PESC category was taken as the AEMC (B). This was then used as an input into the updated hydrological model of Hughes and Münster (1999).

The hydrological model (Hughes and Münster, 1999) indicated that between 16.96% (for quaternary catchment A63C) and 18.91% (for quaternary catchment A50H) of the MAR be left in the river. This section of the Limpopo River is hydrologically highly variable, and the HI scores varied between 18.4 (for quaternary catchment A50H) and 91.2 (for quaternary catchment A63C). Water allocation for RU2 is, therefore, most possibly underestimated as a hydrological index score of 10 or more is considered to be beyond the acceptable range of accuracy (10 or less).

Resource Unit 3

Based on the means of the individual scores of the specialists (see Table 52), the PES of this river section was moderately modified (mean score of 2.9). A PES Category C was assigned. Confidence in this result was, however, moderately low. Specialists agreed that river conditions in RU3 are degrading.

The EIS for RU3 was moderate (score of 2), possibly relating to an EIS Category C (Table 53). Based on biodiversity, RU3 is considered to be ecologically important or unique at a provincial or local scale. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

The PESC and DESC for RU3 fell into the same class, and an AEM category C was imported into the hydrological model of Hughes and Münster (1999).

The hydrological model indicated that 19.57% (for quaternary catchment A80J) of the MAR should be left in the river. As is the case in RU1 and 2, is water allocation possibly underestimated due to the high hydrological variability in this section of the river.

8. KUISEB RIVER

8.1 Introduction

A Desktop reserve determination, following the methodology as set out in Chapter 3, was performed on the Kuiseb River, as prescribed in the Terms of Reference. Due to the nature of this study, no field visit or sampling was done. The respective experts involved in the study were, therefore, dependent on existing data sources. Accordingly, the confidence in the results produced by the determination is low.

The study area was divided into three resource units (RUs): the first comprising of the upper Kuiseb up to Schlesien, the second stretching from Schlesien to Rooibank, and the third from Rooibank to the coast.

A summary by each specialist regarding reference conditions, availability and quality of data used to determine the PESC for each resource unit, follows.

The EISC was also determined through the input of the various specialists. A summary of the PESC, EISC and AEMC for the Kuiseb River, is provided at the end of the chapter. No EWRs were, however, determined due to the lack of hydrological data.

8.2 Hydrology and Geohydrology

The area was geohydrologically divided into three sections (Upper Kuiseb to Schlesien) (hard rock along Kuiseb River); Schlesien to Rooibank (sand/alluvium along Kuiseb River) and from Rooibank to the sea (Dorop North and South Delta).

The development of the world's largest opencast uranium mine at Rossing introduced rapidly increasing demands for water in the area in the early 1970's. At present groundwater is abstracted from the dry bed of the Kuiseb River to supply Walvis Bay with water. The main areas of groundwater abstraction are: Area A (section upstream of Rooibank), Area B (13 kilometers west of Rooibank). Water is also abstracted from the Dorop North and South areas.

The total catchment area of the Kuiseb upstream of Rooibank is 14 700 km^2, and of this only the area upstream of the flow gauging weir of Schlesien on the main river and upstream of the flow gauging station of Greylingshof on the Gaub River should be considered as run-off –producing. These catchments are 6 500 km^2 and 2 490 km^2, respectively. The remaining 5 690 km^2 is largely desert plain yielding run-off to the main river, only in exceptionally wet years. The average annual rainfall is about 159 mm.

More than 400 farm dams, with a total storage capacity of about 16 Mm3, are spread over the Kuiseb Catchment, and it was estimated that the dams have a reduction of about 21% of the average flow in the Kuiseb River.

Gauging at Schlesien began in 1960/1961 and the mean annual run-off equals 20 Mm^3. The mean is of course influenced by rare very high flows and the median = 10 Mm^3/a. During the last 146 years, the river surface flow has reached the Atlantic Ocean on only 15 occasions, which shows the Kuiseb to be an episodic river.

Groundwater levels are in general between 2 and 5 meters below the Kuiseb River.

Figure 34 shows the abstraction/rainfall in the Rooibank A area, from which the good correlation between abstraction and water level is clear. Figure 35 shows the water level versus abstraction in the Dorop South area.

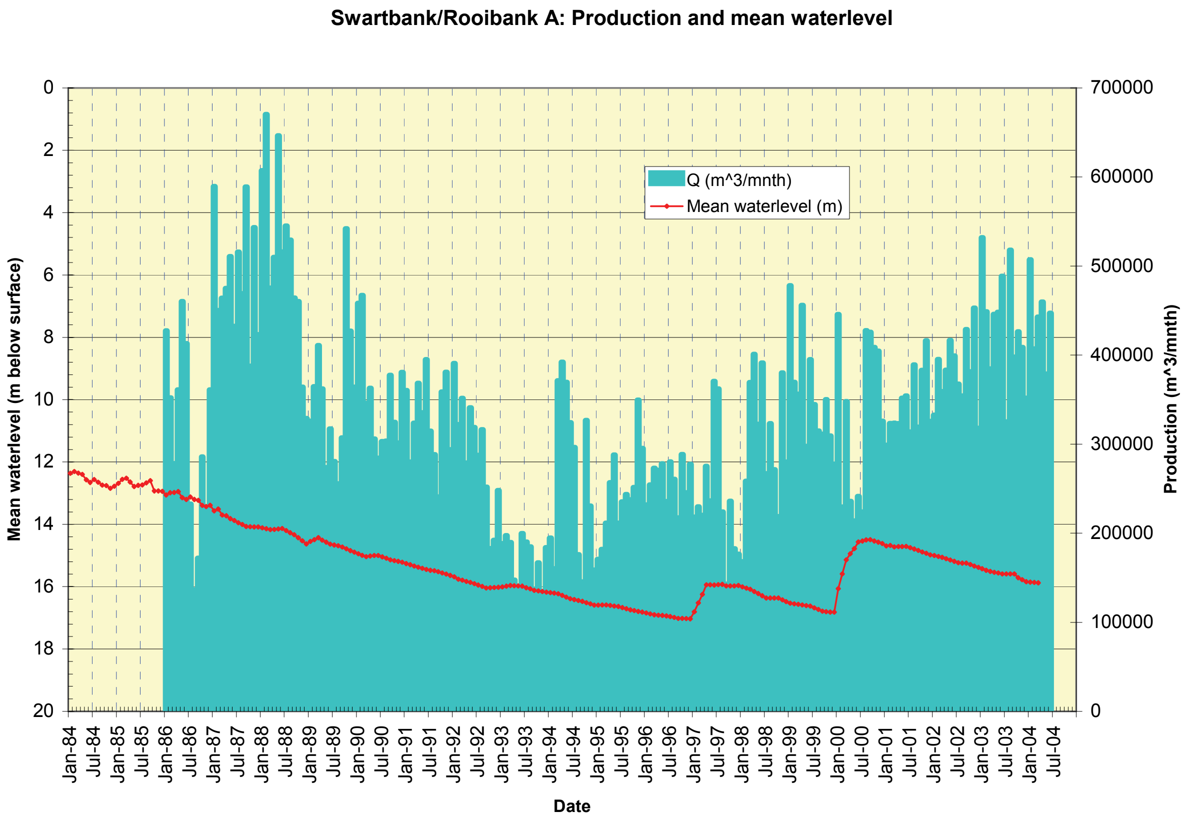

Figure 34 Abstraction versus water level in the Rooibank area.

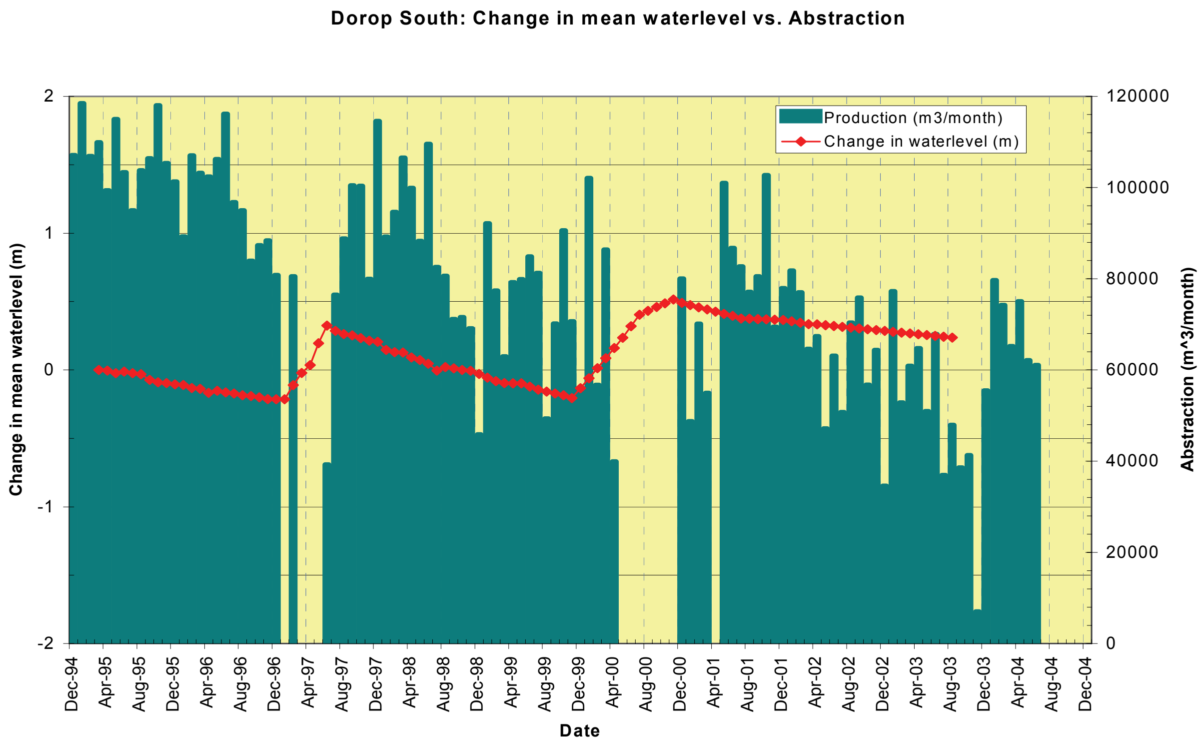

Figure 35 Abstraction versus water level in the Dorop South area.

It is expected that a continuous drawdown of the water level along the Kuiseb River will cause some of the trees to die. It is therefore very important that a specific maximum drawdown water level must be set along the river.

8.3 Geomorphology

A set of maps (Figures 36 to 41) summarise the geomorphological characteristic of the study area. The maps were compiled from various sources and comprises the physical terrain (a DTM), geology, a terrain description and soils of the Kuiseb river catchment. Towns are shown for reference

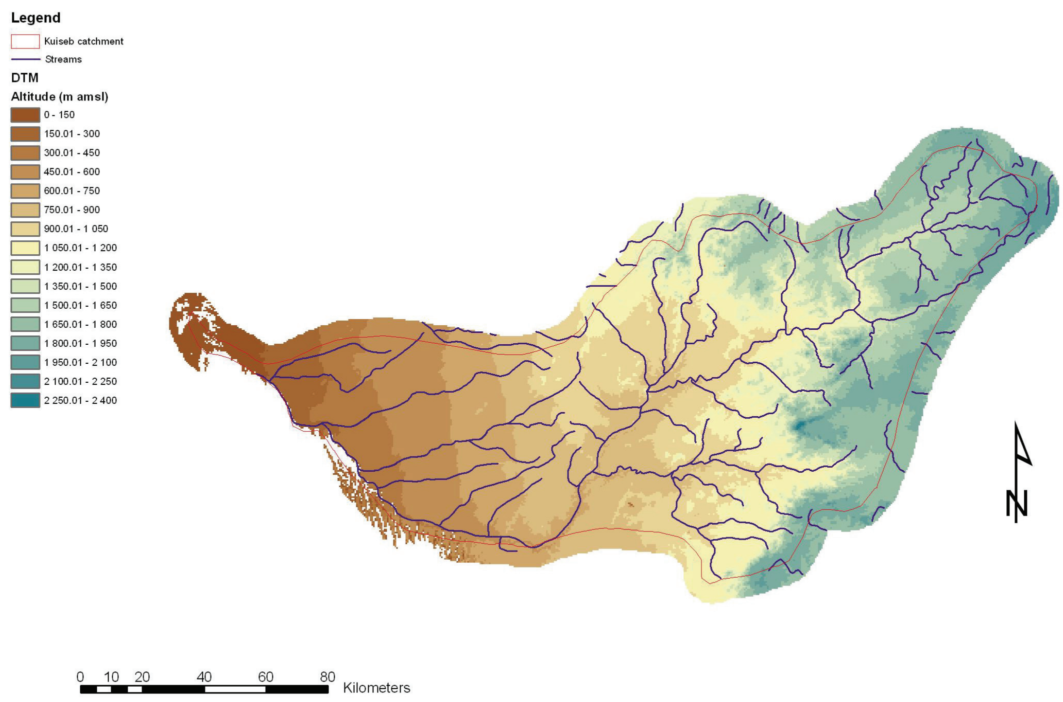

Figure 36 Altitudes in the Kuiseb River catchment.

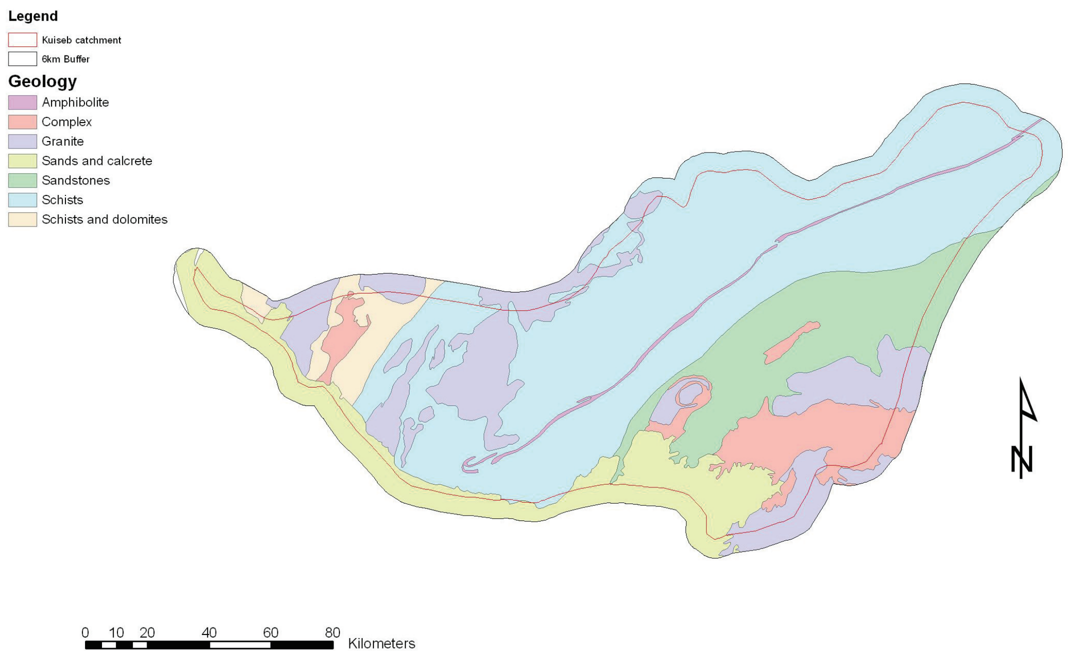

Figure 37 Geology of the Kuiseb River catchment.

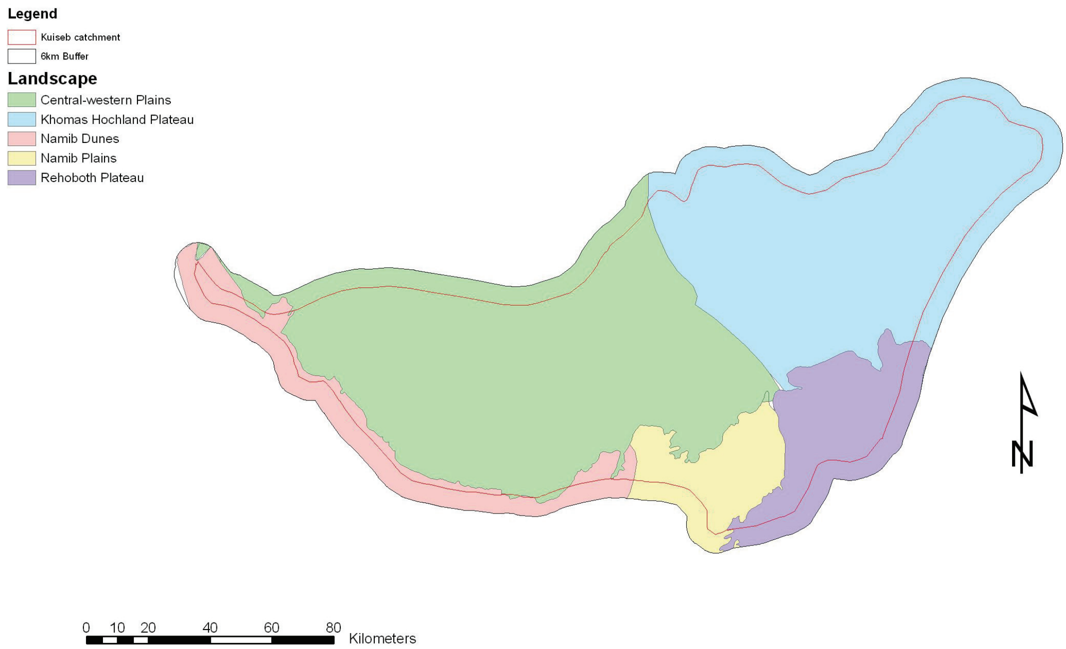

Figure 38 Landscaping features of the Kuiseb River catchment.

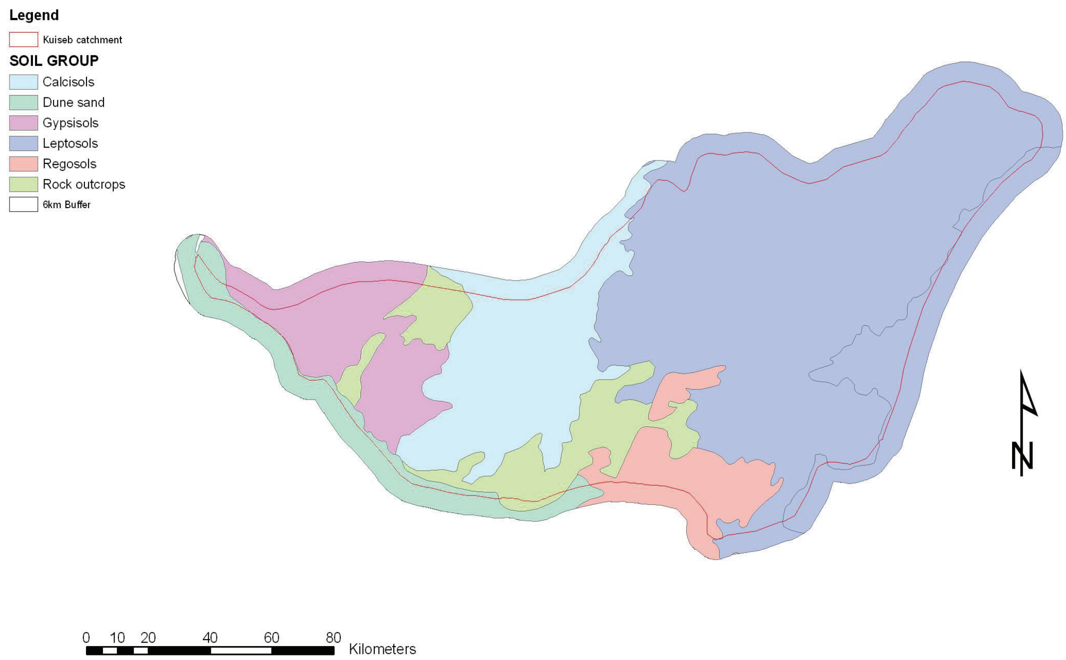

Figure 39 Soil Groups in the Kuiseb River catchment.

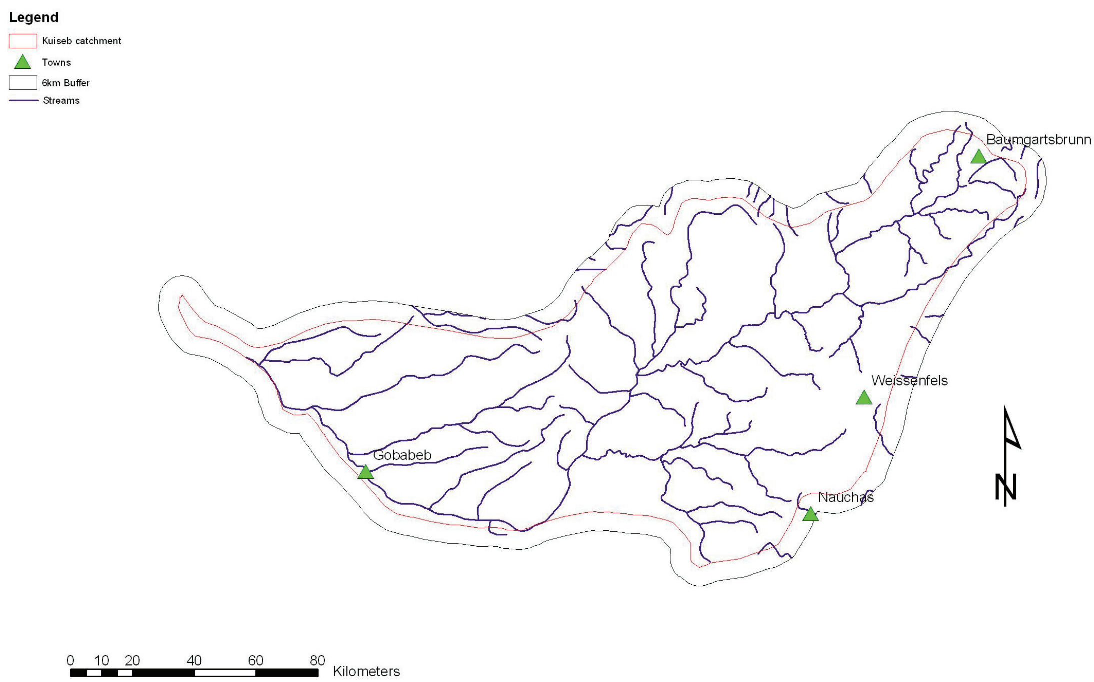

Figure 40 Towns in the Kuiseb River catchment.

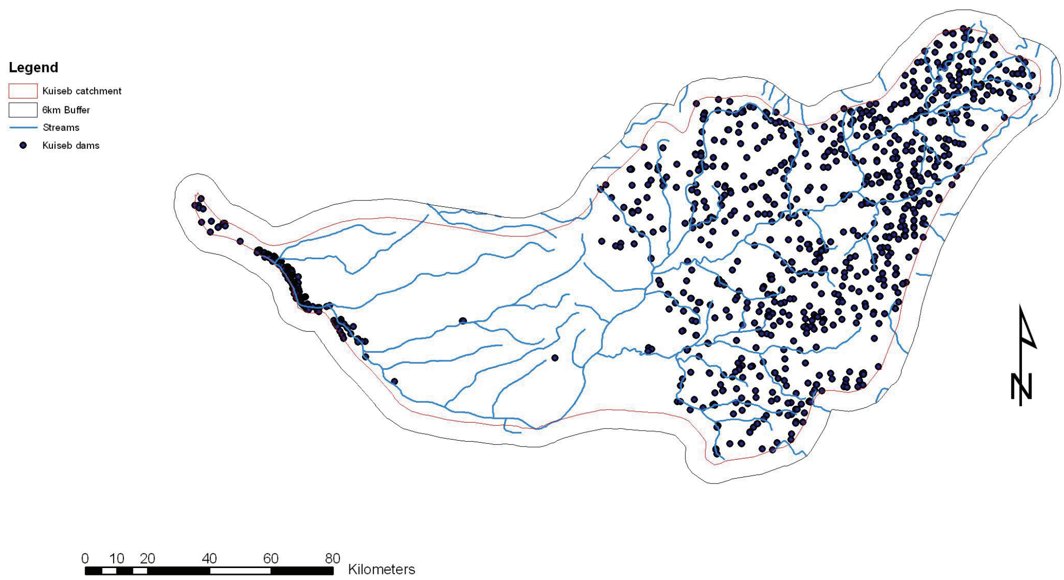

Figure 41 Dams in the Kuiseb River catchment.

Resource Unit 1

Upper Kuiseb to Schlesien

Data available and assessment of quality of data
Data were obtained from the Atlas of Namibia Project (2002) and elevation data from the USGS (2004). The Atlas project – data are available for download from the internet and is accompanied by good metadata. Some problems, however, might be experienced by users regarding the format of, especially, raster data. Some layers (e.g. rivers) also did not conform to the catchments in the dataset.

Present Ecological State and Motivation

PES: 3, Confidence: 2
Human impact in the form of a large number of small dams in the upper catchment is evident.

Resouce Unit 2

Schlesien to Rooibank

Data available and assessment of quality of data
Data were obtained from the Atlas of Namibia Project (2002) and elevation data from the USGS (2004). The Atlas project – data are available for download from the internet and is accompanied by good metadata. Some problems, however, might be experienced by users regarding the format of, especially, raster data. Some layers (e.g. rivers) also did not conform to the catchments in the dataset.

Present Ecological State and Motivation

PES: 3 Confidence: 2
Human impact in the form of a large number of small dams in the upper catchment is evident.

Resource Unit 3

Rooibank to sea

Data available and assessment of quality of data
Data were obtained from the Atlas of Namibia Project (2002) and elevation data from the USGS (2004). The Atlas project – data are available for download from the internet and is accompanied by good metadata. Some problems however might be experienced by users regarding the format of especially raster data. Some layers (e.g. rivers) also did not conform to the catchments in the dataset.

Present Ecological State and Motivation

PES: 2, Confidence: 2
A decrease in surface flow causes the deposition of sand not not to be "flushed" out and results in the clogging of the river bed.

8.4 Water Quality

Resource Unit 1

Data available and assessment of quality of data
The availability of data was a problem and ad hoc data like some chemical properties of water pools (Huntley, 1985) and 2-day flood conditions (Jacobson et al., 2000) had to be used.

Table 48 Rapid status assessment of Kuiseb River.

Variable	Concentration or range	Assessment
Total dissolved salts (TDS)	Clear gradient – increasing downstream Pools: range, 187 – 3,369 mg/ℓ Flood: 196 mg/ℓ (upper section) – 672 mg/ℓ at Rooibank (lower section)	Generally high TDS, which is probably a natural phenomenon
PH	Min = 7.13 (flood); max = 8.8 (pool)	**B / C** (7.5 – 8.0); (8.0 – 8.5)
SP	No data	–
Nitrate	0.3 to 7.8 mg/ℓ	**B / C** Mesotrophic, 0.5 – 2.5
TIN:SP	No data	–
SP/TP (%)	No SP or TP Data	–
TIN:TP	No TP data	–
Dissolved Oxygen	No data	–

TIN = total inorganic nitrogen (ammonium + nitrate); TP = Total phosphorus; SP = soluble phosphate (PO_4-P)

Summary of data
Natural high salinity occurs in the river. The three major mechanisms that control the composition of the Kuiseb River is evaporation, precipitation and rock dominance. The saline character of some of the water holes is partly ascribed to windblown sea salt (M. Seely, pers. comm.). The waters were generally alkaline with high alkalinity and hardness values.

The largest component of organic loading in streams is in the dissolved state. Riparian vegetation can deliver large amounts of organic matter to ephemeral river channels.

The dissolved organic Matter (DOM) concentration measured in the lower Kuiseb River are among the highest reported from any aquatic system, ranging from 5.6 to 228 mg/ℓ with an average of 82 mg/ℓ at peak discharge (Jacobson et al., 2000). The total suspended solids (TSS) were high during flood conditions and ranged between 11.8 and 48 g/L. TSS transport increased from 24,110 to 46,300 tons between the escarpment and Gobabeb, followed by a 98 % reduction between Gobabeb and Rooibank (Jacobson et al., 2000).

Present Ecological State and Motivation
PESC: B/C (see Table 54).

8.5 Riparian Vegetation

Resource Unit 1

Data available and assessment of quality of data.
No quantitative data is available to determine an IFR for the river. A possible reason is the lack of an acceptable method to measure the Ecological Reserve for a episodic river.

Present Ecological State and Motivation
The present ecological state is a 4. The reasons are the building of dams in the catchment.

Resource Unit 2

Data available and assessment of quality of data
No quantitative data available.

Summary of data
The Kuiseb River cuts across three biomes namely the Savanna biome (upper reaches west of Winddhoek), Nama-Karoo biome (middle reaches) and the Desert biome (lower reaches) (Irish, 1994). Lateral, vertical and longitudinal gradients lead to vegetation changing with distance from the channel, elevation above the channel and distance downstream. The change in species composition of the riparian vegetation reflects these gradients.

Dominant types of riparian vegetation:
The riparian vegetation composition varies along the length of the Kuiseb River. The upper reaches have narrow canyons where flow velocity is high and the flood moves over very shallow alluvium or bedrock. In areas where flow velocity is generally lower, but may upon occasion still be quite high, trees such as Ana trees (*Faidherbia albida*) dominate (Jacobson et al., 1995).

Density and diversity of plant species decrease from the upper reaches to the mouth. In the middle reaches riparian forests are primarily composed of large woody perennial trees, with deep roots to reach subsurface water during the dry season. Species found in these forests depend somewhat on geographic latitude, but also on the frequency and size of floods (Jacobson et al., 1995).

Upper reaches

More frequent flooding and narrower channels characterize the upper reaches. The structure of the vegetation is affected by the more frequent flooding causing higher levels of physical damage. The high velocity of the water is also causing more erosion and the subsequent exposure of bedrock. These factors make it harder for plants to become established. Dominant species in these areas are the Ana tree (*Faidherbia albida),* dominant), *Ficus sycomorus, Euclea pseudebenus* and the chasmophyte (plants growing in crevices) *Ficus cordata.*

Lower reaches

The Ana tree (*Faidherbia albida)* dominates the more narrow floodplains as well as the areas close to the stream channel. These trees can coppice when their roots systems get damaged during floods. Dense clumps of Ana trees result are the result of this vegetative growth. These clumps can withstand the force of floods better than individual trees (Jacobson et al., 1995).

The important communities in the Lower Kuiseb are the Ana tree (*Faidherbia albida)* community*,* Camel Thorn community *(Acacia erioloba*)(dominant on broad silt floodplains), Tamarisk community *(Tamarix usneoides), Salvadora persica* community (sandy areas on floodplains), *Suaeda plumosa* community (brackish soils), *Eragrostis spinosa* community (riverbed where floodwater does not sweep plants away), *Pechuel-loeschea leubnitziae* community (areas with a high water table), *Psilocaulon salicornioides* community (brackish soils), *Zygophyllum simplex – Zygophyllum stapfii* community (edge of hummock dunes. Depend on runoff from gravel plains) (Theron et al*.,* 1980, 1985).

In the lower reaches of the river soil moisture rather than flood disturbance has a greater effect (Theron et al., 1980; Jacobson et al., 1995). Infrequent flooding creates harsh environments where only hardy species such as *Acacia erioloba* and *Parkinsonia africana* dominate (Jacobson et al., 1995).

The vegetation of the lower coastal region of the Kuiseb is being influenced by the river's hydrology and the harsh climate of the surrounding desert. Sand barriers from nearby dune fields block the channels. Water dams up behind the dunes after small floods. Saline or freshwater vegetation are present depending on the local conditions (Jacobson et al., 1995).

Wetland communities are also present along the Kuiseb River. These communities are restricted to sites where groundwater is forced to the surface by shallow bedrock.
Most of the species are typically salt-tolerant plants and capable of rooting in saturated soils (Jacobson et al., 1995).

Prominent species are *Phragmites, Typha, Scirpus, Juncellus, Odyssea paucinervis* and *Cyperus* species. Dominant shrubs are *Tamarix usneoides* and *Suaeda plumosa* species (Theron et al., 1980, 1985).

Alien vegetation
Alien plants present in the Kuiseb River system are forming dense stands in places. Prominent exotics are *Prosopis* species, *Datura innoxia, Ricinus communis* and *Nicotiana glauca* (Jacobson et al., 1995).

Flow impacts
Riparian forests are well adapted to the natural variability in flow regimes. Average floods maintain the forests by providing essential nutrients and water. Long spells of drought could cause the water table to drop and older trees may die, opening up spaces for younger trees to fill (Jacobson et al., 1995).

Floods are the source of water and nutrients that keep riparian vegetation alive (Jacobson et al., 1995). Floodwaters carry large loads of sediments (silt), organic matter, nutrients and seeds. Fine organic material, transported from upstream areas within the catchment, is deposited in the lower reaches of the river, on banks and floodplains. As a result riparian forests are very sensitive to change in the runoff from upstream regions caused by climatic change and dam building.

Studies by Jacobson (1997) revealed that large logs, which are deposited during floods, form an important part of the structure within ephemeral rivers ecosystems. During floods, such logs often lodge against trees growing in or along the river channel, creating small blockages. These blockages form sediment traps where sediment, organic material, nutrients and seeds accumulate. These sites provide excellent habitat that support vegetative growth. Furthermore these blockages usually subdivide the stream channel into smaller channels, altering flow patterns and causing changes in the river's course (Jacobson et al., 1995; 2000).

Episodic floods have the most long-lasting impacts on the structure of riparian forests. These floods demolish whole forest reaches, create new channels within the floodplain, and recharge groundwater (Jacobson et al., 1995)

Groundwater influence
In the lower reaches of the river soil moisture rather than flood disturbance has a greater effect.

Ground water stored in the river channel under the sand supports the riparian vegetation during dry periods after floods. In turn the riparian vegetation is a valuable resource of fodder for wildlife and livestock in western Namibia (Jacobson et al., 1995).

According to Jacobson et al. (1995) the depth of the ground water table beneath the alluvial soils plays a critical role in structuring the vegetation communities and is directly related to flooding. The Ana Tree's survival is dependent on continual access to ground water.

The riparian vegetation of the Kuiseb is very sensitive to changes in the hydrological regime. A dramatic decrease in the ground water in 1982 initiated the large die-off of mature Ana trees in the section between Harubes and Soutrivier. This decrease in groundwater levels could be related to a decrease in rainfall as well as the increase in the number of farm dams on privately owned commercial farms in the catchment (Jacobson et al., 1995).

The abstraction of groundwater from the Kuiseb River for Walvisbaai and the Rössing Mine near Swakobmund caused the die-off of Ana Trees in the section between Swartbank and Rooibank (Jacobson et al., 1995).

Present Ecological State and Motivation
The present ecological state is a 3. The reasons are the presence of dams and reduced recharge.

Resource Unit 3

Data available and assessment of quality of data
No quantitative data available.

Present Ecological State and Motivation
The present ecological state is a 1. The reasons are the abstraction of water, less groundwater recharge, 4x4 impact on vegetation cover, firewood collection.

8.6 Invertebrates

The three resource units identified by a group of specialists for the Kuiseb River were accepted for macroinvertebrate analysis. No to very little macroinvertebrate data was however available for these resource units.

Resource Unit 1
Upper Kuiseb to Schlesien

Data available and assessment of quality of data

Habitat available

The river flows from the Khomas Hochland through a moderately incised canyon to the Nausgomab confluence from where the canyon deepens. The canyon floor is rocky, with a few isolated pools, which can persist until late into the dry season. Scattered patches of sparse vegetation is present on local sandbanks (Huntley, 1985)

Data available

In the Kuiseb River, Chironomidae larval exoskeletons and some microcrustacea namely copepods (*Metadiaptomus meridianus*) and Cladocera (*Daphnia* sp., *Ctenodaphnia* sp. and possibly *Moina dubia*) were sampled by Kok and Grobbelaar (1980).

Day (1990) states that when flood waters recede pools of freshwater are left in the riverbed of the Kuiseb River and in the deep canyon section these pools can persist for months. A list of invertebrates found in these pools includes *Hydra*, Turbellaria, Rotifera spp, *Caenestheriella* cf. *australis*, *Eocyzicus sp*., *Leptestheriella* cf. *inermis*, *Branchipodopsis tridens, Streptocephalus* sp. indet., *Alona* sp., *Ceriodaphnia dubia, Macrothrix* cf. *gouldi, Macrothrix triserialis, Moina* spp., *Eucyclops gibsoni, Mesocyclops oblongatus*, Ostracod spp, Baetidae, Libellulidae, Gomphidae, Coenagrionidae, Notonectidae, Naucoridae, Corixidae, Gyrinidae, Hydrophillidae, Dytiscidae, Hydraenidae, Dryopidae, Chironomidae, Culicidae, Tabanidae, Ceratopogonidae.

Curtis (1991) states that after the floods subside in the ephemeral rivers of Namibia, pools are left in the eroded channel beds. These pools dry out rapidly but are however colonized by species capable of rapid colonization such as notonectids, corixids and dytiscids. Depending on the inundation period in the pool some dipteran larvae such as culicids, chironomids and ephemeropteran and odonate nymphs could also be found.

Quality of data

Some historical invertebrate data was available but no specific sites where collections were made are mentioned in the literature. No present day invertebrate data was available.

Summary of data

A combined list of taxa found in non-perennial systems in Namibia is given in Table 55.

Present Ecological State and Motivation

No PESC was determined as no present day invertebrate data was available

Table 49 A list of macroinvertebrate families found in ephemeral and episodic waters (including rain pools in riverbeds) in Namibia (compiled from lists provided by Day, 1990; Curtis, 1991; and Uys, 1996) showing water quality, habitat and flow preferences (data from Thirion, 2004).

Family present	Water Quality preference	Habitat Preference	Flow Preference
Aeshnidae	Moderate quality preference	Cobbles	Any flow (not very slow)
Baetidae	No preference	All habitat types	Fast >0.6 m/s
Ceratopogonidae	Low quality preference	Cobbles	Fast >0.6 m/s
Chironomidae	No quality preference	Gravel, sand & mud	Slow 0.1-0.3m/s
Coelenterata (Hydridae)	No quality preference	Vegetation	Fast >0.6 m/s
Coenagrionidae	Low quality preference	Vegetation	Moderate 0.3-0.6 m/s
Corixidae	Moderate quality preference	Water Column	Slow 0.1-0.3m/s
Culicidae	No quality preference	Water Column	Very slow <0.1 m/s
Dryopidae	Moderate quality preference	Cobbles	Moderate 0.3-0.6 m/s
Dytiscidae	Low quality preference	Water Column	Very slow <0.1m/s
Ephydridae	No quality preference	Gravel, sand & mud	Very slow <0.1m/s
Empididae	Low quality preference	Cobbles	Fast >0.6 m/s
Gomphidae	Low quality preference	Gravel, sand & mud	Moderate 0.3-0.6 m/ss
Gyrinidae	Low quality preference	Water Column	Fast >0.6 m/s
Heteroceridae			
Hirudinea (Glossiphoniidae)	No preference	Cobbles	Slow 0.1-0.3m/s
Hydracarina	Moderate quality preference	Vegetation/Gravel/Sand/Mud	Moderate 0.3-0.6 m/s
Hydraenidae	Moderate quality preference	Vegetation	Moderate 0.3-0.6 m/s
Hydrophilidae	Low quality preference	Vegetation	Slow 0.1-0.3m/s
Leptophlebiidae	Moderate quality preference	Cobbles	Very slow <0.1 m/s
Libellulidae	Low quality preference	Cobbles	Moderate 0.3-0.6 m/s
Naucoridae	Low quality preference	Water Column	Moderate 0.3-0.6 m/s
Nematoda (Monhysteridae)			
Notonectidae	No quality preference	Water Column	Very slow <0.1 m/s
Planorbidae (Bulininae)	No preference	Vegetation	Very slow <0.1 m/s
Psychodidae	No quality preference	Water Column (stagnant)	Very slow <0.1m/s
Simuliidae	Low quality preference	Cobbles	Fast >0.6 m/s
Tabanidae	Low quality preference	Gravel, sand & mud	Slow 0.1-0.3m/s
Tipulidae	Low quality preference	Gravel, sand & mud	Slow 0.1-0.3m/s

Resource Unit 2

From Schlesien to Rooibank

Data available and assessment of quality of data

Habitat available

The upper reaches of the river, from Schlesien to Harubes, runs through a deeply incised canyon. The canyon floor is rocky and some pools are present. From Harubes to Rooibank the river aggrades and has a wide sandy floor. Downstream the riverbed is sandy but divided into sections by bedrock barriers. The sections are elongated basins filled with sand and alluvium deposits. From Swartbank to Rooibank no rock outcrops occur in the riverbed (Huntley, 1985)

Families of terrestrial insects, sampled by Prinsloo (1990), in the Lower Kuiseb River bed suggests that some of the larvae should be present in the pools in the river. Aquatic insects found were Gomphidae, Libellulidae, and Pyralidae.

Summary of data

No data was available

Present Ecological State and Motivation

No PESC was determined as no present day invertebrate data was available

Resource Unit 3

From Rooibank to sea (Atlantic Ocean)

Data available and assessment of quality of data

Habitat Available

The Kuiseb River widens rapidly and forms an extensive delta (Huntley, 1985).
There is usually no flow in this section.

Summary of data

No data was available.

Present Ecological State and Motivation

No PESC was determined as no present day invertebrate data was available.

8.7 Fish

The Kuiseb River does not sustain a natural fish community. Although there have been reports of fish found the Kuiseb (see Martin, 1956 and Dekker, 1988), fish only occur in farm and state dams in the upper part of the catchment. The presence of fish in the Kuiseb River itself is, therefore, temporarily and mostly as a result of fish washing out of overflowing dams in the upper section of the catchment (Van der Waal, 1997). These farm and state dams seem to be stocked with four cichlid species, a clariid, and two exotic species: *Cyprinus carpio* and *Micropterus salmoides* (Curtis et al., 1998).

8.8 People-ecosystem interactions

Four human populations share water along the entire course of the Kuiseb River. They are freehold-tenure farmers in the upper-catchment, communal farmers and the Namib-Naukluft Park in the middle catchment, and residents and industries of Walvis Bay in the lower catchment. In 1995 it was estimated that 25 000 people were living in areas dependent upon the Kuiseb.

The upper catchment – approximately 63% of the river – is shared by more than 2000 people on 109 farms. The area is typified by a large number of farm dams - between one and twenty dams per farm. Groundwater boreholes are the main source for domestic water supply and for livestock for most of the year. Because of the number of dams in the area, farmers have been accused by downstream users of withholding more than their fare share of the water resources. Groundwater in the middle catchment supports communal livestock farmers as well as the wildlife in the national park. The Gobabeb Training and Research Centre, with approximately 30 residents, is also located in the middle segment of the river. Approximately 300 communal farmers and their livestock live in eight villages along the middle and lower Kuiseb within the park and in the area of Walvis Bay. These villages pump water directly from the alluvial aquifer to resident farmers. The aquifer also sustains the residents and industries of Walvis Bay, and in the past the communal farmers accused the town of lowering the alluvial aquifer upon which their indigenous crops depend. Fear has also been expressed that plans for a major dam in the middle reaches of the river to provide water to a new uranium mine would further reduce, or even eliminate, recharge of the lower Kuiseb aquifer.

8.9 Summary

The Kuiseb River was divided into three resource units (Table 56), namely:

RU 1: Upper Kuiseb to Sclesien

RU2: From Schlesien to Rooibank

RU3: From Rooibank to the coast

Table 56 Identification of the Kuiseb River study area and river segments (= resource units).

Specialist field	River segments		
	RU1	**RU2**	**RU3**
Hydrology	Upper Kuiseb to Schlesien	Schlesien to Rooibank	Rooibank to sea
Geohydrology	Upper Kuiseb to Schlesien	Schlesien to Rooibank	Rooibank to sea
Geomorphology	Upper Kuiseb to Schlesien	Schlesien to Rooibank	Rooibank to sea
Water quality	Upper Kuiseb to Schlesien	Schlesien to Rooibank	Rooibank to sea
Riparian veg (*)	Upper Kuiseb to Schlesien	Schlesien to Swartbank (Ururas)	Swartbank - sea
Invertebrates	-	-	-
Fish	-	-	-
Socio-economic	Upper Kuiseb to Schlesien	Schlesien to Rooibank	Rooibank to sea
Decision	Upper Kuiseb to Schlesien	Schlesien to Rooibank	Rooibank to sea

Resource Unit 1

The Present Ecological Status of RU1, based on the means of the individual scores of the specialists (excluding invertebrates and fish; see Table 57), was considered to be largely natural, with some loss of natural habitats. A PES Category B was assigned. Confidence in this result was relatively high.

The EIS for RU1 was determined to be “moderate” (score of 2), possibly relating to an EIS Category C (Table 58). Based on biodiversity, this river section is, therefore, considered to be ecologically important or unique at a provincial or local scale. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

An AEM Category C was assigned to RU1, based on the fact that the PESC (B) was higher than the DESC (C). Due to the lack of hydrological data, no EWR was determined.

Resource unit 2

The mean score of the respective attributes (excluding invertebrates and fish) considered for the PESC, was 3.0 (Table 57), putting RU2 in a PES Category C. Resource Unit 2 is, therefore, considered to be moderately modified. Natural habitats have, to a certain degree, been lost. Confidence in this result was moderately high. The majority of specialists indicated a degrading tendency in river conditions.

Table 57 Identification of the present ecological status category (PESC) for the Kuiseb River.

Specialist field	PES (0 – 5)*			Confidence (1 – 4)#			Motivation			TRAI of change -/0/+◊			Attainable improvement (0 – 5)			Confidence (1 – 4)#		
	RU 1	**RU 2**	**RU 3**	**RU 1**	**RU 2**	**RU 3**	**RU1**	**RU2**	**RU3**	**RU1**	**RU2**	**RU3**	**RU1**	**RU2**	**RU3**	**RU1**	**RU2**	**RU3**
Hydrology	3	3	1	3	3	3	Defined catchment, high runoff	Increased infiltration rate because of lower water table	Breakthrough to sea less frequent, was 1-6, then 1-8 then 1-50 years	-	-	-	3	3	1	3	3	4
Geohydrology	4	3	1	4	3	4	No abstraction or influence by small dams, is considered to be minimal (on groundwater recharge)	Large draw down due to abstraction	Seawater intrusion because of decreased recharge and abstraction	0	-	-	4	3	0	3	3	3
Geomorphology	3	3	2	2	2	2	Human impact (small dams)	Human impact (small dams)	Lower surface flow, aeoleon deposition not flushed out	0	0	-	3	3	3	3	2	2
Water quality (groundwater only, surface water is expected to stay same because it is episodic)	4	3	2	3	3	3	Data available	Not much change, mining activity	Seawater intrusion and abstraction, reduced recharge	0	0	-	4	4	2	3	3	3
Riparian veg	4	3	1	3	3	3	Building of dams	Dams and reduced recharge	Abstraction and less groundwater recharge, 4x4 impact on vegetation cover, firewood collection	-	-		3	3		3	3	

Table 57 continued Identification of the present ecological status category (PESC) for the Kuiseb River.

Specialist field	PES (0 – 5)*			Confidence (1 – 4)[#]			Motivation			TRAI of change -/0/+[◊]			Attainable improvement (0 – 5)			Confidence (1 – 4)[#]		
	RU 1	**RU 2**	**RU 3**	**RU 1**	**RU 2**	**RU 3**	**RU1**	**RU2**	**RU3**	**RU1**	**RU2**	**RU3**	**RU1**	**RU2**	**RU3**	**RU1**	**RU2**	**RU3**
Invertebrates	Could be replaced by other groups (terrestrial mammals, birds, herpetofauna, etc.)																	
Fish																		
Socio-economic (not included in the mean PES score).	4	2	3	3	3	3	Low population density, unchecked access to resource	Increased consumption resource depletion, less recharge	Large population supported by river water (Walvisbaai), community used river for subsistence use	0	-	-	4	2	2	3	3	3
Mean scores	3.6	3.0	1.4	3.0	2.8	3.0							3.5	3.0	1.6	3.0	2.8	3.0

* (0=critically modified; 1=seriously modified; 2=largely modified; 3=moderately modified; 4=largely natural; and 5=natural/unmodified)
[#] (1=marginal/low confidence; 2=moderate confidence; 3=high confidence; and 4=high confidence)
[◊] (“-“=negative change; “0”=no change; and “+”=positive change)

Table 58 Identification of the Attainable Management Class and EWR for the Kuiseb River.

System	EISC	PESC	AEMC
Kuiseb RU 1	2 (Possibly C)	3.6 B	B
Kuiseb RU 2	4 (Possibly A)	3.0 C	B*
Kuiseb RU 3	2 (Possibly C)	1.4 E	D*

*Recommended, managers need to decide on scenarios – water use more efficient, water demand better managed

Resource Unit 2 was considered to be of very high ecological importance and sensitivity (possibly a category A; see Table 58). Based on unique biodiversity, this section of the Kuiseb River is considered to be unique on a national scale or international scale, and is very sensitive to flow modifications. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

As the PESC (C) for RU2 was two categories lower than the DESC (A), the chances of attaining the DESC, are relatively poor. An AEMC B was accordingly assigned. Due to the lack of hydrological data, no EWR was determined.

Resource Unit 3

Based on the means of the individual scores of the specialists (excluding invertebrates and fish), the PES of this river section was seriously modified (mean score of 1.4), resulting in extensive losses of natural habitats (see Table 57). A PES Category E was accordingly assigned. Confidence in this result was relatively high. Specialists agreed that river conditions in RU3 are degrading.

The EIS for RU3 was moderate (score of 2), possibly relating to an EIS Category C (Table 58). Based on biodiversity, RU3 is considered to be ecologically important or unique at a provincial or local scale. The EISC was then converted to the Default Ecological Management Class (DEMC) and the Default Ecological Status Class (DESC).

The PESC (E) for RU2 was two categories lower than the DESC (C). The chances of attaining the DESC are, therefore, poor. An AEM class D was assigned as a lower category is unacceptable.

Due to the lack of hydrological data, no EWR was determined.

9. PAST EWR DETERMINATIONS FOR NON-PERENNIAL RIVERS

This chapter is the results from the review (at desktop level) of the environmental flow requirements/IFR studies on which the RDM methods were based (Mogalakwena, Matlabas, Shisa, Shingwedzi, Bushmans (Eastern Cape) and Gonubie), identifying areas where the methods need refinement, as indicated by the Terms of Reference.

9.1 Hydrology

As already stated, even though the existing extrapolation curves appear to be sensible from a hydrological point of view, they cannot be used with any confidence in rivers with a hydrological index greater than approximately 10. This indicates that a lot of work should be done on non-perennial river systems, as there is not enough data available on the hydrological or hydraulical side. Unfortunately it will be time consuming and very difficult to get enough data for accurate IFR studies. To solve this problem, a model should be constructed with all the unknown elements to make provision for non-perennial river systems.

9.2 Geohydrology

After reviewing the Mogalakwena Dam feasibility study and the Matlabas et al. studies, the following conclusions were made:

- The role of groundwater is two-fold:
  - Even in the case of non-perennial rivers, there is usually a groundwater flow contribution to baseflow in the river.
  - During periods of no flow in the rivers, groundwater is still flowing towards the river, and it is used by riparian vegetation as well as to sustain the water level in pools.

- If there is a correlation between surface topography and water levels in an aquifer, groundwater will flow towards rivers. Three situations could then occur: (a) if the flux is high enough, groundwater will enter the river as baseflow, (b) if the flux is not enough and could either be used by the riparian vegetation or (c) it could be used by riparian vegetation and enter the river at selected places (e.g. at bedding low ripple positions).

- There are 1970 quaternary catchments in SA. The following statistics are derived:
  - In 998 of the quaternary catchments, the rivers are perennial and thus most probably gaining rivers.
  - In 665 of the quaternary catchments, the percentage of no-flow ranges are between 20 and 80. This probably implies non-perennial rivers.

- In only 23 of the quaternary catchments, the rivers are no-flowing for more than 80% of the time, which most probably implies no link with groundwater.

- Fingerprinting, if the water in a pool of the river originated from groundwater and surface water, could be done by doing chemical analyses of the water.

- Existing maps showing probabilities of groundwater contribution to rivers must be viewed with suspicion, especially at positions where the probability is shown as small.

- There is still a lot of research required (meaning real measurements in the field) to understand and shed more light on the issue of groundwater/surface water interaction.

9.3 Geomorphology

In the case studies presented, only the Mogalakwena study used geomorphology as input in the determination of the present ecological state and the EFR.

9.4 Water Quality

No quantitative data available.

9.5 Riparian Vegetation

No quantitative data available.

9.6 Invertebrates

Review of Mogalakwena River Dam Feasibility Study

Uys (1996) wrote a comprehensive chapter on the functioning of aquatic invertebrates in temporary rivers. In this chapter she highlights the fact that very few data are available on invertebrates of temporary rivers in South Africa.

The lack of invertebrate data is a problem in environmental flow assessments in most non-perennial rivers and a once-off sample which is usually done during a rapid reserve determination is not desirable.

Although no invertebrate data was available at the time of the study, mention is made of what flows should be present for invertebrates to survive.

The flow requirements for invertebrates were incorporated into the decisions for each reach of the Mogalakwena River and for this study it was the only option that could be used as no invertebrate collections could be made due to lack of flow before the workshop. This however emphasizes the need to determine if invertebrates should be included in the EWR determinations in non-perennial systems or at least used with low confidence and caution until more data is available and the ecology of these systems are better understood.

Important observations were made during the study such as the fact that the remaining pools in the river act as refugia for biota and that it is important to maintain them with regards to water quality as well as depth. It is also important to maintain the connectivity between these pools during flow periods.

Review of Matlabas, Shisa and Shingwedzi Rivers

No information was available on invertebrates in these rivers and invertebrates were therefore not included in the Reserve Determinations.

Review of Bushmans and Gonubie Rivers

Information was available on invertebrates from rivers in the vicinity of Bushmans and Gonubie Rivers.

No mention is made from which rivers and if the data used came from the same ecoregion, river type (non-perennial) and river reach. Data extrapolated from other nearby rivers would have to be from the same type (non-perennial) river to be of value. Even then it is difficult to predict if the same invertebrates would be found in both systems especially if they are both non-perennial systems.

The presence of weirs was taken into consideration. The weirs would provide added refugia to the system but would also act as barriers to migration.

9.7 Fish

Review of Mogalakwena River Dam Feasibility Study

A thorough report based on historic records of previous field surveys and good local knowledge and understanding of the river was prepared. Due to the absence of present data, extrapolation of data was applied to certain sections of the river where information was not available. Although the extrapolation of data could be problematic under certain circumstances, the good local knowledge of the fish specialists in the Mogalakwena study disqualifies this criticism. Since the Mogalakwena study, methodologies have been improved and standardized.

Review of Matlabas, Shisa, Shingwedzi, Bushmans and Gqonubie Rivers

Desktop reserve assessments were done for the Matlabas, Shisa, Shingwedzi, Bushmans and Gonubie Rivers. From the report it is not clear if, and where, fish sampling was done in the field. On some of the systems, historical records were available and were used. In others, data were extrapolated from neighbouring rivers in the same ecoregion. Very limited information was, however, given on how the PES was determined, making it very difficult to comment on the process. The focus of this study was on hydrology, resulting in very limited information being given on the other components.

9.8 People-ecosystem interactions

This section pays attention to the non-commercial social uses of the Mokgalakwena River and its riparian vegetation user groups who depend on the river flow and riparian vegetation for their daily needs or survival. The information is based on observations made during a helicopter survey flight in 1995, actual visits to two selected sites and open-ended interviews with local users. At the time of the survey, the IFR study area was typified by a severely skewed population distribution, a relatively small economy and a fast growing population – the leading to a mismatch between population size and available resources. Population density in the Mokerong district registered around 80 to 90 persons per km^2 as against 5 to 7 persons per km^2 for the Potgietersrus (now Lephalale) district. The Mokgalakwena River is an important water source in the Limpopo province and supplies the larger urban centres of Lephalale and Mawhelereng, Bakenberg and Mapela with water, while also providing water for numerous small villages north west of Lephalale. Agriculture is the largest land and water user in this river basin, with agricultural activities that include irrigated and dryland cultivation and livestock and game farming.

The former homeland of Lebowa, which is largely a rural, tribal area, comprises a large part of the Mogalakwena catchment area. This former homeland area is characterised by low access to resources, infrastructure and services. Economic activities in these rural areas are mostly comprised of subsistence dryland cropping on sub-economic farming units. The increased demand for riparian vegetation for grazing purposes is putting pressure on the maintenance of riverine habitats. Severe overgrazing and poor land management result in poor soil conditions, increasing the impact of storm run-off and the deposit of topsoil into the river.

Many rural villages experience water shortages for domestic use due to the combined impact of periods of extended drought and lack of adequate water supply infrastructure and technical back-up systems. Constrained access to water supply, as a result of poor water delivery systems, inadequate infrastructure and poor water quality, force local rural households to rely on untreated river water for domestic water supply and stock watering. Abstractions for domestic water use occur along the entire length of the river.

Some areas long the river is severely polluted by human and other waste causing serious health risks. Agricultural runoff, human waste, stock watering and domestic activities such as washing of clothes all contribute to the pollution of the river and reduce the quality of drinking water for rural people.

Poverty and adverse living conditions of rural populations along the river causes a strong reliance on various services offered by the river ecosystem. Specific utilitarian and recreational uses of the river and its riparian vegetation include the following:

- direct water abstraction for household consumption and personal hygiene
- washing of clothes and vehicles
- sand excavations
- gathering of firewood and building material
- dietary supplementation
- stock/game watering and grazing
- swimming/hunting/fishing
- watering of foodplots
- subsistence farming
- medicinal plants
- aesthetic value
- cultural sites
- graves

Although the local residents indicated that opportunities for hunting and fishing were fast diminishing in some areas and non-existent in others, the range of survival strategies that are directly linked to the river and its riparian vegetation, signal the extreme importance of the riverine ecosystem to many rural residents.

9.9 Summary

Tables 59 and 60 are a summary of findings from the previous IFR studies on non-perennial rivers. Discussion on the strengths and weaknesses of the methodologies applied are discussed in Chapter 10.

Table 59 Summary of the findings from the Mogalakwena study.

Specialist field	**Comments on the methodologies followed in the Mogalakwena study?**	**Recommendations for areas where method refinement is needed.**
Hydrology	BBM was not producing scenarios Developed prescriptive method – Cumbersome A mixture of actual and simulated data was used. Actual are, however, more reliable	Methodology needs to be able to produce scenarios.
Geohydrology	The river is fed by groundwater. It therefore plays an important role in the EWR determination. Borehole data was used in study. Groundwater contours were drawn for IFR55 Some limitations on groundwater abstraction, were set	Measures for groundwater protection should be put in place. For the Mogalakwena River, which is fed by groundwater, one needs: 1. Boreholes at each IFR site 2. Rules which control the gradient of the groundwater table
Geomorphology	The study included a complete report by Roy Wadeson following existing methodology (BBM). However, uncertainties were: The source of the data used is not clear Do not agree with terminoplogy used	Relationship between flows and channel morphometry needs to be investigated in non-perennial rivers
Water chemistry	Limited reference to water quality was made in the report. Water quality was not formally included in the BBM	Water quality, which is not formally included in the BBM methodology, needs to be considered on an equal basis as the water quantity component in a reserve determination.
Riparian veg	Impact ratings used to determine PES subjective Sensitivity rating also subjective Coarse method Structured set of motivations for different flows (11 motivations) First time groundwater requirements included (4 motivations)	Refined method to determine PES – been done – need to review for non-perennial systems Improvement of repeatability Riparian veg required minimum baseflow to meet the evapotranspiration needs of the riparian veg
Invertebrates	No invertebrate data collected or available Flow requirements for invertebrates included for each IFR site – generalised requirements Very good chapter by Mandy Uys on invertebrates in non-perennial systems	Central database on what invertebrates are found in non-perennial systems Relationship between invertebrates and flow Dry (pools) and wet season, invertebrate sampling important

Table 59 (Continued Summary of the findings from the Mogalakwena study.

Fish	Had historical information No current fish data Used extrapolated data (with caution)	Sampling of fish would have given better PES Improvement on methodology addresses discrepancies FAII under estimating biological integrity even more so in some non-perennial systems due to lower species richness and low habitat heterogeneity
Social	The social dependence study was done in 1995. Poverty is high in the study area Predictions based on the assumptions made, were valid for that particular time. Some trends have, however, changed since then e.g. the population density and growth rate dropped, and had not increased as predicted	Reliability of current data based on 1991 census Needs updating Revisit population data District demarcation has changed Also revisit methodology, helicopter survey okay for preliminary scan, interviews, PRA focus groups

Table 60 Desktop and Rapid Methodologies: Matlabas, Shisa, Shingwedzi, Bushmans and Gqonubie (worked with naturalised flows).

Comments on the methodologies followed in the Matlabas et al. studies?	**Recommendations for areas where method refinement is needed.**
Manipulated data in order to make desktop work Uncertainty of which data is used in the model (how many years, which part of record). Results produced for non-perennial rivers by the model are questionable	The DSS model needs further assessment re the applicability thereof for non-perennial rivers
There are no geohydrological input into the model.	**NB:** for non-perennial rivers groundwater should always be included. Assumption: Importance of groundwater increases from perennial to non-perennial rivers (semi-permanent to ephemeral to episodic rivers)
No clear indication was given of the method used for geomorphological input.	Adapt or apply some form of remote sensing to determine geomorphological aspects that can be used in a desktop assessment
The focus of the study was on hydrology with minimal input from other specialists (ecologists etc.) No indication was given on the process of other specialists gave their input, making it difficult for other specialists to give comments on the study.	Input from other specialists (ecologists etc.) required
	Very low confidence in the results produced by the model for highly variable rivers stated by IWR Environmental (2000) and Hughes and Hannart (2003) The graphs indicate further investigations required before the model can be used for non-perennial rivers
	NB: paucity of graph points above a Hydrological Index of 10 indicates that this is an area that needs further research Perhaps even review HI less than 10 because of the wide distribution of points
Maybe assumptions used drawing the lines on the Hughes & Hannart (2003) HI/MAR graphs are wrong?	Line should include more of the higher points (or be moved closer to the higher points as part of the precautionary principle) At present, by leaving a number of points above the line and therefore without the water allocation that they should be getting, it accepts the serious decline of a number of ecosystems.

10 ASSESSMENT OF CURRENT METHODOLOGIES

This chapter are the results from a review of the available methods for assessing and managing environmental water requirements, identifying any gaps where methods need to be modified or developed, as was stipulated in the Terms of Reference.

10.1 Hydrology and Geohydrology

There is still a lot of research required (meaning real measurements in the field) to understand and shed more light on the issue of groundwater/surface water interaction.

When determining ecological water requirements for non-perennial rivers groundwater should always be included. An important assumption is made that the importance of groundwater increases from perennial to non-perennial rivers (semi-permanent to ephemeral to episodic rivers).

10.2 Geomorphology

Published geomorphological studies concentrates on processes in rivers and very little has been published indicating the link between river health and geomorphological process. Time and spatial scales also need to be investigated as biological processes and physical processes (such as geomorphology) do act on different scales.

Strengths and weaknesses

Weaknesses in this process is very definitely the lack of site (river) specific knowledge of experts. Remote sensed data can be used but will only give a broad indication of processes and not the detail as required from the BBM.

The way forward

A model to classify quaternary catchments on the basis of parameters or variables useful for EFR determination should be developed for South Africa. With the use of Geo-Information technology and currently available data, such a classification should put the existing EFR determination methods on a better scientific basis. MODDER, a methodology for the analysis of digital drainage systems and river development, developed by Barker (2002) might form a useful basis for such a study.

10.3 Water Quality

The way forward

More attention should be given to phytoplankton biomass and composition determination. The growth of planktonic algae in a water body is related to the presence of nutrients (principally nitrates and phosphates), temperature and light. Therefore, concentrations of chlorophyll fluctuate seasonally and even daily, or with water depth, depending on environmental conditions.

In reviewing several years of data collected in the Experimental Lakes Area in Canada, Schindler et al. (1978) concluded that changes in phytoplankton species composition and the loss of sensitive species from this assemblage were among the earliest reliable indicators of ecosystem stress observed.

Increased nutrient loading in a water body usually increases its capacity to support greater production and maintain larger standing crops of phytoplankton, by raising the thresholds at which either becomes limited. Thus, algal growth and biomass are of the most widely used measures of the trophic status of aquatic ecosystems.

The presence of certain algal species has long been used to classify aquatic ecosystems according to the degree of impact from organic enrichment (e.g., insufficiently or untreated wastewater).

Phytoplankton is sensitive to changes in water quality and, in particular, responds rapidly and predictably to nutrient enrichment in lakes (cf. Watson et al., 1997). Cyanobacterial blooms *(Anabaena, Microcystis, Nodularia, Oscillatoria* etc.) have become an important water quality problem in eutrofied systems in South Africa, Australia and many countries in Europe (Maier et al., 1998).

The inclusion of phytoplankton (algae) biomass (chlorophyll-*a*) and composition, as a water quality indicator, should, therefore, be a priority for future water quality assessments. The resultant phytoplankton population densities cause problems for recreational users, for treatment processes in drinking water supply, and directly to consumers. Users may be merely reluctant to use the water because of its taste and odour but, at worst, they may experience a toxic effect. It is usually specific algal species that are responsible for water quality problems in water treatment plant (Heath et al., 1998).

The concern with healthy natural systems implies that society needs to be very aware and concerned regarding pollutants discharged to the environment as a consequence of development and enhanced living standards. There should be very strong emphasis on pollution prevention and waste reduction in all aspects of society.

Anthropogenic pressures will affect the long-term trophic fate of Seasonal Rivers, whereas year-to-year climatic conditions will influence annual fluctuations.

A good scientific and technical understanding of the aquatic system is essential if it is to be effectively managed.

In particular, information is needed about the conditions of the catchment, the water resource itself, the present water quality and stressors likely to degrade the quality, and uses of the water resource.

10.4 Riparian Vegetation

There are two methods that could be used namely the Riparian Vegetation Index (RVI) method (Kemper 2000) and the IFR method as described by Boucher and Kemper (2001). These methods are both applicable to perennial rivers. Problems could arise if the riparian vegetation of non-perennial streams and rivers are assessed.

Strengths and weaknesses

Kemper (2000) (Riparian Vegetation Index)

Strengths

1. Rapid method.
2. Does not require a high level of vegetation knowledge and experience

Weaknesses

1. Method too coarse to pickup small changes in the riparian systems.
2. Not tested in ephemeral and episodic systems.

Boucher and Kemper (2001)

Strengths

1. Method could pick up relatively small changes in the riparian systems.

Weaknesses

1. Method is time-consuming.
2. Requires a high level of vegetation knowledge and experience,
3. Not tested in ephemeral and episodic systems.

The way forward

In the case of non-perennial, ephemeral and episodic rivers the vegetation becomes increasingly important as a tool to determine the Ecological Reserve for the particular river or stream. The vegetation is the only measurable biotic component as aquatic species such as fish, amphibians, invertebrates, etc. are absent in most of the cases.

New methods to determine the Ecological Reserve of non-perennial, ephemeral and episodic rivers have to be developed to measure the state of the Ecological Reserve.

10.5 Invertebrates

Strengths and weaknesses

At present, due to lack of long term data and a lack of understanding of the ecology of non-perennial systems, invertebrates are not ideal indicators to be used in rapid or desktop reserve determinations in non-perennial rivers.

The complexity of the non-perennial river system in terms of flow variability makes sampling of invertebrates difficult as habitat available is either dry or has very low flow and during wet periods these habitats need to be inundated for at least six weeks for most of the invertebrates to successfully recolonise.

Desktop Reserve determinations rely on historical data as well as present day data to determine the PESC for the quaternary catchment in question. The PESC determined as part of the National Water Balance Model is also used. Very little historical data as well as present day data are available on non-perennial systems. This makes a desktop determination virtually impossible for these systems and one has to rely on the Water Balance Model to provide the PESC and AEMC which would imply a low confidence decision as these values cannot be verified by actual present day data.

Rapid Reserve determinations make use of a once-off sample to determine the present ecological state of the river in terms of invertebrates, A once off sample would not give an accurate picture of what the present state of the invertebrates are in a non-perennial river as the community composition is determined not only by the presence of habitat in these systems but by the availability of flow and the timing and length of the inundation period. The historical flow record of the system also determines the presence of invertebrates. Only long-term data would give an accurate picture of the ecology and present state of the system. Usually historical data is used to determine the expected taxa in the river. As very little historical data are available in non-perennial systems, this is usually not possible, and one has to rely on specialist opinion, which once again implies low confidence as no or very little actual data is available to verify decisions.

The fact that a once off sample is used in rapid reserve determinations is also difficult as non-perennial rivers are dry or have very low flow during certain seasons and no sampling can be done. It is also not advisable to use SASS as a method to determine the presence of invertebrates in the river, as SASS was developed to be used in perennial rivers where there is flow and a diverse habitat present.

Applicability of SASS in non-perennial rivers

SASS on its own is not the ideal method for Environmental Water Requirement (EWR) determination in non-perennial rivers as the index is designed to indicate organic pollution. Many of the invertebrates with low SASS intolerance scores (see Table 18) are also the invertebrates which are usually present in non-perennial rivers due to their ability to survive in variable, harsh conditions by either escaping into sediment to survive or by flying away to other refugia. This however produces low SASS scores indicating a poor to very poor class, which is not always a true reflection of the non-perennial river.

The timing of the SASS determination is also critical in non-perennial systems as seasonal differences in macroinvertebrates appear to be more pronounced (see Harrison, 1966). Boulton and Lake (1992b) also found that the significance of historical events in structuring the community composition of invertebrates in non-perennial systems makes it necessary that long-term data be used to adequately describe the ecology (present ecological condition) of the system. The high flow period in these rivers usually implies flooding when most invertebrates are swept downstream and low flow periods usually occur as stream is drying out and invertebrates have started to leave the system. Sampling during these periods could give a skewed view of the present condition of the system.

Applicability of using the Invertebrate Response Assessment Index (IRAI) method for Invertebrates in non-perennial systems

The Invertebrate Response Assessment Index (IRAI) for macroinvertebrates developed by Thirion (2004) not only uses the SASS4 score, but includes the abundance and presence data of invertebrates found in the system. It also incorporates the flow, habitat and water quality preferences of invertebrates present. By comparing the invertebrates present in the system to what would be expected (either using historical data or professional opinion) and weighting the importance of habitat type, water quality and flow, a Present Ecological Status Class (PESC) is generated. This method is more reliable for use in non-perennial systems as the SASS score itself does not carry all the weight. This method can however not be used in a Desktop Reserve Determination as a site visit where present day data are collected is needed (unless recent data are available possibly from a River Health Monitoring program etc.).

Some disadvantages of using IRAI are the lack of historical data in these systems, as very few rivers have been sampled in these systems and expert knowledge is therefore lacking. The once off sampling used in Rapid Reserve Determinations is also a problem in the IRAI method as discussed under SASS applicability.

Until more research has been done in order to understand the ecology of these systems, any method used would be of relatively low confidence rating.

The way forward

- Lack of data, not only a lack of historical data but a lack of present day data. Data are sometimes not available as it is kept in personal reports or consultants reports and not published. A user friendly national database is imperative to the success of the Reserve determinations in South Africa. Ecoregion, bioregion and river classification would be much more reliable and accurate if data were readily available. Data collected as part of the River Health Monitoring program in South Africa could be valuable in cases where no present day data could be collected during the Reserve Determination.

- Data on invertebrates in non-perennial systems need to include accurate flow data and habitat descriptions. Long term data are needed to accurately describe the ecology of non-perennial systems
- Data on seasonality of invertebrates in non-perennial rivers are also important as this influences time of sampling and interpretation of data.
- The unpredictability of flow makes it difficult to assess the requirements of invertebrates as they are already adapted to harsh conditions. How do we determine what amount of change is critical?
- Deciding which taxa are sensitive in non-perennial systems is also a problem as sensitive taxa in perennial systems are usually those which prefer high water quality, fast flow and stones-in-current (rapids or riffles) habitat. These taxa are usually absent from non-perennial systems as there is seldom fast flow, stones-in-current are scarce and water quality is usually not of high quality due to drying out etc. Do we then still regard these taxa as sensitive in non-perennial systems or are taxa which are adapted to the harsh conditions, the sensitive taxa in non-perennial systems? How far can we alter the already harsh conditions before these taxa disappear?

10.6 Fish

Three indices, the Fish Assemblage Integrity Index (FAII; Kleynhans, 1999a, 2003), a qualitative version of the FAII, and the Fish Response Assessment Index (FRAI, Kleynhans, 2004) were used to determine the present ecological status (PES) of the river segments under investigation.

Fish Assemblage Integrity Index (FAII)

Strengths

The Fish Assemblage Integrity Index (FAII) is a multi-metric index based on a comparison between aspects of the expected and observed fish assemblages (Kleynhans, 1999a; 2003). The method integrates information on the fish community in a specific stretch of the river, and was designed for use in the River Health Programme.

- A wide range of fish community attributes are considered. This enables the fish expert to identify those aspects of community response that may be responsible for a given unsatisfactory rating (Karr et al., 1996).

Weaknesses

- The FAII was developed for the biomonitoring of fish in a river stretch as part of the River Health Programme, and may, therefore, not be ideally suited for use in EWR studies.
- Lack of historical records on the distribution of fish species in non-perennial rivers is a common problem. The setting of the reference conditions under such circumstances is then up to the specialist conducting the survey who is not always acquainted with local conditions.
- Homogeneity of habitat types, especially under conditions of low flow conditions. Fast deep and fast shallow habitats are very scarce in non-perennial rivers under conditions of low flow. The high occurrence of weirs and dams in these rivers, further contribute to this situation in that the river tends to become a longitudinal series of pools behind weirs.
- As a result of the high variability and unpredictability of rainfall and flow in non-perennial river systems, fish assemblages in these rivers tend to consist of hardy generalists. Specialist fish species are often absent from such systems, making early detection of modified conditions difficult. A study on the fish community of the Modder River indicated that no clear differences could be detected between fish diversity and abundance at the four habitat types "slow deep", "slow shallow", "fast deep" and "fast shallow" (Avenant, 1999). This could be due to the generalist nature of most of the fish species present, as well as the lack of fast-flowing habitats in the Modder River.
- Natural low species richness of some non-perennial rivers. (The FAII is actually considered unsuited for rivers hosting a low species richness, and cannot be considered responsive to change in biological integrity, Kleynhans, 1999a).
- Lack of life-history information on fish species, especially with regards to reproduction and migratory behaviour. This is especially relevant for reserve studies in non-perennial studies.
- How important are periods of no-flow to biota of non-perennial systems.
- The FAII is strongly based on the intolerance index of fish species based predominantly on incidental observations and professional judgments (Kleynhans, 1999a). Some of the species rated as sensitive (tolerance rating above 3), do not seem to be sensitive species in some non-perennial systems of Free State. This issue needs further investigation.
- The ideal time of sampling remains a debatable point. Kleynhans and Engelbrecht (1999) advise sampling to be conducted under conditions of low flow. Although this should not be a problem with Intermediate and Comprehensive studies, only one field visit is made with Rapid assessments. Sampling conducted during low flow conditions (winter in the Free State) usually gives a under estimation of the fish present at the site. This could be corrected by using historical information, which is unfortunately scant or absent for most Free State streams. Local expertise is therefore very important.

- A certain degree of accuracy is lost when the index is applied on the data of only one or two sites per river reach, as could be the case with Rapid Determinations. This could lead to an underestimation of biological integrity for the river segment.

Qualitative Fish Assemblage Integrity Index (FAII)

Strengths

- The qualitative version of the FAII can be used in reserve determination studies on rivers with very low species richness, lacking historical data.
- The index could be useful when limited sampling data is available .for river segments

Weaknesses

- The index seems to overestimate biological integrity, and should possibly be used in conjunction with the quantitative FAII.
- The index could be prone to the subjectivity of the specialist completing the index. As metrics are rated on a scale of "0" to "5", one number more or less could influence the result. This may also influence the repeatability of the index.
- In the present study no field sampling was done and information on the health/conditions of fish sampled, abundances for the fish sampled and information on the in-stream habitat were not available for all resource units. As a result these metrics could not be considered in the calculation of the PES, lowering the confidence in the results.

Fish Response Assessment Index (FRAI)

Strengths

- The method seems to be better suited for seasonal streams and rivers in the Free State (having low species diversity, mostly generalist fish species and limited habitat heterogeneity, especially during conditions of low flow conditions). Results obtained by using this index seem to be more realistic than those produced by the other two indices (FAII and Qualitative FAII).
- This index could be applied on limited fish data.

Weaknesses

- A relative high level of professional expertise is needed to apply FRAI.
- Knowledge of local conditions is needed to ensure effective decision-making in the FRAI method, especially in the absence of adequate data on fish and the instream habitats.
- Sampling success in winter tend to be very poor for the non-perennial rivers of the Free State. The question may be asked to what extent does the absence of fish at a sampling site in winter reflects poor habitat conditions as a result of river degradation or a natural seasonal phenomenon.

The way forward

- An investigation into the applicability and suitability of the different fish indices in non-perennial systems, especially ephemeral system.
- Does seasonality have an effect on the results of reserve determination studies with regards to the fish component.
- More information is needed on the importance and functioning of aquatic refugia in non-perennial river systems, especially with regards to the management of such refugia.
- More information is needed on the life histories of most fish species, especially with regards to reproduction.
- A question that needs to be answered: is drought necessary for the maintenance of populations in intermittent streams?

General

- The lack of continuous hydrological records for the majority of non-perennial rivers should be addressed. A start needs to be made in measuring flow in these systems. It is of critical importance that the knowledge base on rivers is extended to seasonal and ephemeral river systems.
- Reserves that have been determined should be implemented and monitored in order to give feedback.

10.7 People-ecosystem interactions

Detailed socio-economic studies on the social uses of non-perennial rivers are scarce, and in some cases where such studies have been conducted the data tend to be dated (Mokgalakwena), or even inconsistent (Kuiseb). In general, however, the development of socio-economic matrixes for the assessment of uses is a significant step towards the refinement of an appropriate social methodology for the study area. Such matrixes can only benefit from similar approaches and instruments that have been developed by practitioners in the area of social impact assessments.

The problem with dated socio-economic data, such as in the case of the Mokgalakwena river, cuts across two issues. Firstly, the past ten years have seen significant changes in the population structure and dynamics of the southern African region, and in the South African population in particular. Working with population data and projections of the early 1990s therefore will undoubtedly result in a skewed profile when it comes to an assessment of future environmental water requirements. Secondly, since 1994 municipal boundaries in South Africa have changed drastically as a result of new local and district demarcations by the Demarcation Board. This makes any comparison between existing socio-economic circumstances and those of the early 1990s even more difficult, especially in cases where boundaries of communities or social groups dependent on the resource have been affected by re-demarcation.

Lastly, it would appear that the methodology of participatory rural appraisal (PRA) has been neglected or ignored in most socio-economic studies looking into the social dependence on the river resource. The reality of large segments of the rural population in southern Africa, however, is that researchers are facing a population profile typified by high levels of illiteracy and low socio-economic status. In these circumstances it is highly advised to adapt a methodology that could generate an optimum understanding of rural people's dependency on the river system and their interaction with the river ecosystem. Qualitative approaches such as PRA, focus groups and key informant interviews should therefore be integrated into a comprehensive methodological design suitable for the unique challenges posed by the different target populations in rural areas.

The way forward

Riverine resources offer an important asset to livelihoods of rural communities. Approximately 75% of the population in African countries are rural, the majority of whom are small farmers who produce about 70% of agricultural output in the region (Ladele 1999). These small farmers are largely poor and illiterate, and at the mercy of harvest failures, loss of cattle or loss of earning potential. Their direct dependence on freshwater flow systems in arid and semi-arid regions causes them to dwell much on myths, religious ideas and cultural practices. Such systems are therefore not only of economic and health value, but they also play a role in cultural, religious and recreational matters.

Water scarcity is believed to be setting the development ceiling for many African nations, since water shortages are constraining improvements in agriculture, industry and domestic use (Harrison 1993:53). Humankind has, however, succeeded in pushing the environmental limits quite far to benefit their societal development. However, achieving these gains for human societal and economic progress has often come at the expense of the natural ecosystems that support human society. Therefore, social and cultural practices may indeed have aided humankind to increasingly alter the natural environment, but this may well lead to the demise of those very social and cultural practices that have underpinned human interaction with the natural environment.

Although the socio-cultural interactions of local people with freshwater ecosystems are relatively poorly documented, there is nevertheless evidence to suggest that such interactions are far from random, but rather imbedded in well-established cultural value systems and practices. In some cases, these practices are directly linked to a profound sacred status attached to many rivers, pools and water sources, as in the case of many indigenous communities in southern Africa. Such perceptions constitute a powerful mechanism for protecting water resources and for coping with fluctuations in flow systems. In southern Africa in particular, the religious, cultural and spiritual significance that indigenous people attach to rivers and lakes has a powerful impact on the utilisation and protection of natural water resources in the region.

A better understanding of the interaction between population dynamics and freshwater flow systems is a first step to inform policies that will be able to make these relationships more sustainable. More specifically, such policies should, amongst others, be sensitive to local contexts and draw on multidisciplinary knowledge. Policies should further account for the upstream and downstream effects of river developments and interactions, and encourage communities to become involved in the design and implementation of river-basin management projects. Some specific issues that may be of relevance to policy formulation include the following: the relationship between land tenure and freshwater rights; estimates of the economic value of water resources in various contexts; soil and water conservation techniques; indigenous water management strategies; coping strategies of communities in arid- and semi-arid regions during times of water scarcity; and, population-freshwater system relationships in or near protected areas and wetlands.

11 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This study is a first attempt to structure an environmental water requirement determination approach for non-perennial rivers, which cover two-thirds of South Africa. The problem that we were and are faced with is that the methods currently available for the determination of environmental water requirements for South Africa's rivers are based on perennial rivers. Thus far, the use of existing methods has often been unavoidable due to knowledge gaps and time constraints, but this is not a sufficient solution to ensure the long-term protection of non-perennial river systems. It is important to note that non-perennial rivers are ecologically fragile and alterations to their hydrological systems can have far-reaching effects. Therefore it is of utmost importance that new, sufficiently well-researched methods be found and developed to assess the environmental water requirements for non-perennial rivers with acceptable levels of confidence.

The following are more specific conclusions:

11.1 Ecotyping

During the present project's workshop, a scale was adopted, supported by a map, which divided the country into areas of perenniality of rivers. The categories were based on the periodicity of inundation of quarters of the year, i.e. inundation for less than one quarter of the year on average resulted in an episodic river, for more than three quarters of the year on average, a semi-permanent river, and the category in between, namely between one quarter of the year and three quarters of the year on average, an ephemeral river. According to this proposal, the country is divided into four main areas, with the perennial rivers mostly in the southwest and east. The rest of the country is divided among the non-perennial rivers, namely the semi-permanent rivers in a narrow band to the interior of the perennial rivers, with their greatest concentration in the southeastern midlands, the ephemeral rivers covering most of the central and northern areas, and the episodic rivers in the northwestern arid areas of Namaqualand and the Kalahari.

11.2 Nylsvley case study

The Terms of Reference for the project required a rapid desktop reserve determination to be done on Nylsvley as an example of a seasonal river. In consultation with the WRC, this was changed to a "preliminary" or "desktop" reserve determination, as no provision for field visits and field sampling was made in the contract. This provided further difficulties, in the sense that, the new revised RDM methodology did not make provision for a desktop reserve determination. The combined use of the procedures for desktop estimates of the water quantity component of the Ecological Reserve of Kleynhans (1999b) and the revised RDM methodology was, therefore, inevitable.

In the absence of field data, including adequate flow data, specialists were dependent on existing data sources. Although Nylsvley is considered to be a relatively well-studied

system, existing information is patchy, and recent information was especially difficult to obtain.
For example, no social data or references to socio-economic studies on the Nylsvley were available, and was excluded from the study. Confidence in the results of the reserve determination is, therefore, low.

The study showed that:

- No flow occurs for about 25% of the year, making pools a major water source for aquatic life. Groundwater is, therefore, expected to play a very important role in sustaining water levels in these pools. In order to effectively manage water levels in these pools, it is proposed that a constraint on groundwater gradient towards the rivers must be specified.
- Based on the data available, the PES of the two resource units were, respectively, categorised as Classes B (largely natural) and C (moderately modified).
- The second resource unit, which includes Nylsvley itself, was considered to be of high ecological importance and may be sensitive to flow modifications.
- The output of the Hughes DSS and DRIFT hydrological models, applied for the first resource unit, differed. The amount of water allocated by the DRIFT model was 20-30% higher than what the Hughes DSS advised. It seems as if the Hughes methods allocate insufficient water to non-perennial systems. This issue needs further research.
- The hydrological index for the second resource unit was 13.2, which Hughes (IWR Environmental, 2000) considers beyond the acceptable range of accuracy (10 or less).

Recommendations

- In order to effectively manage water levels in these pools, it is proposed that a constraint on groundwater gradient towards the rivers must be specified.

11.3 Limpopo River case study

A desktop reserve determination was done for the Limpopo River. No field visits or sampling was done and specialists were dependent on existing data sources. Existing information, including hydrological data, is patchy and recent information was especially difficult to obtain. Confidence in the results of the reserve determination is, therefore, low.

The study area was divided into three resource units (RUs): the first stretching from the confluence of the Marico and Crocodile Rivers downstream to the Limpopo-Mokolo confluence, the second from below the Limpopo-Mokolo confluence to the confluence with the Sashe River and the third RU stretches from below the Sashe-confluence to where the Luvuvhu River joins the Limpopo.

The study showed that:

- No flow occurs for about 23% of the year, making pools (both artificial and natural) major water source for aquatic life. Groundwater is, therefore, expected to play a very important role in sustaining water levels in these during times of no-flow.
- Natural and artificial pools act as critically important refugia for aquatic biota during times of low-flow and should be protected from over-utilisation.
- Based on the data available, the PES of all three resource units were considered to be moderately modified and was categorised as Class C.
- The Limpopo River (all three resource units), was determined to be of moderate ecological importance and sensitivity.
- Flow in the Limpopo River proved to be highly variable and the hydrological index varied from 13.4 to 91.2, falling outside of the acceptable range of accuracy (10 or less) for Hughes and Münster's (1999) hydrological model.
- Water allocated by the DSS model for the Limpopo River is, therefore, most possibly an underestimation of the EWR of the river. Further research is needed on this matter.

Recommendations

- In order to effectively manage water levels in pools, it is proposed that a constraint on groundwater gradient towards the rivers must be specified.
- An investigation is needed test if the water allocated by the DSS model is enough?

11.4 Kuiseb River case study

In answer to the Terms of Reference for the project, a desktop reserve determination, following a combination of the procedures for desktop estimates of Kleynhans (1999b) and the revised RDM methodology, was done for the Kuiseb River. No field visits were made and no sampling was conducted. In the absence of field data, especially adequate flow data, specialists were dependent on existing data sources. Existing data was patchy and recent information was lacking for certain specialist fields (e.g. aquatic invertebrates). Also, due to the absence of flow data, no EWRs were determined.

The study indicated that:

- Even though the Kuiseb River is an episodic river with a highly variable flow regime, several human communities are dependent on water from the river.
- Riparian vegetation along the river is maintained by average floods and is very sensitive to changes in the runoff from the upper part of the catchment. During dry periods, the vegetation is supported by groundwater, making it sensitive to a drop in the water table.
- Based on the data available, the PES of the three resource units were, respectively, categorised as Classes B (largely natural), C (moderately modified) and E (seriously modified). Indications are that river conditions are deteriorating in a downstream direction.

- The middle section of the river (RU 2) was considered to be of high ecological importance and may be sensitive to flow modifications. This section of the river section act as an important migration route for several species, and plays, therefore, an important role in sustaining current biodiversity.

Recommendations

- A specific drawdown water level must be set for groundwater abstraction along the river.

11.5 Review of past EWR determinations

The Terms of Reference for the project required a review of IFR determinations previously done on non-perennial systems. Two studies were reviewed, namely a pre-feasibility study on the Mogalakwena River, and a study done by by IWR Environmental (2000) to investigate improvements to the hydrological extrapolation method used in Desktop (Level 1) and Rapid (Level 2) determinations of the ecological reserve.

Mogalakwena pre-feasibility study

A review of the methodologies used in the Mogalakwena study indicated the following:

- A need definitely exists for producing different flow scenarios in a reserve determination to enhance decion-making.
- A mechanism is needed to be put into place for the protection of groundwater. In a system fed by groundwater, boreholes are needed at each EWR site, as well as guidelines to control the gradient of the groundwater table.
- The relationship between flows and channel morphometry in non-perennial rivers needs further investigation.
- Water quality, which is not formally included in the BBM methodology, needs to be considered on an equal basis as the water quantity component in a reserve determination.
- The methodology used to determine the PES for the riparian vegetation needs to be reviewed for non-perennial rivers. The method should also be improved with regards to repeatability.
- A central database on the invertebrates found in non-perennial rivers needs to be established.
- The correct timing for the sampling of invertebrates in non-perennial rivers should be investigated.
- The relationship between flow and the nature of the invertebrate community needs to be investigated.
- The methodology used to determine the PES based on the fish community may underestimate biological integrity in some non-perennial rivers due to lower species richness and habitat heterogeneity.
- More appropriate methodologies should be applied and recent data banks be accessed for socio-economic assessments such as the Mogalakwena study, and should be included in reserve determinations.

It is recommended that:

- Procedures for the protection of groundwater be developed.
- The relationship between flow/no-flow and the biota (invertebrates, fish and riparian) be investigated.
- Water quality be considered as being equally important as the water quantity component, in reserve determinations.

Study on the Matlabas, Shisha, Shingwedzi, Bushmans (Eastern Cape) and Gqonubie Rivers to investigate improvements to the hydrological extrapolation method used in Desktop (Level 1) and Rapid (Level 2) determinations of the ecological reserve.

The study of these five rivers focused strongly on hydrology and very limited information was provided on the other components.

- The extrapolation curves need to be further investigated before the model may be used in non-perennial rivers. The paucity of graph points above a HI of 10 indicates that this area needs further research. The line should include more of the higher points (or be moved closer to the higher points as part of the precautionary principle). At present, by leaving a number of points above the line, and therefore without the water allocation that they should be getting, it accepts the serious decline of a number of ecosystems.
- No geohydrological input was made into the model. Geohydrological data was not considered in the hydrological model.
- No information was available on geomorphology and water quality, and it is uncertain if these specialist fields were considered in the study.
- No, or very limited information, was supplied on the methodologies used to determine the PES of riparian vegetation, invertebrates and fish. It is not clear from the report how these indicators were used in the dtermination of the PESC.
- No socio-economic data was considered in the study.

It is recommended that:

- The applicability of the Hughes DSS of Hughes and Munster (1999) for non-perennial rivers be further investigated.
- Groundwater should be included in hydrological modelling for non-perennial rivers. It is suggested that the importance of groundwater increases from semi-permanent to ephemeral to episodic rivers.
- Remote sensing be used to determine geomorphological aspects in desktop or rapid EWR assessments.

11.6 Assessment of current methodologies

In correspondence with the Terms of Reference for the project, existing methodologies used in the respective specialist fields, were reviewed.

Hydrology

The Hughes DSS is currently the only viable method by which the quantity component of the ecological reserve may be estimated (IWR Environmental, 2000). Deficiencies related to the range of hydrological indices are, however, a significant limitation to the use of the method in rivers that have a hydrological index in the range 10 to 80. Existing extrapolation curves appear to be sensible from a hydrological point of view but cannot be used with any confidence in rivers with a highly variable flow-regime. Currently there is not enough data available on the hydrological or hydraulic side. Therefore, a lot of work remains to be done on non-perennial river systems. Unfortunately it will be time consuming and very difficult to get enough data for accurate EWR studies. To solve this problem, a model should be constructed with all the unknown elements to make provision for non-perennial river systems.

Recommendations

- More emphasis should be placed on groundwater in EWR assessments for non-perennial systems.

Geohydrology

The importance of the groundwater component is becoming increasingly important when moving from perennial to non-perennial rivers (semi-permanent to ephemeral to episodic rivers). Also, the link between groundwater and surface water needs greater emphasis.

Recommendations

- More emphasis should be placed on groundwater in EWR assessments for non-perennial systems.
- Further research, including field measurements, is required to shed more light on the interaction between groundwater and surface water.

Geomorphology

Published geomorphological studies concentrates on processes in rivers and very little has been published on the link between river health and geomorphological process. Time and spatial scales need to be investigated as biological processes and physical processes (such as geomorphology) do act on different scales.

Evident is the lack of site (river) specific knowledge of experts. Remote sensed data can be used but will only give a broad indication of processes and not the detail as required from the BBM.

Recommendations

- A model should be developed to classify quarternary catchments on the basis of parameters or variables useful for EWR determinations in South Africa. With the use of Geo-Information technology and currently available data, such a classification should put the existing EWR determination methods on a better scientific basis. MODDER, a methodology for the analysis of digital drainage systems and river development, developed by Barker (2002) might form a useful basis for such a study.

- Time and spatial scales need to be investigated as biological processes and physical processes (such as geomorphology) do act on different scales.
- Remote sensed data can be used in rapid reserve assessments to give a broad indication of geomorphological processes.

Water Quality

The rapid RDM determination for water quality focuses strongly on chemical parameters. The inclusion of phytoplankton (algae) biomass (chlorophyll-*a*) and composition should, therefore, be included as a water quality indicator in future water quality assessments. The current methodology is, however, under review.

Recommendations

- Phytoplankton (algae) biomass (chlorophyll-*a*) and composition should be included as a water quality indicator in future water quality assessments.

Riparian Vegetation

Two methods are currently used, namely the Riparian Vegetation Index (RVI) method (Kemper 2000) and the IFR method as described by Boucher and Kemper (2001). Both of these methods are applicable to perennial rivers, and are not ideally suited for use in non-perennial systems.

Kemper's (2000) RVI is a rapid method that does not require a high level of vegetation knowledge and experience. The method is, however, too coarse to pickup small changes in the riparian systems. Although the IFR method of Boucher and Kemper (2001) could pick up relatively small changes in the riparian systems, it is time-consuming and requires a high level of vegetation knowledge and experience.

Riparian vegetation becomes increasingly important in ephemeral and episodic rivers due to the possible absence of other aquatic biota. It is, therefore, of critical importance that current methodologies are tested and adapted for use in non-perennial systems, or more suitable methodologies developed.

Recommendations

- The applicability of current methodologies in especially ephemeral and episodic rivers should be investigated.

Invertebrates

Long term data is needed to accurately describe the ecology and present state of non-perennial rivers due to their unpredictability in terms of flow. Very few studies have been done on non-perennial rivers and very little data is available.

The historical and present day hydrological record determines the invertebrates present in the system. The lack of data (historical as well as present day) inhibits the use of invertebrates as an indicator of the present state of the system and therefore the use of invertebrates to determine the EWR of a non-perennial river.

The use of SASS as a method to determine the PES of a non-perennial river is questionable as the method was developed to be used in perennial rivers (with flow and habitat diversity as prerequisites). The use of IRAI as a method is more acceptable as it incorporates SASS data as well as the flow, water quality and habitat preferences of expected and observed invertebrates. This method however also needs historical data and where this is not available one has to rely on expert opinion which lowers the confidence of the results obtained.

Recommendations

- A user friendly national database should be compiled from data available in reports, Rivers Database etc. and research in non-perennial rivers to collect data on invertebrates should be encouraged.
- Scientists doing studies on invertebrates should include accurate flow data and habitat descriptions in their results.
- Studies to determine the sensitivity of invertebrates, in terms of flow and length of dry period, in non-perennial rivers should be carried out as this would aid in the interpretation of flow conditions suggested during EWR studies.

Fish

Three indices, the Fish Assemblage Integrity Index (FAII; Kleynhans, 1999a, 2003), a qualitative version of the FAII, and the Fish Response Assessment Index (FRAI, Kleynhans, 2004) are used to determine the present ecological status (PES) of the river segments. Of these, FRAI seems to be better suited for use in non-perennial rivers.

FRAI is developed for use in EWR assessments, and preliminary results obtained in non-perennial rivers are very satisfactory. A relative high level of professional expertise and knowledge of local conditions is needed to ensure effective decision-making, especially in the absence of adequate data on fish and instream habitats.

Recommendations

- The applicability and suitability of the different fish indices, especially FRAI, in non-perennial systems, should be investigated.

- The intolerance index of certain fish species should be reviewed for non-perennial systems.
- The ideal time of sampling in non-perennial should be established, especially for rapid assessements where only one field visit is made.
- Knowledge of local fish communities and conditions should be valued and, where possible, included or consulted in reserve determination assessments.
- More information is needed on the importance of habitat connectivity and the functioning of aquatic refugia
- More information is needed on the role that seasonality and disturbances may play in the maintenance of fish populations in intermittent streams
- More information is needed on the life histories of most fish species, especially with regards to reproduction and migratory behaviour.
- The importance of conditions of no-flow to biota of non-perennial systems should be investigated.
- The lack of continuous hydrological records for the majority of non-perennial rivers should be addressed.
- It is of critical importance that the knowledge base on rivers is extended to seasonal and ephemeral river systems and reserves that have been determined should be implemented and monitored in order to give feedback.

People-ecosystem interaction

Recent and detailed socio-economic studies on the social uses of non-perennial rivers are scarce. The development of socio-economic matrixes for the assessment of the river uses is, however, a significant step towards the refinement of an appropriate social methodology for the study area. Such matrixes can only benefit from similar approaches and instruments which have been developed by practitioners in the area of, amongst others, social impact assessments.

The methodology of participatory rural appraisal (PRA) has been either neglected or ignored in most socio-economic studies looking into the social dependence on the river resource. In circumstances where a population profile is typified by high levels of illiteracy and low socio-economic status (such as in the case of many deep rural populations), it is highly advised to adapt a methodology that could generate an optimum understanding of rural people's dependency on the river system and their interaction with the river ecosystem. Qualitative approaches such as PRA, focus group sessions and key informant interviews should therefore be integrated into a comprehensive methodological design suitable for the unique challenges posed by the different target populations in rural areas.

Recommendations

- Qualitative approaches such as PRA, focus groups and key informant interviews should be integrated into a comprehensive methodological design suitable for the unique challenges posed by the different target populations in rural areas.

- A better understanding of the interaction between population dynamics and freshwater flow systems is needed to inform policies that will be able to make these relationships more sustainable.
- Specific issues that should be considered in policy formulation include the following: the relationship between land tenure and freshwater rights; estimates of the economic value of water resources in various contexts; soil and water conservation techniques; indigenous water management strategies; coping strategies of communities in arid- and semi-arid regions during times of water scarcity; and population-freshwater system relationships in or near protected areas and wetlands.
- Standard participatory techniques such as Participatory Rural Appraisal (PRA) should be supplemented with approaches like in-depth interviews of key informants, triangulation, focus groups and participatory workshop sessions at the host villages.
- Close collaboration between social and biophysical scientists should be a priority throughout the participatory process, especially with regards to the setting of flow scenarios.

12 REFERENCES

Abell, D.L. 1956. An ecological study of intermittency in foothill streams of central California. Ph.D. Thesis. University of California, Berkeley.

Acreman, M.C., Farquharson, F.A.K., McCartney, M.P., Sullivan, C., Campbell, K., Hodgson, N., Morton, J., Smith, D., Birley, M., Knott, D., Lazenby, J., Wingfield, R., Barbier, E.B. 2000. Managed flood releases from reservoirs: issues and guidance. Report to DFID and the World Commission on Dams. Centre for Ecology and Hydrology, Wallingford, UK.

Adams, W.M. 2001. *Green development: environment and sustainability in the Third World*. Routledge, London.

Ahnert, F. 1998 Introduction to Geomorphology. London; Arnold

Allanson, B.R. 1995. An Introduction to the Mangement of Inland Water Ecosystems in South Africa. WRC Report No. TT 72/95. Pretoria; Water Research Commission.

Angliss, M.K. 2002. A Biomonitoring survey of the Mogol (Mokolo) River Catchment (Limpopo). Report for Limpopo Environmental Affairs.

Angliss M.K. 2004a. A Biomonitoring survey of the Nzhelele River falling on Maremani Nature Reserve. Unpublished report. Limpopo Environmental Affairs.

Angliss, M.K. 2004b. A Biomonitoring Survey of the Crocodile (West) Catchment, Limpopo Province, undertaken during 2004. (in Prep). Limpopo Environmental Affairs.

ANZECC, 2000. *Australian and New Zealand guidelines for fresh and marine water quality*, National Water Quality Management Strategy, Paper No. 4, Volume 1 – The Guidelines.

Arthington, A.H., 1998. Comparative evaluation of environmental flow assessment techniques: review of holistic methodologies. Land and Water Resources Research and Development Corporation Occasional Paper No 26/98. Canberra, Australia.

Arthington, A.H., King, J.M., O'Keeffe, J.H., Bunn, S.E., Day, J.A., Pusey, B.J., Blüdhorn, D.R., and Tharme, R.E. 1992. Development of an holistic approach for assessing environmental water requirements of riverine ecosystems. Pp 69-76. In: Pigram,J.J. and Hooper, B.P. (eds). Water allocation for the environment. Proceedings of an international seminar and workshop. Armidale, Australia.

Arthington, A.H. and Lloyd, R., (eds), 1998. Logan River trail of the Building Block Methodology for assessing environmental flow requirements. Workshop Report. Centre for Catchment and Instream Research and Department Natural Resources, Brisbane, Australia.

Arthington, A.H. and Zalucki, J.M., (eds), 1998. Comparative evaluation of environmental flow assessment techniques: review of methods. Land and Water Resources Research and Development Corporation Occasional Paper No 27/98. Canberra, Australia.

Arthington, A.H., Brizga, S.O., Choy, S.C., Kennard, M.J., Mackay, S.J., McCosker, R.O., Ruffini, J.L., Zalucki, J.M. 2000. Environmental flow requirements of the Brisbane River downstream of Wivenhoe Dam. South East Queensland Water Corporation, Brisbane, and Centre for Catchment and In-Stream Research, Griffith University, Brisbane, Australia. 539 pp.

Arthington, A.H., Rall, J.L. and Kennard, M.J. 2002. Assessment of the Environmental Flow Requirements of Fish in Lesotho Highlands Rivers using the Drift Methodology. In: Proceedings from Environmental Flows for River Systems. An International Working Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002. Cape Town.

Arthington, A.H., Tharme, R.E., Brizga, S.O., Pusey, B.J. and Kennard, M.J. 2003. Environmental flow assessment with emphasis on holistic methodologies. In: R Welcomme and T. Petr (eds). Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries, Volume 2.

Atkins, R.P. Deeley, D.M. and McAlpine, K.W. 1993. Managing the aquatic environment. *Fertilizer Research* 36: 171-175.

Atlas of Namibia Project. 2002. Directorate of Environmental Affairs, Ministry of Environment and Tourism. (See also Mendlesohn *et al.*, 2002) URL: http://www.dea.met.gov.na/data/atlas/atlas_web.htm

Avenant, M.F. 1999. An investigation of the fish community of the Modder River (Free State Province, Republic of South Africa), as a basis for a biomonitoring program. M.E.M. Mini-dissertation. University of the Free-State, Bloemfontein.

Barker, C.H. 2002 `n Geomorfologiese Ondersoek na Landskap Ontwikkeling in die Sentraal-Vrystaat. `n Toepassing met behulp van `n Geografiese Inligtingstelsel. Unpublished PhD Thesis, Bloemfontein; University of the Free State

Basson, M.S. and Rossouw, J.D. 2003a. *Limpopo Water Management Area: Overview of Water Resources Availability and Utilisation.* Department of Water Affairs and Forestry, Pretoria.

Basson, M.S. and Rossouw, J.D. 2003b. *Luvuvhu and Letaba Water Management Area: Overview of Water Resources Availability and Utilisation.* Department of Water Affairs and Forestry, Pretoria.

Basson, M.S. and Rossouw, J.D. 2003c. *Crocodile (West) and Marico Water Management Area: Overview of Water Resources Availability and Utilisation.* Department of Water Affairs and Forestry, Pretoria.

Batchelor, G.R. and Tarbotton, W.R. 1981. The Nyl floodplain: A unique South African ecosystem Threatened. Report to the chief director of Nature and Environmental Conservation. Transvaal Provincial Administration, Pretoria.

Bell-Cross, G. and Minshull, J.L. 1988. The fishes of Zimbabwe. Trustees of the National Museums and Monuments of Zimbabwe, Harare.

Bernardo, J.M. and Alves, M.H. 1999. New perspectives for ecological flow determination in semi-arid regions: A preliminary Approach. In: *Regulated Rivers: Research and Management* 15:221 – 229.

Birkhead, A.L., van Coller, A.L. and James, C.S. 1996. Modelling water availability to riparian vegetation in an impacted river system. Proceedings of 2nd IAHR symposium on habitat hydraulics. *Ecohydraulics* 2000. Quebec Canada.

Boersma, N. 1996. Social dependence on the riverine ecosystem. Starter document: Instream Flow Requirement Workshop on the Mogalakwena River. Department of Water Affairs and Forestry, Pretoria.

Bormans, M., Sherman, B.S. and Webster, I.T. 1999. Is buoyancy regulation in cyanobacteria an adaptation to exploit separation of light and nutrients? *Marine and Freshwater Research* 50: 897-906.

Boucher, C. 2002. Flows as determinants of riparian vegetation zonation patterns in selected southern African rivers. In: Proceedings from Environmental Flows for River Systems. An International Working Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002. Cape Town.

Boulton, A.J. 1989. Over-summering refuges of aquatic macroinvertebrates in two intermittent streams in central Victoria. *Transactions of the Royal Society of Science Australia* 113:23-24.

Boulton, A.J. 2003. Parallels and contrast in the effects of drought on stream macroinvertebrate assemblages. *Freshwater Biology* 48:1173-1185.

Boulton, A.J. and Suter, P. J., 1986. Ecology of temporary streams—an Australian perspective. In: De Deckker, P. and Williams, W.D. (eds.), Limnology in Australia. CSIRO/Junk Publications, Melbourne.

Boulton, A.J. and Lake, P.S. 1990. The ecology of two intermittent streams in Victoria, Australia. I. Multivariate analyses of physicochemical features. *Freshwater Biology* 24: 123-141.

Boulton, A.J. and Lake, P.S. 1992a. The ecology of two intermittent streams in Victoria, Australia. II Comparisons of faunal composition between habitats, rivers and years. *Freshwater Biology* 27: 99-121.

Boulton, A.J. and Lake, P.S. 1992b. The ecology of two intermittent streams in Victoria, Australia. III Temporal changes in faunal composition. *Freshwater Biology* 27: 99-121.

Boulton, A.J., Sheldon, F., Thoms, M.C., Stanley, E.H. 2000. Chapter 18. Problems and constraints in managing rivers with variable flow regimes. In: Boon, P.J., Davies, B.R., Petts, G.E. (eds). *Global Perspectives on River Conservation: Science, Policy and Practice*. John Wiley and Sons Ltd: 415-430

Bowling, L.C. and Baker, P.D. 1996. Major cyanobacterial bloom in the Barwon-Darling River, Australia, in 1991, and underlying limnological conditions. *Marine and Freshwater Research* 47: 643-657.

Braune, E. 1985. Aridity and hydrological characteristics: Chairman's summary. *Hydrobiologia* 125:131-136.

Brierley, G. J., 1994. River reach analysis as a geomorphic toolfor river classification. Pages 111–117 In: Uys, M.C. (ed.), Classification of rivers and environmental health indicators. Proceedings of a joint South African/Australian workshop, Cape Town. Water Research Commission Report No. TT 63/94, Pretoria.

Brizga, S.O., 1998. Methods addressing flow requirements for geomorphological purposes. Pp.8-46. In: Arthington, A.H., Zalucki, J.M. (eds). Comparative evaluation of environmental flow assessment techniques: review of methods. *Land and Water Resources Research and Development Corporation Occasional Paper No*. 27/98. Canberra, Australia.

Brizga, S.O., Arthington, A.H., Pusey, B.J., Kennard, M.J., Mackay,S.J., Werren, G.L., Craigie,N.M., Choy, S.J.,2002. Benchmarking, a "top-down" methodology for assessing environmental flows in Australian rivers. Paper presented at the

Environmental Flows for River Systems. An International Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002, Cape Town, South Africa.

Brown, C.A., Eekhout, S. and King, J.M. 1996. National Biomonitoring Programme for Riverine Ecosystems: Proceedings of spatial framework workshop. NBP Report Series No.2. Institute for Water Quality Studies, Department of Water Affairs and Forestry, South Africa.

Brown, C.A. and King, J.M. 2000. Environmental flow assessment for rivers. A summary of the DRIFT Process. *Southern Waters Information* Report 01/00. Southern Waters, University of Cape Town, Cape Town.

Brown, C.A. and Louw, D. 2001. Breede River Basin: BBM Application. Reserve Determination for the Breede River, Western Cape. Unpublished Southern Waters/IWR Environmental Report to Department of Water Affairs and Forestry.

Brown, C.A. and Joubert, A. 2003. Using multicriteria analysis to develop environmental flow scenarios for rivers targeted for water resource management. Water SA. 29(4):365 – 374.

Brown, C., Colvin, C., Hartnady, C., Hay, R., Le Maitre, D. and Rieman, K. 2003. Ecological and environmental impacts of large-scale groundwater development in the Table Mountain Group; Draft discussion document, Water Research Commision, Pretoria.

Brown, L.R. 1998. Facing Nature's Limits. In Polunin N. 1998. Population and global Security. Cambridge: Cambridge University Press pp. 251-270

Brown, L.R. and Halweil, B. 1999. Populations outrunning water supply as world hits 6 billion. Internet: http://www.worldwatch.org/press/news/1999/09/23/ Accessed: 6/5/2004

Brunsden, D. 2001 A critical assessment of the sensitivity concept in geomorphology. *Catena* 42:99 – 123.

Bunn, S.E., Loneragan, N.R., Yeates, M., 1998. The influence of river flows on coastal fisheries.Pp. 106-114. In: Arthington, A.H. and Zalucki, J.M. (eds). Comparative evaluation of environmental flow assessment techniques: review of methods. *Land and Water Resources Research and Development Corporation Occasional Paper No*. 27/98. Canberra, Australia.

Bunn, S.E. and Arthington, A.H. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environmental Management* 30, (1): 492-507.

Cambray, J.A., Alletson, D.J., Kleynhans, C.J., Petitjean, M.O.G. and Skelton, P.H. 1989. Flow requirements of fish. In: Ecological flow requirements for South African rivers. A.A. Ferrar (Ed). South African National Scientific programmes Report No. 162. CSIR, Pretoria.

Canton, S.P., Cline, L.D., Short, R.A. and Ward, J.V. 1984. The macroinvertebrates and fish in a Colorado stream during a period of fluctuating discharge. *Freshwater Biology* 14: 311-316.

Capon, S.J. 1998. Chapter 5. Assessing Environmental Flows in a Highly Variable Ephemeral Catchment: The Cooper Creek Study. In: Water for the Environment: Recent Approaches to Assessing and Providing Environmental Flows. Proceedings of a One-day Forum held at Bardon Professional Centre, Brisbane, 29 April 1998. Arthington, A.H. and Zalucki, J.M. (eds.)

Capon, S.J. 2002. Variable Flood Pulses and Dynamic Floodplains: Potential Impacts of Water Extraction on Riparian Plant Communities in Large Arid Cartchments. In: Proceedings from Environmental Flows for River Systems. An International Working Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002. Cape Town.

Capone, T.A. and Kushlan, J.A. 1991. Fish community structure in dry-season stream pools. *Ecology* 72(3): 983-992.

Carmichael, W.W. 1994. The toxins of cyanobacteria. *Scientific American*, January 1994.

Chapman, D. (ed.), 1996. *Water Quality Assessments. A guide to the use of biota, sediments and water in environmental monitoring* (2nd edition). Published on behalf of UNESCO, WHO, and UNEP by E and FN Spon, London and New York: 626pp.

Chorley, R.J. and Kennedy, B.A. 1971: Physical Geography: A Systems Approach. Prentice-Hall, London.

Christelis, G. and Struckmeier, W., 2001. *Groundwater in Namibia: An explanation to the hydrogeological map*. Windhoek: Department of Water Affairs.

Chutter, F.M. 1967. Hydrobiological Studies on the Vaal River and some of its tributaries, including an Introduction to the Ecology of *Simulium* in the lower reaches. Unpublished PhD Thesis. Rhodes University. Grahamstown.

Chutter, F.M. 1970. Hydrobiological studies in the catchment of the Vaal Dam, South Africa. Part 1. River zonation and benthic fauna, *Internationale Revue der gesamten Hydrobiologie* 55:445-494.

Chutter, F.M. 1973. An ecological account of past and future of South African rivers. *Newsletter of the Limnological Society of Southern Africa*. 21:22-34.

Chutter, F.M. 1998. Research on the Rapid Biological Assessment of Water Quality Impacts on Streams and Rivers. Report No. 422/1/98. Water Research Commission, Pretoria.

Chutter, F.M. and Heath, R.G.M. 1993. Relationships between low flows and the river fauna of the Letaba River. WRC Report no. 293/1/93. Water Research Commission. Pretoria.

Closs, G.P. and Lake, P.S. 1995. Drought, differential mortality and coexistence of native and an introduced fish species in south east Australian intermittent stream. *Environmental Biology of Fishes* 47: 17-26.

Coetzee, M.A.S. and Rogers, K.H. 1991. Environmental correlates of plant species distribution on the Nyl River floodplain. *South African Journal of Aquatic Science* 17: 44-50.

Cohen, J.E.1995. *How many people can the earth support?* WW Norton, London.

Comin, F.A. and Williams, W.D., 1994. Parched continents: our common future? In: Margalef, R. (ed), *Limnology Now: A Paradigm of Planetary Problems*. Elsevier Science.

Cooke, R.U. and Doornkamp, J.C. 1990. Geomorphology in Environmental Mangement. A New Introduction (2nd Ed). Claredon, Oxford.

CSIR Environmentek. 1999. Water quality on disc. Water quality data from the Hydrological Information System (HIS) supplied by the Directorate of Hydrology and the Institute for Water Quality Studies (Version 1.0). CSIR, Pretoria.

Curtis, B., Roberts, K.S., Griffin, M., Bethune, S. HAY, C.J. and Kolberg, H. 1998. Species richness and conservation of Namibian freshwater macro-invertebrates, fish and amphibians. *Biodiversity and Conservation* 7: 447-466.

Curtis, B.A. 1991. Freshwater macro-invertebrates of Namibia. *Madoqua* 17(2): 163-187

Dallas, H.F. 2002. Spatial and temporal heterogeneity in lotic systems: Implications for defining Reference Conditions for Macroinvertebrates. Paper presented at the 3rd Waternet/Warfsa Symposium “Water Demand Management for Sustainable Development” held in Dar es Salaam, 30-31 October 2002.

Dallas, H.F. and Day, J.A. 1993. The effect of water quality variables on riverine ecosystems: A review. Report No. TT61/93. Water Research Commission, Pretoria.

Dallas, H.F. and Day, J.A. 2004. *The effect of water quality variables on aquatic ecosystems: A Review*. Report No. TT 224/04. Water Research Commission, Pretoria: 222 pp.

Davies S. 2000. Effective drought mitigation: linking micro and macro levels. In Wilhite DA. (ed.). 2000. *Drought: Volume II.* London: Routledge, pp. 3-16

Davies, B and Day, J. 1998. Vanishing Waters. University of Cape Town Press, Cape Town.

Davies, B.R., O'Keeffe, J.H. and Snaddon, C.D. 1993. A synthesis of the ecological functioning, conservation and management of South African river systems. Water Research Commission Report No TT62/93. Water Research Commission, Pretoria. 232 pp.

Davies, B. R., Thoms, M.C., Walker, K.F., O'Keeffe, J.H. and Gore, J.A., 1994. Dryland Rivers: their ecology, conservation and management. In: Calow, P. and Petts, G.E. (eds). The rivers handbook. Volume 2. Blackwell Scientific Publications, Oxford.

Day, J.A. 1990. Environmental correlates of aquatic faunal distribution in the Namib Desert. In: Seely, M.K. (ed.). Namib ecology: 25 years of Namib research. *Transvaal Museum Monograph* 7 : 99-107. Transvaal Museum. Pretoria.

Deacon, A. 2000. Fish monitoring in the Luvuvhu River catchment (in KNP). Kruger National Park, South African National Park. Unpublished.

De Moor, I.J. and Bruton, M.N. 1988. Atlas of alien and translocated indigenous aquatic animals in southern Africa. South African National Scientific Programmes Report No. 144, CSIR, Pretoria.

Dekker, 1988. Letter to the Editor. *Ichthos* 20:17.

Department of Environment Affairs and Tourism. 1999. State of the environment South Africa – an overview. Department of Environment Affairs and Tourism, Pretoria.

Department of Environment Affairs and Tourism. 2001. Environmental and Tourism Potential Atlas. CD-ROM National and Provincial data sets. Department of Environment Affairs and Tourism, Pretoria.

Department of Land and Water Conservation. 2002. Environmental water requirements for the Kangeroo River catchment. Revision III. Report to Shoalhaven-Illawarra Water Management Committee.

Department of Water Affairs. 1986 Bestuur van die Waterhulpbronne van die Republiek van Suid-Afrika. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry. 1996a. Mogalakwena River Dam Feasibility Study. Pre-feasibility Stage. Working Report 9. Proceedings of a Workshop to Determine Instream Flow Requirements of the Mogalakwena River. 12 to 16 February 1996. Prepared by Southern Waters Ecological Research and Consulting.

Department of Water Affairs and Forestry. 1996b. *South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems.* Department of Water Affairs and Tourism, Pretoria: 159 pp.

Department of Water Affairs and Forestry. 1997. White Paper on a National Water Policy for South Africa, Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry. 1999. *Resource directed measures for protection of water resources: River Ecosystems – Version 1.0*. Department of Water Affairs and Tourism, Pretoria.

Department of Water Affairs and Forestry. 1999. Resource Directed Measures – River Ecosystems, Volume 3. Pretoria.

Department of Water Affairs and Forestry. 2003a. Resource Directed Measures. Module 1. Introductory Module. October 2003. Department of Water Affairs and Tourism, Pretoria.

Department of Water Affairs and Forestry. 2003b. Water Quality Management Series No. MS 8.3. *A guide to conduct Water Quality Catchment Assessment Studies:* In support of the Water Quality Management Component of a Catchment Management Strategy. Edition. Pretoria

Dickens, C.W.S. and Graham, P.M. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. *African Journal of Aquatic Science* 27:1-10.

Dinar, A. and Keck, A. 2000. Water supply variability and drought impact and mitigation in sub-Saharan Africa, in Wilhite DA (Ed.) *Drought.* Vol II. Routledge, London: 129-148.

Dollar, E.S.J., James, C.S., Rogers, K.H. and Thoms, M.C. 2004. A framework for interdisciplinary understanding of rivers. Presentation delivered at the Southern African Society of Aquatic Scientists Conference 2004 held in Midrand, Gauteng. Unpublished.

Dortch, M.S., Martin, J.L., 1989. Water quality modeling of regulated streams. In: Gore, J.A. and Petts, G.E. (eds). *Alternatives in regulated river management*. CRC Press, Inc., Florida.

Downing, J.A. and McCauley, E. 1992. The nitrogen : phosphorus relationship in lakes. *Limnology and Oceanography* 37: 936-945.

Dunbar, M.J., Gustard, A., Acreman, M.C., Elliott, C.R.N., 1998. Review of overseas approaches to setting river flow objectives. *Environment Agency R&D Technical Report* W6B(96)4. Institute of Hydrology, Wallingford, United Kingdom.

Du Toit, W. 1996. Geohydrology. In: Mogalakwena River Dam Feasibility Study. Pre-feasibility Stage. Working Report 9. Proceedings of a Workshop to Determine Instream Flow Requirements of the Mogalakwena River. 12 to 16 February 1996. Prepared by Southern Waters Ecological Research and Consulting

Dysan, M., Bergkamp,G., Scanlon, J. (eds). 2003. Flow. The essentials of environmental flows. IUCN, Gland, Switzerland and Cambridge, UK.

Engelbrecht, G.D. and Mulder, P.F.S. 2000. Allozyme variation in *Chiloglanis paratus* and *C. pretoriae* (Pisces, Mochokidae) from the Limpopo River system, southern Africa. *Water SA* Vol. 26(1): 111-114.

Extence, C., Balbi, D.M. and Chadd, R.P. 1999. River flow indexing using British benthic macro-invertebrates: a framework for setting hydro-electrical objectives. *Regulated Rivers Research and Management* 15:543-574.

Fausch, K.D., Torgersen, C.E., Baxter, C.V. and Li, H.W. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. *Bioscience* 52: 483-498.

Friedman, J.M. and Lee, V.J. 2002. Extreme floods, channel change, and riparian forests along ephemeral streams. *Ecological monographs.* Vol. 72(3): 409-425.

Frost, P.G.H. 1987. The regional landscape: Nylsvlei perspective. South African Scientific Programmes Report No. 133. Foundation for Research Development, Pretoria.

Furness, H.D. and Breen, C.M. 1980. The vegetation of seasonally flooded areas of the Pongolo River Floodplain. *Bothalia* 13: 217-231.

Gaigher, I.G. 1969. Aspekte met betrekking tot die ekologie, geografie en taksonomie van varswatervisse in die Limpopo- en Incomatiriviersisteem. Ph.D. tesis, Rand Afrikaans University, Johannesburg.

Gaigher, I.G. 1973. The habitat preferences of fishes from the Limpopo River System, Transvaal and Mocambique. *Koedoe* 16: 103-116.

Gardner, G. 2002. The challenge for Johannesburg: creating a more secure world, in World Watch Institute (Ed.) *State of the world 2002*. WW Norton and Company, New York: pp. 3-23.

Gardner, K.M., 1999. The importance of Surface Water/Groundwater Interaction. EPA Report: EPA-910-R-99-013. Environmental Protection Angency, United States of America.

Garland, G.G. 1990. The Soil Spoilers. In: Indicator Project South Africa 1990 Rotating the Cube. pp 69 - 72. University of Natal, Durban.

Gilmore, K.S. 1978. A fishery survey of Sashi Dam. Unpublished report of the Department of Agriculture and Fisheries, Ministry of Agriculture, Botswana.

Gilnear, D.J., Heal, K.V. and Stephen, A. 2002. Hydrology and the ecological quality of Scottish river ecosystems. *The Science of the Total Environment.* 294:131 – 159

Gippel, J.C. and Stewardson, M.J. 1998. Use of wetted perimeter in defining minimum environmental flows. *Regulated Rivers Research and Management* 14:53-67.

Gonzalez, O.T. 1996. Formulating an ecosystem approach to environmental protection. *Environmental Management* 20: 597-605.

Gordon, N.D., McMahon, T.A. and Finlayson, B.L., 1992. *Stream Hydrology – An Introduction for Stream Ecologists*. John Wiley, Chichester.

Götze, A.R., Cilliers, S.S., Bezuidenhout, H. and Kellner, K. (in press). Analysis of the riparian (land type) of the proposed Vhembe-Dongola National Park, Limpopo Province, South Africa. *Koedoe.*

Graf, W.L. 1988. Fluvial Processes in Dryland Rivers. Berlin; Springer-Verlag.

Gregory, K.J. and Walling, D.E. 1973. Drainage Basin Form and Process, a geomorphological approach. Edward Arnold, London.

Gupta, A. 1998. *Ecology and development in the Third World*. Routledge, London.

Haines, A.T., Finlayson, B.L. and McMahon. T.A.,1988. A global classification of river regimes. *Applied Geography* 8:255–272.

Harper, C.L. 2004. *Environment and Society: Human perspectives on environmental issues*. Upper Saddle River: Pearson Prentice Hall.

Harper, D.M., Smith, C., Barham, P. and Howell, R. 1995. The ecological basis for the management of the natural environment. In: Harper, D.M. and Ferguson, A.J. (eds.). *The Ecological Basis for River Management*. John Wiley and Sons. Chichester.

Harris, G.P. 1986. *Phytoplankton Ecology. Structure, function and fluctuation*. Chapman and Hall, London.

Harrison, A.D. 1966. Recolonisation of a Rhodesian stream after drought. *Archiv fur Hydrobiologie.* 62: 405-421.

Harrison, P. 1993. The Third Revolution: Population, Environment and a Sustainable World London: Penguin.

Harrison, P. and Pearce, F. 2000. AAAS Atlas of population and environment. Berkeley: University of California.

Hart, B.T. 2002. Water quality guidelines, In: Burden, F.R., McKelvie, I.D., Forstner, U., and Guenther, A. (eds.), *Environmental Monitoring Handbook,* McGraw Hill, New York, 1 100 pp.

Hart, B.T., and Campbell, I.C., 1994. Ecological classificationscheme for Australia. Pages 87–100. In: Uys, M.C. (ed.), Classification of rivers and environmental health indicators. Proceedings of a joint South African/Australian workshop, Cape Town. Water Research Commission Report No. TT 63/94, Pretoria.

Heath, R.G., Steynberg, M.C., Guglielmi, R. and Maritz, A.L. 1998. The implications of point source phosphorus management to potable water treatment. *Water Science and Technology* 37: 343-350.

Helmer, R. and Hespanhol, I. (ed.). 1997. *Water Pollution Control – A Guide to the use of water quality management principles.* World Health Organizationn, WHO/UNEP.

Hessen, D.O., Hindar, A. and Holtan, G. 1997. The significance of nitrogen runoff for eutrophication of freshwater and marine recipients. *Ambio*, 26: 312-320.

Heyns, P., Montgomery, S., Pallett, S. and Seely, M.K. (eds), 1997. *Namibia's water: A decision makers' guide*. Windhoek: Ministry of Agriculture, Water and Rural Development/Desert Research Foundation of Namibia.

Hicken, E.J. 1984. Vegetation and river channel dynamics. *Canadian Geographer*. 28(2): 111-126.

Higgens, S.I. and Rogers, K.H. 1993. The Nyl River Floodplain: Situation report and preliminary statement of impacts of the proposed Olifantsspruit Dam. Centre for water in the environment report 3/93. University of the Witwatersrand, Johannesburg.

Higgins, S.I., Coetzee, M.A.S., Marneweck, G.C. and Rogers, K.H. 1996. The Nyl River floodplain, South Africa, as a functional unit of the landscape: A review of current information. *African Journal of Ecology* 34: 131-145.

Horne, A.J. and Goldman, C.R. 1994. *Limnology* (2nd edition). McGraw-Hill, Inc., New York, 576 pp.

Hughes, D.A. 1999. Towards the incorporation of magnitude frequency concepts into the building block methodology used for quantifying ecological flow requirements of South African rivers. SA 25 (3), 279-284

Hughes, D.A. & Münster, F. 1999. A decision support system for an initial "low-confidence" estimate of the quantity component of the reserve for rivers. IWR, Rhodes University, Grahamstown.

Hughes, D.A. and Münster, F. 2000. Hydrological Information and Techniques to Support the Determination of the Water Quantity Component of the Ecological Reserve for Rivers. WRC Report No. TT 137/00. Water Research Commission, Pretoria.

Hughes, D.A. and Münster, F. 2002 Determining the water quantity component of the ecological reserve for South African rivers: hydrology: report. *S A Waterbulletin* 28 (Iss 2): 12-13

Hughes, D.A. and Hannart, P. 2003. A desktop model used to provide an initial estimate of the ecological instream flow requirements of rivers in South Africa. *Journal of Hydrology* 270: 167 – 181.

Hughes, J.D. 2002. *An environmental history of the world: Humankind's changing role in the community of life*. Routledge. London.

Huisman, J., Van Oostveen, P. and Weissing, F.J. 1999. Critical depth and critical turbulence: Two different mechanisms for the development of phytoplankton blooms. *Limnology and Oceanography* 44: 1781-1787.

Humphries, P. and Baldwin, D.S. 2003. Drought and aquatic ecosystems: an introduction. *Freshwater Biology* 48: 1141-1146.

Huntley, B.J. (Editor), 1985. The Kuiseb Environment: The development of a monitoring baseline. A Report to the Committee for Terrestrial Ecosystems National Programme for Environmental Sciences. South African National Scientific Programmes Report No. 106: 138 pp.

Internet http://www.ngo.grida.no/soesa/nsoer/resource/wetland/reserve.htm Wetlands and the National Water Act: the Ecological Reserve

Internet http://www.trc.govt.nz/PDFS/Freshwater%20Plan/ Regional Freshwater plan for Taranaki.

Irish, J. 1994. The biomes of Namibia, as determined by objective categorization. *Navorsinge van die Nasionale Museum* 10 (13): 550-592.

IWR Environmental. 2000. Improvements to the hydrological extrapolation method for use in the Level 1 (Desktop estimate) and Level 2 (Rapid) determinations of the ecological reserve. DWAF Report P.RSA/00/0699. Department of Water Affairs and Forestry, Pretoria.

IWR Environmental, 2004. RDM Revision: Ecological Reserve (rivers, quantity). IWR, Rhodes University, Grahamstown.

Jacobsen, N.H.G. and Kleynhans, C.J. 1993. The importance of weirs as refugia for hippopotami and crocodiles in the Limpopo River, South Africa. *Water SA*. 19: 301-306.

Jacobson, P.J. 1997. An ephemeral perspective of fluvial ecosystems: viewing ephemeral rivers in the context of current lotic ecology. Unpublished Ph.D. dissertation, Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Jacobson, P.J.; Jacobson, K.M. and Seely, M.K. 1995. Ephemeral rivers and their catchments: sustaining people and development in western Namibia. Desert Research Foundation, Windhoek. pp160.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L. and Cherry, D.S. 2000. Variaton in material transport and water chemistry along a large ephemeral river in the Namib Desert. *Freshwater Biology* 44: 481 – 491.

Jarvie, H.P., Whitton, B.A. and Neal, C. 1998. Nitrogen and phosphorus in east British rivers: Speciation, sources and biological significance. *Science of the Total Environment* 210/211: 79-109.

Johnson, N. Revenga, C. and Echeverria, J. 2001. Managing water for people and nature. *Science* 292 (5519):1071-1072. Internet: http://web11.epnet.com/citation.asp Accessed: 25/5/2004.

Jones, G. 2003. Recovering from the drought. In: Watershed, February 2003. *CRC for Freshwater Ecology*, Canberra.

Joubert, A.R., and Hurly, P.R. 1994. Grouping South African rivers using flow-derived variables. Pages 27–42. In: Uys, M.C. (ed.), Classification of rivers and environmental health indicators. Proceedings of a joint South African/ Australian workshop, Cape Town. Water Research Commission Report No. TT 63/94, Pretoria.

Jowett, I.G., 1997. Instream flow methods: A comparison of approaches. *Regulated Rivers: Research and Management* 13: 115-127.

JPL, 2004 Shuttle Radar Topography Mission. The Mission to Map the World Internet: http://www2.jpl.nasa.gov/srtm/index.html

Kadlec, J.A., 1976. Methodologies for assessing instream flows for wildlife. In: Stalnaker, C.B. and Arnette, S.C. (eds). *Methodologies for the determination of stream resource flow requirements: an assessment*. U.S. Fish and Wildlife Services, Office of Biological Services Western Water Association.

Karr, J.R. and Dudley, D.R. 1981. Ecological perspective on water quality goals. *Environmental Managment* 5: 55-68.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R. and Schlosser, I.J. 1986. Assessing biological integrity in running waters: a method and its rationale. *Illinois Natural History Survey Special Publication* 5.

Kemper, N.P. 2000. Riparian Vegetation Index. Final report. Institute for Research, Pretoria.

Kemper, N.P. and Boucher, C. 2000. Vegetation (Chapter 16). In: King,J.M., Tharme, R.E., and De Villiers, M. (Eds) Environmental flow Assessments of rivers: Manual for the Building Block Method. Water Research Commission Technology Transfer Report No 2000. Water Reasearch Commission, Pretoria.

King, J.M. 2000. Introduction. In: Environmental flow requirements for rivers: King, J.M., Tharme, R.E. and De Villiers, M.S. (Eds.) Manual for the Building Block

Methodology. Water Research Commission Report No. TT131/00. Water Reseach Commission, Pretoria.

King, J. M. 2002. Overview of the Building Block Methodology. I: King, J.M., Tharme, R.E. and De Villiers, M.S. (Eds). Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. pp 169 – 194. WRC Report No: TT 131/00. Water Research Commission, Pretoria.

King, J.M. 2004. An overview of the development of methodologies for the determination of environmental flow requirements. Oral presentation delivered at a one-day Environmental Water Requirements conference, 4 August 2004, Bloemfontein.

King, J.M., Henshall-Howard, M-P., Day, J.A. and Davies, B.R. 1987b. Leaf-pack dynamics in a southern African mountain stream. *Freshwater Biology* 18:325-340.

King, J.M., Tharme, R.E. and De Villiers, M.S. (Eds). 2000. Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. WRC Report No: TT 131/00. Water Research Commission, Pretoria: *340 pp*.

King, J.M., de Moor, F.C. and Chutter, F.M., 1992. Alternative ways of classifying rivers in South Africa. Pages 231–228. In: Boon, P.J., Calow, P. and Petts G.E. (eds.), River conservation and management. Wiley Ltd., Chichester.

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

King, J., Tharme, R and Brown, C. 1999a. Definition and Implementation of Instream Flows. Southern Waters, University of Cape Town, Cape Town.

King, J.M., Tharme, R.E. and Brown, C.A. 1999b. Definition and implementation of instream flows. Thematic review for the World Commission on Dams. Stalnaker, C., Lamb, B.L., Bovee, K. and Bartolow, J. 1995. The Instream Flow Incremental Methodology: a primer for IFIM. Biological Report 29, National Biological Service, U.S. Department of the Interior. http://www.fort.usgs.gov

King, J.M. and Schael, D.M. 2001 Assessing the Ecological Relevance of a Spatially-nested Geomorphological Hierarchy for River Management. WRC Report No. 754/1/01. Water Research Commission, Pretoria.

King, J., Brown, C. and Sabet, H. 2003. A Scenario-Based Holistic Approach to Environmental Flow Assessments for Rivers. Rivers Research and Applications. Vol 19:619 – 639.

King, J.M., Day, J.A., Davies, B.R. and Henshall-Howard, M-P. 1987a. Particulate organic matter in a mountain stream in the south-western Cape, South Africa. *Hydrobiologia* 154: 165-187.

Kleynhans, C.J. 1980. A checklist of fish species of the Crocodile and Matlabas Rivers (Limpopo system) of the Transvaal. *Journal of the Limnological Society of southern Africa* 6(1):33-34.

Kleynhans, C.J. 1983. A checklist of fish species of the Mogol and Palala Rivers (Limpopo system) of the Transvaal. *Journal of the Limnological Society of southern Africa* 9(1):29-32.

Kleynhans, C.J. 1984. Die verspreiding en status van sekere seldsame vissoorte van die Transvaal en die ekologie van sommige spesies. Unpublished D.Sc. dissertation, University of Pretoria, Pretoria.

Kleynhans, C.J. 1986. The distribution, status and conservation of some fish species of the Transvaal. *South African Journal of Wildlife Research* 16(4): 135-144.

Kleynhans, C.J. 1991. The Nyl River floodplain: its ichthyfauna and conservation status. Report to the Chief Director of Nature and Environmental Conservation, Transvaal Provincial Administration, Pretoria.

Kleynhans, C.J. 1996a. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa). *Journal of Aquatic Ecosystem Health* 5: 41-54.

Kleynhans, C.J. 1996b. A general assessment of the instream flow requirements of fish species of the Mogalakwena and Sterk Rivers. Starter document: Instream Flow Requirement Workshop on the Mogalakwena River. Department of Water Affairs and Forestry, Pretoria.

Kleynhans, C.J. 1999a. Section C: Procedure for desktop estimate of the water quantity component of the Ecological Reserve, for use in the National Water Balance. Resource Directed Measures for protection of Water Resources: River Ecosystems. Department of Water Affairs and Forestry. South Africa.

Kleynhans, C.J. 1999b. Desktop present ecological status assessment for use in the National Water Balance Model (R3). In: Resource Directed Measures for Protection of Water Resources: River Ecosystems (Version 1.0). Department of Water Affairs and Forestry, South Africa.

Kleynhans, C.J. 1999c. The development of a fish index to assess the biological integrity of South African Rivers. *Water SA* 25(3): 265-278.

Kleynhans, C.J. 2003. National Aquatic Ecosystem Biomonitoring Programme: Report on a National Workshop on the use of Fish in Aquatic System Health Assessment. NAEBP Report Series No.16. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

Kleynhans, C.J. 2004. Habitat Flow Stressor Response approach to ecological water requirements of fish. In: Louw, M.D., Kleynhans, C.J., Thirion, C., Hughes, D. and O'Keeffe, J. 2004. Ecoclassification and Habitat Flow Stressor Response Manual. First Draft.

Kleynhans, C.J. and Engelbrecht, J.S. 1999. The use of ecological information on fish in the specification of the flow component of the reserve (Desktop, Rapid, Intermediate and Comprehensive Determinations) (R20). In: MacKay, H. and Guest, L. 1999. Resource Directed Measures for Protection of Water Resources: River Ecosystems (Version 1.0). Department of Water Affairs and Forestry, South Africa.

Kleynhans, C.J. and Engelbrecht, J.S. 2000. Fish. In: Environmental flow assessments for rivers: King, J.M., Tharme, R.E. and De Villiers, M.S. (Eds.) Manual for the Building Block Methodology. Water Research Commission Report No. TT131/00.

Kleynhans, C.J. and Hoffman, A. 1992a. First record of *Oreochromis macrochir* (Boulenger, 1912) (Pisces: Cichlidae) from the Limpopo River in sourthern Africa. *South African Journal of Aquatic Science* 18 (1/2): 104-106.

Kleynhans, C.J. and Hoffman, A. 1992b. New distribution records for *Clarias theodorae* Weber 1897, *Barbus eutaenia* Boulenger 1904, *Barbus polylepis* Boulenger 1907 and *Opsaridium zambezense* Peters 1852, from the Waterberg, Transvaal South Africa. *South African Journal of Aquatic Science* 18 (1/2): 107-111.

Kleynhans, C.J. and Moolman, J. 2004. Considerations in the determination of ecological flow requirements of the Limpopo River. Oral presentation at Workshop on Environmental Water Requirements in Non-Perennial Systems held on 4 August 2004 at the Centre for Environmental Management, University of the Free State, Bloemfontein.

Kleynhans, C.J., Thirion, C. & Moolman, J. 2004. A Level I & II Ecoregion classification system for South Africa, Lesotho and Swaziland. Draft Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

Knighton, D. 1998. Fluvial Forms and Processes. Arnold, London.

Köhler, J. 1993. Growth, production and losses of phytoplankton in the lowland River Spree. I. Population dynamics. *Journal of Plankton Research*, 15: 335-349.

Kok, H.M. 1980. Ecological status of some important fish species of the Pongolo floodplain, KwaZulu, South Africa. Unpublished Ph.D. Thesis. University of Natal.

Kok, O.B. and Grobbelaar, J.U. 1980. Chemical properties of water-holes in the Kuiseb River Canyon, Namib Desert. *Journal of the Limnological Society of South Africa* 6: 82-84.

Ladele, A.A. 1999. *Environmental education, drought and the rural man: implications for policy makers and farmers in sub-Saharan Africa*. Conference paper. (International Conference on Integrated Drought Management, Pretoria 20-22 September 1999).

Lake, P.S. 2003. Ecological effects of perturbation by drought in flowing waters. *Freshwater Biology* 48:1161-1172.

Lancaster, J. and Belyea, L.R. 1997. Nested hierarchies and scale-dependence of mechanisms of flow refugium use. *Journal of the North American Benthological Society* 16: 221-238.

Lane, S.N., Chandler, J.H. and Richards, K.S. 1998. Landform Monitoring, Modelling and Analysis: Land *Form* in Geomorphological Research. In: Lane, SN, Richards, KS and Chandler, JH (Eds) Landform Monitoring, Modelling and Analysis. pp 1 - 17 Chichester; Wiley

Lange, J. Liebundgut, P. and Schick, A-P. 2000. The Importance of Single Events in Arid Zone Rainfall-Runoff Modelling. Physics and Chemistry of he Earth (B) 25(7-8):673 – 677

Larimore, R.W., Childers, W.F. and Heckrotte, C. 1959. Destruction and re-establishment of stream fish and invertebrates affected by drought. *Transactions of American Fisheries Society* 88: 261-285.

Lerner, D.N. 1996. Surface water – groundwater interactions in the context of groundwater resources; WRC and IAH (South Africa) workshop on groundwater – surface water issues in arid and semi-arid areas, Pretoria, October 1996.

Le Roux, J.S. 1990. Die landvorme en landskappe van die Oranje Vrystaat: Produkte van rotsmateriaal, verwering, erosie en tyd. Professorale intreerede. Bloemfontein, Universiteit van die Vrystaat.

Loar J.M., Sale, M.J., Cada, G.F., 1986. Instream flow needs to protect fishery resources. *Water Forum '86: World Water Issues in Evolution*. Proceedings of ASCE Conference/HY. IR, EE,WR, WW Divs. Long Beach, California, August 4-6, 1986.

Loutit, p., 1991. Western flowing ephemeral rivers and their importance to wetlands in Namibia. *Madoqua* 17(2): 135-140

Louw, D. 2003. Role of fish indices in IFR's (Quantity component of Ecological Reserve). In: Kleynhans, C.J. National Aquatic Ecosystem Biomonitoring Programme: Report on a National Workshop on the use of Fish in Aquatic System Health Assessment. NAEBP Report Series No.16. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

Louw, D. 2004. How to use this manual. In: Ecoclassification and Habitat Flow Stressor Response Manual. Louw, D., Kleynhans, C.J., Thirion, C., Hughes, D and O'Keeffe (eds). Department of Water Affairs and Forestry, Pretoria, South Africa.

Louw, D., Kleynhans, C.J., Thirion, C., Hughes, D and O'Keeffe, J. 2004. Ecoclassification and Habitat Flow Stressor Response Manual. First Draft. Project: 2002-148. Department of Water Affairs and Forestry, Pretoria, South Africa.

Louw, D., O'Keefe, J. and Kleynhans, C.J. 2004. Ecoclassification process. In: Louw, D., Kleynhans, C.J., Thirion, C., Hughes, D.A. and O'Keefe, J.H. 2004. *Ecoclassification and HFSR manual*. First Draft. Project number 2002-148. Prepared by IWR Source to Sea for Resource Quality Services. Department of Water Affairs and Forestry, Pretoria, South Africa..

Lovett, S. and Price, P. (eds). 1999. Riparian Land Management Technical Guidelines, Volume 1: Principles of Sound Management, Land and Water Resources Research and Development Corporation, Canberra. Chapter 1.

Maamri, A., Chergui, H. and Pattee, E. 1997. Leaf litter processing in a temporary northeastern Moroccan River. *Archiv für Hydrobiologie* 140: 513-531.

Mac Arthur, R.H. and Wilson, E.O. 1967. *The theory of Island Biogeography*. Princeton University Press, Princeton.

MacKay, H., Moloi, B. 2003. Chapter 13. The importance of instream flow requirements for decision-making in the Okavango River basin. In: Transboundary rivers, sovereignty and development: Hydropolitical drivers in the Okavango River basin. Turton, A., Ashton, P., Cloete, E. (eds).

Magalhães, A.R. 1993. Drought and policy responses in the Brazilian Northeast, in Wilhite DA (ed.). 1993. *Drought assessment, management, and planning: Theory and case studies*. USA: Kluwer Academic publishers. :181-198

Magoulick, D.D. and Kobza, R.M. 2003. The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biology* 48: 1186-1198.

Maier, H.R.; Dandy, G.C. and Burch, M.D., 1998. Use of artificial neutral networks for modelling cyanobacteria *Anabaena* spp. in the River Murray, South Australia. *Ecological Modelling*, 105: 257-272.

Malan, H.L. and Day, J.A., 2002. Linking discharge, water quality and biotic response in rivers: A literature review. *WRC Report No. 956/2/02*, 132 pp.

Malan, H.L. and Day, J.A. 2002. Linking Discharge, Water Quality and Potential Effects on Aquatic Biota, within the Reserve Determination Process. In: Proceedings from Environmental Flows for River Systems. An International Working Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002. Cape Town.

Mander, M., Williams, C., Veck, A., Mullins, D. and Huggins, G. 2003. *Thukela System Resource Economics Report.* Department of Water Affairs and Forestry, South Africa.

Martin, H. 1956. Wenn es Krieg gibt, gehen wir in dem Wüste. Union Verlag, Stuttgart.

Matthews, W.J., 1988. North American streams as systems for ecological study. *Journal of the North American Benthological Society* I7(4): 387-409.

Matthews, W.J. 1998. *Patterns in Freshwater Fish Ecology*. Chapman and Hall. New York.

Matthews, W.J. and Styron, J.T. 1981. Tolerance of headwater versus mainstream fishes for abrupt physicochemical change. *American Midlands Naturalist* 105: 149-158.

McCormick, P.V. and Cairns, J., jr. 1997. Algal indicators of aquatic ecosystem condition and change. In: Wang, W., Gorsuch, J.W. and Hughes, J.S. (Eds.). *Plants for Environmental Studies.* CRC Press LLC, New York, USA, pp. 177-207.

McCosker, R.O., 1998. Methods addressing the flow requirements of wetland, riparian and floodplain vegetation. Pp. 47-65. In: Arthington AH, Zalucki JM (eds). Comparative evaluation of environmental flow assessment techniques: review of methods. *Land and Water Resources Research and Development Corporation Occasional Paper No*. 27/98. Canberra, Australia.

McCully, P. 1998. *Silenced Rivers: The Ecology and Politics of Large Dams*. London: Zed Books.

Mendlesohn, J., Jarvis, A., Roberts, C and Robertson, T. 2002. Atlas of Namibia: A portrait of the Land and it's People. Cape Town; David Philip Publishers.

Meybeck, M. and Hlemer, R. 1996. Introduction. In: Chapman, D. (Ed.) *Water Quality Assessments. A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring.* 2nd Edition. Chapman and Hall, London.

Meybeck, M., Kuusisto, E., Mäkelä and Mälkki, E. 1996. Chapter 2 – Water Quality, In: *Water Quality Monitoring – A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes.* UNEP/WHO.

Middleton, N. 1995. *The global casino: an introduction to environmental issues*. London: Edward Arnold.

Milner, A.M. 1994. System recovery. In, P.Calow & G.E. Petts (eds.): The rivers handbook. Vol. 2. Blackwell Scientific Publications. London.

Milton, K. 1996. *Environmentalism and Cultural Theory*. London: Routledge

Moralee, R.D., van der Bank, F.H. and van der Waal, B.C.W. 2000. Biochemical genetic markers to identify hybrids between the endemic *Oreochromis mossambicus* and the alien species, *O. niloticus* (Pisces: Cichlidae). *Water SA* 26(2): 263-268.

Mosley, M.P., 1983. Flow requirements for recreation and wildlife in New Zealand rivers – a review. *Journal of Hydrology (N.Z.)* 22(2): 152-174.

Mussared, D.1997. Living on Floodplains. The Cooperative Research Centre for Freshwater Ecology. The Murray-Darling Basin Commission. Chapter 6.

Myers, N. and Kent, J. 1995. *Environmental exodus: an emergent crisis in the global arena*. Washington: Climate Institute.

Naiman, R.J., Ionzarich, D.G., Beechie, T.J. and Ralph, S.C., 1992. General principles of classification and the assessment of conservation potential in rivers. In: Boon, P.J., Calow, P. and Petts G.E. (eds.), River conservation and management. Wiley Ltd., Chichester.

Newenham, J. and Chavalala, M.S. 2003. Determining Instream Flow Requirement Monitoring Protocol. WRC Report No. 1101/1/03. Water Research Commission. Pretoria.

Nir, D. 1983. Man, A Geomorphological Agent: An Introduction to Anthropic Geomorphology. Jerusalem; Keter

Noble, R.G. and Hemens, J. 1978. Inland Water Ecosystems in South Africa – A review of research needs. South African Scientific Programmes Report No. 34. Foundation for Research Development, Pretoria.

National State of the Environment Report for South Africa. 1999. Issued by The Department of Environmental Affairs and Tourism. Private Bag X447, Pretoria. Available from the Internet. URL: http://www.environment.gov.za.

O'Keeffe, J. 1999. Appendix R21: The procedure for generating aquatic invertebrate information for the intermediate and comprehensive Ecological Reserve (Quantity) for rivers. Resource Directed Measures for Protection of Water Resources: River Ecosystems. Department of Water Affairs and Forestry. South Africa

O'Keeffe, J.2000. Environmental flow assessments: Background and assumptions. In: Environmental flow assessments for rivers: King, J.M., Tharme, R.E. and De Villiers, M.S. (Eds.) Manual for the Building Block Methodology. Water Research Commission Report No. TT131/00.

O'Keeffe, J., Weeks, D.C., Fourie, A. and Davies, B.R. 1996. A pre-impoundment study of the Sabie-Sand River System, Mpumalanga with special reference to predicted impacts on the Kruger National Park. Volume 3: The effects of the proposed impoundments and management recommendations. WRC Report No. 294/2/96. Water Research Commission. Pretoria.

O'Keeffe, J. H. 1986. Ecological research on South African rivers – a Progress synthesis. *South African National Scientific Programmes Report No.* 121. Council for Scientific and Industrial Research, Pretoria.

O'Keeffe, J.H. and Hughes, D.A. 2002. The Flow Stressor-Response Method for Analysing Flow Modifications: Applications and Developments. In: Proceedings from Environmental Flows for River Systems. An International Working Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002. Cape Town.

O'Keeffe, J.H. and Uys, M. 2000. Chapter 20. The role of classification in the conservation of rivers. . In: Boon, P.J., Davies, B.R., Petts, G.E. (eds). *Global Perspectives on River Conservation: Science, Policy and Practice*. John Wiley and Sons Ltd.: 445-458

O'Neill, B. and Balk, D. 2001. *World population futures*. Washington: Population Reference Bureau (*Population Bulletin* 56 [3])

Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77: 118-125.

Palmer, C. and O'Keefe, J.H. 1994. Aquatic invertebrates of the Luvuvhu River and their habitat requirements. Luvuvhu IFR 26-28 July 1994 at Mountain View. Department of Water Affairs and Forestry.

Palmer, C.G., Peckham, B., Soltau, F. 2000. Chapter 22. The role of legislation in river conservation. In: Boon, P.J., Davies, B.R., Petts, G.E. (eds). *Global Perspectives on River Conservation: Science, Policy and Practice*. John Wiley and Sons Ltd.: 475-491

Palmer, C.G., Rossouw, N., Scherman, P-A. and Muller, W.J. 2002. The Development of Methods to Integrate Water Quality into Riverine Environmental Flow Assessments. In: Proceedings from Environmental Flows for River Systems. An International Working Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002. Cape Town.

Parsons, R.P. 2004. Surface Water-Groundwater Interaction in a Southern African Context. WRC Report No. TT 218/03. Pretoria, South Africa.

Parsons, R., and MacKay, H., 2000. Determination of the groundwater component of the Reserve using the Intermediate Reserve Determination method. Pp. 999-1004. In: Sililo *et al.* (eds). Groundwater: past achievements and future challenges. Balkema, Rotterdam.

Peckarsky, B.L., 1983. Biotic interactions or abiotic limitations? A model of lotic community structure. In: Fontaine III, T.D. and Bartell, S.M. (eds.), Dynamics of lotic ecosystems. Ann Arbor Science Publishers, Ann Arbor.

Pelser, A.J. and Steyn, P. 2002. An age of thirsty people: exploratory notes on future water-scarcity and water conflicts in sub-Saharan Africa. *Journal for Contemporary History* 27(1): 81-100.

Pelser, A.J. 2001. Evaluating the social impacts of drought and water scarcity: towards the development of guidelines, in Viljoen MF (Ed.). Towards the development of guidelines for the evaluation of social, economic and political impacts of drought and water scarcity. Water Research Commission, Pretoria: 5-63.

Pelser, A.J. 2002. *Health implications of environmental degradation*: *current trends and future impacts.* Presentation at the OPE National Cluster Conference on 'The protection of the human environment for sustainable development'. Bloemfontein, 21-24 May 2002.

Pelser, A.J. 2004. Health, environment and development in South Africa. In: Van Rensburg HCJ (ed.) *Health and health care in South Africa*. Schaik, Pretoria: 171 - 214.

Petrella. 2001. The Water Manifesto. South Africa: David Philip.

Pimanta, M.T. 2000. Water balances using GIS. *Physics and Chemistry of the Earth (B)* 25(7-8):695 – 608

Plummer, M.L. 1999. To fetch a pail of water. *Natural History* 108(1): 56-65.

Poff, N.L., and Ward, J.V., 1989. Implications of streamflow variability for lotic community structure: A regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences.* Vol 46:1805–1817. Report No. TT 63/94, Pretoria.

Pollard, S., 2000. Social use of riverine resources. Chpt 9: 95-116. In: King, J.M., Tharme, R.E., and De Villiers, M.S. (eds). Environmental flow assessments for rivers: Manual for the Building Block Methodology. *Water Research Commission Technology Transfer Report* No. TT131/00. Water Research Commission, Pretoria. 340 pp.

Pollard, S. 2002. *Giving people a voice: Providing an environmental framework for the social assessment of riverine resource use in the Sabie Riv*er, South Africa. Cape Town: University of Cape Town (Freshwater Research Unit).

Postel, S. and Richter, B. 2003. *Rivers for Life: Managing Water for People and Nature*. Washington: Island Press

Postel, S. and Wolf, A. 2001. Dehydrating Conflict. Foreign Policy (Sept/Oct) 2001: 2-9.

Potgieter, F.J. 1974. 'n Ekologiese studie van die rooiborskurper *Tilapia melanopleura* (Dumeril, 1859) (Pisces: Cichlidae) in Transvaal met verwysing na geassosieerde varswatersoorte. M.Sc. Dissertation, Rand Afrikaans University, Johannesburg.

Population Reference Bureau (PRB). 1996. *Water and population dynamics*. Population Reference Bureau, Washington.

Population Reference Bureau (PRB). 1997. *World population and the environment*. Population Reference Bureau, Washington.

Power, M.E., Stout, R.J. Cushing, C.E., Harper, P.P., Hauer, F.R. Matthews, W.J., Moyle, P.B., Statzner, B. and Wais de Badgen, I.R., 1988. Biotic and abiotic controls in stream and river communities. *Journal of the North American Benthological Society* 7(4): 456–479.

Prewitt, C.G. and Carlson, C.A., 1980. Evaluation of Four Instream Flow Methodologies Used on the Yampa and White Rivers, Colorado. Biological Sciences Series Number Two. Bureau of Land Management: Denver, CO.

Prinsloo, G.L. 1990. Commentary of the insect fauna of the lower Kuiseb River, Namib Desert. In: Seely, M.K. (ed.). Namib ecology: 25 years of Namib research. *Transvaal Museum Monograph* No 7: 67-75. Transvaal Museum, Pretoria.

Puckridge, J.T., Costelloe, J.F. and Walker, K.F. (Undated) DRY/WET Modelling ecological responses to vhange in the hydrological regimes of arid zone rivers. Project 62, The National Wetlands Research and Development Program.

Ractliffe, G. 1996. Mogalakwena Pre-feasibility study. Mogalakwena IFR Workshop Proceedings. First Draft. Workshop held at Bosveld Hotel, Usutu on 12-16 February 1996. Proceedings compiled by Southern Waters Ecological Research and Consulting cc. for Department of Water Affairs and Forestry.

The Republic of South Africa. 1998. The National Water Act, Act 36 of 1998. Government Printer, Pretoria.

Reiser, D.W., Ramey, M.P., Lambert, T.R., 1987. Considerations in assessing flushing flow needs in regulated stream systems. Pp. 45-57. In: Craig JF, Kemper JB (eds). *Regulated streams: advances in ecology*. Plenum Press, New York.

Reiser, D.W., Ramey, M.P., Wesche, T.A. 1989. Flushing flows. In: Gore, J.A. and Petts, G.E. (eds). *Alternatives in regulated river management*. CRC Press, Inc., Florida.

Reynolds, C.S. 1996. Algae In: Petts, G.E. and Calow, P. *River Biota: diversity and dynamics.* Blackwell Science, Oxford, 6-26.

Richards, K. 1982. Rivers, Form and Process in Alluvial Channels. London; Methuen

Richter, B.D., Baumgartner, J.V., Wigington, R. and Braun, D.P., 1997. How much water does a river need? *Freshwater Biology* 37:231-249.

Richter, B. and Postel, S. 2004. Saving Earth's Rivers. *Issues in Science and Technology* 20(3): 31-36. Internet: http://web19.epnet.com/citation.asp Accessed: 13/7/2004

Robbins, E. 1998. *Water, Water Everywhere*. Internet: http://www.emagazine.com/September-october 1998/0998feat1.htm Accessed: 4/3/2000.

Rogers, K.H. 1980. The vegetation of the Pongolo floodplain: distribution and utilization. In Bruton, M.N. and Cooper, K.H (eds.). *Studies on the ecology of Maputaland.* pp 69-77.

Rogers, K.H. and Higgins, S.I. 1993. The Nyl floodplain as a functional unit of the landscape. Preliminary synthesis and future research. Centre for water in the environment report 1/93. University of the Witwatersrand, Johannesburg.

Rogers, K.H. and Biggs, H. 1999. Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. *Freshwater Biology* 41: 439-451.

Roos, J.C. and Pieterse, A.J.H. 1995. Salinity and dissolved substances in the Vaal River at Balkfontein, South Africa. *Hydrobiologia*, 306: 41-51.

Roos, J.C. and Pieterse, A.J.H. 1996. Seasonal variation of phytoplankton biomass in the Middle Vaal River, South Africa. *Water SA*, 22: 33-42.

Rooseboom, A. 1992. Sediment Transport in Rivers and Reservoirs – A South African Perspective. WRC Report No. 297/1/92. Pretoria; Water Research Commission.

Rooseboom, A., Verster, E., Zietzman, H.L. and Lotriet, H.H. 1992. The Development of a New Sediment Yield Map of Southern Africa. WRC Report No. 297/2/92. Pretoria; Water Research Commission.

Roux, D.J. 1997. National aquatic ecosystem biomonitoring programme: Overview of the design process and guidelines for implementation. NAEBP Report series No 6. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria.

Roux, D., de Moor, F., Cambray, J. and Barber-James, H. 2002. Use of landscape-level river signatures in conservation planning: a South African case study. Conservation Ecology 6(2): 6. [Online] URL: http://www.consecol.org/vol 6/iss2/art6. Accessed 11 October 2004.

Rowlston, W. S. 1991. The hydraulics of the Nyl River Floodplain: A qualitative description. Unpublished report. Department of Water Affairs and Forestry, Pretoria.

Rowntree, K. 2000. Geomorphology. In: King, J.M., Tharme, R.E. and De Villiers, M.S. (Eds). Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. pp 169 – 194. WRC Report No: TT 131/00. Pretoria; Water Research Commission.

Rowntree, K.M. and Wadeson, R.A. 1999. A hierarchical geomorphological model for the classification of selected South African rivers. Final Report. WRC Report No. 497/1/99. Water Research Commission, Pretoria.

Russell, I.A. 1997. Monitoring the cpnservation status and diversity of fish assemblages in the major rivers of the Kruger National Park. Unpublished Ph.D. thesis, University of the Witwatersrand, Johannesburg.

Rutherford, M.C. and Westfall, R.H. 1994. Biomes of southern Africa: an objective categorization (2nd edn.). *Memoirs of the Botanical Survey of South Africa* 63:1-94.

SAIRR (South African Institute of Race Relations). 2001. *South Africa Survey 2001/2002*. Johannesburg: SAIRR.

Satellite Applications Centre, 1999. National Landcover Database. CD-Rom National and Provincial data sets. CSIR, Pretoria.

Schindler, D.W., Fee, E.J., and Ruszcynski, T. 1978. Phosphorus input and its consequences for phytoplankton standing crop in the Experimental Lakes Area and similar lakes. *Journal of the Fisheries Research Board of Canada* 35: 190-196.

Schlosser, I.J. 1991. Stream fish ecology: a landscape perspective. *BioScience* 41(10): 704-712.

Scholes, R.J and Walker, B. H. 1993. An African savanna. Cambridge University Press, Cambridge, U.K.

Schulz, G.W.C. and Schoonbee, H.J. 1999. Aspects of the length, mass, fecundity, feeding habits and some parasites of the shortfin minnow, *Barbus brevipinnis* (Cyprinidae) from the Marite River, Mpumalanga Province, South Africa. *Water SA* 25(2): 257-264.

Schulze, R.E. 1997. South African Atlas of Agrohydrology and –Climatology. WRC Report No. TT 82/96. Pretoria; Water Research Commission.

Schumann, A.H. and Geyer, J. 2000. GIS-Based Ways for Considering Spatial Heterogeneity of Catchment Characteristics. *Physics and Chemistry of the Earth (B)* 25(7-8):691 – 694

Schumm, S.A. 2003. The Fluvial System. (Reprint of the first edition 1977). Caldwell; Blackburn.

Seely, M., Henderson, J., Heyns, P., Jacobson, P., Nakale, T., Nantanga, K., Schachtschneider, K., 2002. Ephemeral and endorheic river systems: Their relevance and management challenges. Paper presented at Workshop One of the Okavango Pilot Project, Maun, Botswana, 8-12 September 2002.

Seely, M., Henderson, J., Heyns, P., Jacobson, P., Nakale, T., Nantanga, K., Schachtschneider, K., 2003. Ephemeral and endorheic river systems: Rrelevance and management challenges. In: Turton, A., Ashton, P. and Cloete, E. (eds). *Transboundary rivers, sovereignty and development: Hydropolitical drivers in the Okavango River basin*. Pretoria.

Shafik, H.M., Herodek, S., Vörös, L., Présing and Kiss, K.T. 1997. Growth of *Cyclotella meneghiniana* Kutz. I. Effects of temperature, light and low rate of nutrient supply. *Annls Limnol*. 33: 139-147.

Sinclair Knight Merz Pty Ltd. 2001. Environmental Water Requirements to Maintain Groundwater Dependent Ecosystems. Commonwealth of Australia, GPO Box 787, Canberra ACT 2601.

Skelton, P. 2001. A complete guide to the freshwater fishes of southern Africa. Struik, Cape Town.

Smakhtin, V.U. 2001. Low flow hydrology: a review. *Journal of Hydrology* 240:147 – 186.

Smith, H., Wood, P.J. and Gunn, J. 2003. The influences of habitat structure and flow permanence on invertebrate communities in karst spring systems, *Hydrobiologia* 510: 53-66

Smith, V.R., Tilman, G.D., and Nekola, J.C. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution*, 100: 179-196.

Sommaruga, R. and Robarts, R. D. 1997. The significance of autotrophic and hetero-trophic picoplankton in hypertrophic ecosystems. *FEMS Microbiology Ecology*, 24: 187-200.

Stalnaker, C.B. and Arnette, S.C. 1976. Methodologies for the determination of stream resource flow requirements: an assessment. U.S. Fish and Wildlife Services, Office of Biological Services Western Water Association.

Stalnaker, C., Lamb, B.L., Hendriksen, J., Bovee, K. and Bartholow, J. 1995. The Instream Flow Incremental Methodology: A Primer for IFIM. Biological Report 29, March 1995. US Department of the Interior. National Biological Service. Washington, D.C.

Stanford, J.A. 1998. Rivers in the landscape: introduction to the special issue of riparian and groundwater ecology. *Freshwater Biology* 40, 402-406.

Stanley, E.H., Buschman, D.L., Boulton, A.J., Grimm, N.B. and Fischer, S.G. 1994. Invertebrate resistance and resilience to intermittency in a desert stream. *American Midland Naturalist*. 131: 288-300.

Steenkamp, M.K.J., Engelbrecht, G.D. and Mulder, P.F.S. 2001. Allozyme variation in a Johnston's topminnow, *Aplocheilichthys johnstoni*, population from the Zambezi River system. *Water SA* 27(1): 53-55.

Steinberg, C.E.W. and Hartmann, H.M. 1988. Planktonic bloom-forming Cyanobacteria and the eutrophication of lakes and rivers. *Freshwater Biology*, **20**: 279-287.

Stewardson, M.J. and Gippel, C.J. 1997. Instream environmental flow design: a review. Draft report. Cooperative Research Centre for Catchment Hydrology, Department of Civil and Environmental Engineering, University of Melbourne. Victoria, Australia.

Stewardson, M.J. and Gippel, C.J. 2003. Incorporating flow variability into environmental flow regimes using the Flow Events Method. Rivers Research and Applications. Vol 19:459 – 472.

Steynberg, M.C., Adam, K. and Pieterse, A.J.H. 1998. An algal monitoring protocol: The strategic link between reservoir and treatment process. *Water Science and Technology* 37: 153-157.

Swales, S. and Harris, J.H., 1995. The expert panel assessment method (EPAM): a new tool for determining environmental flows inregulated rivers. In: Harper, D.M. and Ferguson, A.J.D. (eds). *The ecological basis for river management*. John Wiley & Sons, New York.

Tarbotton, W.R. 1987. The Nyl Floodplain. *Fauna and Flora* 45,

Tarbotton, W.R. 1991. Flooding and the avifauna of the Nyl floodplain. Report to the chief director of Nature and Environmental Conservation. Transvaal Provincial Administration, Pretoria.

Teague, W.R and Smit, G.N. 1992. Relations between woody and herbaceous components and the effects of bush clearing in southern African savannas. *Grassland Society of Southern Africa* 9 (2): 1992-08-03.

Tennant, D.L. 1976. Instream flow requirements for fish, wildlife, recreation and related environmental resources. *Fisheries* 1: 6-10.

Tharme, R.E., 1996. Review of international methodologies for the quantification of the instream flow requirements of rivers. Water law review final report for policy development, for the Department of Water Affairs and Forestry, Pretoria: Freshwater Research Unit, UCT.

Tharme, R.E. 2000. The present status of environmental flow methodologies in Sotuh Africa. In: Environmental flow requirements for rivers: King, J.M., Tharme, R.E. and De Villiers, M.S. (Eds.) Manual for the Building Block Methodology. Water Research Commission Report No. TT131/00.

Tharme, R.E. 2003. Global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. Rivers Research and Applications 19.

Tharme, R.E., 2002. A Global Perspective on Environmental Flow Assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. Paper presented at the Environmental Flows for River Systems. An International Conference on Assessment and Implementation. Incorporating the Fourth International Ecohydraulics Symposium. 3 – 8 March 2002, Cape Town, South Africa.

Theron, G.K., van Rooyen, N. and van Rooyen, M.W. 1980. Vegetation of the Lower Kuiseb River. *Madoqua* 11(2) 327-345.

Theron, G.K., van Rooyen, N. and van Rooyen, M.W. 1985. Vegetation of the Lower Kuiseb River. In Huntley, B.J. (ed.). The Kuiseb environment: the development of a monitoring baseline. South African Scientific Programmes Report No. 106. Foundation for Research Development, Pretoria.

Thirion, C. 2003. How does SASS derived integrity classes compare with the FAII derived classes? In: Kleynhans, C.J. 2003. National Aquatic Ecosystem Biomonitoring Programme: Report on the use of Fish in Aquatic System Health Assessment. NAEBP Report Series No. 16. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

Thirion, C. 2004. Aquatic Invertebrates. In: Louw, D., Kleynhans, C.J., Thirion, C., Hughes, D.A. and O'Keefe, J.H. 2004. *Ecoclassification and HFSR manual*. First Draft. Project number 2002-148. Prepared by IWR Source to Sea for Resource Quality Services. Department of Water Affairs and Forestry. Pretoria.

Thoms, M., Suter, P., Roberts, J., Koehn, J., Jones, G., Hillman, T. and Close, A. 2000. Report of the River Murray Scientific Panel on Environmental Flows. River Murray – Dartmouth to Wellington and the Lower Darling River. June 2000. Chapters 2 and 3.

Thorne, C.R., Hey, R.D. and Newson, M.D. (Eds). 1997. Applied Fluvial Geomorphology for River Engineering and Management. Chichester; Wiley

Thornes, J.B. 1994. Channel processes, evolution and history. In: Abrahams, A.D. and Parsons, A.J. (Eds). Geomorphology of Desert Environments. pp288 – 317. London: Chapman and Hall

Tinley, K.L. 1976. The ecology of Tongaland. Wildlife Society of Southern Africa, Natal Branch, Durban.

Towns, D.R. 1985. Limnological characteristics of a South Australian intermittent stream. Brown Hill Creek. *Australian Journal of Marine and Freshwater Research* 36: 821-837.

Towns, D.R. 1991. Ecology of leptocerid caddisfly larvae in an intermittent South Australian stream receiving *Eucalyptus* litter. *Freshwater Biology* 25: 117-129.

Tramer, E.J. 1977. Catastrophic mortality of stream fishes trapped in shrinking pools. *American Midland Naturalist* 97: 469-478.

Trihey, E.W. and Stalnaker, C.B. 1985. Evolution and application of instream flow methodologies to small hydropower ,developments: an overview of the issues. In: Proceedings of the Symposium on Small Hydropower and Fisheries, Olson, F.W., White, R.G. and Hamre, R.H. (eds). Aurora, CO.

Turnbull, M., 2002. Life in the extreme. *Africa Geographic* June 2003:46-51.

UNEP (United Nations Environment Programme). 2002. *Global environment outlook 3.* London: Earthscan.

UNESCO. 2003. *Water for People, Water for Life: The United Nations World Water Development Report*. World Water Assessment Programme (WWAP). Barcelona: UNESCO/Bergahn.

UNFPA (United Nations Population Fund). 2001*. Footprints and milestones: population and environmental change (The state of world Population 2001).* New York: UNFPA.

Internet: http://edcsgs9.cr.usgs.gov/pub/data/srtm/

Internet: http://www.mfe.govt.nz/publications/water/anzecc-water-quality-guide-02/

Internet: http://www.who.int/water_sanitation_health/resourcesquality/watpolcontrol/en/

Internet: http://www.who.int/docstore/water_sanitation_health/wqmonitor/ch04.htm

USGS. 2004: SRTM data

Uys, M.C. 1996. The Functioning of Aquatic Invertebrates in temporary Rivers - macroinvertebrate starter document for Mogalakwena Pre Feasibility Study IFR Workshop held at Bosveld Hotel, Usutu. 12-16 February 1996. Institute for Water Research, Rhodes University. Grahamstown (Unpublished document)

Uys, M.C. and O'Keeffe, J.H. 1997. Simple Words and Fuzzy Zones: Early Directions for Temporary River Research in South Africa. *Environmental Management* 21(4): 517-531.

Uys, M.C. The Functioning of Aquatic Invertebrates in Temporary Rivers. Grahamstown; Rhodes University.

Valett, H.M., Fisher, S.G., Grimm, N.B., Stanley, E.H. and Boulton, A.J. 1992. Hyporheic-surface water exchange: implications for the structure and functioning of desert stream ecosystems. In: Proceedings of the First International Conference on Groundwater Ecology. Stanford, J.A. and Simons, J.J. (Eds). American Water Resources Association, Bethesda, Maryland: 395-405.

Van Coller, A.L. and Rogers, K.H. 1996. A basis for determining the in-stream flow requirements of the riparian vegetation along the Sabie River within the Kruger National Park. Centre for water in the environment report 2/96. University of the Witwatersrand, Johannesburg.

Van Coller, A.L., Rogers, K.H. and Heritage, G.L. 1997. Linking riparian vegetation types and fluvial geomorphology along the Sabie River within the Kruger National Park, South Africa. *African Journal of Ecology* 35: 194-212.

Van der Waal, B.C.W. and Bills, R. 2000. Oreochromis niloticus (Teleosti: Cichlidae) npw in the Limpopo River System. *South African Journal of Science* 96 (January): 47-48.

Van der Waal, B.C.W. 1997. Some observations of the fish life in a seasonal river. *Sth. Afr. J. aquat. Sci.* 23(1): 95-102.

Van der Waal, B.C.W. 2002. Another fish on its way to extinction? Science in Africa, Merck. Accessed on 28/06/2004 http://www.scienceinafrica.co.za/2002/january/tilapia.htm1

Van Veelen, M. 1996. Mogalakwena River Study: Preliminary Water Quality Situation Analysis. BKS Inc Report Number I04/168.

Van Rooyen, N. and Bredenkamp, G. 1996. Sweet Bushveld (17) and Mixed Bushveld (18). In: Vegetation of South Africa, Lesotho and Swaziland. Low, A.B. and Rebelo, A.T. (Eds.) Department of Environmental Affairs and Tourism, Pretoria.

Vegter, J.R. and Pitman, W.V. 1996. Recharge and stream flow; Position paper presented at WRC-sponsored workshop on "Groundwater – surface water issues in arid and semiarid areas", Warmbaths, October 1996.

Vlok, W., van Vuren, J.H.J., Cook, C.L., Greenfield, R.G., Hoare, D.B., Victor, J.E. and Wepener, V. 2005. Framework for the sustainable management of wetlands in the Limpopo Province with Nylsvley as a reference model. WRC Report 1258/01/05.

Wadeson, R. 1996. *Geomorphological characteristics of the Mogalakwena River and the potential impacts of impoundments*. In: Ractliffe, G. 1996. Mogalakwena Pre-feasibility study. Mogalakwena IFR Workshop Proceedings. First Draft. Workshop held at Bosveld Hotel, Usutu on 12-16 February 1996. Proceedings compiled by Southern Waters Ecological Research and Consulting cc. for Department of Water Affairs and Forestry.

Walker, K.F., Sheldon, F., Puckridge, J.T. 1995. A perspective on dryland river ecosystems. *Regulated Rivers: Research and Management* 11:85-104.

Ward, R.C. 1975. Principles of hydrology; McGraw-Hill, London.

Ward, J.V. 1985. Thermal characteristics of running waters. *Hydrobiologia* 125 31-46.

Waters, B.F., 1976. A methodology for evaluating the effects of different stream flows on salmonid habitat. In Symposium on Instream Flow Needs, Orsborn, J.F. and Allman, C.H. (eds). American Fisheries Society: Bethseda, MD, USA.

Water Research Commission. 1996. Water-related National Concerns. *SA Waterbulletin* Special Edition: 7.

Watson, S.B., McCauley, E. and Downing, J.A. 1997. Patterns in phytoplankton taxonomic composition across temperate lakes of differing nutrient status. *Limnol. Oceanogr*. 42(3): 487-495.

Weeks, D., O'Keefe, J., Fourie, A. and Davies, B.R. 1996. A pre-impoundment study of the Sabie-Sand River System, Mpumalanga with special reference to predicted impacts on the Kruger National Park. Volume 1: The ecological status of the Sabie-Sand System. WRC Report No. 294/1/96. Water Research Commission. Pretoria.

Werger, M.J.A. 1974. Concepts and techniques applied in the Zürich-Montpellier method of vegetation survey. *Bothalia* 11:309-323.

Wesche, T.A. 1985. Stream channel modifications and reclamation structures to enhance fish habitat. In: Gore, J.A. The restoration of rivers and streams. Butterworth, London.

Wetzel, R.G. 1983. *Limnology*. Saunders College Publishing, Philadelphia, New York, 767 pp.

Whittaker, D., Shelby, B., Jackson, W., Beschta, R., 1993. Instream flows for recreation: a handbook on concepts and research methods. USDI National Parks Service, Alaska Region. Anchorage, Alaska.

Wiggins, G.B., Mackay, R.R. and Smith, I.M. 1980. Evolutionary and ecological strategies of animals in annual temporary pools. *Archiv fur Hydrobiologie Supplement* 58 1/2: 97-206.

Wilkinson, M.J. 1988. Arid Landscapes. In: Moon, B.P. and Dardis, G.F. The Geomorphology of Southern Africa. Half Way House; Southern

Williams, W.D. 1985. Biotic adaptations in temporary lentic waters, with special reference to those in semi arid and arid regions. *Hydrobiologia* 125: 85 – 110.

Williams, D.D., 1987. *The Ecology of Temporary waters*. Timber Press, Portland, Oregan

Williams, W.D., 1988. Limnological imbalances: An antipodean viewpoint. *Freshwater Biology* 20: 407-420.

Williams, D.D. and Hynes, H.B.N. 1976. The Ecology of Temporary Streams. 1. The Faunas of two Canadian Streams. *Internationale Revue der gesamten Hydrobiologie* 61: 761-787.

Williams, D.D. and Hynes, H.B.N. 1977. The Ecology of Temporary Streams. II General remarks on Temporary Streams. *Internationale Revue der gesamten Hydrobiologie* 62: 53-61.

Winter, T.C., Harvey, J.W., Franke, O.L. and Alley, W.M. 1999. Ground water and surface water – a single resource; USGS Circular 1139, United States Geological Survey, Denver.

Wissinger, S.A. 1997. Cyclic Colonization in Predictable Ephemeral Habitats: A Template for Biological Control in Annual Crop Systems. *Biological Control* 10: 4-15.

Wofsy, S.C. 1983. A simple model to predict extinction coefficients and phytoplankton biomass in eutrophic waters. *Limnology and Oceanography* 28: 1144-1155.

Xu, Y., Titus, R., Holness, S.D., Zhang, J. and van Tonder, G.J. 2002. A hydrogeomorphological approach to quantification of groundwater discharge to streams in South Africa; *Water SA* 28 (4): 375 – 380.

Zawada, P.K., Hattingh, J. and van Bladeren, D. 1996. Paleoflood Hydrological Analysis of Selected South African Rivers. WRC Report No. 509/1/96. Pretoria; Water Research Commission.