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4. A prototype methodology for Environmental Water Assessments for non-perennial rivers

4.1. Introduction

Following the field research in the earlier phases of the project, focus changed in the final year to development of a prototype approach for Environmental Water Assessments (EWA) for non-perennial rivers.

The multidisciplinary team met at a workshop in Bloemfontein from 2-5 October 2007 to begin the process of development. This was followed by a second meeting of a larger group in Bloemfontein on 17-18 October 2007 to discuss implementation of the Ecological Reserve and, to a small extent, EWA methods for wetlands and non-perennial river systems. The implementation discussion is being dealt with outside of this project and is not referred to again here. A follow up workshop was held in March 2008 where the prototype EWA method was tested on the Seekoei River.

This chapter draws together the three sets of discussions on EWAs for non-perennial rivers and describes an emerging prototype methodology. The test application of the methodology on the Seekoei River is described in Chapter 5.

4.2. Key features of non-perennial rivers relevant to an EWA methodology

Non-perennial rivers are primarily distinguished from perennial ones by their hydrological regime, which is spatially and temporally much more variable, and by the loss of connectivity of surface water within the system as flow periodically fails and surface water is confined to isolated pools that may themselves dry up eventually. The hydrological variability results in high levels of unpredictability of surface flow and, indeed, surface water, in time scales from days to a few years, although over very long time scales some broad-scale predictability could emerge. Long-term data that could be used to search for broad-scale predictability are usually unavailable because these river systems are in arid parts of the country, with poor rainfall and so there are few, if any, rainfall and flow gauges per catchment.

Similarly, the location of surface water in pools during periods of no surface flow is difficult to predict although, similarly to the above, analysing the river at the landscape level rather than at the level of geomorphological river reaches might provide some insights on why pools are where they are.

The variability and unpredictability in the flow regime – the fundamental driving force of the river – result in high levels of disturbance for the riverine biotas. Species tend to have life-cycle strategies that can cope with periodic and unpredictable flood and desiccation, with some aestivating and others depending on pools as refugia. Species that cannot cope with such conditions tend to be rare or absent, whilst even those that can may, or may not, appear in any one pool in any one year. Animal assemblages in isolated pools may reflect a deliberate choice by individuals or species, such as fish that appear to choose pools with lower conductivity before surface water flow stops, or simply be a list of which species arrived at and survived in that water body. The latter is an example of the 'clinging to the wreckage' model of community organisation, in which species barely or never interact because the assemblage is in a perpetual state of recovery from disturbance (Hildrew and Giller 1994). Riparian vegetation may be the most obvious and persistent biological component of the ecosystem of such rivers, tapping into underground flows and perhaps showing some greater community development around persistent pools. Classic examples of the persistence of such vegetation are the 'linear oases' – the green ribbons of trees – along dry channels in the deserts and semi-deserts of Namibia and north-western South Africa. These are essential resources for local people and wildlife.

4.3. Challenges facing EWAs for non-perennial rivers

4.3.1. Hydrological modelling

Hydrological data are usually the start and end points in environmental water assessments. The start point is a description of the Present-Day and, to the extent possible, the natural surface flow regime at key points along the river's length. These conditions are the major driver of the river's nature and form the basis of interpretation, by the specialist team, of the river's present biophysical nature. With the present condition of the river ecosystem described to the extent possible, the flow regimes linked to any potential water-related management intervention of interest can be simulated, and these can then be interpreted in terms of the predicted physical, chemical and biological responses. The final hydrological output of a flow assessment is a description of flows needed to attain and maintain a range of possible future ecosystem conditions that would be brought about by the different management interventions.

The above process relies heavily on being able to satisfactorily model the movement of water through the catchment. In this respect, non-perennial systems pose several challenges to hydrological modellers that are unique or more severe than those faced with perennial rivers, of which the following may pertain to varying degrees:

- few if any rainfall and runoff gauge sites within a catchment
- rainfall and runoff data sets of insufficient length to detect trends
- uncertainty in model calibration due to poor quality and quantity of measured rainfall and runoff data
- the links between surface and groundwater hydrology, and the influence of sub-surface water on stream flow, poorly understood
- disaggregation of simulated monthly data to describe individual flood events requires a high degree of specialisation and is not usually feasible, so flood events will be poorly described, if at all.

These difficulties result in simulated hydrological data that are probably of low accuracy.

4.3.2. Understanding pools

Isolated pools appear at various points along a river system as surface flow ceases. These pools are one of the most distinguishing of all characteristics of non-perennial rivers and are important refugia for many of the riverine plants and animals. They may also be important support features in an otherwise arid landscape for a wide variety of wildlife and for local rural people.

The location, nature and means of persistence of pools are also poorly understood. It is usually not known why they occur where they do, and so it is not possible to easily predict where they are likely to occur in an unstudied river. It is assumed that pools appear in the same place each time flow stops, but this may not be true nor is it usually understood what creates the geomorphological condition for pool formation. Some pools persist at the same water level through months of no rainfall whilst others close by gradually shrink and dry up, again, for reasons assumed but not necessarily obvious or ease to prove. Uncertainty as to their location and their individual persistence makes management of them as refugia difficult.

Not only the location, timing and persistence of pools, but also their chemistry can be highly unpredictable. Pools within the same general landscape and same geomorphological reach can differ markedly in their values for variables such as conductivity, probably due to differences in the amount and source of underground recharge. This is a feature that may also be apparent in other types of non-river water bodies such as floodplains (e.g. Berg River floodplain) and wetlands (e.g. the Agulhas wetland system). Again, because the main influence is likely to be underground water, there is no easy way of predicting the chemistry of individual pools or even of pools within one river reach or longitudinal zone.

4.3.3. Connectivity

Connectivity between pools is one of the most important attributes of non-perennial rivers. Occurring intermittently, it allows transport of sediments and nutrients along the system, mixing of gene pools, and movement of organisms to other refugia and dilution of poor-quality pool water. Because of the poor coverage of flow gauging stations and uncertain nature of hydrological data for such systems, connectivity is not well recorded and cannot be simulated with great accuracy. Simulated monthly hydrological data, however, will indicate in general when high-flow events occur and thus give some insight into the occurrence of connected flow along the system.

4.3.4. Surface water and sub-surface water interactions

Much of the nature of non-perennial rivers and their pools is dictated by the interactions between surface and sub-surface waters. At different times or places water may be flowing underground into the river from catchment and bank storage or flowing out of the river into such storage. Water may also be flowing along the river in underground channel aquifers, replenishing pools and filling wells dug by people in the riverbed. Such surface-subsurface interactions affect the occurrence of flow, the existence and persistence of the pools, and the amount of water stored in the alluvial material beneath and adjacent to the channel (Hughes, 2005). Close cooperation between hydrologists experienced in the hydrology of ephemeral rivers and geohydrologists with suitable experience of the system being investigated is essential in order to provide meaningful insights into the hydrological functioning of such systems.

4.3.5. Extrapolation

Under such high levels of physical, chemical and biological unpredictability, extrapolation of ecosystem attributes over long stretches of river is of uncertain value mostly because much of the time the data will be from isolated pools that are behaving differently. Two years of study of the Seekoei River convinced the research team that variability was so high that data from one reach or pool could not with confidence be extrapolated to unstudied reaches or pools. For any extrapolation to be true it would have to be at such a coarse level that it could well be meaningless as, for instance, by predicting that a pool would have aquatic invertebrates (of unknown families, genera and species). The inability to extrapolate data means that, at present, generalisations cannot be made with confidence unless they are of very coarse resolution, and so our understanding of the rivers remain at the level of individual study sites.

4.3.6. Establishing Reference Condition

For much the same reasons that acceptable extrapolation was seen to be difficult, the team found that standard South African procedures for setting a Reference Condition (Kleynhans and Louw, 2007a) could not be followed for the Seekoei with acceptable levels of scientific confidence. There was a lack of recent and historical data, confounded by an inability to gain a comprehensive understanding of the system through extrapolation from studied sites. For most disciplines involved in the Seekoei study there were too few, if any, data upon which to judge a past natural state or the degree to which the present state differed from this. Any attempt at setting a Reference Condition would be no more than an educated guess, with little scientific foundation.

Setting a Reference Condition is one of the early stages in the South African Ecological Reserve Determination method (DWAF, 2002 – see **Figure 4-1**). The inability to complete this step provided one of the earliest doubts that the current approach used for perennial systems could be followed for non-perennial rivers.

4.4. EWAs for perennial rivers

In the National Water Act (Act 36 of 1998) an ecosystem-based management of water resources was legislated. This requires tools for resource management that are sufficiently flexible to take into account the extreme differences within South Africa in terms of the socio-economic conditions and natural variability of aquatic ecosystems (DWAF, 2002).

Methods for EWA were developed (DWAF, 1999) and, especially for the quantity reserve for rivers, were upgraded in 2002 (DWAF, 2002) (**Figure 4-1**)

The EWA procedure was developed and tested on various perennial rivers with success. It has however not been tested extensively on non-perennial rivers and some of the EWAs for non-perennial rivers have highlighted shortcomings in the procedure. Some of the main shortcomings are: lack or shortage of gauging weir data, gaps in and inaccurate runoff and rainfall data, complications in hydrological modeling, lack or shortage of historical data, difficulty in setting up references conditions. The next section attempts to address these shortcomings as the methodology for non-perennials is developed.

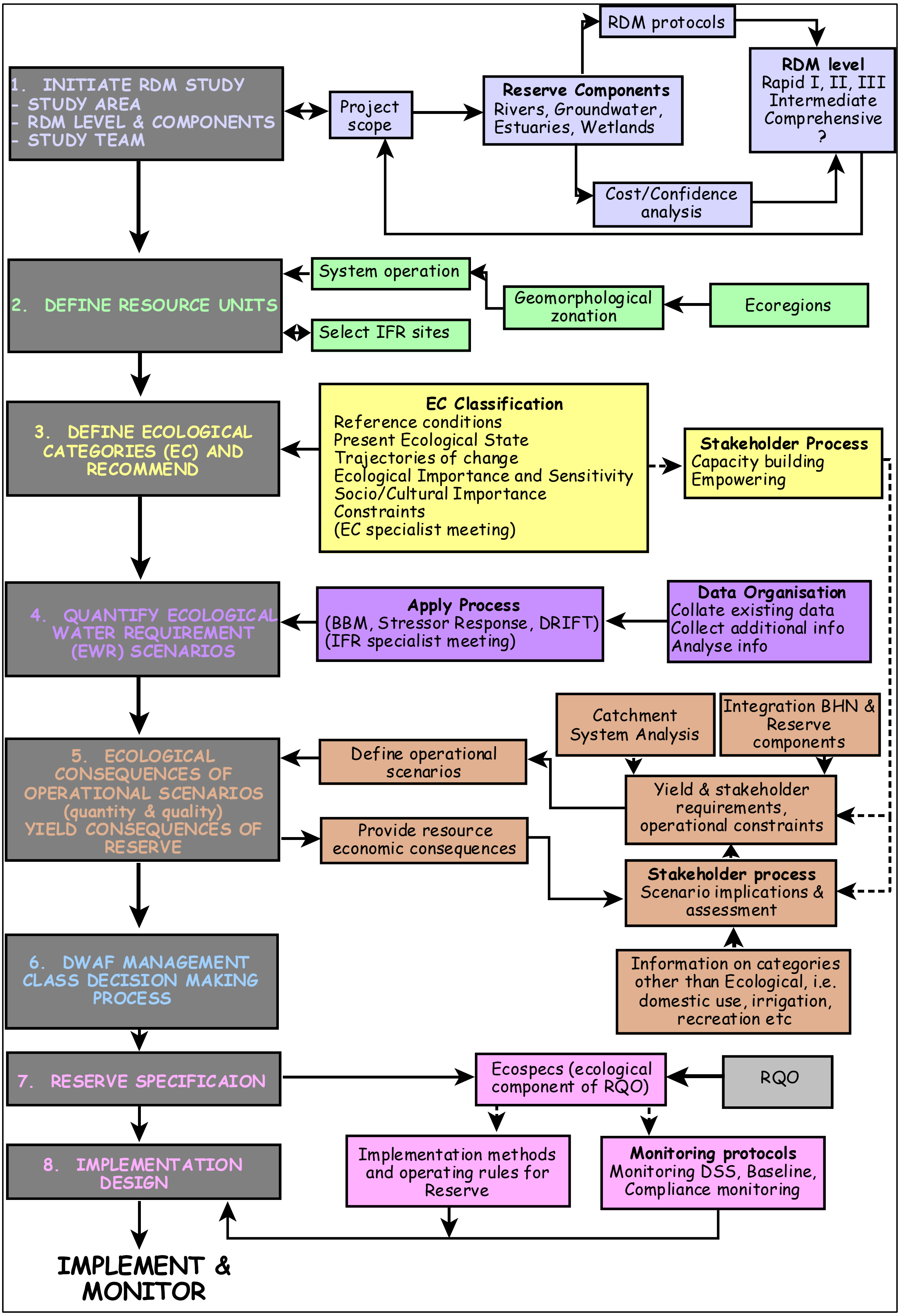

Figure 4-1 The EWA process for perennial rivers (adapted from DWAF, 2002).

4.5. Assumptions made when developing an EWA methodology for non-perennial rivers

Several assumptions were made at the start of the Seekoei project or during its course that guided the thinking and eventual nature of the prototype EWA methodology suggested for testing for non-perennial systems. The main ones were as follows:

- the methodology needed to be able to create scenarios, which means it needed to encompass a process for predicting change even though the systems were highly unpredictable in many ways
- the start and end points would again be the hydrological data, with the final output of the process being a table of hydrological data that linked a range of condition classes for the river with relevant flows to achieve each (i.e. the scenarios)
- it would be important to follow and adapt as necessary the current approach for perennial rivers, but not be constrained by it if this seemed unacceptable
- focus should be on the required output rather than attempting to follow a set method
- interactions between surface and subsurface water would be an important focus
- consideration of pools would be an important focus
- major floods are important in maintaining pools and would be a major focus
- consideration of catchment changes could be a useful short cut to predicting river change, and could be used, for instance, to predict changes in sediment dynamics and delivery of pollutants to the river.
- as setting the Reference Condition was proving difficult, a more suitable approach might be to start with the present condition (which the scientists have studied and to some extent understand) and then to describe how this could change in the following scenario-creation phase (in other words the standard Ecostatus assessment could not be followed, although parts of it might be used). Any knowledge of the historic Reference Condition would continue to be useful in terms of developing an understanding of how and why the river has changed to date and therefore the trajectory of likely change in the future.
- Stakeholder consultation would be necessary for three reasons: 1) to gain understanding of the past and present nature of the river, especially where data are few; 2) to make input into the process on their concerns and issues, so that the status of each of these could be addressed in each scenario; and 3) so that they could feedback to decision-makers on their level of acceptability of each scenario
- An Ecological Category would not be recommended. Such a recommendation appears to be an historical anomaly within the present method for perennial rivers, leads to confusion and is unnecessary as the stakeholders and government should guide this decision. Some of the stakeholders will be scientists representing the case for conservation, and so an ecological recommendation does not appear to be necessary from the scientists who did the assessment

- predictions of change would be coarse, possibly: pristine (Condition A); healthy (Condition B); working (C/D) and very degraded (E), with the shift to one or other of these stages representing a state change (such as an ephemeral river becoming a perennial one due to water transfers in from another catchment)
- Few indicators of change would be used in the scenarios
- Only coarse predictions of change would be possible for each indicator, possibly negligible, moderate and large change
- The EWA should be rapid and coarse, with more accent on local investigation at the licencing stage in order to assess the possible impact on specific pools or reaches.

4.5. The prototype EWA methodology for non-perennial rivers

Drawing on the research findings on the Seekoei River, the growing experience of the project team and the various guidelines and protocols emanating from the wider body of scientists employed in this work, a prototype methodology has begun to emerge for EWAs for non-perennial rivers. This was tested as a trial application of a comprehensive assessment for the Seekoei River in March 2008; once a comprehensive EWA methodology has been finalised, the process for more rapid assessments will be completed. The comprehensive approach described here provides as its output a description of the expected status of key biophysical and socio-economic indicators under a range of possible future flow management options.

The prototype methodology comprises 11 phases and 28 activities (**Figure 4-2**).

4.5.1. Phase 1: Initiate the EWA study (within DWAF)

Activity 1: Define the river in terms of perenniality

At the earliest stage of an EWA, whether it is a pre-emptive activity or in response to a licence application, a decision has to be made on whether or not to follow the approach used for perennial rivers. If the river is perennial then the standard EWA approach for perennial rivers should be used (**Figure 4-1**). If the river is non-perennial then this EWA approach for non-perennial rivers should be used, followed by Steps 6 to 8 in **Figure 4-1**.

- If the river has adequate coverage of gauging weirs, then obtain the relevant flow data from DWAF. Parts of river systems can be non-perennial whilst other parts are perennial, and the data collected should be relevant to the sections of river to be assessed. The data should be assessed by a hydrologist for quality, patched if necessary, and then a Flow Duration Curve is created for each gauging point. These will provide the degree of non-perenniality of the system.

- If the river has inadequate or no gauging data, then two possible approaches are suggested by Hughes (2008). "*Either use some of the existing, standard modelling approaches and attempt to infer some of the finer scale processes from the information generated by the model. Or use more detailed modelling approaches and extrapolate from limited observed data to provide necessary inputs*." WR90 or the updated WR2005 database could provide important information but the data should be checked against any available information for a specific site or part of the relevant catchment. For more detail on method please refer to Hughes (2008).
- Once the degree of non-perenniality is established, **Table 4-1** indicates which type of non-perennial system the river is. It is necessary to know this because different types of rivers may require different multidisciplinary teams for EWAs.

Table 4-1 Categories of flow persistence, adapted from Rossouw *et al*. (2005).

River flow type	**Perennial**	**Non-perennial**		
		Semi-permanent	**Ephemeral**	**Episodic**
Degree of flow persistence	Usually perennial, although may cease flowing for a short while in extreme droughts	No flow 1%-25% of time	No flow 26%-75% of time	No flow at least 76% of time; flows briefly only after rain
Seasonality	Seasonal or non-seasonal			
Examples		Modder (F.State) Mokolo (Limpopo) flows 72-87% of time.	Seekoei River (N.Cape) Touws (E. Cape) flows 28 % of time	Kuiseb (Namibia) Swartdoring and Kys Rivers (N. Cape) flows 12% of time

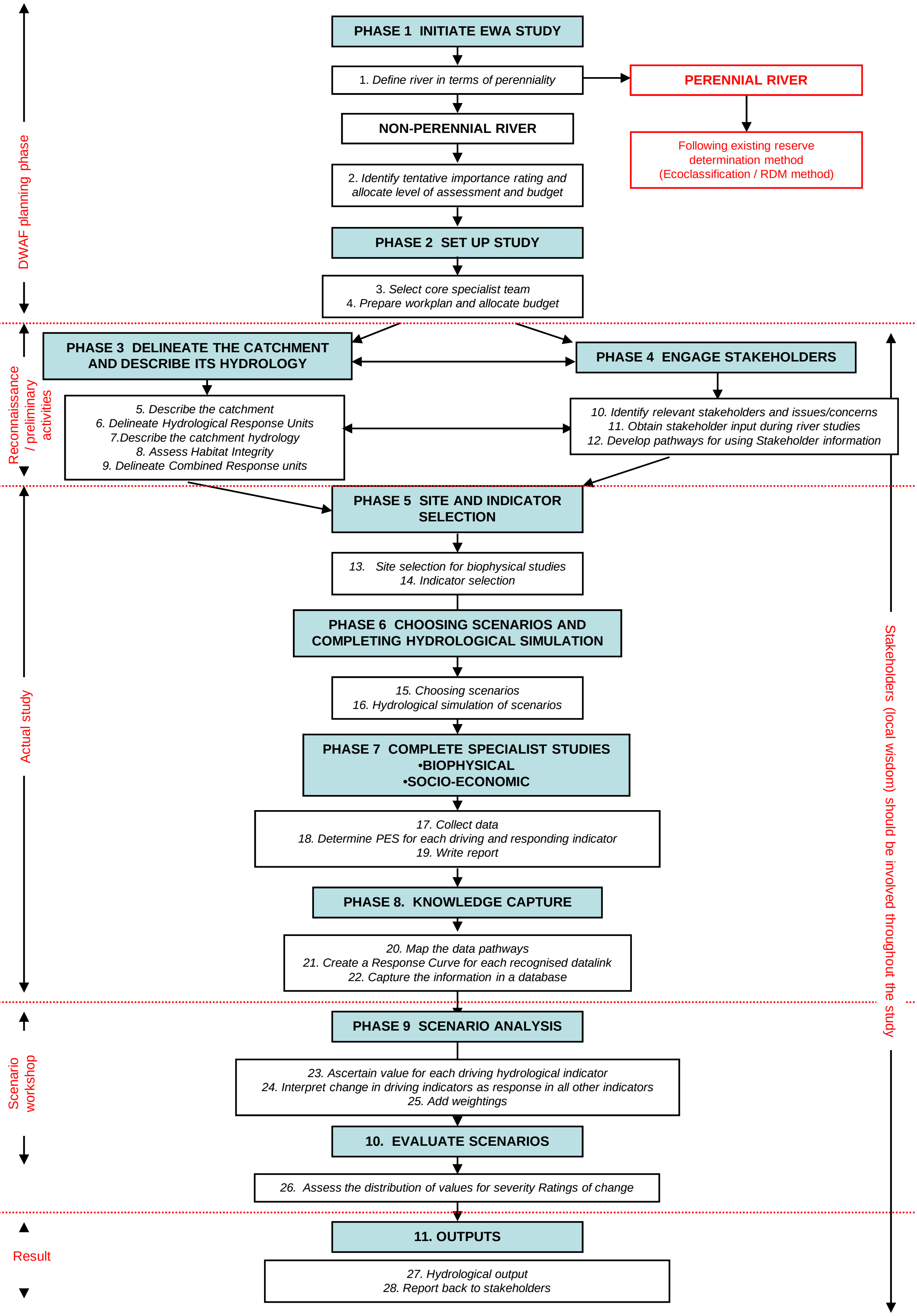

Figure 4-2 **The 11-phase process proposed for EWAs for non-perennial rivers.**

Activity 2: Identify tentative importance rating and allocate level of EWA and budget

- Importance rating: The true ecological importance and sensitivity (EIS) of a river system can only be ascertained after specialist studies, and this is especially true for non-perennial rivers because they act as vital oases in otherwise dry landscapes. However, to trigger the EWA, an early guide to the EIS status of a river can be obtained from Resource Quality Services, DWAF.
- Allocation of level for EWA: To determine the level of EWA, a process is followed which includes consideration of issues such as, *inter alia,* type of proposed development, impact of proposed development and the EIS rating (as determined above under importance rating). A cost/benefit analysis is also completed. The result is a cost/confidence matrix for the range of EWA methods: Comprehensive, Intermediate, Rapid (I, II and III) and Desktop (DWAF, 2002) and a budget, both of which are determined by DWAF and advertised in a tendering process

4.5.2. Phase 2: Set up study

Activity 3: Select core specialist team

Select a core study team that represents key disciplines: For non-perennial systems this will likely consist of a project leader, a hydrologist, a geohydrologist, a geomorphologist/geographer/GIS specialist, a socio-economist and a river ecologist. All should have local knowledge of the river system, because these are usually data-poor systems and heavy reliance will be made on the specialists' intuitive understanding of them.

Activity 4: Prepare workplan and allocate budget

At this point, a budget and workplan should be prepared and approved and, in consultation with DWAF, the range of scenarios to be considered should be agreed. This is essential, as the chosen range will guide the kinds of data to be collected, appropriate specialists needed and the analyses to be done. By example, it would be fruitless attempting to predict how the river could change if its flow was to become more intermittent if the reality is likely to be that it will receive an inter-basin transfer of water and move toward perennial flow.

Human resources required

- Project Leader
- Core EWA team
- DWAF RDM personnel
- DWAF personnel from planning department

4.5.3. Phase 3: Delineate the catchment and describe its hydrology

In non-perennial rivers, where data are limited and extrapolation to unstudied reaches is uncertain, new approaches may be of use to help describe and understand the system. One key characteristic of this prototype EWA methodology is an intensive use of catchment data to help understand the nature of the river. This is linked with hydrological analyses and habitat integrity assessment to produce a division of the catchment into Combined Response Units (CRUs) that are relatively homogeneous in terms of natural features and land use. The Combined Response Units (CRUs) are similar to the Integrated Units of Analysis produced by DWAF's Water Resource Classification System (Dollar et al. 2007), and the Reserve Assessment Units (RAUs) of Kleynhans and Louw (2007b), and time might prove that these should be harmonized into one concept and one term.

The Combined Response Units (CRUs) would then guide the selection of sites for the EWA.

Activity 5: Describe the catchment

The catchment should be described in as much detail as possible with appropriate maps included to assist the specialists in collecting data (relevant to the particular catchment area) on their specialist fields and to identify the main areas of impact in the catchment. This would then also assist the GIS specialist (and/or Catchment geomorphologist) in determining the Combined Response Units and the team in identifying specific scenarios.

Data from various sources indicated in **Table 4-2** could be consulted.

Table 4-2 Data used in catchment description

Data Required	Data source	Procedure	Uses
Quaternary catchments	WRC and DWAF database	Produce map indicating quarter-nary catchments in selected study area	Used by Hydrologist in Hydrological modelling and by specialists to find data on specialist field.
Ecoregions	DWAF database	Produce level 1 and 2 ecoregion map of study area	Assist specialists in collecting data for relevant ecoregions and supplies general information on slope, vegetation type, geology etc.
Land cover	Latest land cover database (CSIR land cover 1996 or 2000)	Quantify land cover classes in terms of area (ha) that it covers	Provides indication of activities around river.
Geology	Council of Geological Sciences (CGS) (various dates depending on maps available)	Produce geology map for study area.	Information on contribution of rock types to water quality in catchment.
Geohydrology	DWAF database	Produce map of geohydrology in study area	Provides information on the groundwater contribution in the catchment
Vegetation	SANBI – Vegetation of South Africa and Lesotho (Mucina & Rutherford 2006)	Produce vegetation map for study area	Information used by Riparian vegetation specialist.
Catchment study reports when available	DWAF library in Pretoria	Collate any information relevant to study area	Provides specialists with recent and historical data.
ISP (Internal Strategic Perspective) reports	DWAF database	Collate any information relevant to study area	Provides background information on study area

Activity 6: Delineate Runoff Potential Units (RPUs)

A Hydrological Response Unit (HRU) is defined in Bevan (2001) as a parcel of the land surface described in terms of similar soil, vegetation and topographic characteristics while Vieux (2004) uses the term Hydrological Unit to describe a geographical area representing part or all of a surface drainage basin with distinct hydrological features. To determine HRUs, Bevan (2001) proposes an overlay of soil, vegetation and topographical data.

A Runoff Potential Unit (RPU) is similar to a HRU but the following layers namely catchment, slope, infiltration rate, vegetation cover, rainfall intensity and flow accumulation, are also included in the determination.

It is the contention of the author (geomorphologist) that information from the whole catchment and not just instream areas should be used in a) the demarcation of the streams to be investigated and b) determining the location of monitoring sites.

Catchment geomorphology is one of the most important drivers of processes such as erosion, hydrology and sedimentation.

The method proposed and described in Appendix 4.2 uses Geographic Information Systems as a tool to analyse and model geomorphic processes and to provide team specialists with detailed background data.

Description of the RPUs could also be used by the hydrologist to assist in the description and modelling of the catchment hydrology.

Activity 7: Describe the catchment hydrology

It is very important to consider the basin as a whole and identify the variations that are likely to occur before setting up a hydrological model. Non-perennial systems will have specific characteristics that depend on the climate, geology, topography, soils and vegetation, combined with highly interdependent impacts. One of the most important components of any hydrological study of semi-arid regions is therefore the development of a conceptual idea of the main processes that occur within the specific catchments (Hughes, 2008).

Information on the RPUs could therefore be used in assisting the hydrologist in accessing the knowledge needed on climate, topography, geology, soils, vegetation and drainage pattern which can in turn provide a great deal of information about possible active processes in the study area.

The process and method used to describe the catchment hydrology is provided in Hughes (2008).

One of the variables which was included in the delineation of RPUs was flow accumulation. Flow accumulation uses the number of elements (pixels) in a raster digital terrain model to calculate the accumulated number of elements upstream from a cell that will provide flow to that cell. This can then be multiplied with the cell size to give an estimate of the potential runoff. With an overlay of layers representing infiltration and evapo-transpiration, an estimate of the actual amount of water in the form of channel flow for a rainfall event can be made.

Activity 8: Assess the Habitat Integrity

Kleynhans et al. (2008) state that the "*Assessment of habitat integrity is based on an interpretation of the deviation from the reference condition. Specification of the reference condition follows an impact-based approach where the intensity and extent of anthropogenic changes are used to interpret the impact on the habitat integrity of the system. To accomplish this, information on abiotic changes that can potentially influence river habitat integrity are obtained from surveys or available data sources. These changes are all related and interpreted in terms of modification of the drivers of the system: hydrology, geomorphology and physico-chemical conditions and how these changes would impact on the natural riverine habitats.*"

Habitat integrity could be assessed using either an aerial survey, ground site survey or a desktop approach using available maps, aerial photos, satellite images and possibly also GOOGLE Earth images depending on the budget allocated.

The method used can be summarised as the

- collection and collation of existing data
- identification of assessment units
- selection of asssessment reaches and sites
- IHI (Integrated Habitat Integrity Assessment) survey (aerial, groundsite or desktop)
- completion of the model to determine Instream and Riparian Habitat Integrity (Kleynhans et al. 2008).

A detailed description of the method developed by Kleynhans et al. (2008) is available from DWAF, Pretoria.

The outcome of an habitat integrity assessment is a georeferenced database as well as maps with information on the location of structures in river (weirs. dams, pumps), roads, bridges, alien vegetation, vegetation removal, dry or irrigated lands, erosion, industries, mines and towns.

The habitat integrity database and maps, in conjunction with landcover and land-use data, can now be used as an overlay with the RPUs which were identified in *Activity 6*.

Activity 9: Delineate Combined Response Units (CRUs)

It is proposed that Combined Response Units (CRUs) can now be delineated by superimposing the RPUs with information from the Hydrological Models and Habitat Integrity Assessment.

CRUs identified would be response units that are relatively homogenous in geomorphological characteristics, hydrology, anthropogenic impacts and habitat types.

The CRUs would assist the team in identifying the areas where the system is under the most stress (where added development or impacts would alter the integrity of the system the most) or an area that is close to natural (or contains critical habitat for biota) and therefore needs to be assessed. Sites would then be selected within each CRU or if this would require too many sites to be assessed only the critical CRUs could be selected where sites should then be identified.

The information from the CRUs would also assist the team in identifying relevant scenarios for the catchment.

Human resources required

- Project leader
- Geomorphologist/geographer/GIS
- Hydrologist
- Geohydrologist
- River ecologist
- Socio-economist
- DWAF RDM personnel
- DWAF regional representative

4.5.4. Phase 4: Engage stakeholders

The scenarios that will be developed should reflect the major issues and concerns of the relevant major groupings of stakeholders. The outcome for each of these issues and concerns should be spelled out in each scenario, enabling stakeholders to assess each scenario and voice their level of acceptability of it to government.

Involving the stakeholders early in the process not only helps identify the major issues, but also provides invaluable input on the past and present nature of the river where data are few. This is particularly important for non-perennial rivers as there may be very little other information on the river or its users.

Stakeholder involvement is a two-way process that proceeds through three main activities:

(i) identification of stakeholders
(ii) making contact with stakeholders
(iii) continual engagement with stakeholders and feedback on final outcomes.

Activity 10: Identify stakeholders and their issues/concerns

Identify the major stakeholder groups through public announcements and meetings as per Appendix 4.1. Identify the major issues and concerns of the various stakeholder groups regarding the river, and its importance in their lives. **Table 4-3** provides a guide to the kinds of information required, which is expanded upon in Appendix 4.1. Some of this information may not be amenable to direct economic valuation, but will be translated into economic terms in later specialist analyses. Analyse and summarise the information in preparation for the identification of indicators for the data-gathering and scenario-creation activities.

Table 4-3 Items to be addressed in the preliminary stakeholder analysis.

Stakeholder Group	**Score***		
Item	**Not important**	**Important**	**Extremely important**
Social importance			
1. Direct dependence on the river for subsistence (e.g. water, reeds, medicinal plants, fishing)			
2. Cultural use of the river			
3. Recreation/tourism linked to the river			
4. Aesthetic values of the river			
5. Rare or endangered species			
6. Value of the river in the landscape			
Economic importance			
1. Poverty alleviation			
2. Human well-being			
3. Health			
4. Food assurance			
5. Economic value (macro-economic; environmental goods and services; landuse)			
6. Demographics directly related to the river.			
Other issues			
1. Any other aspects of the river and its use that are of concern to stakeholders			

*The importance of each item is rated as follows: Not important = not important at any scale; important = important at a local or regional scale; extremely important = important at a national or international scale.

Activity 11: Obtain stakeholder input during river studies, on the nature of the river and its users

The field visits by the EWA team provide a unique opportunity to interact with the landowners and other locals on the nature and history of the river. In addition to the list of items in **Table 4-3**, any other information on the river gained in conversation should be captured. Useful information could include:

- the distribution, nature and persistence of pools
- the history of flooding, including times and flood levels
- anything to do with water chemistry
- the distribution of fish species in wet and dry periods

- specific kinds of use of the river by farmers, subsistence users, livestock and wildlife
- current and recent land-use practices, with their positive and negative influences on the river
- planned or possible future land-use changes
- present and past nature of the riparian vegetation
- any history of riverine pest plant or animal species

Activity 12: Develop pathways for the stakeholder information to be included in later phases of the EWA.

The third stakeholder activity mentioned above is the 'continual engagement with stakeholders and feedback on final outcomes' throughout the EWA process (Appendix 4.1). Of relevance here is the need to ensure that the information from Activities 10 and 11 is used when planning the selection of indicators (Activity14) and sites (Activity 13), scenario-creation (Activity 15) and data-gathering (Activity 17) activities.

Human resources required

- Project leader
- Socio-economist
- Remainder of core team
- DWAF RDM personnel
- DWAF regional representative

4.5.5. Phase 5: Site and indicator selection

Once the assessment has begun, the Response Units identified and the stakeholder consultations begun, the need for representation of additional disciplines within the study team may be identified and appointments made within budget. The full team can then proceed with two key activities that must be completed before any field work begins.

Activity 13: Site selection for biophysical studies

The number of sites along the river for data gathering will be dictated primarily by the time and financial budget. Once decided, sites should be established within each, or the most important, Response Units emerging from Phase 3. To some extent this can be a desktop exercise, to agree on the general location of each site, with the final locations chosen in the field.

The first part of the desktop analysis is the choice of Response Units in which sites will be located. Criteria for selection should be agreed by the team in consultation with DWAF, and could include:

- areas with high numbers of people dependent on the river
- areas of high conservation importance or great scenic beauty
- areas in which major water-resource developments are planned or possible
- areas in which the river is in need of rehabilitation through improvement of the flow regime
- areas where the river has rare species, habitats or features
- river zones that are particularly sensitive to manipulations of the flow regime

With the Response Units chosen, a desktop analysis should proceed to tentatively identify a potential study site within each. This analysis should employ maps, satellite imagery, aerial photographs and any other appropriate information, and consider such criteria as:

- accessibility, both in terms of roads, and landowner's permission
- suitability as a future monitoring site
- proximity to a gauging weir
- the degree to which the site would represent the Response Unit
- availability of scientific or social data
- a point for which hydrological modelling can be done.

The final choice of site locations will be done at the river, and should preferably be done at times of low flow when the general physical nature of the river bed can be seen. Additional criteria to consider at this stage are:

- input from the landowner on the nature of the river
- a physical diversity that characterises the river within the Response Unit
- inclusion of flow-sensitive habitats, such as riffles, if they exist
- banks and the active channel in good ecological condition
- suitability for hydraulic modelling, if such is planned, such as sites where the river flows straight, in a single channel, with a relatively un-complex flow pattern; it may be necessary, however, to model more complex sites, for instance , where flow floods over to floodplains.

During the site-selection visit, some information can usefully be collected for use by the team in planning their studies. This could include:

- photographs, with accompanying notes:
    - upstream and downstream river sections
    - habitat diversity at the site
    - flow types

    - nature of the riparian zone and wider landscape, including developments and disturbances to the river
- water-quality and invertebrate samples
- local input on the distribution and annual movement of fish species
- completion of site characterisation forms, as per Dallas (2005) (Appendix 4.3).

Activity 14: Indicator selection

Indicators are attributes of the system that can be used in the scenarios to describe change. In water-allocation studies they should be variables that can be expected to respond to changes in flow or water levels. They should cover the main physical, chemical, biological and social aspects of the river ecosystem, including issues of interest or concern to stakeholders to the extent possible.

For non-perennial rivers, it is suggested that the list of indicators should be short and, with trial and error, possibly generic for all such rivers. A preliminary list is given that it was felt captured the essence of non-perennial systems:

- Driving indicators
    - hydrological (from modelling exercise)
        - connectivity
        - floods for channel maintenance and sub-surface recharge
        - sediment delivery
- Responding indicators
    - physical and chemical
        - pool size and/or numbers (pool availability)
        - channel aquifer recharge
        - riparian aquifer recharge
        - water quality variable (possibly conductivity)
    - biological
        - riparian vegetation cover
        - aquatic/marginal vegetation cover
        - number of important (unique, threatened, sensitive to flow, habitat or/and water quality) invertebrate taxa
        - abundance of invertebrate pest taxa
        - status of indigenous fish community
        - abundance of exotic fish
        - terrestrial wildlife
        - contribution to parent river
    - social
        - socio-economics

- social well-being

Any of these indicators can be de-activated where not relevant. Others can be added if the stakeholder activities indicate their need and it is agreed that their changes could be predicted. The guiding criterion is that they should be amenable to some level of prediction of how they would change with catchment developments.

Human resources required

- Project leader
- Full EWA team
- DWAF RDM personnel
- DWAF regional representative

4.5.6. Phase 6: Choosing scenarios and hydrological simulation

In the early days of method development for environmental flow assessments, at the request of DWAF, a desired state for the condition was recommended by scientists, and the flows required to achieve and maintain this were described (the Building Block Methodology: King et al., 2000). This kind of prescriptive approach was not amenable to queries: it produced a single answer for a single desired state and could not easily provide answers to 'what if' questions asked by planners and managers, such as "what would happen if we omitted one of the required floods?"

Additionally, the approach was being challenged from several sources because of the implication that scientists were making decisions about future river condition that should more appropriately be done by government and society as a whole. Thirdly, river scientists were re-defining their role as one of providing technical information on a range of management options rather than of making recommendations on one option.

Later method development, both of the BBM and of alternative methods, moved to address these problems and the general trend has been toward approaches that allow the analysis of possible management (usually development) scenarios. Each scenario begins with the simulation of the flow regime that would pertain under that development, followed by the predicted physical, chemical and biological responses of the river ecosystem and finishes with the predicted positive and negative social, resource-economic and macro-economic (if wished) impacts.

Activity 15: Choosing scenarios

Where data are few – the most common situation – it is best to choose fewer rather than more scenarios as there will not be the knowledge to make predictions that distinguish between many similar scenarios. A prioritised list of four to six scenarios is a useful starting point, with those chosen being as dissimilar as possible in terms of the likely future changes within the catchment. The final choice of scenarios should be made in consultation with DWAF and after stakeholder consultation. Input from the hydrologist is important as the scenarios chosen must be amenable to hydrological modelling and potentially be able to demonstrate quite different future flow regimes.

Activity 16: Hydrological simulation

Hughes (2008) provides a detailed description of the approach for simulating the hydrology of non-perennial rivers. In terms of the Indicators listed in Activity 14, the outputs of this simulation should include, per selected hydrological modelling site, information on:

- connectivity
- general indication of the flooding regime likely to influence channel morphology
- sediment delivery.

Human resources required

- Project leader, with comment by all team members
- DWAF RDM personnel
- DWAF regional representative
- Hydrologist

4.5.7. Phase 7: Complete the specialist biophysical and socio-economic studies

Scenarios and indicators chosen in Phase 5 and 6 should guide the specialists in the type of data required to predict changes in the river. Appointed specialists collect data at each chosen EWA site, determine the Present Ecological State (PES) in terms of their particular discipline and write a specialist report.

Activity 17: Collect data

Data from specialist studies are used to understand the functioning of the ecosystem and the relationship between it and its users, in order to develop a predictive capacity of how all could change with flow change. The specialists need to be able to develop an understanding of the relationship 1) between flow/water level changes (drivers) and each indicator, or 2), between indicators, so that flow/water changes can be transformed into changes in the value of indicators.

Specialists collect and analyse data from each EWA site using their own good-practice methods. Seasonal (summer and winter or if possible in all four seasons) data collection is necessary as well as sampling in a wet and dry year if possible. Most methods available are developed for use in perennial rivers and either have to be adapted using expert opinion or results have to be interpreted keeping the differences between perennial and non-perennial rivers in mind. Some appropriate methods of investigation can be gleaned from the Building Block Methodology Manual (King *et al.*, 2000), and such flow studies as King *et al.* (2004) and Birkhead *et al.* (2005) as well as from individual specialist studies in chapter 3 of this report.

The Socio-economist collects data during formal stakeholder meetings as well as during informal meetings with local inhabitants at each of the sites. Data collection is an ongoing exercise throughout the study and is used, *inter alia,* as an input to scenario selection and to aid the determination of ecological importance and sensitivity (EIS) of the system.

Activity 18: Determine Present Ecological State (PES) for each driving and responding indicators

The PES is used in the scenario evaluation to indicate the change at the EWA site from the present to the state expected under that particular scenario.

The PES for each of the driving indicators (Connectivity, Floods and Sediment delivery) and responding indicators (Fish, Macro-invertebrates and Riparian vegetation) have to be determined before the scenario workshop. Most of the non-perennial rivers have little to no historical data and it is virtually impossible to determine a reference (natural) condition with any confidence. Most of the current methods used to determine PES rely strongly if not completely on a comparison of observed data and expected data (reference data). As the reference condition cannot usually be defined for a non-perennial river, there is no high confidence PES method for such rivers and specialists therefore need to use expert opinion supported by collected field data and historical records (if available) to provide a PES category . Explanations and motivation for the PES category decided on has to be included by each specialist. The generic ecological categories for PES are provided in **Table 4-4.**

Table 4-4 Generic ecological categories for PES (modified from Kleynhans 1996 and Kleynhans 1999).

ECOLOGICAL CATEGORY	DESCRIPTION SCORE	(% OF TOTAL)
A	Unmodified, natural	90-100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-89
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39
F	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

The PES of the driving indicators and the responding indicators together with causes, consequences and trajectories of change are then evaluated using the following guidelines and a combined PES category is determined for each EWA site.

- The driving indicators are examined and if one of these is in a lower category than the responding indicators then the causes, sources and trajectories of change are examined. If the responding indicators (Fish, Macro-invertebrates and Riparian vegetation) are likely to follow the critical (lowest PES category) driving indicator then the combined PES category will usually be the same category as the critical driving indicator. If not then the PES may be set in the same category as the critical responding indicator.
- If the responding indicators category is in the same or lower category than the driving indicators then the causes, origins and trajectories are examined and confidence in the assessment of each component is considered. The combined PES category will usually be set in the same category as the critical responding indicator (DWAF, 2002).

This combined PES category is then used in the scenario evaluation to indicate the change at the EWA site from the present to the state expected under that particular scenario.

Activity 19: Write reports

Specialists need to complete reports including the following:

- Executive summary
- Methods used
- Indicators chosen
- Results

    - Data collected should be in presented in such a way that it is ready to be interpreted in response curves and the links between indicators and flow/water depth are clear.
    - PES
- Discussion
- References

Human Resources required:
All specialists

4.5.8. Phase 8: Knowledge capture

Once the specialist reports are completed, the knowledge is captured for use in the construction of scenarios (see Section 4.5.6). In early Environmental Flow Assessments, scenario predictions of change were the results of the specialists attempting to synthesis all the likely influences – in effect, running an ecosystem model in their heads - and producing an overall prediction of change for any one indicator. One of the more recent procedures for knowledge capture involves creating Response Curves of all major identified relationships, between:

- a river's flow regime and its ecological condition (e.g. the relationship between floods and a fish guild)
- ecological condition and social welfare (e.g. the relationship between water quality and human health)
- ecological condition and resource economics (e.g. the relationship between riparian vegetation and household incomes through construction materials);
- and more.

These Response Curves tease out the individual driving and responding parts of the ecosystem for any particular flow change, allowing each specialist to concentrate on their own part of the ecosystem model without being pushed to anticipate how other parts might be behaving.

The Response Curves are constructed by the EWA team. It is worth repeating that team members should be senior experts in their fields and have a deep understanding of local conditions and non-perennial rivers. Explicitly, this is not a task for generalists, as data are to a large extent being replaced by expert opinion.

Activity 20 Map the data pathways

The physical and chemical specialists construct flow diagrams that show the links that exist between the three hydrological drivers (connectivity, floods, sediment delivery) and their indicators (pools, channel and riparian aquifer recharge and water quality) (see Activity 14), explaining the importance and nature of the link. For pools, for instance, all three hydrological drivers could be seen as potentially affecting pool size/number and so they will show as three links feeding into “Pools”. If any of the three physical/chemical indicators strongly influence each other, then this link is also shown. Pool size and number, for instance, might affect aquifer recharge.

Once the hydrological, physical and chemical links have been satisfactorily captured then the biologists repeat the process with their indicators, showing any direct links from any of the earlier ones to any of theirs. Finally, the sociologists repeat the exercise, showing the hydrological, physical, chemical and biological indicators linked to each of their indicators.

The final result is a diagram of how information flows through the team as they make their predictions. In effect, this is the layout of the ‘ecosystem model’. An example of such a flow diagram can be seen in Chapter 5 in final report.

A Response Curve is then constructed for each link, describing the conceptual relationship to the best of the specialist’s ability. One example would be to capture our understanding of how “Pools” change with changes in “Connectivity”. Each Response Curve describes the relationship on the assumption that only those two indicators are changing, with the rest of the ecosystem remaining unchanged.

Activity 21: Create a Response Curve for each recognised data link

The Response Curves (**Figure 4-3**) have a common format, whether they be for physical, ecological or social links. Each starts with illustrating the Present Day condition. This is known for the independent variable (Connectivity in **Figure 4-3**), either from the hydrological modelling exercise or from a previous response curve identified in the data-flow diagram, and is depicted as Zero for the dependent variable (Pool Availability in **Figure 4-3**).

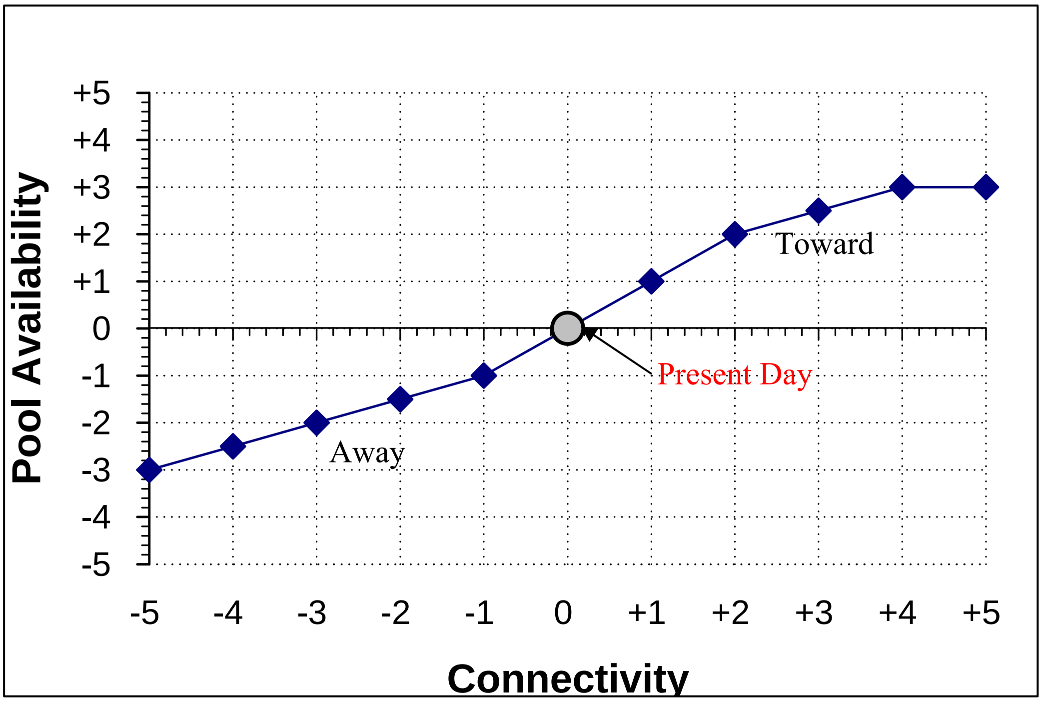

Figure 4-3 Hypothetical response curve showing changes from Present Day in Pool Availability as a result of changes in Connectivity. The direction of change is also identified as a move toward or away from natural**.**

The shape of the Response Curve is then completed, using the Severity Ratings 1 to 5 as guides (**Table 4-5**). Severity Ratings are used as it is usually impossible to quantify the predicted change in true quantitative terms. They:

- give semi-quantification to predictions where true quantification is impossible;
- standardise the unit of prediction for all indicators.

Table 4-5 Severity Ratings of Change (King and Brown, 2006)

Severity Rating	**Severity of change**	**Equivalent loss (% decrease in abundance/ area/concentration/number)**	**Equivalent gain (% increase in abundance/ area/concentration/number)**
0	None	no change	no change
1	Negligible	0-20% loss	1-25% gain
2	Low	21-40% loss	26-67% gain
3	Moderate	41-60% loss	68-250% gain
4	High	61-80% loss	251-500% gain
5	Very high	81-100% loss	501% gain to ∞

Each Response Curve created should be accompanied by:

- an explanation of the shape of the curve
- details of the information source and level of confidence in its shape.

The Response Curves between two indicators may differ from site to site and have different explanations, and so it is important that they are site specific. Fewer rather than more indicators should be chosen, because the more indicators, the more data pathways and Response Curves, and thus the more complex the model being built.

Activity 22: Capture the information in database

The information on the shape of each Response Curve is captured electronically, perhaps using Excel or other suitable software.

Human resources required

- Full EWA Team

4.5.9. Phase 9: Scenario analysis

Activity 23: Ascertain value for each driving hydrological indicator

Scenario analysis begins with the outputs of the hydrological analysis being interpreted for the driving indicators – in this case, Connectivity, Floods and Sediment Delivery (**Table 4-6**). By way of example, an 80% increase in Connectivity, taken from the hydrological model (probably the Flow Duration Curve) would transform into a +3 Severity Rating (**Table 4-5**).

Table 4-6 Hypothetical predictions of change in the three driving variables for three scenarios, using Severity Ratings of change.

Driving indicator	Severity Ratings			
	Present Day	Scenario 1	Scenario 2	Scenario 3
Connectivity	0	+3	+1	-1
Floods	0	+3	+2	-1
Sediment delivery	0	0	+2	-2

Activity 24: Interpret change in driving indicators as response in all other indicators

These values become the driving values in linked Response Curves. For instance, on a Response Curve showing the relationship between Connectivity and Pools, a +3 value for Connectivity could read off as a, say, +2.5 value for Pools – in other words, Pools would increase in abundance/size by 26-67% under this scenario. The values for all indicators are systematically ascertained in this way, using the data-flow pathways identified in Activity 20 (see **Table 4-7**).

Table 4-7 Hypothetical excerpt of a spreadsheet for a scenario, showing the predicted severity ratings for several linked indicators

Scenario 1 at Site 2 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		3		1		3
Flood regime		3		1		3
Sediment delivery		0		1		0
Channel aquifer	Connectivity	0	--	1	1	0
Riparian aquifer	Connectivity	0	--	1	0.500	0.000
	Flood regime	0	--	1	0.500	
Pools	Connectivity	2.5	T	1	0.250	1.250
	Flood regime	2.5	T	1	0.250	
	Sediment delivery	0	--	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Connectivity	-1.5	T	1	0.333	-1.500
	Flood regime	-3	T	1	0.333	
					0.000	
	Channel aquifer	0	--	1	0.333	
Riparian vegetation cover					0.000	-1.500
	Flood regime	-3	T	2	0.500	
					0.000	
	Channel aquifer	0	--	1	0.250	
	Riparian aquifer	0	--	1	0.250	
					0.000	

Activity 25: Add weightings

Where more than one indicator feeds into another, their combined influence has to be judged on the receiving indicator through use of a weighting system. The relative influences of the three hydrological indicators feeding into "Riparian vegetation cover", for instance, have to be weighted to produce one statement (weighted sum) on the resulting outcome for riparian vegetation cover, so that this single statement can be used by any subsequent indicator, such as "status of indigenous fish community".

The specialists initially use expert knowledge to decide on a weight for each driver of a receiving indicator (column 5 in **Table 4-7**). They then calculate the weighted allocation per driver as a proportion of 1. Each weighted allocation is multiplied by its value from the relevant Response Curve. Finally, the resulting values are combined, usually as an average, to provide a final value for how the receiving indicator is predicted to change under that scenario. This value can then in turn become a driving value for a receiving indicator further along the sequence.

The final set of predictions for any scenario can be summarised in tabular, graphic or text form.

4.5.10. Phase 10: Evaluate the scenario in terms of ecological condition

The values emanating from a table of responses (e.g. **Table 4-7**) can be used to provide a preliminary estimate of the overall shift in ecological condition of the ecosystem. The methods are still in the developmental stage and should be assessed and amended as appropriate. The method used here is from DRIFT (Brown and Joubert 2003), with condition being expressed as a change from Present Day (i.e. the PES).

Activity 26: Assess the distribution of values for Severity Ratings of Change

- If at least 85% of the indicators have a predicted Rating of Change (Response curve value) of 1 or 0 and none has a value of more than 2, then the system under that scenario remains in the present ecological condition.
- If at least 85% of the indicators have a predicted Rating of Change (Response curve value) of 2 or less, and none is more than 3, then the system changes one category from the present ecological condition.
- If at least 85% of the indicators have a predicted Rating of Change (Response curve value) of 3 or less, and none is more than 4, then the system changes two categories from the present ecological condition.
- If at least 85% of indicators have a predicted Rating of Change (Response curve values) of 4 or less, then the system changes three categories from the present condition.

The additional information housed within each Response Curve shows if the shifts in ecological condition (i.e. the Ratings) are toward or away from natural. Similar 'Toward' and 'Away' values cancel each other out. The majority of the remaining values are then accepted as the direction of change toward or away from natural.

Example:

If **Table 4-7** is used as an example and the PES at the site is a B then the system would change by two categories under Scenario 1 because 85 % of the indicators are 3 or less and none is more than 4. The system would therefore be in an A category under Scenario 1 where impoundments are removed from the system. The change is toward natural as most indicators are changing toward natural and the category would be an A as there is only one category higher than a B category. If the system was changing away from natural it would be changing to a D category under this particular set of values.

4.5.11. Phase 11: Outputs

The two main recipients of the scenario outputs are DWAF, which will eventually make any decision regarding management of the river system, and the stakeholders, who should make input into this decision in terms of the level of acceptability of each scenario.

Activity 27: Hydrological output

Hughes and Louw (2002) recommended that the same format output be generated from all the possible methods of the Reserve Determination process. The most useful output for DWAF is a table of flows (expressed as volumes or mean monthly flows) for each month of the year and for several levels of assurance.

The table of flows would probably consist mostly of no-flow periods. These no-flow periods are essential in the functioning of non-perennial rivers but the period of flow is also very important as this is where the connectivity of the river is assured.

Resources required: DWAF RDM personnel, hydrologist and geohydrologist

Activity 28: Report back to stakeholders

The assessed scenarios should now be presented to the stakeholders by a core EWA team or person. The stakeholders have the opportunity to indicate the degree of acceptability of each scenario and to express their fears. Once the scenario output is finalized it is published in the Gazette and an appeal process is followed.

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Appendix 4.1 Identify stakeholders and their concerns

Stakeholder education and buy-in as to why the non-perennial river is important and its needs to be protected is important as a prerequisite to obtaining socio-economic data. The empowerment of the stakeholder and transparency offered by the interviewer is very important so that the correct data/extent of problems etc. can be obtained. And that buy-in and trust can be fostered.

Stakeholders should be involved form the start of the EWA process and a possible stakeholder engagement process is provided in Table 1

Table 1: A possible stakeholder engagement process.

Engagements	Strategy	Detail
First announcement	*Involve Communication Expert* Press statements: local newspapers / radio Announcements and notices Letters to key stakeholders Follow-up confirmations	Project statement Request for participation: to identify concerns and issues related to the river Invitation to meeting Participatory process defined
First meeting	Coordinated by expert facilitator	Agenda: Orientation: Inventory of existing knowledge (local wisdom and understanding as well as existing research), data sources and gaps Identify issues and concerns Next phase Provide contact details and process for engagement
Follow-up/ continuous engagement	Website / newsletter / follow-up meeting(s)	Provide contact details of liaison person
Report on scenarios and feedback from stakeholders	Presentation by core EWA person	Recognition of stakeholders importance Feedback on degree of acceptability of each scenario
publication in Gazette		
Final stakeholder engagement	Presentation by DWAF spokesperson	Addressing fears
Appeal process	Key stakeholder representatives	

Data needed in preliminary stakeholder analysis

The socio-economic data required is important to ascertain the following social and economic values.

Supporting information for Table 4.2 follows.

Social values

- Nature, extent and vulnerability of the river ecosystem subsistence users
- Non-economic value, i.e. social value of the river ecosystem as:
  - Drinking water
  - Fishing / food source
  - Recreation / tourism (aesthetic appeal)
  - Use for ceremonies / cultural used
  - Source of raw material for livelihood items and cultural crafts (eg. wood/clay bowls/jars)

Economic values

- Direct economic value of the river, e.g.:
  - As a source of house hold drinking water? (purification process)
  - Household use irrigation – garden / lawns / vegetable garden
  - Stock watering (number of stock watered, alternative water sources, suitability for stock watering, etc)
  - Value as stock grazing – reeds, river banks, river trees and shrubs
  - Water abstraction for irrigation (winter grazing fodder bank, commercial vegetables, crops, etc.)
  - Tourism / recreation activities for which money is raised
  - Other economic goods and services obtained from the river
- Economic implications of changes to natural and man-made goods and services provided by the river (i.e. to ascertain the expected extent of changes from the norm)
- Economic implications of river changes in terms of economic costs of increased bank erosion, increased flooding, unprecedented channel changes, etc.

Examples of the type of leading questions that could be asked to ascertain the above are as follows:

- How important is the river to you?
- Is it economic importance of just aesthetical importance?
- What economic activities rely on the river (tourism / cattle watering / household and staff drinking water, etc.)

Appendix 4.2 Delineation of Runoff Potential Units (RPUs)

The fundamental boundary for a RPU in this study will be the boundaries of drainage basins as delineated by hydrological modelling tools and described in the method section below. It is proposed that a primary RPU consists of basins at least one order lower than the highest order catchment in the study area. The Seekoei as modelled as an example in this study is a seventh order stream.

Method

Data Needs and Sources

A list of data required to delineate RPUs are provided in Table 1

Table 1 Data needed to delineate RPUs

Purpose	**Type / Format**	**Source 1**	**Alternative source**
Quaternary catchments	Polygon	WRC (WR90)	ENPAT
Digital terrain model	Grid / point	Shuttle Radar Topography mission (SRTM) (GLCF, UMD)*	1:50 000 topo. maps
Geology	Polygon	CGS	ENPAT
Landtypes	Polygon	ISWC	ENPAT
Land use	Polygon	ENPAT	
Landcover	Polygon	CSIR	ENPAT
Streams	Polyline	1:50 000 topo. maps	ENPAT
Dams / Weirs / Wetlands	Polygon	1:50 000 topo. maps	ENPAT / WRC (WR90)
Vegetation	Polygon	SANBI (Mucina & Rutherford)	ENPAT
Precipitation	Point	SA Weather services	WRC (WR90)
Base maps	TIFF	CD; S&M	
Arial photos	JPG/ TIFF	CD; S&M	
Landsat Images	TIFF	GLCF, UMD*	

* See list of references for the URL

Note: ArcGIS Desktop 9.2 (ArcView) was used in the test study. Users of other software packages should adapt the method according to the capabilities and the interface of their programs.

1. Exploratory spatial data analyses (ESDA)

The quaternary catchments are used to delineate an initial catchment boundary. It should be noted that the demarcation of the WR90 catchments does not follow natural watersheds and that a final watershed would need to be delineated later in the study. The quaternary catchments are dissolved and buffered to 5km in order to provide a single boundary for the study area. It is recommended that the coordinate system for the data at this stage is set to WGS84 (the Hartebeesthoek '94 datum is not accepted for raster data in ArcGIS Desktop). The extent of the layer gives a reference in order to find the relevant base maps (topographical, etc.)

This data are overlaid on 1:250 000 topo-cadastral (TIFF) and 1:50 000 topographical maps (TIFF and shp) to explore the catchment's general characteristics such as settlements, farms and other major natural features such as rivers, dams, roads, railways, etc. Satellite images (IMG) could also be used. The base maps can be printed and provided to team members to assist in site selection and data gathering. The base maps can also be used to delineate the main stream of the river and for the extraction of coordinates to be used for navigation during the helicopter surveys.

2. Digital Terrain Model (DTM) construction

The DTM forms the foundation for the geomorphic analyses of a catchment and should be as accurate as possible. NASA's Shuttle Radar Topography Mission data (GLCF) provides a 3 arc-second (~90m in the current study area) grid in 1 x 1 degree tiles, which can be used as a base data set for the construction of the DTM. Additional data from the 1:50 000 topographical vector data (contours, spot heights and trig. beacons) could be used to augment the SRTM data. If the researcher wants to add the additional data, recommended in mountainous areas, the grid and contours must be converted to points and merged with digitized spot heights and trig beacons. The data were clipped on the buffered study area boundary prepared earlier.

It is recommended that the data set be reprojected into a Cartesian coordinate system at this stage as decimal degrees (the default units in ArcGIS) are difficult to use for area and distance calculations. In the test study the SALo 25 system were used. (Projection:

Transverse Mercator ≈ Gauss Conformal, Central meridian 25° East, Datum and spheroid: WGS84 and Units: meter).

Natural neighbours can be used as an interpolation method. This step also allows the researcher to use a different grid resolution than the original data. In the test study, a grid size of 50m was used but this can safely be reduced to 20m (Barker (in prep)). It should be noted that a smaller grid size increases the processing time for interpolation.

3. Stream and flow modelling

The functions used in this step are available in the Spatial Analysis (Hydrology and Surface tools) and ArcHydro Tools (Maidment, 2002) extensions for ArcView. The input for all the steps must be a raster data set.

3.1 Fill sinks

The constructed DTM were filled to eliminate sinks (unnatural artefacts from the interpolation process). **Note:** If pans or other natural depressions are present in a catchment, the fill sinks tool should be used with care as these depressions will also be filled.

3.2 Slope

Slope was derived using degrees and percent rise with the Slope function (Spatial Analyst Tools, Surface).

3.3 Terrain preprocessing

The different functions needed for hydrological analyses and modelling are available in the Spatial Analyst tools; Hydrology.

3.3.1 Flow direction (FlowDir)

The function creates the flow direction from each cell to its steepest downslope neighbour. (The process should yield results of only 1 (E), 2 (SE), 4 (S), 8 (SW), 16 (W), 32 (NW), 64 (N), 128 (NE). Any other value will make the next step impossible). The input is the filled DTM.

3.3.2 Flow accumulation

The tool creates a raster data set of accumulated flow to each cell. The input is the FlowDir layer.

3.3.3 Delineation of streams

To create a raster of streams a map algebra function should be used on the flow accumulation grid to apply a value of 1 (true) to indicate cells which will have an inflow from cells above a specified threshold value. In ArcHydro tools this threshold is defaulted to 1% of the total value of the flow accumulation grid but can be user defined.

The CON or SETNULL function can be used e.g.

CON (FlowAcc >100, 1) or SETNULL (FlowAcc < 100, 1)

For the test study a value of 250 cells or 62.5 ha was used to indicate the area of overland flow before channel flow would start (cf Barker, 2002). The order of the stream networks can be assigned to the grid after this step. Options include Strahler's or Shreve's methods (Stream Order tool).

3.3.4 Stream Link

This step ensures that a unique value is assigned to section of the linear raster grid representing streams (3.3.3). It uses the stream grid and the flow direction raster as input.

3.3.5 Delineation of catchments (Basins)

The Watershed tool in ArcView uses the streamlink grid and the flow direction grid as input to determine the contributing area above a set of cells (streams) in a raster. The size of the catchments is determined by the threshold value used in 3.3.3. The basins can be converted to features using Spatial analyst. This layer will also provide the final watershed for the catchment (boundary for the study area).

4. RPU delineation

Step 3.3.5 delineated all basins in the study area.

RPU's are then extracted by using the Strahler order of catchments. An example is RPU 5, representing all the fifth order basins in the catchment (Figure 8). The few gaps can be filled in with fourth order basins flowing directly into the seventh order stream.

Graff (2002:79) 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 (combined Cs,Cv and Cp, see Table 2))

I = Rainfall intensity ($mm\ h^{-1}$)

A = Drainage area (km^2)

Variables used (see Table 2)

1 NDVI (inverted and used as substitute for vegetation cover)

2 Slope (as percentage rise)

3 Erodibility (Average K-value per land type, inverted and used as substitute for infiltration)

4 Drainage area and Flow accumulation

Variables 1, 2 and 3 were reclassified into four classes each (Figure 1, 2 & 3) namely:

Low runoff potential

Low – medium runoff potential

High – medium runoff potential and

High runoff potential

Table 2 Comparison to variables from the rational method to substitutes used in the Seekoei Catchment

Variable	**Value**	**Run-off potential**	**Substitute used**
Cs Slope			**None**
<3%	0.01	Low	
3 – 10%	0.06		
10 -30%	0.12		
>30%	0.22	High	
Cp Infiltration rate			**K-Value**
A	0.03	Low	High
B	0.06		
C	0.12		
D	0.21	High	Low
Cv Vegetation / Landuse			**NDVI**
Thick Bush	0.03	Low	High
Cultivated land	0.07		
Grassveld	0.17		
Thick karoo	0.20		
Poor karoo	0.23		
Bare ground	0.26	High	Low
Drainage area			**Flow accumulation**

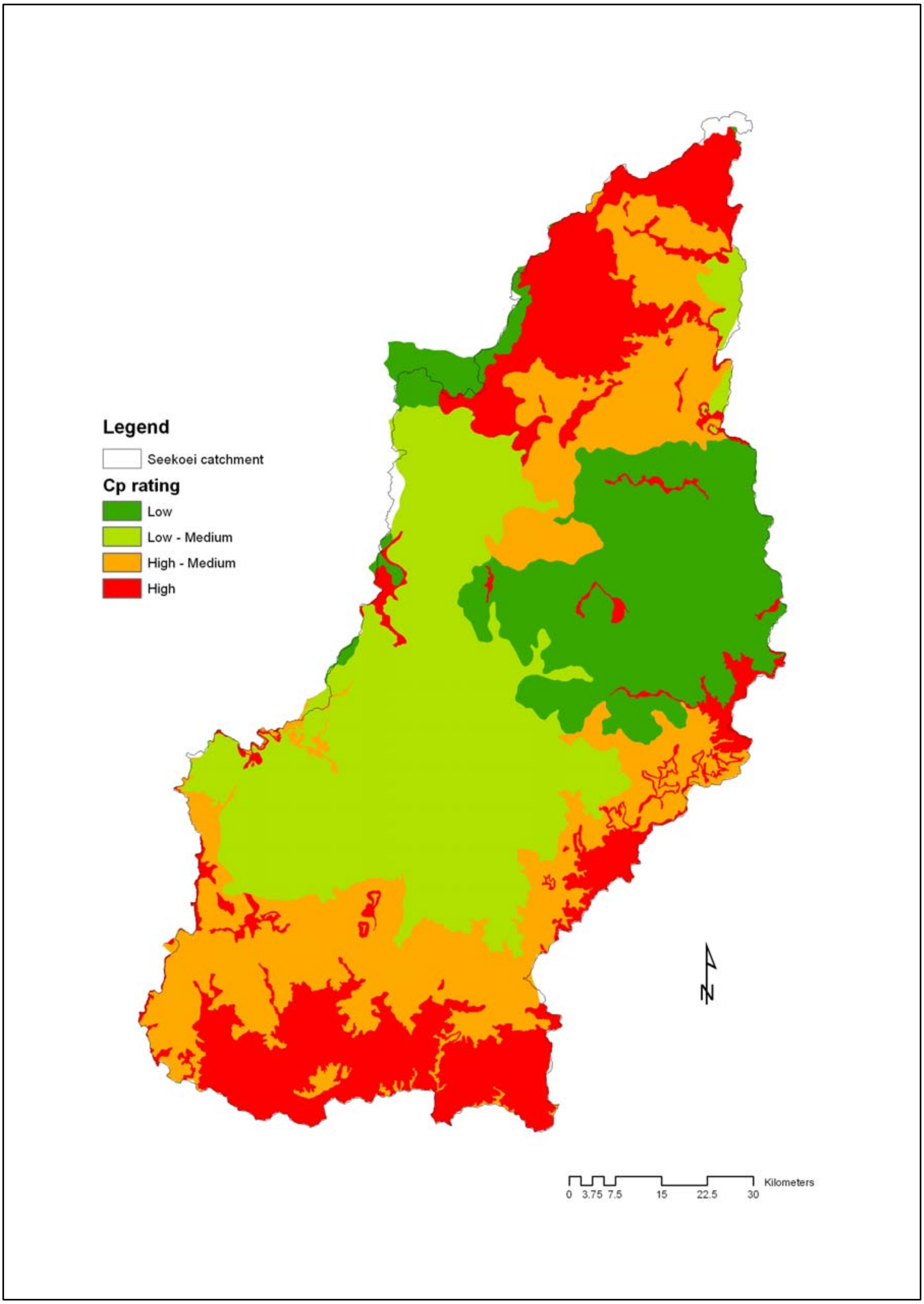


Figure 1 Runoff Potential Rating for landtypes

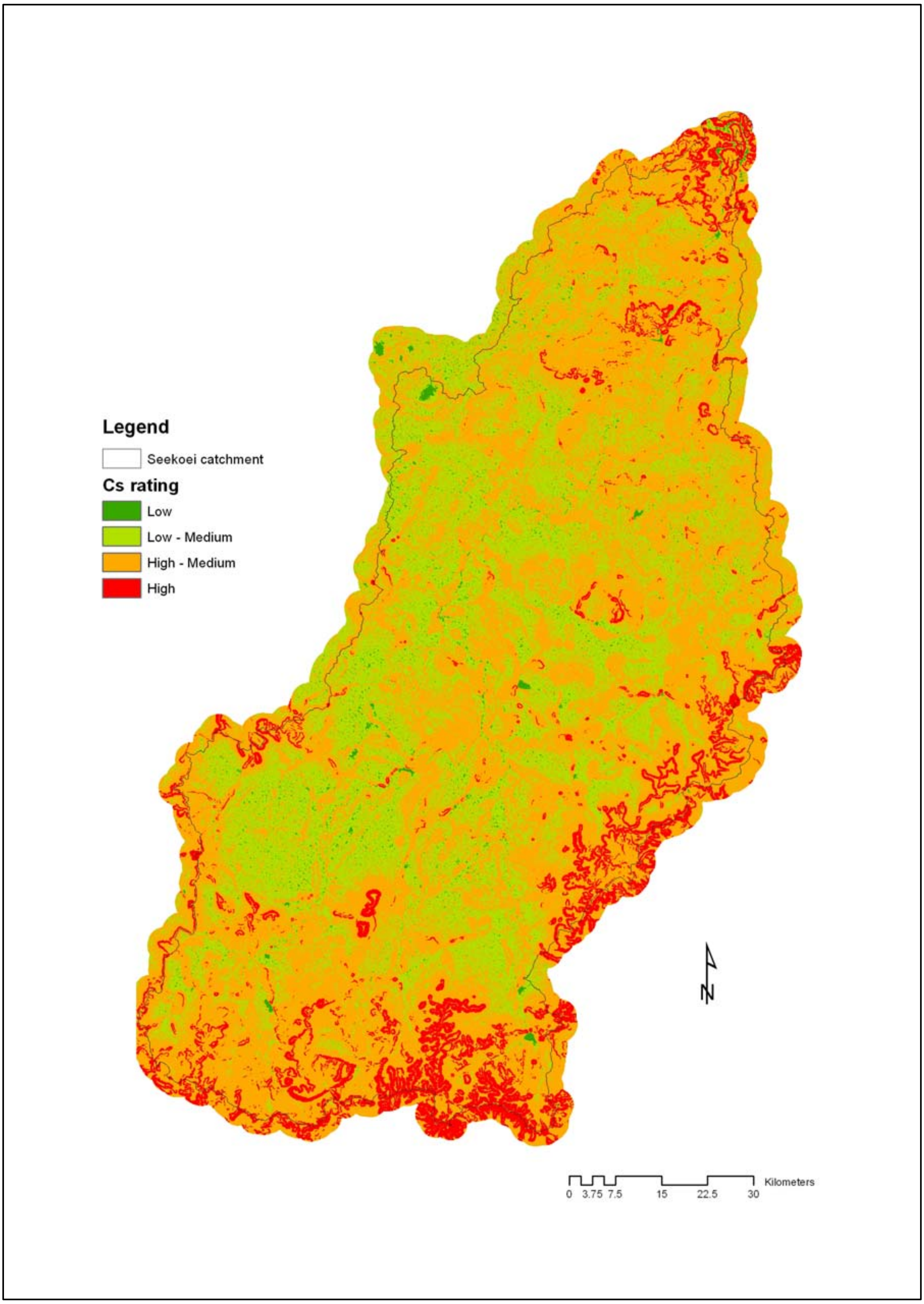


Figure 2 Runoff Potential Rating for Slope

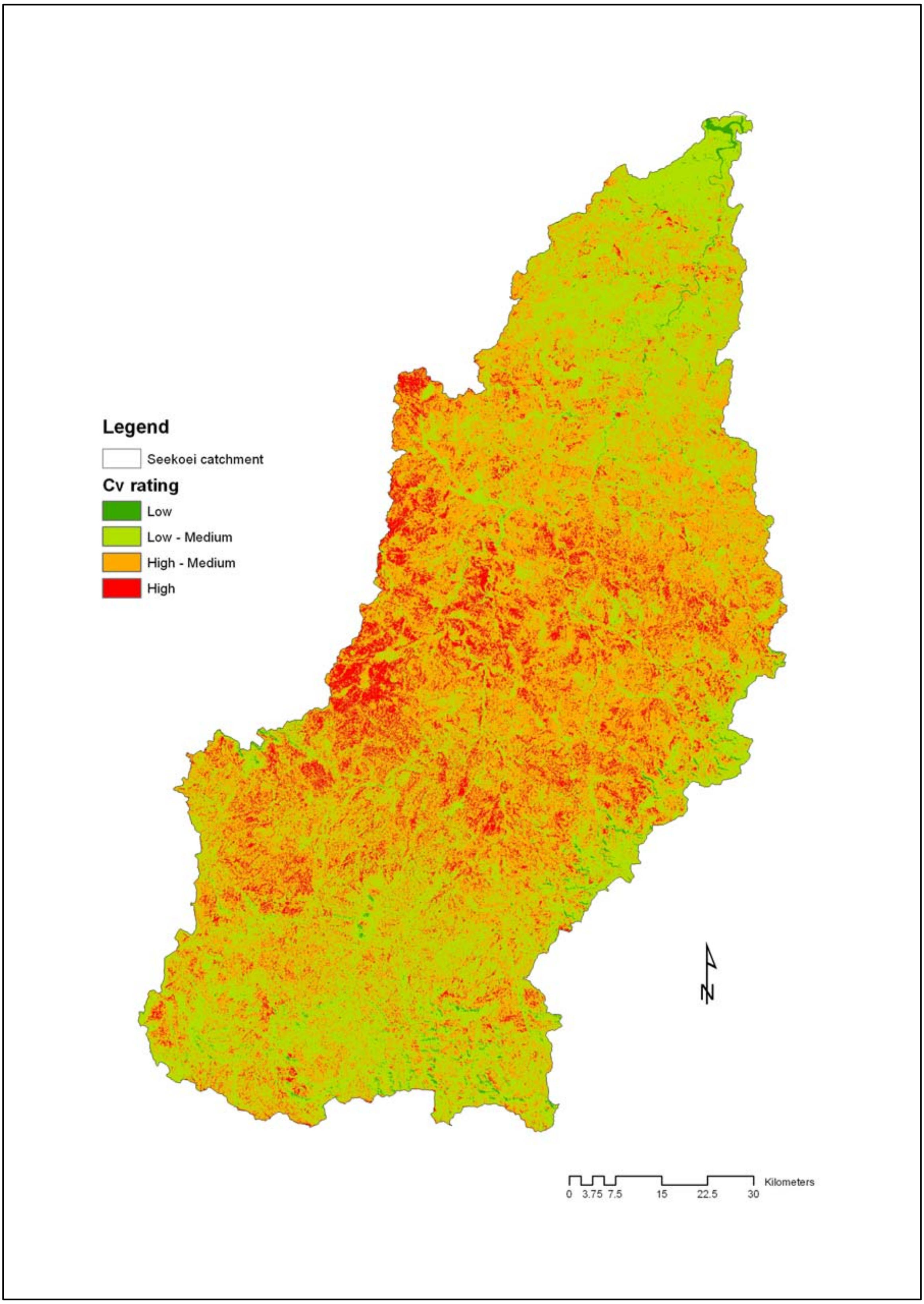


Figure 3 Runoff Potential Rating for Vegetation

A Boolean ”OR” combination of the three physical properties, Vegetation, Land type and slope yielded maps displayed in Figures 4, 5, 6 and 7 indicating the high, high to medium, medium to low and low RPUs identified in the catchment.

The results of the combination were extracted per fifth order basin and joined to the spatial data (Figure 8) to enable the researcher to identify the basins with the highest to lowest runoff potential (Figure 9).

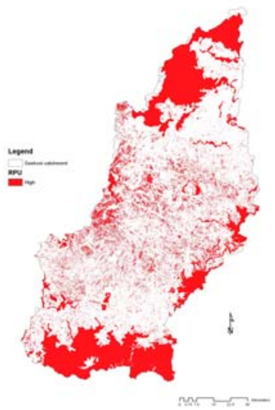


Figure 4 High RPUs

Figure 5 High to Medium RPUs

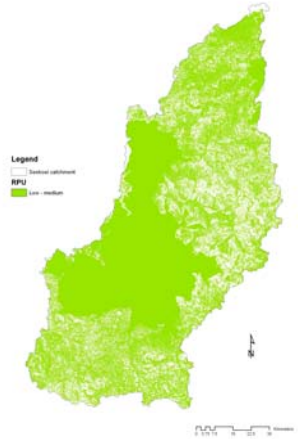


Figure 6 Medium to Low RPUs

Figure 7 Low RPUs

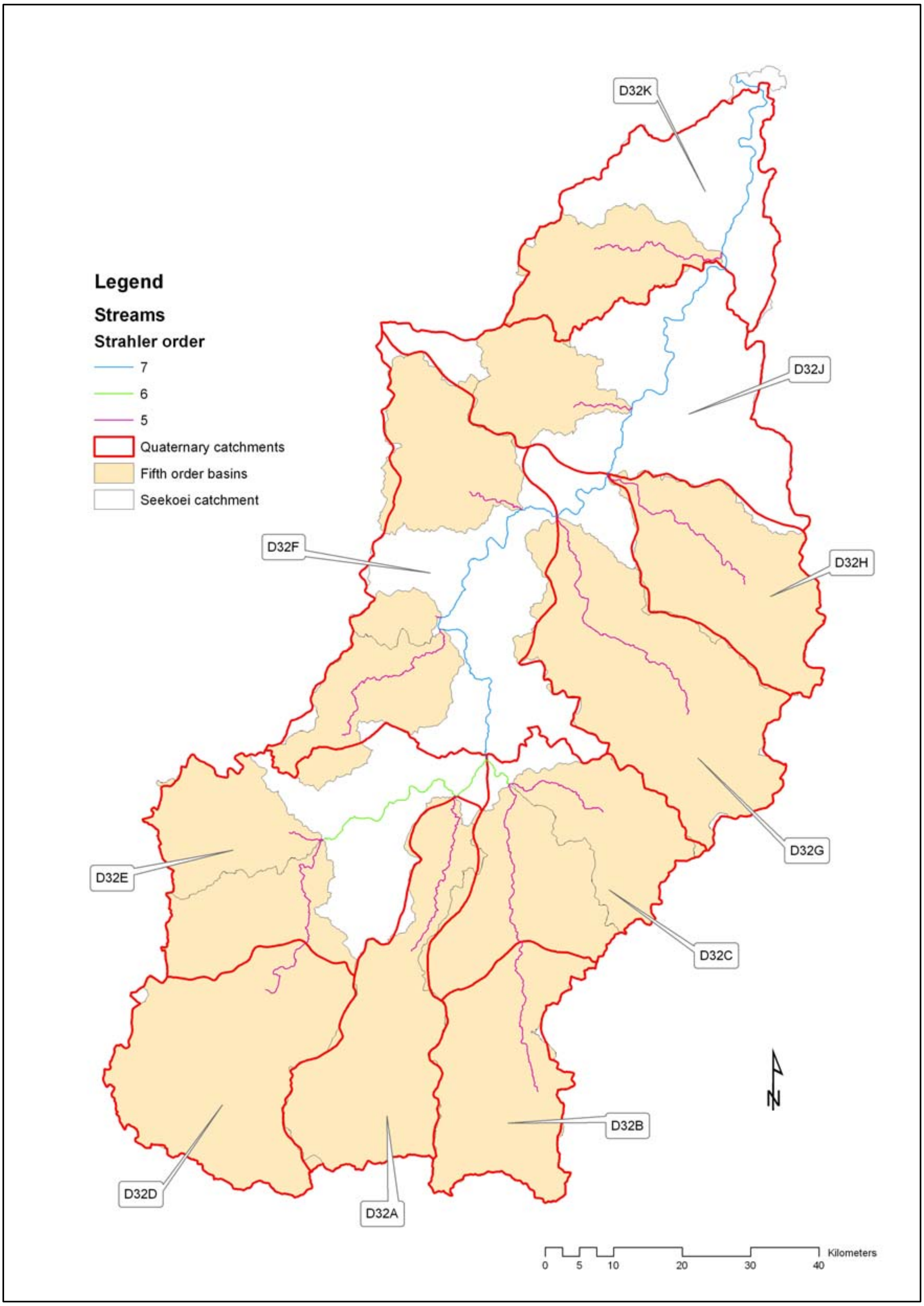


Figure 8 Fifth order basins in the Seekoei Catchment

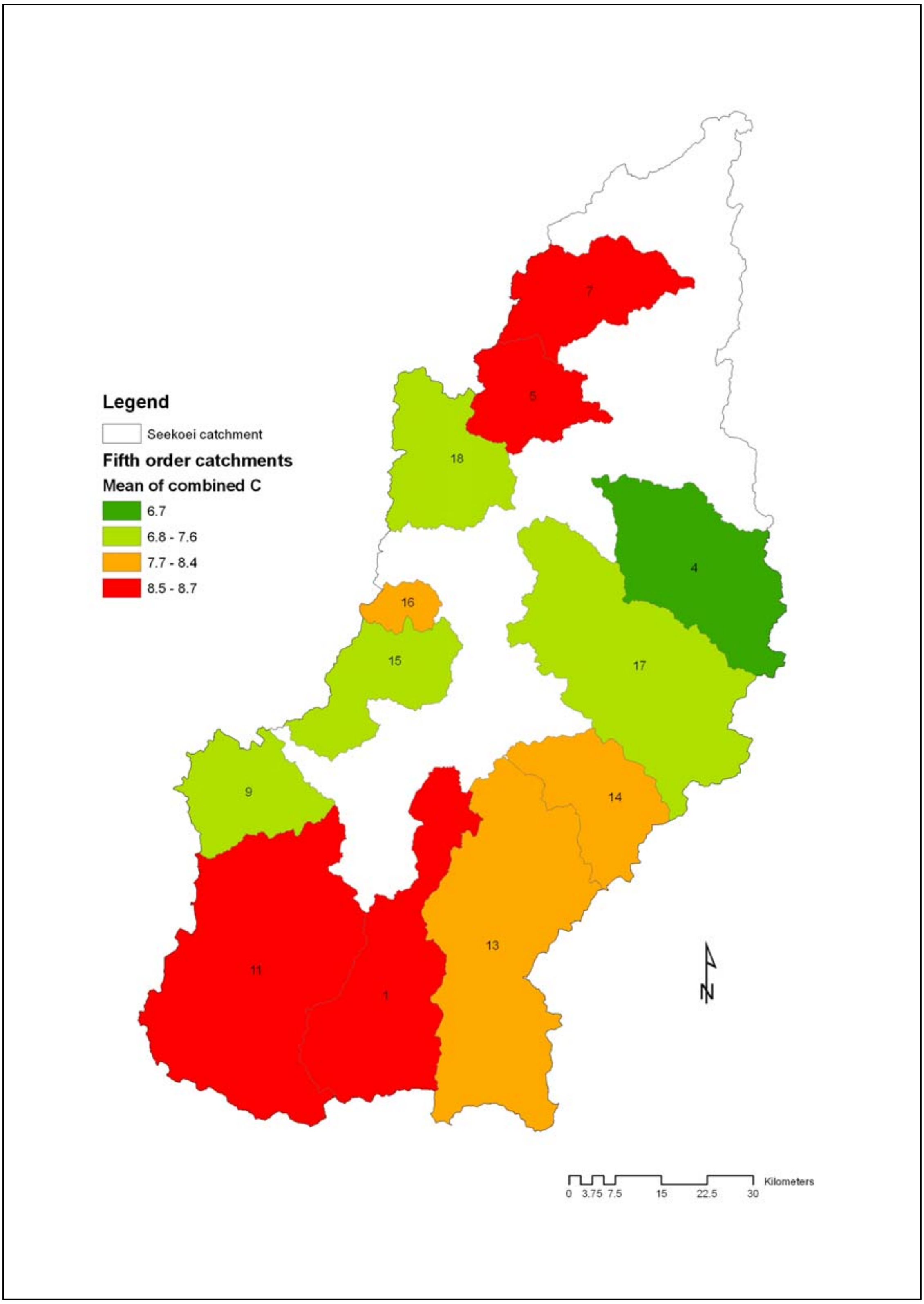


Figure 9 Extracted combined (Cs, Cv and Cp) rating for C per fifth order catchment

Appendix 4.3: Site characterisation forms (taken from Dallas, 2005).

RIVER HEALTH PROGRAMME: FIELD-DATA SHEETS

Assessor Name(s)			
Organisation		Date	/ /

NB: An explanation of the terminology used in the field-data sheets is given in the associated River Health Programme - Site Characterisation field-manual.

SECTION A: SITE INFORMATION (to be filled in before or during initial visit to site)

1. GENERAL SITE INFORMATION

Site information - assessed at the site

RHP Site Code		Project Site Number	
River		Tributary of	

Latitude and longitude co-ordinates:

Degrees-minutes-seconds	or Decimal degrees	or Degrees & decimal minutes	
S ° ' . "	S . °	S ° . '	Cape datum Clarke 1880
E 0 ° ' . "	E 0 . °	E 0 ° . '	WGS-84 datum HBH94

Site Description					
Map Reference (1: 50 000)		Site Length (m)		Altitude (m)	

Longitudinal Zone	Source zone	Mountain headwater stream	Mountain stream	Transitional	Upper foothill	Lower foothill	Lowland river
	Rejuvenated cascades (gorge)	Rejuvenated foothill	Upland floodplain	Other:			

Hydrological Type: "natural"	Perennial	Seasonal	Ephemeral	
Hydrological Type: "present-day"	Perennial	Seasonal	Ephemeral	
Associated Systems:	Wetland	Estuary	Other:	Distance:
Additional Comments:				

Desktop / spatial information – data used for classifying a site and subsequent querying of data

Political Region		Water Management Area	
Ecoregion I		Ecoregion II	
Secondary Catchment		Quaternary Catchment	
Water Chemistry Management Region			
Vegetation Type		Geological Type	
Contour Range (m): From:		to:	
Source Distance (km)		Stream Order	

Rainfall Region	Summer	Winter	Aseasonal	Other:			
DWAF Gauging Station	Yes	No	Code:	Distance Upstream		Or Downstream	

2. LOCATION DETAILS

Sketch a map of the site showing the following details: scale, north, access to site, roads, bridges/crossings, gauges/ instream barriers, buildings, flow direction. Record the following:

Location and Landowner Detail:				Contact No.:		
				Notify Owner?	yes	no
Permit Required?	yes	no	Details:			
Key Needed?	yes	no	Details:			
Farm Name:				Farm Reg. Code:		
Comments:						

SECTION B. CATCHMENT CONDITION AND LAND-USE (to be checked on each visit to site)

Assessor Name(s)			
Organisation			
Date	/ /	Time	

1. PHOTOGRAPHIC RECORD

		Photograph Number	Comments
Photographs	Upstream		
	Downstream		
	Bank to bank		
	Specific features		

2. CONDITION OF LOCAL CATCHMENT - Rate extent (land-use) or impact on a scale of 0 to 4: 0–none; 1–limited; 2–moderate; 3–extensive; 4-entire. Indicate level of confidence: High (H), medium (M) or low (L).

Land-use	**Within riparian zone**	**Beyond riparian zone**	**Potential impact on River Health**	**Level of confidence (H,M,L)**	**Comments (e.g. distance upstream/downstream, time since disturbance, etc.)**
Afforestation - general					
Afforestation - felled area					
Agriculture - crops					
Agriculture - livestock					
Agriculture - irrigation					
Alien vegetation infestation					
Aquaculture					
Construction					
Roads					
Impoundment (weir/dam)					
Industrial Development					
Urban Development					
Rural Development					
Informal settlement					
Recreational					
Sewage Treatment Works					
Nature Conservation				N/A	
Wilderness Area				N/A	
Litter/debris					
Disturbance by wildlife					
Other:					

3. CHANNEL CONDITION (In-channel and bank modifications) - Rate impacts on a scale of 0 to 4: 0–none; 1–limited; 2–moderate; 3–extensive; 4-entire

In-channel and bank modifications	Upstream		Downstream		Comments
	Impact score	Distance	Impact score	Distance	
Bridge – elevated; in channel supports					
Bridge – elevated; side channel supports					
Causeways / low-flow bridges					
Bulldozing					
Canalisation – concrete / gabion					
Canalisation – earth / natural					
Gabions / reinforced bank					
Fences – in channel					
Gravel, cobble and/or sand extraction					
Roads in riparian zone - tar					
Roads in riparian zone - gravel					
Dams (large)					
Dams (small) / weir					
Other:					

4. INDEX OF HABITAT INTEGRITY - Rate impacts on a scale of 0 to 25: 0 - none, 1 to 5 - limited, 6 to 10 - moderate, 11 to 15 - extensive, 16 to 20 - extreme, 21 to 25 - critical (see manual for explanation). Indicate level of confidence: High (H), medium (M) or low (L).

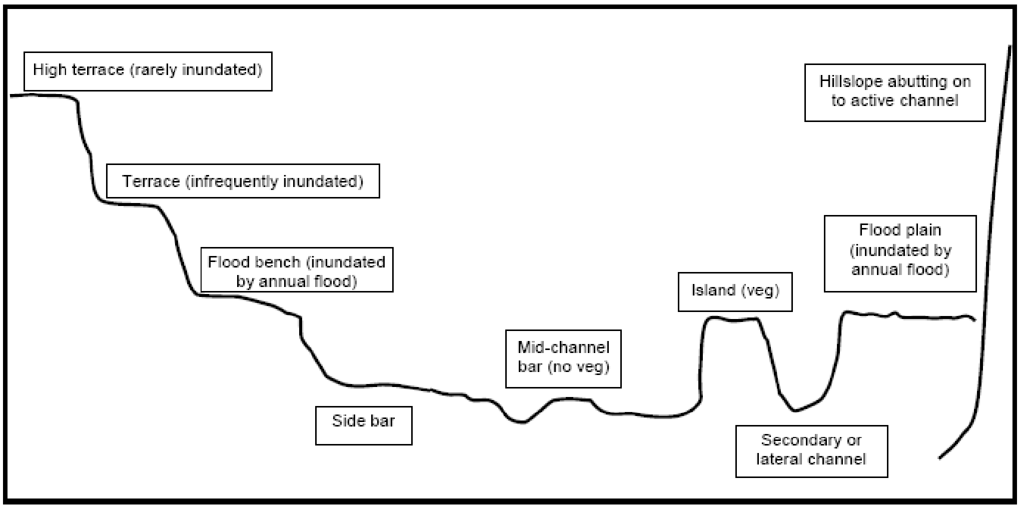
CRITERION	Score	Level of confidence (H,M,L)	Comment
INSTREAM			
Water abstraction (presence of pumps, irrigation etc.)			
Extent of inundation			
Water quality (clarity, odour, presence of macrophytes etc.)			
Flow modifications			
Bed modification (bulldozing of bed)			
Channel modification			
Presence of exotic macrophytes			
Presence of exotic fauna (e.g. fish)			
Presence of solid waste			
RIPARIAN ZONE			
Water abstraction (presence of pumps, irrigation etc.)			
Extent of inundation			
Water quality (clarity, odour, presence of macrophytes etc.)			
Flow modifications			
Channel modification			
Decrease of indigenous vegetation from the riparian zone			
Exotic vegetation encroachment			
Bank erosion			

5. CHANNEL MORPHOLOGY

Channel type: tick channel type indicating dominant type(s)				
Bedrock				
Mixed bedrock and alluvial - dominant type(s)	sand	gravel	cobble	boulder
Alluvial with dominant type(s)	sand	gravel	cobble	boulder

Indicate the cross-sectional features present on the left and/or right banks (see diagram below) – **Note** Left Bank is when looking downstream.

Cross Sectional Feature	Left Bank	Right Bank
High terrace (rarely inundated)		
Terrace (infrequently inundated)		
Flood bench (inundated by annual flood)		
Side bar		
Mid-channel bar (no vegetation)		
Island (vegetation)		
Secondary or lateral channel		
Flood plain (inundated by annual flood)		
Hillslope abutting onto active channel		



SECTION C: FIELD-BASED DATA FOR EACH SITE VISIT

1. GENERAL SITE VISIT INFORMATION

Assessor Name(s)			
Organisation			
Date	/ /	Time	

Water level at time of sampling -tick appropriate category

Dry	Isolated pools	Low flow	Moderate flow	High flow	Flood

Velocity and discharge estimates - optional

Horizontal distance (m)						
Velocity (ms^{-1})						
Depth (m)						
Water surface width (m):		Discharge (m^3s^{-1}):				

Significant rainfall in the last week? - i.e. likely to have raised the water level

Yes	No	Comment:

Canopy Cover -tick appropriate category

Open	Partially Open	Closed	Comment:

Impact on stream habitat - Rate impacts on a scale of 0 to 3: 0 – no impact; 1- limited impact; 2 – extensive impact; 3 – channel blocked

	Score	Source: local / upstream
Coarse woody debris		
Other:		

Water chemistry data – Recording of the *in situ* measurements is also included in the SASS5 data-sheet – please complete here if doing the full RHP assessment. Instruments should be positioned in the clearly-flowing points on the river where possible.

Instruments in fast flow?	Yes	No	If no, where:	
Samples collected?	Yes	No	Date sent for analysis?	
Water filtered?	Yes	No	Volume filtered (mL):	
Samples frozen?	Yes	No	Other preservation?	
Name of institution to which samples were sent:				

Variable	Value	Units
pH		
Conductivity		
Temperature		
Dissolved Oxygen (mgl^{-1})		
Percentage O_2 Saturation		

Water turbidity - tick appropriate category

Clear	Discoloured	Opaque	Silty	Comment:
Turbidity (if measured (NTUs)				
Secchi Depth (m)				

2. STREAM DIMENSIONS - estimate widths and heights by ticking the appropriate categories; estimate average depth of dominant deep and shallow water biotopes.

(m)	< 1	1-2	2-5	5-10	10-20	20-50	50-100	>100
Macro-channel width								
Active-channel width								
Water surface width								

Bank height – Active channel			
(m)	**< 1**	**1-3**	**>3**
Left Bank			
Right Bank			

Dominant physical biotope	Average Depth (m)	Specify physical biotope type
Deep-water (>0.5m) physical biotope (e.g. pool)		
Shallow-water (<0.5m) physical biotope (e.g. riffle)		

3. SUBSTRATUM COMPOSITION - Estimate abundance of each material using the scale: 0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 - entire

Material	Size class (mm)	Bed	Bank
Bedrock			
Boulder	> 256		
Cobble	100 – 256		
Pebble	16 – 100		
Gravel	2 – 16		
Sand	0.06 – 2		
Silt / mud / clay	< 0.06		

Degree of embeddedness of substratum (%)
0-25
26-50
51-75
76-100

4. INVERTEBRATE BIOTOPES (present at a site compared to those actually sampled)

Summarised river make up: ('pool'=pool only; 'run' only; 'riffle/rapid' only; '2mix'=2 types, '3mix'=3 types)				
pool	run	Riffle/rapid	2 mix	3 mix

Rate abundance of each SASS and specific biotope present at a site using the scale: 0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – entire. Add additional specific biotopes if necessary.

		Specific Biotope					
SASS Biotope	Rating		Rating		Rating		Rating
Stones in current		Riffle		Run		Boulder rapid	
		Chute		Cascade		Bedrock	
Stones out of current		Backwater		Slackwater		Pool	
		Bedrock					
Marginal vegetation in current		Grasses		Reeds		Shrubs	
		Sedges					
Marginal vegetation out of current		Grasses		Reeds		Shrubs	
		Sedges					
Aquatic vegetation		Sedges		Moss		Filamentous algae	
Gravel		Backwater		Slackwater		In channel	
Sand		Backwater		Slackwater		In channel	
Silt/mud/clay		Backwater		Slackwater		In channel	