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EXECUTIVE SUMMARY

1. Introduction

The South African National Water Act, Act 36 of 1998, requires that the environmental reserve be determined for each significant water body before licenses may be issued. Methods currently available for the determination of environmental water requirements in South African rivers are based on perennial rivers and are seen to be needing verification for use on non-perennial rivers. This research programme began by identifying which existing methods, i.e. those being used on perennial rivers, might initially seem to be suitable for use and where further work needs to be done (see Rossouw et al., 2005). It then took this research a step further with an overarching objective to develop a prototype methodology for determining the environmental water requirements for non-perennial rivers. This would be based on field-based knowledge acquired during comprehensive research on a range of non-perennial systems. The specific terms of reference were to:

1.1 Define the different-sized tasks to be completed.

1.2 Select a set of researchers to contribute their appropriate knowledge to complete the tasks.

1.3 Choose the systems and sites for field studies

1.4 Examine the available information and set the general schedule of field visits.

1.5 Carry out the field research.

1.6 Develop a prototype methodology.

1.7 Complete a trial application of the Environmental Water Assessment methodology

1.8 Revise the prototype Environmental Water Assessment methodology as necessary and recommend the next phase of activities.

In order to achieve the study's objectives, research was conducted in five phases: (i) selecting a suitable river system; (ii) preparing the sampling sites for field visits; (iii) sampling in the field; (iv) developing a trial methodology; and (v) testing the trial methodology. The first three phases served to develop an understanding of an ephemeral river ecosystem, while phases iv and v focused on the development and testing of the prototype methodology, respectively.

2. Establishing a field-based knowledge of a non-perennial system

2.1 Selecting a suitable river system for study

The study deviated from its original objective to do field-sampling in each of the three types of non-perennial rivers recognised in Rossouw et al. (2005), namely Semi-permanent, Ephemeral and Episodic. A decision was taken, and approved by the project's Steering Committee, to rather concentrate the sampling effort on one non-perennial river system closer to Bloemfontein where most of the team members were based. This allowed team members frequent access to the river and enabled them to develop an in-depth knowledge of one system, rather than superficial knowledge of three systems.

An important requirement in selecting a suitable system was the availability of good quality hydrological data in order to allow hydrological modelling. Accurate long-term hydrological records proved to be very scarce for non-perennial systems in the central and dry western parts of the country and only one suitable river was found relatively close to Bloemfontein. The Seekoei River had reliable flow and stage data for one point in the lower part of the river (gauging weir D3H015) over a period of 25 years and was, therefore, selected for the study.

The Seekoei River is an ephemeral southern tributary of the Orange River. It has its origin just southeast of Richmond in the Northern Cape Province and flows in a northeasterly direction, joining the Orange River at Vanderkloof Dam. The river is situated in the Upper Orange Water Management Area (D3 sub-drainage region) and flows through the Nama Karoo 26.03 ecoregion.

2.2 Site-selection

Four sampling sites were selected on the Seekoei River, one in the upper part of the catchment, one in the middle part and two in the lower section of the catchment. Site-selection was chiefly based on the macro-reaches (distinct geomorphological reaches based on the river's longitudinal profile) identified for the river, river condition as determined by a Habitat Integrity Assessment, and information obtained during a reconnaissance visit to the river. The need, however, for a more comprehensive approach that incorporates catchment information, hydrological data, river condition and input from stakeholders became clear as the study progressed and an alternative GIS/landscape-based approach was proposed as part of the new methodology. It is believed that such an approach could contribute the following to future projects:

- Facilitate greater understanding of the catchment and catchment processes before sampling sites are selected.

- Guide the selection of suitable indicators for river sections, as well as the appropriate expertise needed.
- Assist in the development of scenarios specifically relevant to a catchment.
- Reduce costs and increase the efficient use of time as a result of improved and more informed project planning.

2.3 Collection of field data

Field data were collected for ten specialist fields in the Seekoei River over a two-year period, namely hydrology (to a limited extent); geohydrology; hydraulics (to an extent); catchment geomorphology; fluvial geomorphology; water quality; riparian vegetation; aquatic macroinvertebrates, fish and socio-economic issues (to an extent). Thirteen field visits were made to the river between March 2006 and March 2008: two by the full team in March and September 2006, one by the geomorphology team in July 2006 and eleven six-weekly routine sampling visits.

The field-based data collected for the Seekoei River served as a basis on which an understanding of the river's ecological functioning could be developed. This understanding, together with the specialists' previous experience of working in similar systems, formed the foundation of the prototype methodology proposed in this study.

2.4 An overview of the ecological functioning of the Seekoei River

The upper part of the Seekoei River catchment is steep with floodout type channels, resulting in surface water becoming dispersed very quickly on the flat plain immediately downstream. The lower reaches of the river, where sites EWR3 and 4 are located, is situated in a gorge extending approximately 8 km and starts a few km upstream of the gauging weir at the outlet of quaternary catchment D32J. This high topography area occupies 20 to 30% of the total area of D32J (1112.5 km^2) and is drained by 12 major tributary streams. Although this area covers a small area of the total catchment, most of the flow recorded at the measuring weir is generated here, and so the area proved to have a major influence on the flow regime. For example, while surface flow was lacking in the upper catchment in August 2006, flow records at the gauging station suggest that a flow event with a peak of 2 m^3s^{-1} occurred in the lower parts.

The existence of prolonged flow (after events) only in the lower part of the catchment is attributed to unsaturated zone drainage from the high topography area in the vicinity of the gorge. Whether this represents concentrated outflow at the base of a perched aquifer or more distributed lateral flow (interflow) through fracture zones is not known. The results, in terms of the contribution to base flow, should be quite similar. It is postulated that after major rainfall events the quantity of this flow could be quite substantial, either because of a greater head caused by additional recharge, or because a larger number of springs are active.

One of the most critical issues that has potential to impact on ecological functioning in non-perennial rivers systems is the dynamics of pool storage. Pools in the Seekoei River occur mostly upstream of hydraulic controls. In the upper part of the catchment the controls tend to be sedimentary features, and in the lower parts dolerite intrusions. Under drying conditions, the dynamics of the pool storage in the lower part of the catchment seemingly depends upon the balance between spring discharge and pool evaporation, which will differ between seasons. In the upper parts of the catchment, where there is little evidence of spring flow, it is possible that small contributions to pools are made through connections with the ground water, but these are expected to be relatively small due to the low hydraulic gradients. Most of the pools in the upper part of the catchment are therefore expected to dry out relatively rapidly, depending on the evaporative demand.

Water quality at the four sampling sites differed not only in salt concentrations, but also in ion dominance. Salt concentrations at Site EWR1 (>1000 mg/ℓ) were consistently higher than at the three downstream sites (average of 450 mg/ℓ). Salt concentrations at EWR sites 3 and 4 showed an increase with a decrease in pool depth, mainly as a result of evaporation and/or evapotranspiration. Na and Cl were the dominant ions at all EWR sites, except EWR2 where Ca, Na and Mg were dominant, indicating a strong geological effect. Ca, SO_4 and Mg were the dominant ions at the two interflow springs monitored. This high variability between sites makes it difficult to predict the expected water quality of pools/reaches not sampled.

The influence of the steep topography in the lower part of the river was also evident in the distribution of riparian plant species. Riparian vegetation at EWR sites 1 and 2 was restricted to sedges, rushes and a few hygrophilous grasses. The absence of trees and shrubs from the flat plain is thought to be a result of the severe frost in winter. The hills and ridges at sites EWR3 and 4 provide a more protective environment for these growth forms, and several indigenous trees and shrubs are found here. Even though similarities exist between EWR1 and 2, distinct differences between the plant communities of these sites were noted.

Invertebrate composition at sites EWR1 and 2, comprising isolated pools, differed from that at sites EWR3 and 4 with pools and riffle biotopes, even when EWR3 and 4 were reduced to isolated pools after a long dry period. The macro-invertebrate community was more diverse at sites EWR3 and 4 with 36 and 33 families compared to the 21 and 23 families sampled at EWR1 and 2 between March 2006 and October 2007. The presence of the invertebrates appeared to be related to the hydrological phase ("pool", "onset of flow" or "flow") at the site, as well as to biotope availability.

The fish community of the Seekoei River is naturally species poor, and consists of hardy generalist species. Fish species richness and diversity increased downstream with one minnow species present at EWR1 and seven species (including two exotics) recorded at EWR4. Shallow water plays a major role in protecting young fish from predation by larger fish, the latter being more common in deeper water. When pools dry out, young fish are forced from the extensive flat shallow vegetated areas into steeper-sided deeper pools where they are more vulnerable. The high number of weirs restricting flow and the longitudinal migration of fish is of concern; only during major flow events can fish circumvent weirs.

The socio-economic profile of the population utilizing the Seekoei River is made up of established commercial farmers and their workers. General farming activities are game and stock farming, or a combination of livestock, game and limited opportunistic irrigation agriculture (predominantly producing fodder for livestock). A large number of dams and weirs exist in the river course for irrigation abstraction, stock watering and recreation.

3. The nature of non-perennial rivers

3.1 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 to 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. 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. The prototype method and its development

4.1 Assumptions made when developing the method

A number of 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:

- 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.
- The focus should be on the required output rather than attempting to follow a set method.
- The interactions between surface and subsurface water would be an important focus
- The consideration of pools would be an important focus.
- Major floods are important in maintaining pools and would be a major focus.
- Catchment attributes could be useful input to the method because of the likely lack of data on the river itself.
- 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 for the various

scenarios. 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.
- 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 licensing stage in order to assess the possible impact on specific pools or reaches.

4.2 Challenges facing EWAs for non-perennial rivers

Six major challenges were identified for determining EWAs for non-perennial rivers, namely hydrological modelling, understanding pools, connectivity, surface-sub-surface water interactions, extrapolation of data and establishing reference conditions:

Hydrological modelling

Hydrological data are usually the start and end points in environmental water assessments. The starting 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 drivers 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 model the movement of water through the catchment satisfactorily. 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 ground water 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.

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 and their livestock.

The location, nature and means of persistence of pools are 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 and predictions of how they could change 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.

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.

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.

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.

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 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.

4.3 The prototype methodology

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 was developed for EWAs for non-perennial rivers. The methodology, at present, resembles a comprehensive approach comprising 11 phases and 28 activities and the process for more rapid assessments will be completed once this approach has been finalised. It 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. Seventeen key indicators were selected for the Seekoei River: three driving indicators: Connectivity of surface water, Floods for channel maintenance and Sediment delivery and 14 responding indicators: Pools, Channel aquifer, Riparian aquifer, Water quality variable (for the Seekoei conductivity was used), Riparian vegetation cover, Aquatic/marginal vegetation, Number of important invertebrate taxa, Abundance of invertebrate pest taxa, Status of indigenous fish community, Abundance of exotic fish, Terrestrial wildlife, Contribution to parent river and a Quantitative and a Qualitative socio-economic indicator. By selecting these indicators, the team attempted to identify and represent the most important characteristics of the Seekoei River, in order to be able to predict how each would respond to changes in the catchment. The various phases and activities of the prototype methodology (presented in Figure 1) are described in Chapter 4 of this report, and only the main aim of the various phases is presented here:

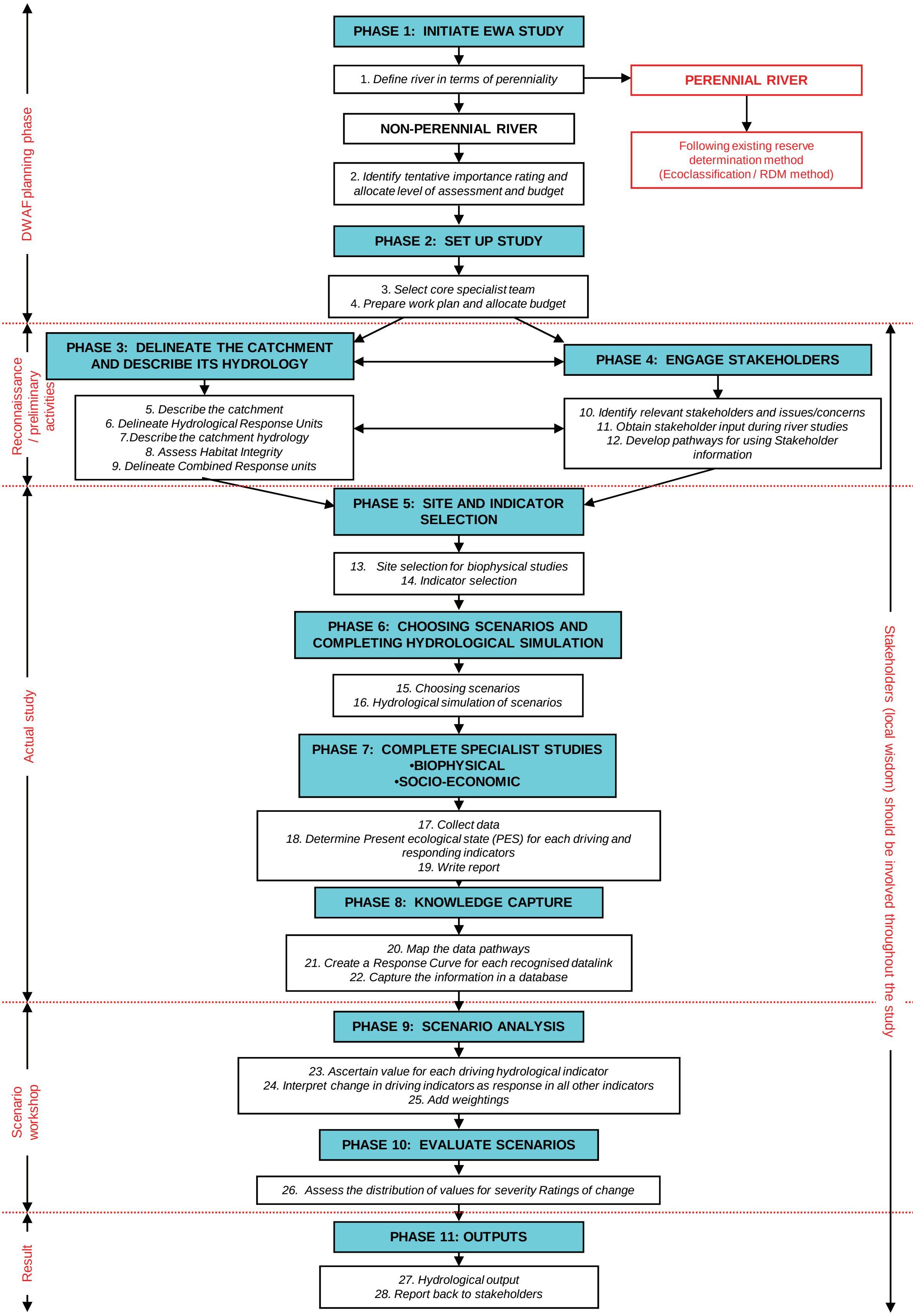

Figure 1: The 11-phase process proposed for EWAs for non-perennial rivers.

Phases 1 to 2: deal with initiating and setting up the study;

Phases 3 and 4: focus on the accumulation of catchment information in order to identify the important catchment processes, components and issues that require further consideration in the study and on which site and indicator selection will be based;

Phases 5 to 7: aim to choose realistic and applicable future scenarios for the catchment and to gather, document and process the data (on the selected indicators) needed to analyse and evaluate these scenarios during the next phase;

Phase 8: captures the acquired knowledge in Response Curves and a database;

Phase 9 to 10: consider and predict the impacts that the chosen scenarios might have on the selected biophysical and socio-economic indicators;

Phase 11: advises the relevant decision-making body of the outcome of the study and providing feedback to the community of stakeholders.

4.4 Key features of the proposed prototype methodology

The key features of the method are:

- The prototype method clearly places an important emphasis on creating an understanding of the nature of the river and its catchment. The method makes provision for a small core team to use available data and information on the physical catchment, together with the issues and concerns pointed out by stakeholders, to develop a preliminary basic understanding of catchment processes which will inform and guide subsequent project planning.
- Another important feature of the method is that information on the catchment as a whole, as opposed to the river channel only, is considered in river delineation. It aims to integrate the Runoff Potential Units (RPUs; homogenous units based on soil type, catchment slope, infiltration rate, vegetation cover, rainfall intensity and flow accumulation) with the outcome of the hydrological analysis and the Habitat Integrity Assessment (based on the method of Kleynhans et al., 2008) in order to create Combined Response Units (CRUs), which serve as a basis for site-selection and specialist studies.
- The proposed method uses a number of generic attributes of the river, referred to as indicators, which are sensitive to water level and other changes in the catchment. In the Seekoei River study, three driving and 14 responding indicators were proposed. The method, however, makes provision that any of the indicators can be de-activated where not relevant. Other indicators can also be added if needed.
- The proposed approach also provides an unbiased way to capture the knowledge, experience and wisdom of specialists by means of Response Curves. These curves can

then be used, in a structured way, to predict how the river would change in response to certain scenarios or flow management options.

- The method further recognizes the particularly important role that stakeholders could play in EWAs for non-perennial rivers. There is often very little information and data available on these rivers and their users. Involving the stakeholders from early on in the assessment provides a mechanism to obtain information on the past and present nature and uses of the river and to identify issues and concerns that should be reflected in the scenarios considered for the catchment.

5. Testing the prototype methodology on the Seekoei River

5.1 Application of the methodology on the Seekoei River

The prototype methodology, which was finalised towards the end of this project, was applied in two steps on the Seekoei River. In the first step Phases 8 to 10 were applied at a Scenario workshop in March 2008 in Bloemfontein, while the application of Phases 3 to 7 followed thereafter. These were applied in a desktop exercise to test the method's practicability. This implied that:

- Phases 1 and 2, for which the responsibility lies mainly with the DWAF, were not carried out,
- The proposed stakeholder process, as set out in Phase 4, was not conducted,
- It was not possible to select alternative study sites based on the new approach,
- The RPUs were not fully integrated with the results from the hydrological analysis and the habitat integrity assessment in order to create CRUs as required by the new approach.
- A final hydrological output was not produced for the Seekoei River.

5.2 Evaluation of the methodology

Overall, the team was satisfied with the results produced by the method and how well the method reflected their intuitive knowledge of the system. They were, however, confronted with a number of difficulties during application of the method on the Seekoei River. This implied that interim measures were needed at a number of occasions in order to proceed with method application and that some of the foundational steps were not completed satisfactorily. These would require rethinking and/or further development. The most important of these are:

Delineation of the river (or catchment) into homogenous units

Although runoff potential units (RPUs) were created for the Seekoei River, the team was unable to superimpose the hydrological data on these units to form combined response units (CRUs). This was mainly due to an incompatibility of scale – hydrological models makes use of quaternary catchments which are not compatible with the fifth order basin level used for RPU delineation in the Seekoei River. Further research is therefore needed to investigate how fifth order basins could be linked to the hydrological models. The CRUs are crucial, as they guide selection of representative sites which are the focus for data collection, interpretation and for scenario analysis.

Hydrological modelling

Simulated data could only be produced for two of the three hydrological indicators identified for the Seekoei River, namely surface water connectivity and channel maintenance floods. No simulated data on the delivery of sediment from the catchment to the river channel could be produced by the hydrological models used despite this being agreed with the.

The uncertainties associated with the results produced by the hydrological model were, to a large extent, related to the fact that most of the real observations were taken from the gauging station situated at the outlet of the catchment while substantial spatial differences in the hydrological processes existed in the catchment. It was, therefore, impossible to calibrate the model for quaternary catchments in the upper and middle parts of the Seekoei River.

Hydrological modelling for floods was done in a parallel modelling exercise using the Nash-Muskingum routing model. The areal reduction factor in the model was set to generate results at the outlet of sub-catchment D32J in order to be consistent with the observed flow data at gauging station D3H015. Simulated data on channel maintenance floods were accordingly only available for the two downstream sites closest to D3H015.

The lack of simulated data presented the team with a major obstacle and approximations were used to fill the gap. The development of a model to supply data on sediment delivery is a priority in the further development of the prototype method.

Selection of suitable scenarios for the catchment

The results produced by the hydrological models for the three hypothetical scenarios chosen for the catchment proved to be very unsatisfactory in that the models did not appear to be sensitive enough to reflect the scenario changes in catchment conditions. Other problems that curtailed hydrological simulation were:

- The fact that most of the runoff observed at the gauging station is generated in quaternary catchment D32J at the lower end of the catchment, and that this quaternary catchment was unlikely to be subjected to a great deal of development.
- The uncertainties that exist with regards to the processes associated with a development-driven deterioration in the catchment, lacking observed data.
- Difficulties with converting land use changes into model parameter changes, especially due to the fact most of the catchment is fairly flat and sparsely vegetated.
- The low gradient that prevails in the majority of the Seekoei catchment, lessening the impacts on the river resulting from land-use change. Land-use change may have a more profound impact in steeper catchments.
- The fact that the flood regime is already very variable (as for most systems in semi-arid regions), making it difficult to predict and interpret additional change.
- Increased abstraction from boreholes was not expected to have a large impact on the water levels of in-stream pools (unless it was quite intensive and close to the river channel) as the ground water contributes little water to the pools.
- The highly variable distribution patterns and robust generalist nature of the aquatic biota, which made it very difficult to predict biotic responses to small changes in pool dynamics.
- The fact that most disciplines collected field data at a smaller spatial scale than the quaternary catchment level used in hydrological modelling, and that these data were not temporally representative due to the short period of sampling. Improved results could be obtained for EWAs if the different disciplines could collect and use data at the same level of resolution.

Determination of the PES for indicators

The indicators used to describe the present ecological state (PES) for river components in perennial Reserve Determinations (e.g. Hydrological Driver Assessment Index, HAI; Geomorphology Driver Assessment Index, GAI; Physico-chemical Driver Assessment Index, PAI; Fish Response Assessment Index, FRAI; Macro Invertebrate Response Assessment Index, MIRAI; Riparian Vegetation Response Assessment Index, VEGRAI) could not be effectively used on the Seekoei due to the following reasons:

- A different set of driving indicators was selected for the Seekoei, namely Connectivity, Channel maintenance floods and Sediment delivery, compared to Hydrology, Geomorphology and Water quality used as driving indicators for perennial rivers.
- Workable versions of the proposed indices, with the exception of the FRAI, MIRAI and VEGRAI were not yet available for application on the Seekoei River.
- Difficulties with setting reference conditions for river components in the absence of recent and historical information.

- The FRAI, MIRAI and VEGRAI were not ideally suited for use in the Seekoei River but were applied with modifications (see specialist chapters on fish, macroinvertebrates and riparian vegetation, respectively, for further discussion).

This is an area that needs further investigation and consideration, as it would be ideal to have a standard method or set of rules by which the PES for each indicator could be determined. Each of the proposed Multi Criteria Decision Making Approach (see Kleynhans and Louw, 2008) models should therefore be evaluated for use on non-perennial rivers by the relevant disciplines as they become available.

Scenario analysis

The analyses of the chosen scenarios were curbed first by the lack of simulated hydrological data on Sediment delivery and Floods, and second by searching for a way to acceptably calculate the combined influence of indicators on a responding indicator (in cases where more than one indicator could act as a driver).

For the Seekoei River, specialists initially listed all drivers that could have an influence on a specific responding indicator. The combined effect of the all listed drivers was then calculated as a sum of the products of the Response Curve values and the weightings rescaled to 1 in order to provide one final value for the responding indicator. (This final value was needed as an input to obtain a Response Curve value for the subsequent indicator). It became clear however that the number of drivers affected the final value of the responding indicator, which was lower when there were more drivers. This resulted in a situation where the values for some of the final responding indicators were so diluted, that it became difficult to interpret them by means of the Ratings of Change table (Table 4.5). Using these small numbers to obtain Response Curve values for subsequent indicators was problematic in that most response values were less than 1, resulting in rather meaningless answers.

This was noted as an important problem that needs consideration in the next phase of the project. As an interim measure it was decided to

- Reduce the number of drivers for each responding indicator, leaving only the ones that best describe the functionality of non-perennial systems. No limit was placed as yet on the number of drivers for the present study, but this is a matter that should be investigated in future.
- Adhere to the straight weighted sum for the present study. Although it is true that more drivers would dilute the overall effect, it should still reflect what the system of drivers and indicators set up is indicating.

Evaluation of scenarios

The fact that "abundance Response Curves", and not Response Curves of ecosystem integrity, were prepared for the Seekoei had three important implications for the final evaluations of the scenarios. First, this implied that we ended up with both positive and negative Response Curve ratings which could cancel each other out in certain instances. Second, determining the direction of change was complicated by the fact that we had both toward (Ts) and away (As) ratings in one column. Third, these two problems made it very difficult to apply the rules according to which it was decided if a state change occurred or not. These problems would, however, be resolved by using integrity curves in future applications of the method.

6. Conclusions and the way forward

6.1 Conclusions

- In accordance with the study's overarching aim, a prototype methodology for determining the Environmental Water Requirements for non-perennial rivers was developed.
- The proposed methodology, as it stands now, resembles a comprehensive approach comprising 11 Phases and 28 Activities. Once this methodology has been verified and finalised, the process for more rapid assessments will be extracted from it.
- The method 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. Seventeen indicators were selected to represent the non-perennial nature of the Seekoei River:

  Driving indicators:
  Connectivity of surface water,
  Floods for channel maintenance
  Sediment delivery

  Responding indicators
  Physical-chemical
  Pools,
  Channel aquifer,
  Riparian aquifer,
  Water quality variable (for the Seekoei conductivity was used),
  Biological
  Riparian vegetation cover,
  Aquatic/marginal vegetation,
  Number of important invertebrate taxa,

Abundance of invertebrate pest taxa,
Status of indigenous fish community,
Abundance of exotic fish,
Terrestrial wildlife,
Contribution to parent river and a
Socio-economic
Quantitative indicator
Qualitative indicator.

- While some of the method's features are similar to those used in e.g. DRIFT (King et al., 2004) and other South African methods (e.g. Ecoclassification, see Kleynhans and Louw, 2008), it has some unique features e.g. the comprehensive GIS/landscape-based approach to identify integrated units of analysis on which site-selection is based and the fact that change is described from present conditions due to difficulties in setting reference conditions in non-perennial systems.
- The method was successfully applied on the Seekoei River, but a number of steps need further consideration and development. These are

  Harmonising the hydrological model/s with the 5th order basins in order to allow the delineation of the catchment into Combined Response Units.

  Developing a model that can provide data on Sediment delivery.

  Assessing the suitability of the suite of Multi Criteria Decision Making Approaches proposed in Kleynhans and Louw (2008) for determining the PES of the corresponding indicators (between perennial and non-perennial methods) in non-perennial rivers and to develop new approaches where new indicators have been introduced e.g. Connectivity, Pools, etc.

  Formalising the selection of drivers for each responding indicator and establishing a protocol for integrating the values of these drivers into one final value for the responding indicator.

6.2 The way forward

The prototype methodology was applied to the Seekoei River and now needs to be tested and modified, using a range of non-perennial systems in order to assess its universal applicability.

In a follow-up study which has been approved by the WRC, the methodology will be tested on three suitable systems in different parts of the country. Ideally, appropriate information will be collected at well-chosen sites for each system, followed by method application. A final assessment would ideally give us a methodology, consisting of a set of methods, which would then be available for universal application and refinement.

Monitoring of the Seekoei River will continue, at the same time in a parallel phase, albeit at reduced intensity, in order to record longer-term variability in the system.

7. Outline of the report

The report is structured as follows:

- **Chapter 1** introduces the report and provides some important background information;
- **Chapter 2** describes the physical characteristics of the Seekoei River and provides an overview of the understanding acquired;
- In **Chapter 3** the constraints and challenges of completing EWAs for non-perennial rivers are discussed, as well as some of the constraints and challenges experienced in the specialists studies;
- The new prototype methodology is presented and described in **Chapter 4**; and
- Its practicability tested on the Seekoei River in **Chapter 5**.
- **Chapter 6** provides a discussion of the method's strengths and weaknesses; with
- Conclusions and recommendations listed in **Chapter 7**.

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Dr Chris Dickens	INR
Prof Chris James	University of the Witwatersrand
Dr Heather Malan	University of Cape Town, Freshwater Research Unit
Dr Neels Kleynhans	Department of Water Affairs and Forestry
Prof Kevin Rogers	University of the Witwatersrand, Centre for Water in the Environment
Dr Mary Seely	Desert Research Foundation of Namibia
Ms Carole Roberts	Desert Research Foundation of Namibia
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Mr Niël van Wyk	Department of Water Affairs and Forestry
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- The information used to compile the Landcover map (Figure 2.10) is the intellectual property of the CSIR and the Agricultural Research Council and was used herein by permission.

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LIST OF 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
CGS	Council for Geological Sciences
CRU	Combined Response Unit
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of Variation
DEAT	Department of Environmental Affairs and Tourism
DEMC	Default Ecological Management Class
DESC	Default Ecological Status Class
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphates
DO	Dissolved Oxygen
DRIFT	Downstream Response to Imposed Flow Transformation
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
EFA	Environmental Flow Assessment (also known as Instream flow Assessment: IFA)
EFR	Environmental Flow Requirement (also known as IFR: Instream Flow Requirement)
EIS/C	Ecological Importance and Sensitivity/ Category
EMC	Ecological Management Class
ERC	Ecological Reserve Category
EWA	Ecological Water Assessment
EWR	Ecological Water Requirements or Environmental Water Requirements
FAII	Fish Assemblage Integrity Index
FRAI	Fish Response Assessment Index
FV	Fast flow through Vegetation
GAI	Geomorphology Driver Assessment Index
GGP	Gross Geographical Product
GIS	Geographical Information System
GPS	Global Positioning System
GSM	Gravel, Stones, Mud
HAI	Hydrology Driver Assessment Index
HFSR	Habitat Flow Stressor Response
HI	Hydrological Index
HRU	Hydrological Response Unit
HUGHES DSS	Decision Support System
IFIM	Instream Flow Incremental Methodology
IFR	Instream Flow Requirement (also known as Environmental/Ecological Flow Requirement:EFR)
IHI	Instream Habitat Integrity
ISP	International Strategic Perspective
LID	Large Infrequent Disturbance
MAP	Mean Annual Rainfall/Precipitation
MAR	Mean Annual Runoff
MIRAI	Macro-invertebrate Response Assessment Index
MVI	Marginal Vegetation Invertebrates
N	Nitrogen
NWA	National Water Act

NWBM	National Water Balance Model
NWRS	National Water Resource Strategy
P	Phosphorous
PAI	Physico-chemical Driver Assessment Index
PES	Present Ecological Status Class
PRA	Participatory Rural Appraisal
RAM	Resource Assessment and Management
RAU	Reserve Response Unit
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RHI	Riparian Habitat Integrity
RPU	Runoff Response Unit
RQO	Resource Quality Objectives
RVA	Range of Variability Approach
RVI	Riparian Vegetation Index
SASS	South African Scoring System (Invertebrate indexing system)
SANBI	South African National Botany Institute
SANSBA	South African National Spatial Biodiversity Assessment
SI	Suitability Index (as in SI curve, also known as HIS curve)
SIC	Stones-in-Current
SRP	Soluble Reactive Phosphate
SS	Slow and Shallow
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
TWQR	Target Water Quality Range
VEGRAI	Riparian Vegetation Response Assessment Index
WLRT	Worsley Likelihood Ratio Test
WMA	Water Management Area
WRC	Water Research Commission

CHAPTER 1
INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Introduction

All but the largest rivers in the semi-arid west of South Africa are non-perennial, and in the neighbouring states, southern Zimbabwe, Botswana, southern Angola and Namibia are equally dry and their rivers non-perennial. The climate in this semi-arid to arid region is highly variable, the environment fragile and easily disturbed, but the people living in the region require an acceptable degree of assurance in their water supply.

Conventionally, the groundwater resource is tapped in these areas, but recognition of the continuity of the groundwater and surface water resource indicates that this may not be as sustainable an option as previously thought. It is, therefore, important that methods are developed which can assess the environmental water requirements of non-perennial rivers with acceptable confidence.

The South African National Water Act requires that the environmental reserve be determined for each significant water body before licenses may be issued. Methods currently available for the determination of environmental water requirements in South Africa are based on perennial rivers and are seen to be needing verification for use on non-perennial systems. This research programme to date has addressed the need by identifying which existing methods, i.e. those being used on perennial rivers, might initially seem to be suitable for use and where further work needs to be done. It has shown up areas of difference in reserve determination methodology between perennial and non-perennial systems. These include considering the changing relevance of groundwater in relation to surface water in systems of differing non-perenniality.

As relationships between groundwater and surface water change, so will the management of these two components change. Therefore it would be important to know the surface water hydrology in relation to groundwater influences. Standard hydrological models cannot predict along the whole hydrological spectrum from perennial to episodic, so water licensing will have to be based on a new understanding or model of the hydrology. Currently licensing is based on a model which does not reflect reality in non-perennial systems, so the results it produces are meaningless.

We initially envisaged that we would study three non-perennial systems, one in each of the categories identified by the previous study, namely non-permanent, ephemeral and episodic, within South Africa. On each system three sites would ideally be chosen in a sequence: source, middle and lower reaches. The position of the sites would allow researchers to understand the critical groundwater-surface water relationships. The rivers and sites chosen would ideally be in good ecological condition; have gauging weir data, i.e. a good hydrological record, at least at the upper and lower ends or each river; have good borehole data, i.e. geohydrological knowledge of depth, as well as water quality information; have subsistence users somewhere along the length of the river; and have adequate literature. Site visits should cover wet and dry conditions, during which researchers will develop an understanding of the functioning of each system at biotic and abiotic levels, namely hydrological, geohydrological, different categories of the biota, and socio-economic.

But this was very idealistic for reasons that soon became obvious. Firstly, the great variability of rainfall in dry areas meant that we would need a great many years of observations to get some idea of the range of conditions, so in the short term the terms non-permanent, ephemeral and episodic had little meaning. Secondly, reliable flow data was, with rare exception, almost absent for non-perennial rivers. Thirdly, logistics dictated that we could not simply visit far-off systems as rainfall episodes might dictate, so we needed a river close enough to Bloemfontein to allow more frequent visits. Fourthly, wet and dry seasons became something of a joke because the river we eventually chose had not flowed for 18 months before we started, it flowed for the full first calendar year of study, and reverted to a set of pools for the next full calendar year. And finally, rivers that tend to dry out do not tend to have subsistence users along their banks.

So we chose the Seekoei as the river to be studied. It is relatively near to Bloemfontein and has good flow records for its lower reaches. It also proved a good choice for the differences between its upper and lower reaches.

The first six months of study were used for initial preparation, to appoint experts, to define the task of each expert and to choose the sites. The next 18 months were devoted to research on the system, e.g. by two compulsory visits on a seasonal basis as well as some opportunity visits (if perhaps a flood might arise). The last twelve months was used for methodology development, leading to trial application of an Environmental Water Assessment, based on the collected data for each system separately. A prototype Environmental Water Assessment Methodology, applicable to a range of systems was an important product. We were however sorely tested in trying to use existing methodologies so a new methodology was developed, with due acknowledgement of the methodology used on perennial rivers.

Communication of all phases of the work throughout the region is crucial to its success. To this end, a communication strategy ensured that all interested parties knew what was being done and would be able to make appropriate input into the continuing process.

1.2 Terms of reference

The main objective of this study was to perform a comprehensive research exercise to establish a field-based knowledge of a selected range of non-perennial systems. The specific terms of reference were to:

1.2.1 Define the different-sized tasks to be set to each of a set of researchers to be chosen.

1.2.2 Select a set of researchers to contribute their appropriate knowledge to evaluate the current methodologies in the field.

1.2.3 Choose the systems and sites for field studies

1.2.4 Examine the available information and set the general schedule of field visits.

1.2.5 Carry out the field research.

1.2.6 Develop trial methodology.

1.2.7 Trial application of Environmental Water Assessment methodology

1.2.8 Produce a prototype Environmental Water Assessment methodology.

Further verification of the prototype Environmental Water Assessment methodology should follow on a range of non-perennial systems.

1.3 Background on the Seekoei River study

The overarching aim of the study on the Seekoei River was to develop a field-based knowledge of an ephemeral system in order to develop a prototype EWA methodology suitable for application on such river systems. The study was conducted in five phases: (1) selection of the river system; (2) preparation for field visits; (3) sampling in the field; (4) development of the trial methodology; and (5) application of the trial methodology. The first three phases served to develop an understanding of the Seekoei River ecosystem, while phases 4 and 5 focused on the development and application of the prototype methodology. A summary of the activities performed under each of the phases is presented in Figure 1.1.

As is true for most projects, many uncertainties existed at the beginning of the study. Except for the twenty-year hydrological record (for one point in the lower part of the catchment), no other historical or long term records were available to the team. Inevitably, this complicated project planning. The many mistakes made and the lessons learned along the way, however, greatly contributed to method development. Field sampling was conducted over a period of nearly two years, allowing the team to develop valuable field-based experience on an ephemeral river system. This field experience proved very useful once the project reached the method development stage. However, two years of field data in a river system that is hydrologically unpredictable, are by no means sufficient. It presented the team with a snapshot view of the ecosystem at a set point in time, but did not shed light on long term cycles.

This project differed from the DWAF-initiated RDM studies in two aspects. First, the main focus was not on producing a final answer to be used by the relevant authorities, but rather on the process of getting to an appropriate answer. Second, the study was not limited to using only methods officially recognised by the DWAF although the intention at the outset was to use these if appropriate. Because of the difficulty in using some standard DWAF-recognised methods, several of the specialists, eventually, applied alternative methods, or additional methods, to those generally proposed for the different specialist fields. Discussions on the methods used by each specialist, as well the suitability of these methods for ephemeral rivers, are included in the specialist chapters (included on CD).

Although the methodology proposed in Chapter 4 is still in the early stages of development, it is presented within the DWAF context in recognition of their responsibility to give effect to the RDM. If the proposed methodology is to be acceptable to the relevant authorities after additional testing and further development, it needs to operate within this framework.

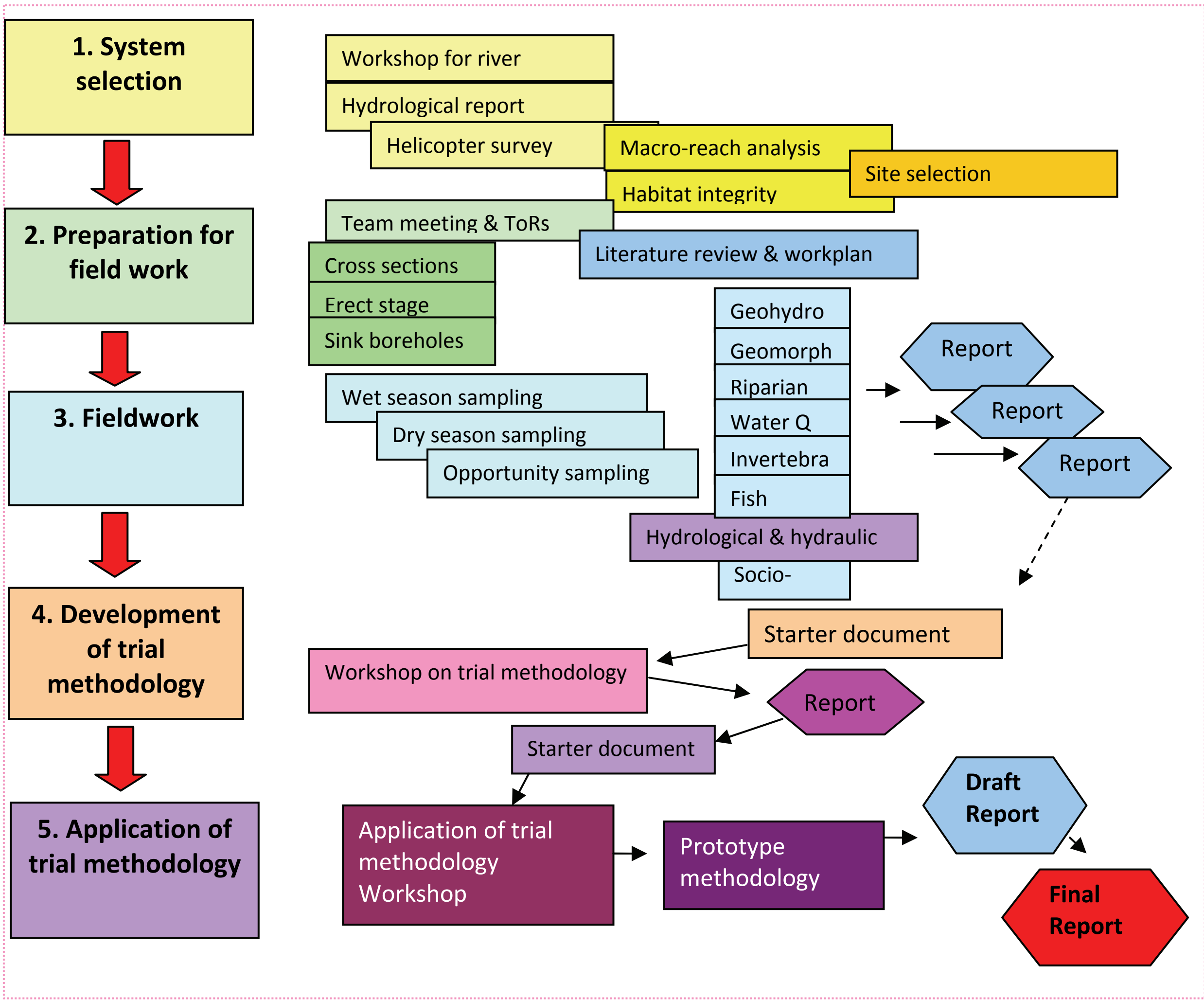

Figure 1.1: A graphic presentation of the steps and actions taken in the Seekoei River project.

1.3.1 *The selection of a suitable river system for the study*

The Seekoei River was selected for study at a system-selection workshop in Bloemfontein in July 2005. Although several rivers in the Limpopo River system (e.g. Lephalala, Mogalakwena, Marico and Little Letaba) and the upper and middle Orange River system (e.g. Kraai, Modder, Riet, and Caledon) were considered, it was decided to rather select a river system closer to Bloemfontein, where most of the study team are based. This would allow the study team more frequent access to the river, enabling them to develop a better understanding of the river ecosystem. Such an understanding, which would form the basis of the prototype method, would then be tested on other non-perennial river systems such as the Limpopo or its tributaries in a subsequent study.

An important requirement in selecting a suitable system was the availability of good quality hydrological data in order to allow hydrological modelling. An investigation by Steÿn (2005) into the availability and quality of the hydrological records of rivers in the upper Orange catchment revealed only one suitable river relatively close to Bloemfontein. The Seekoei River, an intermittent southern tributary of the Orange River, had reliable gauging weir data for one point in the lower part of the river (gauging weir D3H015) over a period of 25 years and was, therefore, selected for the study.

1.4 Study team

The core project team comprised of eleven specialists representing ten specialist fields or disciplines (Table 1.1). Most of these specialists were associated with the University of the Free State and have previous experience and knowledge of local systems and conditions in the Free State and Northern Cape. Due to the fact that the riparian community consisted exclusively of commercial farmers, an agricultural economist (instead of a sociologist and economist) was included in the study.

Table 1.1: The study team and their specific field of expertise involved in the Seekoei River study.

Discipline	**Specialist appointed**	**Affiliated Institution**
Project leader	Prof. Maitland Seaman	Centre for Environmental Management (CEM), University of the Free State
Project advisor	Dr. Jackie King	Freshwater Research Unit, University of Cape Town
Project coordinator	Marinda Avenant	CEM, University of the Free State
Hydrology	Prof. Denis Hughes	Institute for Water Research, Rhodes University
Geohydrology	Prof. Gerrit van Tonder	Institute for Groundwater Management, University of the Free State
Catchment geomorphology	Dr. Charles Barker	Department of Geography, University of the Free State
Fluvial geomorphology	Dr. Evan Dollar	CSIR*
Water quality	Ms. Linda Rossouw	Private consultant
Riparian vegetation	Dr. Johann du Preez	Department of Plant Sciences, University of the Free State
Aquatic macroinvertebrates	Ms. Marie Watson	CEM, University of the Free State
Fish	Ms. Marinda Avenant	CEM, University of the Free State
Socio-economics	Dr. Jack Armour	Department of Agricultural Economics, University of the Free State*
Hydraulics	Dr. Evan Dollar	CSIR*

*At the time.

1.5 References

Steÿn, E.C. 2005. Availability and expected quality of hydrological data for the Seekoei River and the upper Riet River catchment. Department of Water Affairs and Forestry, Kimberley.

CHAPTER 2
SEEKOEI RIVER CATCHMENT AND ECOLOGY OF THE RIVER

2.1 Introduction

In concurrence with the overarching aim of this study to develop a field-based knowledge of an ephemeral system as a basis for the development of a prototype EWA methodology for non-perennial rivers, a decision was taken at the System Selection Workshop, held on 11 July 2005, to focus the field effort on one suitable river close to Bloemfontein where most team members were based. This would allow the specialists more frequent access to river and enable them to visit the river when needed and not only during scheduled field visits. The decision was approved by the project's Steering Committee on 19 September 2005.

The river found to be the most suitable for the purpose of the study was the Seekoei River. The Seekoei, an ephemeral southern tributary of the Orange River situated approximately 250 km southwest of Bloemfontein, had a reliable flow and stage and flow record of more than 25 years (since 1981) for one point in the lower section of the river. A number of ephemeral rivers in the Upper and Lower Orange Water Management Areas were considered, but the Seekoei was the only one with an accurate hydrological record.

This chapter has two aims: first to describe the physical characteristics of the Seekoei River catchment and the four sampling sites selected for study, and second to provide a summary of the knowledge gathered on the ecological functioning of the river.

2.2 Study area

The Seekoei River catchment, which falls in the Upper Orange Water Management Area (WMA), lies between 31.473 S and 24.1203 E (source) and 30.2895 S and 25.0187 E (junction with Orange River) in the D3 sub-drainage region and comprises quaternary catchments D32A to H and D32J to K (Figure 2.1). The main tributary is the Klein Seekoei River, which rises in the Sneeuberge in the Eastern Cape and joins the Seekoei main just upstream of gauging weir D3H001 (not operational) at the border of quarternary catchments D32C, D32E and D32F. Other tributaries that enter

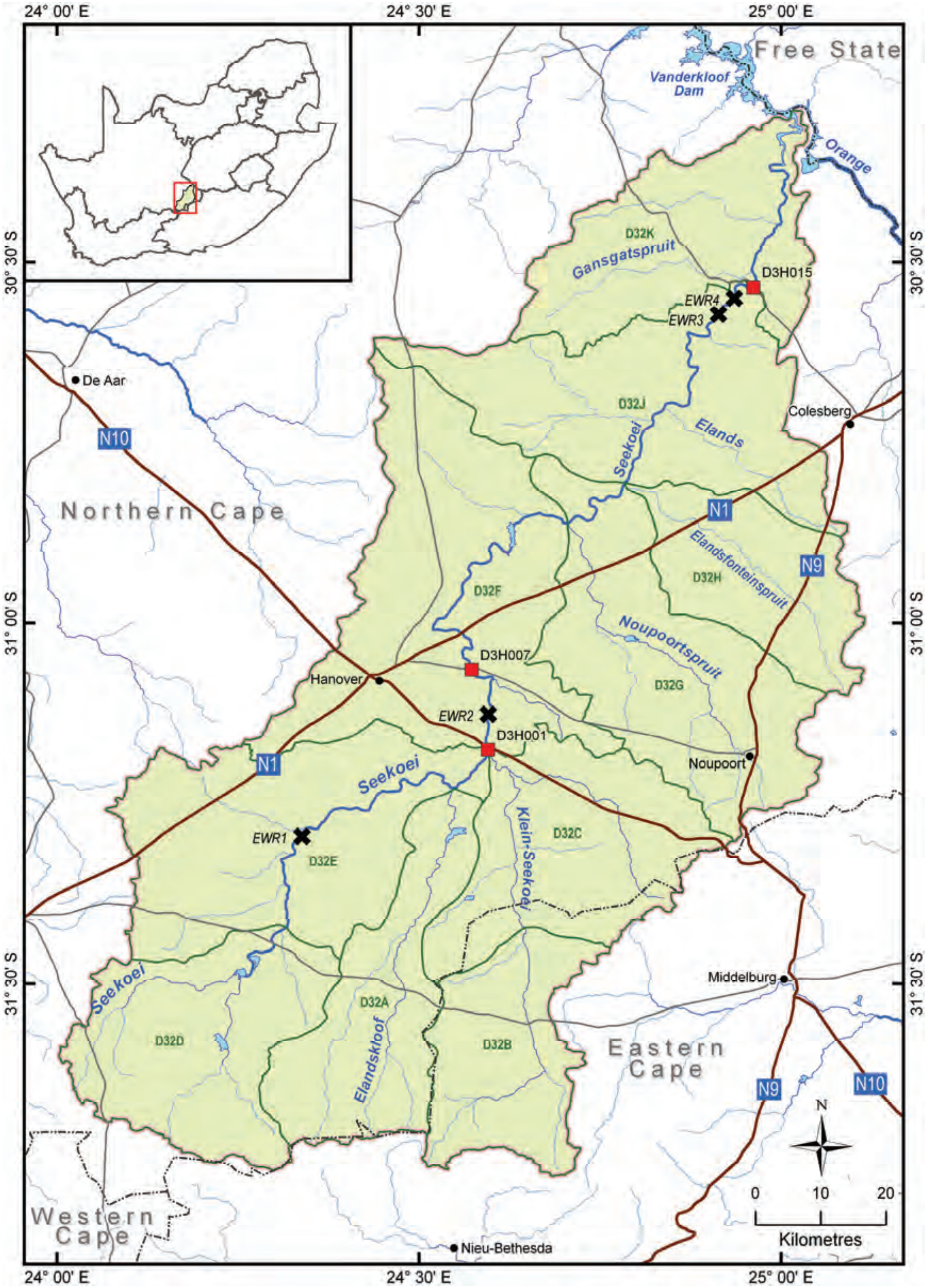

Figure 2.1: The Seekoei River catchment (sub-drainage D3). Main tributaries, quaternary catchments and gauging weirs are indicated. Sampling sites EWR1 to EWR4 are indicated by black crosses. (Data sources: Institute for Water Quality Studies (IWQS), DWAF and Chief Directorate of Surveys and Mapping).

the Seekoei River are the Elandskloof River (D32A), Noupoortspruit (D32G), Elandsfonteinspruit (D32H), Elands River (D32J) and Gansgatspruit (D32K).

2.2.1 *Geology, geomorphology and topography*

The two main tributaries of the Seekoei Rivers originate in the Sneeuberge and drains part of the Upper Karoo geomorphic province (Partridge et al., 2006). The landscape is dominated by flat-lying Karoo Supergroup sediments that have been intruded by innumerable sills and dykes of dolerite (Figure 2.2). The upper and middle sections of the catchment are dominated by Adelaide Subgroup mudrocks and subordinate sandstones, with intrusions of dolerite (Cole et al., 2004), while the lower catchment comprise of Tierberg Formation shales, siltstones and sandstones and dolerite-capped koppies (Le Roux, 1993). Dolerite sills and rings control the geomorphology and landscape of much of the Karoo basin (cf. Du Toit, 1905; Cole et al., 2004). The bed of the Seekoei River is often just above the bedrock (and indeed, is often incised into/contacts bedrock) and is therefore strongly influenced by the relationship between the softer Karoo sediments and the position and breaching of dolerite sills and dykes. Valley form tends to be broad in the Karoo sediments and alluvium but confined where the river passes through dolerite and/or dolerite-capped Karoo sediments.

According to Dollar (2005), the river channel flows in alluvium for approximately 80% of its length. The alluvium consists mainly of medium-to fine-grained sand, together with pebbles and coarser-grained sand deposits (Cole et al., 2004). These alluvial deposits may date back as far as early Pleistocene or even Pliocene (De Wit, 1993).

The catchment is situated between 1200 m to 1700 m above sea level. Its topography is mostly flat and has a mean catchment slope of 1 to 4% (Hughes, 2008). Steeper slopes do however occur closer to the catchment boundaries, as well as in an isolated area in the lower part of the catchment, where the Seekoei River passes through a gorge (quaternary catchment D32J; see Figure 2.3). Here, the river channel is flanked by dolerite ridges, rising to a height of about 200 m close to the river, compared to less than 20 m for the rest of the catchment (Hughes, 2008).

2.2.2 *Climate (Rainfall and temperature, evaporation)*

The catchment experiences large fluctuations in both daily and seasonal temperatures, with ranges of 16.1°C between day and night, and 13.9°C between maximum summer and winter temperatures (Weather SA). Summers are hot (average daily maximum temperature for January is 32.3°C, with 25 of the 31 days reaching temperatures

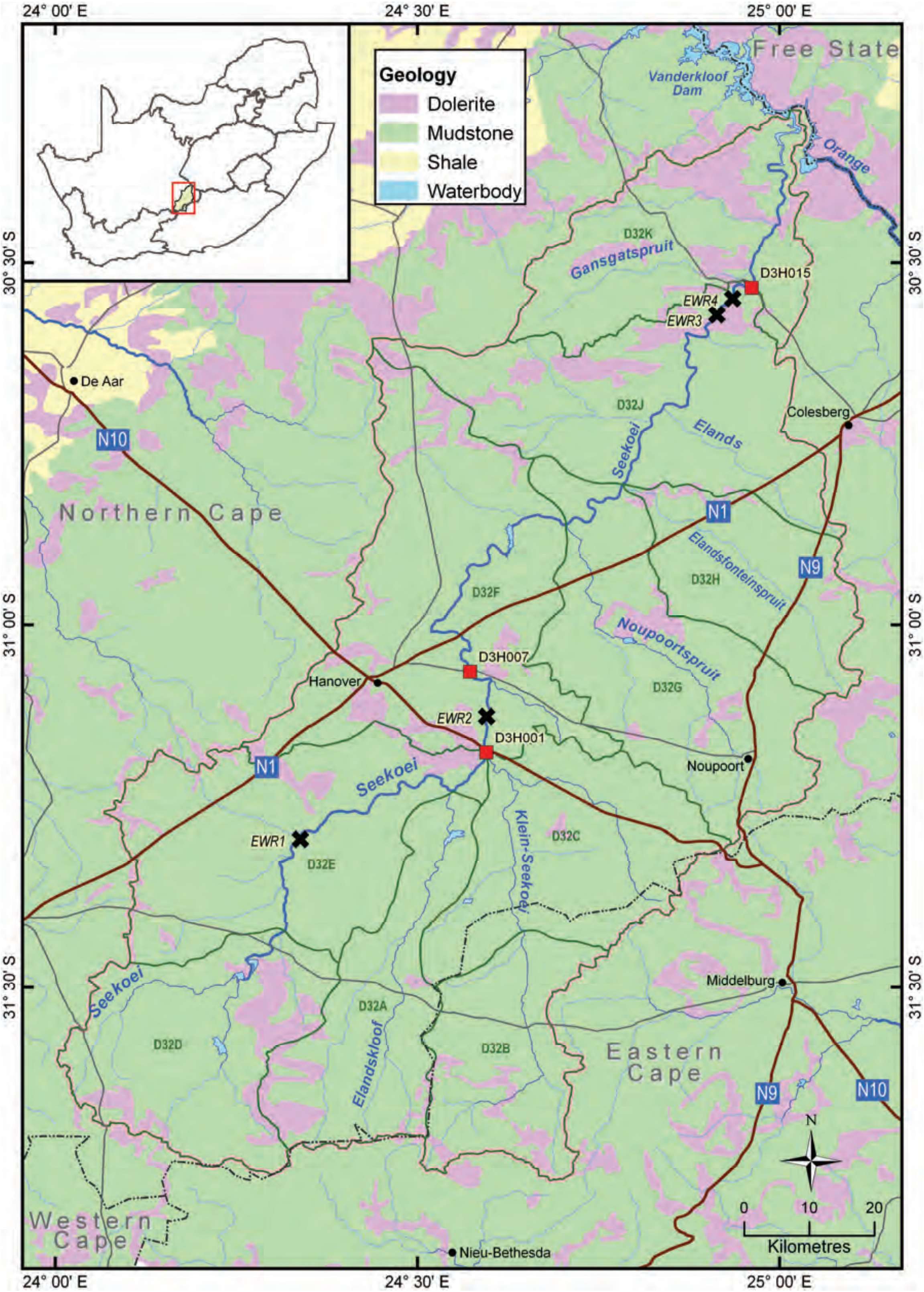

Figure 2.2: Geology of the Seekoei River catchment. (Data sources: ENPAT, 2001; IWQS, DWAF and Chief Directorate of Surveys and Mapping).

above 30°C), and winters cold (average daily minimum temperature for June, the coldest month, is 0.6°C; Venter et al., 1986). Frost occurs frequently between May and October (average 158 days/year).

Rainfall in the catchment occurs mostly in summer (October and March), with the mean annual rainfall ranging between 250 and 400 mm (Figure 2.4). The rainfall is further highly variable, not only between years but also between months. A monthly coefficient of variation of about 1.1 was calculated by Hughes (2008), while Venter et al. (1986) reported that only 65% to 70% of years receive a rainfall greater than 85% of the annual average for the catchment. Interestingly, Plug and Sampson (1996) report that rainfall in the Seekoei catchment might have been considerably higher in the past than at present. Palynological data from hyrax dung accumulations suggest that the grass cover, and by inference rainfall, was much more exuberant between 500 to 200 BP than at present.

Evaporation in the catchment varies between 1900 mm in the high-lying areas to 2500 mm in the western and lower part of the catchment (Figure 2.5). Evaporation, therefore, exceeds rainfall by between 6 to 8 times in the catchment. The Nama Karoo biome, wherein this catchment falls, has an average annual duration of bright sunshine of greater than 70% of that possible (Schulze, 1965 cited in Rutherford and Westfall, 1994), so that evapotranspiration in the region is high, especially in summer. A rainfall deficit of between 200 and 220 mm may occur in December (Venter et al., 1986).

2.2.3 *Geohydrology*

The Seekoei River catchment has a recharge rate of 6.4% (Dr. R. Dennis, pers. comm.). Recharge is highest in the northeastern part of the catchment where the river flows into Vanderkloof Dam and lowest in the southwest where recharge occurs at a rate of approximately 3 mm per year (Figure 2.6). The level of ground water in the catchment is presented in Figure 2.7 and varies between 5 m below ground level to 10 m below ground level.

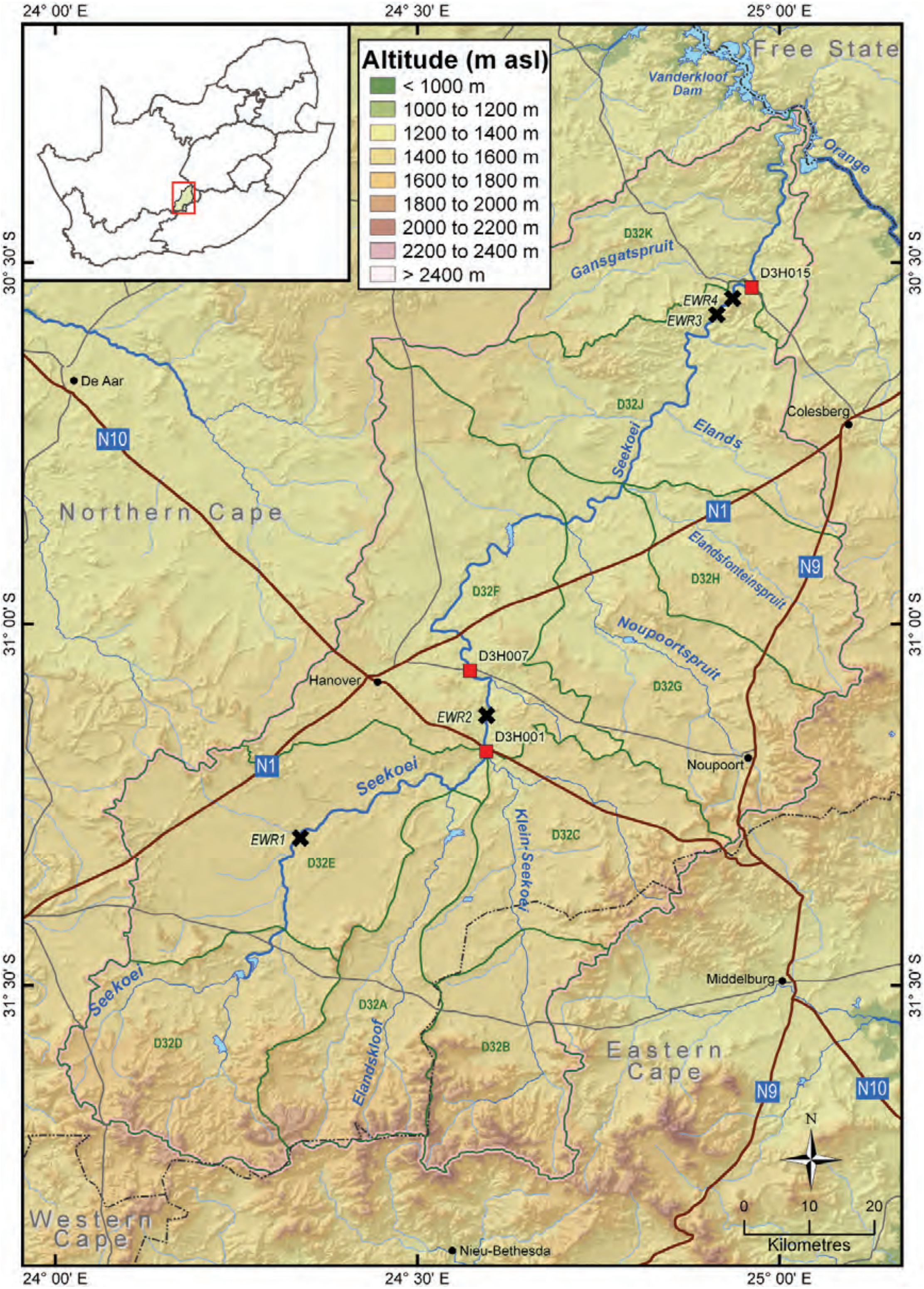

Figure 2.3: Topography of the Seekoei River catchment. (Data sources: IWQS, DWAF; Chief Directorate of Surveys and Mapping; Shuttle Radar Topography Mission, 2000, National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA)).

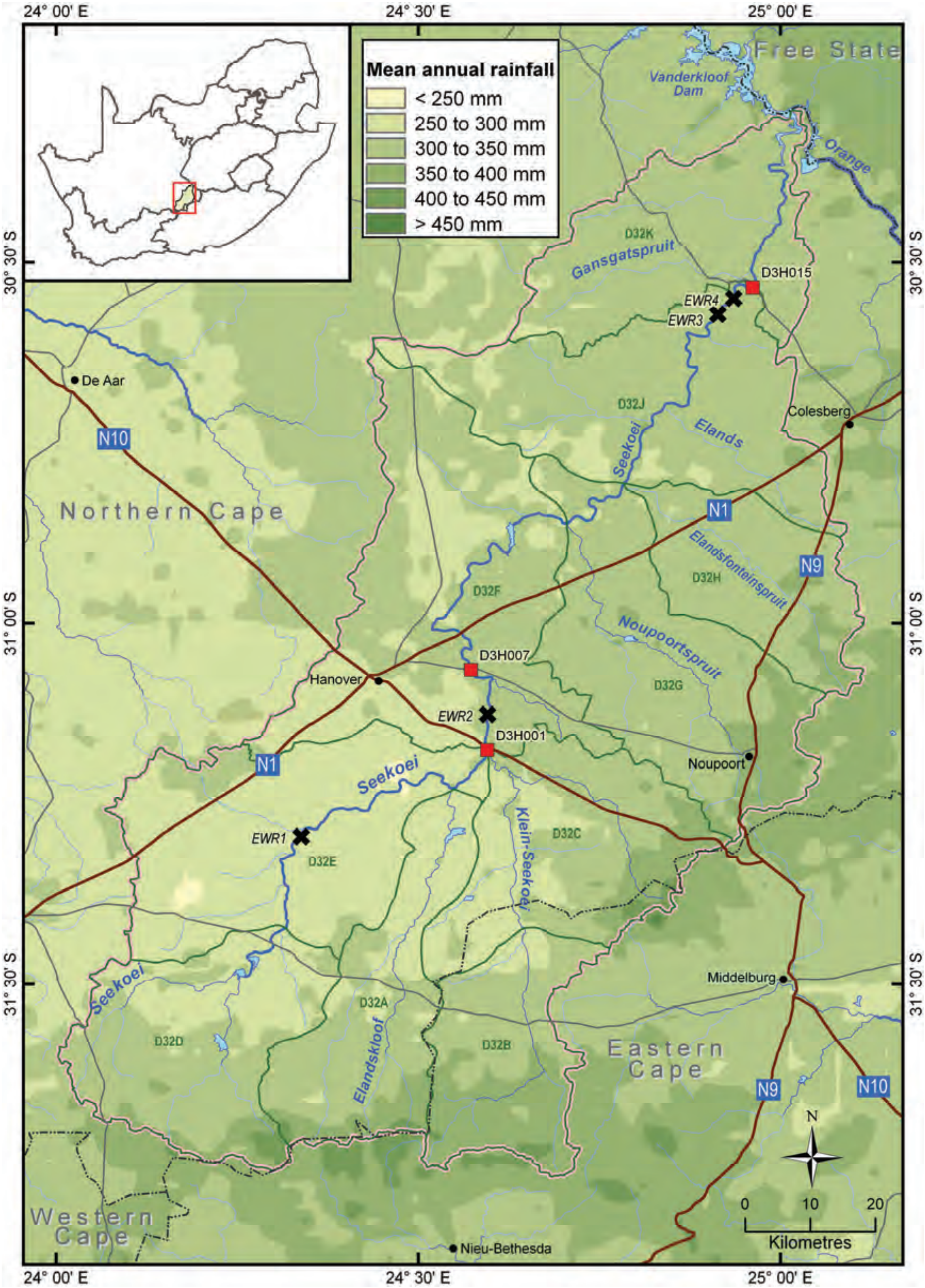

Figure 2.4: **Mean annual rainfall (mm) for the Seekoei River catchment. (Data source: Schulze, 1997).**

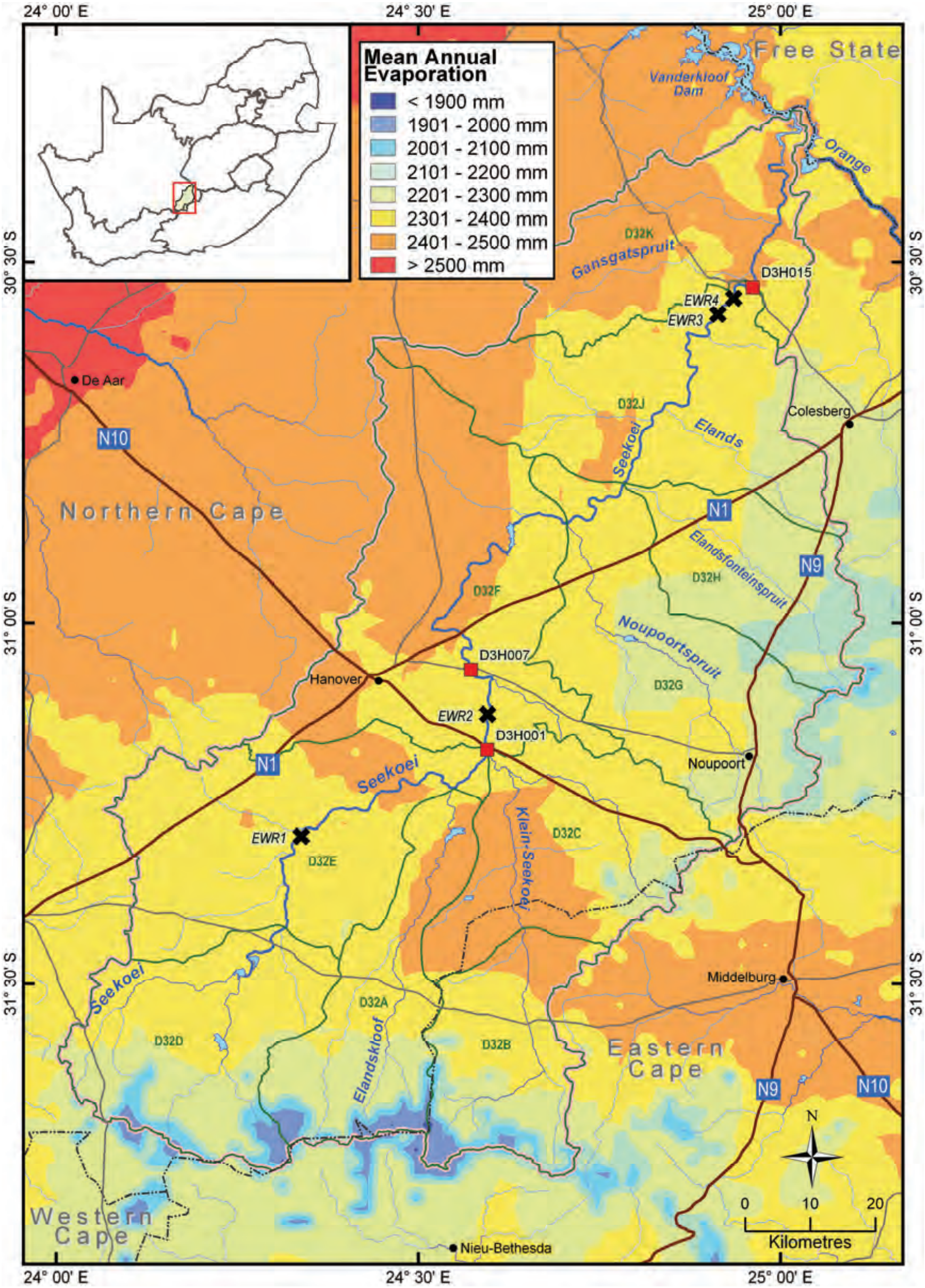

Figure 2.5: Mean annual evaporation (mm) for the Seekoei River catchment. (Data sources: Schulze, 1997; IWQS, DWAF and Chief Directorate of Surveys and Mapping).

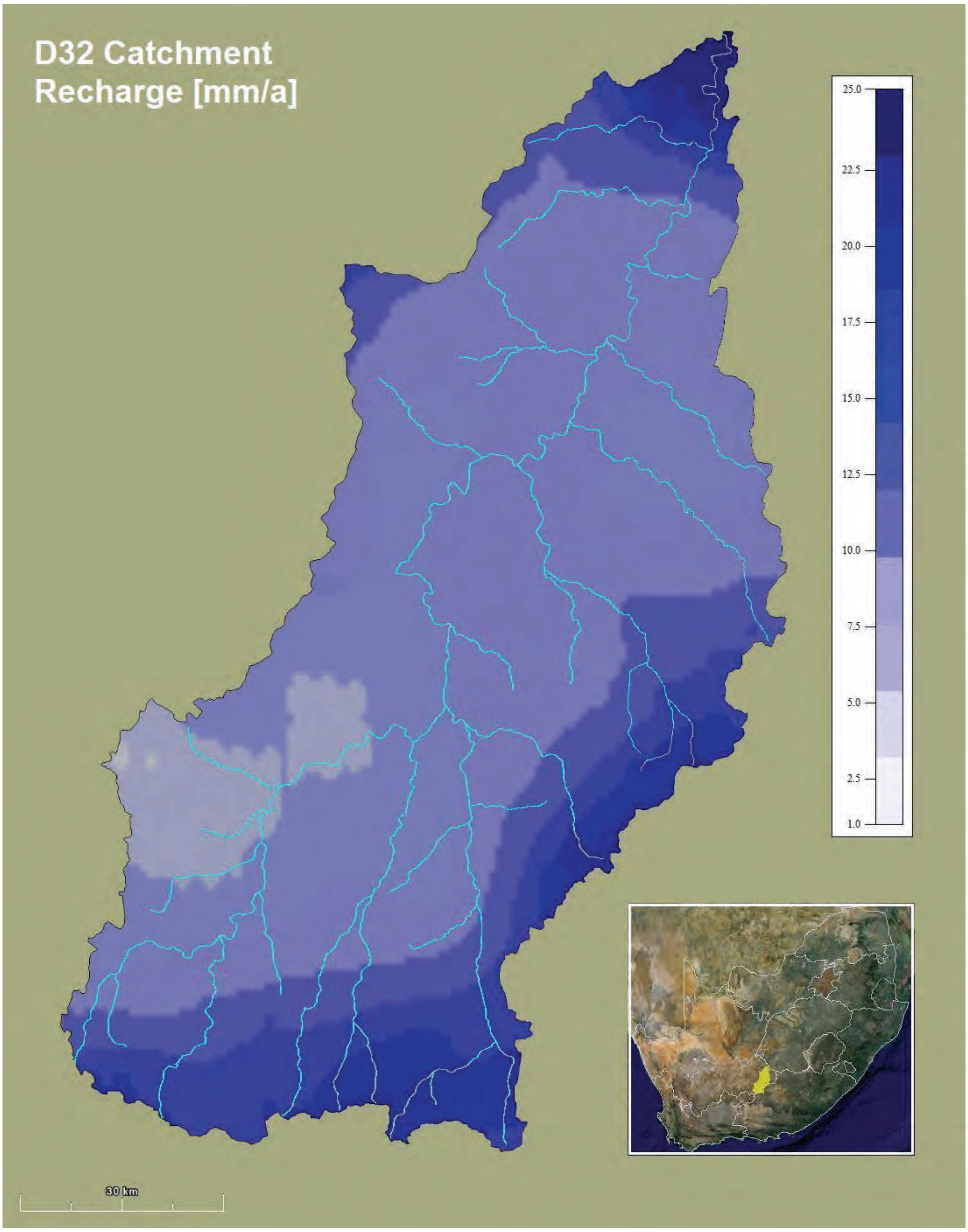

Figure 2.6: The rate of ground water recharge (indicated in mm/year) for the Seekoei River catchment (D32). (Map prepared by Dr. R. Dennis, Institute for Groundwater Studies, UFS).

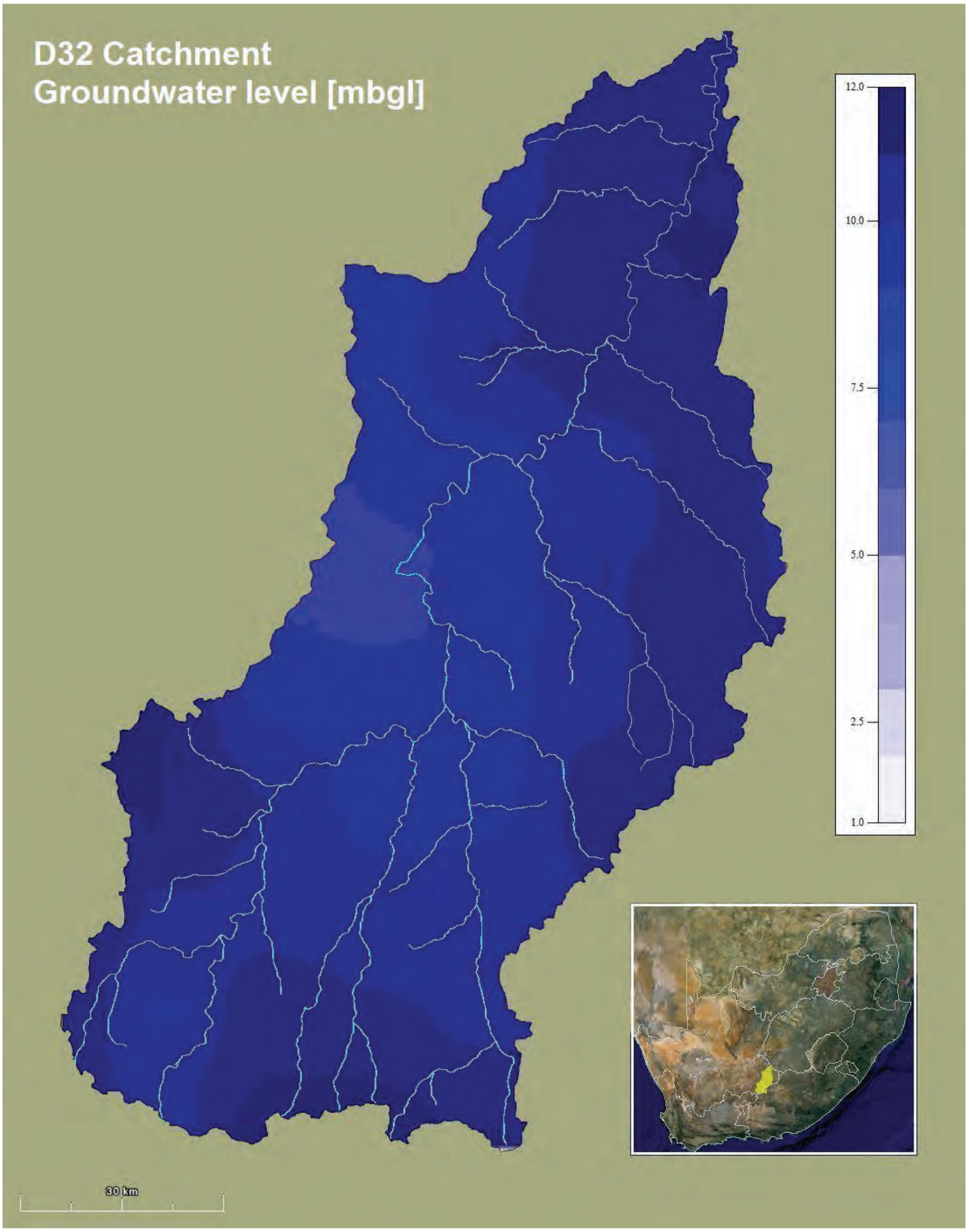

Figure 2.7: The level of ground water (indicated in meters below ground level) for the Seekoei River catchment (D32). (Map prepared by Dr. R. Dennis, Institute for Groundwater Studies, UFS).

2.2.4 *Vegetation*

The Seekoei River catchment is situated in the Nama Karoo Biome which covers most of the vast central plateau region of the Western and Northern Cape Provinces. Two main vegetation types occur in the catchment, namely Besemkaree Koppies Shrubland and Eastern Upper Karoo (see Figure 2.8; Mucina and Rutherford, 2006).

The Besemkaree Koppies Shrubland is found on the slopes of koppies and is dominated by small leaf dwarf shrubs in the lower canopy, and tall shrubs such as *Rhus erosa, R. burchelli, R. ciliata, Euclea crispa* subsp. *ovata, Diospyros austro-africana* and *Olea europaea* subsp. *Africana* in the upper layer (Mucina and Rutherford, 2006). The Eastern Upper Karoo vegetation is prevalent on flat or gently sloping plains, and is dominated by small-leaved dwarf shrubs and white grasses such as *Aristida* and *Eragrostis.* The grass cover increases with the amount of rainfall experienced (Mucina and Rutherford, 2006).

Other vegetation types that also occur in the catchment are Upper Karoo Hardeveld (on steep rocky slopes), Northern Upper Karoo (flat areas in the northwestern part of the catchment), Karoo Escarpment Grassland (summit of mountains and hills), Tarkastad Montane Shrubland (rocky ridges and slopes) and Highveld Saltpans (pans; Mucina and Rutherford, 2006).

2.2.5 *Ecological classification*

The Seekoei catchment is situated chiefly in the Nama Karoo Level I ecoregion (26) with only small patches in the south and southeastern part of the catchment falling in the Drought Corridor (18; Kleynhans et al., 2004). Three Level II ecoregions are recognised: 26.03; 18.01 and 18.06 (see Figure 2.9). Level II ecoregions are based on a combination of altitude, rainfall, runoff variability, air temperature, geology and soil (Kleynhans et al., 2004).

The main stem of the Seekoei falls mainly in the Lower foothill longitudinal zone with only three stretches in the middle section being classified as Lowland river (see Figure 2.9). This classification, which is based on Rowntree and Wadeson's (2000) geomorphological zonation of river channels, implies that the Seekoei's main stem is a low-gradient alluvium channel with sand and gravel dominating the bed. The upper reaches of the Seekoei and the various small tributaries are classified as Upper foothills indicating steeper slopes (gradient of 0.005-0.019; Rowntree and Wadeson, 2000).

2.2.6 *Land use in the catchment*

In early historical times the Seekoei River valley supported very large herds of game dominated by springbok, quagga and wildebeest, which congregated about the abundant natural springs (Bollong and Sampson, 1999), as well as predators such as lion (Sampson and Sampson, 1994). The abundance of game and other food sources, such as birds, fish and crabs, supported Bushmen in the Seekoei River headwaters and valley at least since the late Holocene (Plug and Sampson, 1996). Bushmen were still occupying natural shelters in the upper Seekoei River valley until approximately 1820.

Between 1760 and 1770, Dutch stock farmers (trekboers) established themselves on the banks of the Seekoei River (Sampson and Sampson, 1994). In 1798 the Seekoei River was officially recognised as the Cape boundary by Governor Van Plettenberg when he set up a marker there. By the late 1870's the valley was entirely taken up by farms (Plug and Sampson, 1996) and an elaborate network of wagon trails existed (Neville et al., 1994). These tracks were not only used by farmers, but by hunters, traders, missionaries, explorers and fortune-seekers, especially after the discovery of diamonds in Kimberley (Neville et al., 1994). Some of these early travellers described the Seekoei River and its tributaries as a seasonal river, consisting of a long chain of pools (zeekoegaten) during dry periods (Holmes, 2001). These early accounts also frequently make mention of droughts or floods, illustrating the event driven nature of the flow regime.

The establishment of agriculture in the Seekoei River catchment has had several ecological implications, such as:

Large scale destruction of large game populations in the eighteenth century due to hunting [1](Plug and Sampson, 1996)

- The introduction of domestic mammal species.
- Deforestation of the natural vegetation in order to plant crops like wheat.
- The degradation of Karoo veld as a result of the extensive wagon trail network (Neville et al., 1994)
- The erection of weirs and small dams in the river channel (Holmes, 2001).

---

[1] Three hippopotami were reintroduced in 2005 on the farm New Holme, Hanover district, after the last hippopotami were shot in 1775 (Volksblad, 14 December 2005).

A study by Holmes (2001) and others (Foster et al., 2007; Boardman et al., 2003) investigating environmental change in the upper Seekoei catchment area over the past 60 years, indicated the presence of extensive sheet, rill and gully erosion. From historical aerial photographs of the area it was clear that gully networks have cut back into valley headwaters at numerous locations within the catchment. Also, that sedimentation filled several weirs to their tops, and that even though artificial structures did not remedy erosion and sedimentation it raised saturation levels in their immediate upstream environments.

At present land use in the catchment comprises mostly of agricultural activities, such as game and stock farming, or a combination of livestock, game and limited opportunistic irrigation agriculture (predominantly fodder for livestock; see Figure 2.10).

2.2.7 *Infrastructure*

There are no major towns that have an influence on the river but the river flows through the Richmond, Hanover, Philipstown and Colesberg areas. Hanover and Noupoort are situated on the watershed between the Seekoei and Brak Rivers and the Seekoei and Fish Rivers respectively and both use boreholes to supply urban needs (see Figure 2.10). There is some diffuse irrigation from small dams on the Seekoei River (DWAF, 2004).

A large number of impoundments, 59 weirs, seven dam walls and 22 earth dams, occur on the river (Watson and Barker, 2006) most of which are due to agricultural activities.

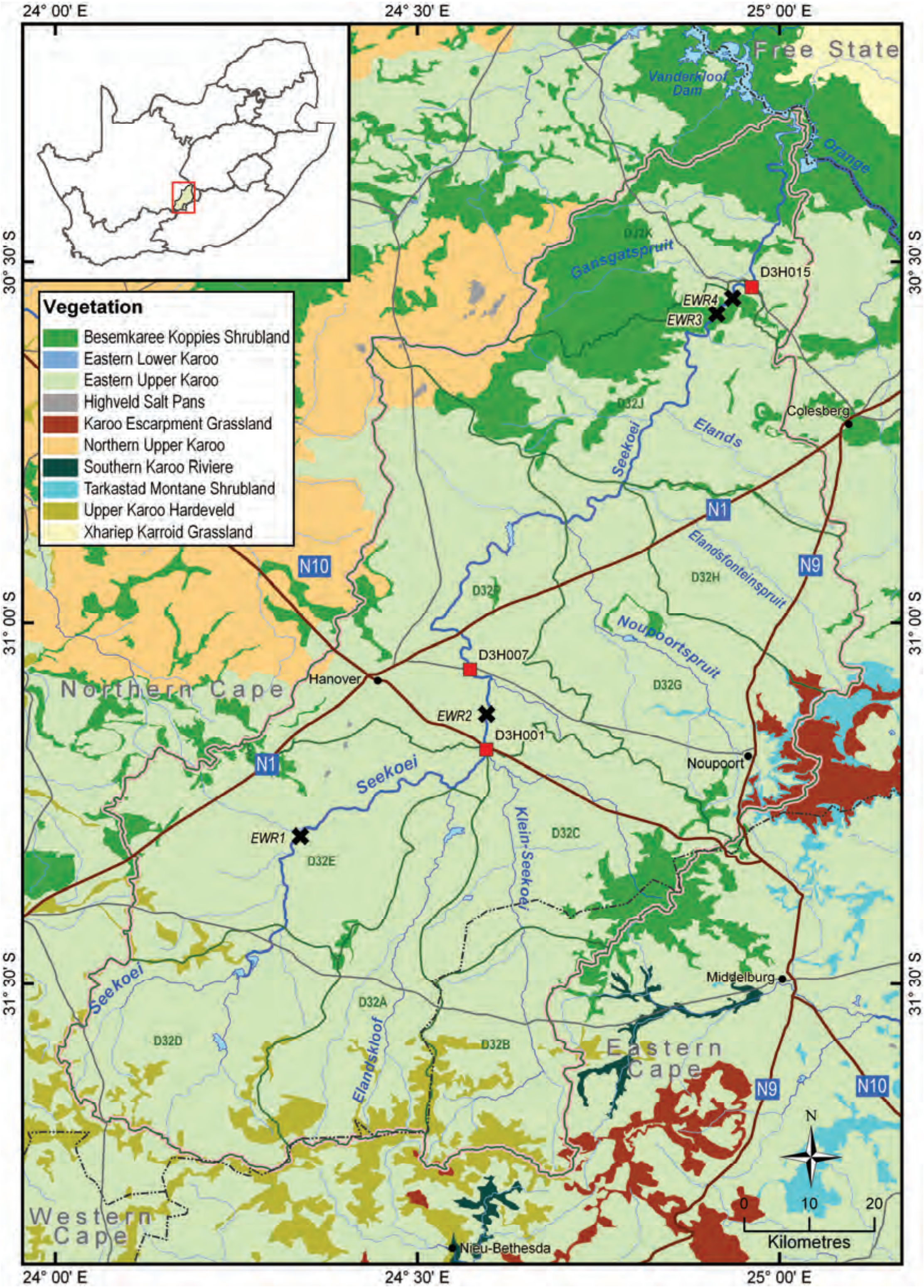

Figure 2.8: Vegetation types represented in the Seekoei River catchment. (Data sources: ENPAT, 2001; IWQS, DWAF and Chief Directorate of Surveys and Mapping).

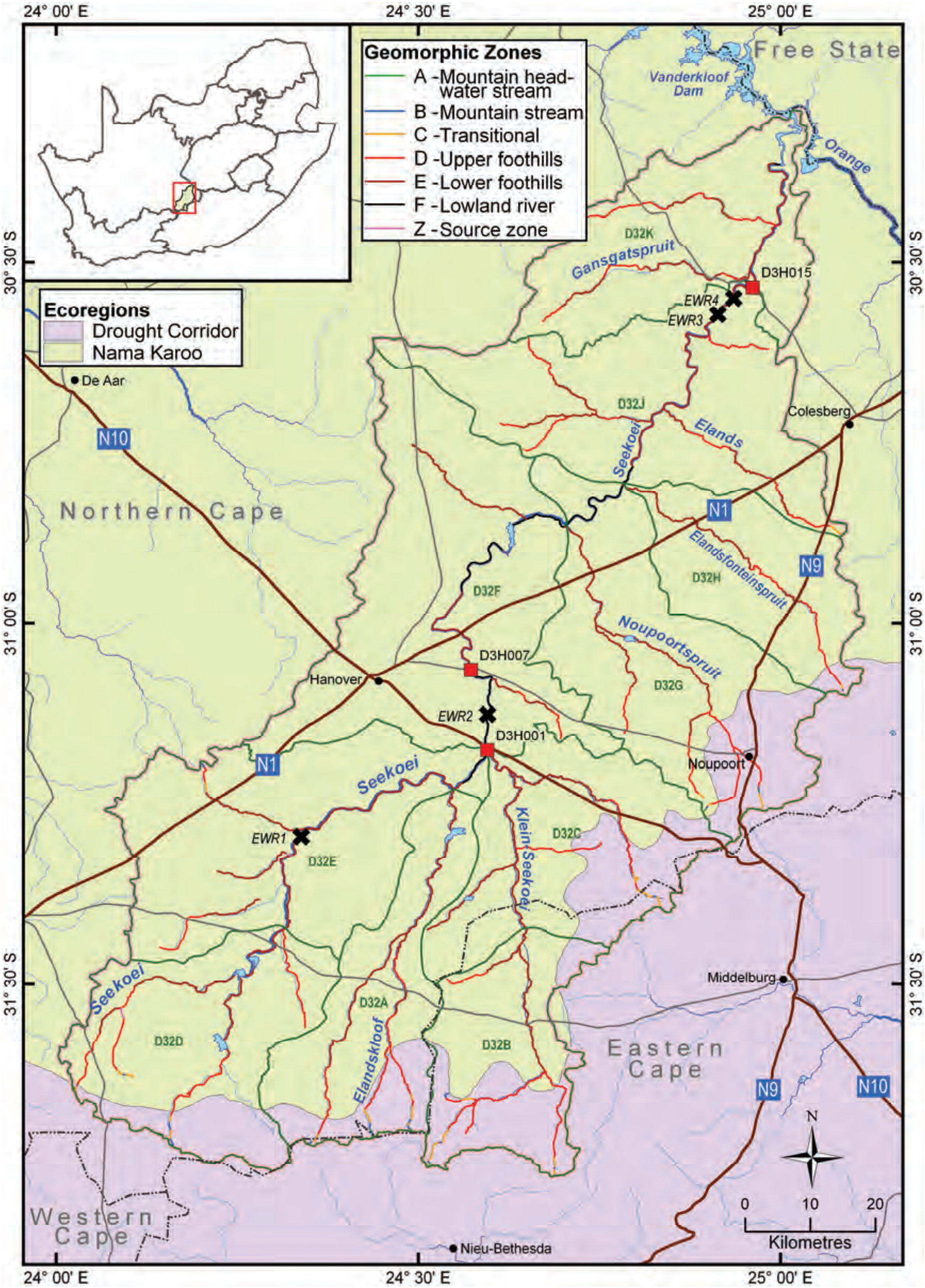

Figure 2.9: Ecoregions and geomorphological classification for the Seekoei River and tributaries. (Data sources: IWQS, DWAF and Chief Directorate of Surveys and Mapping).

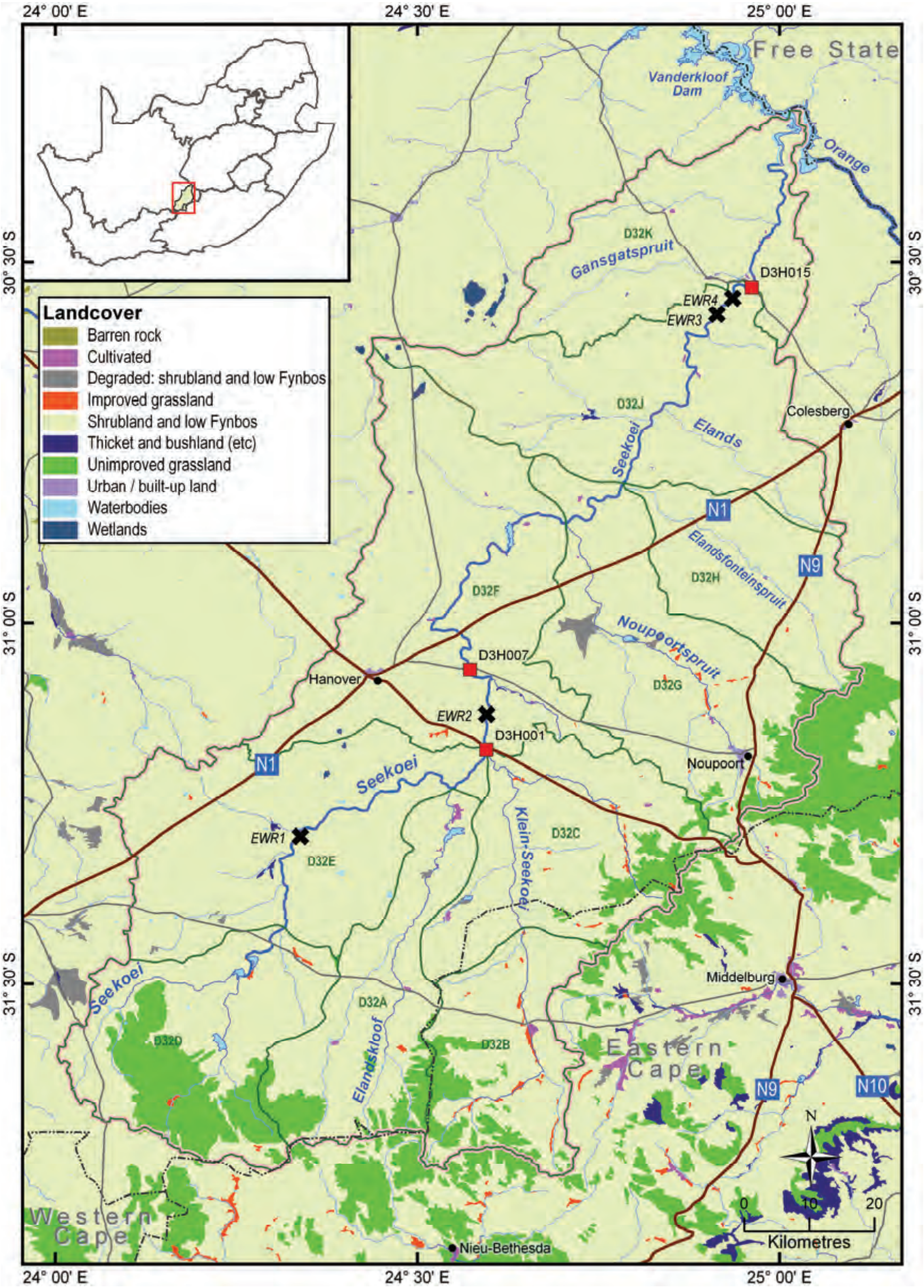

Figure 2.10: Landcover for the Seekoei River and tributaries. (Data sources: CSIR/ARC National Land-cover Database 2000; IWQS, DWAF and Chief Directorate of Surveys and Mapping).

2.3 Field sampling in the Seekoei River

2.3.1 Sampling frequency

Field data were collected for ten specialist fields in the Seekoei River over a two-year period, namely hydrology (to a limited extent); geohydrology; hydraulics (to an extent); catchment geomorphology; fluvial geomorphology; water quality; riparian vegetation; aquatic macroinvertebrates, fish and socio-economic issues (to an extent). Thirteen field visits were made to the river between March 2006 and March 2008: two by the full team in March and September 2006, one by the geomorphology team in July 2006 and eleven six-weekly routine sampling visits (see Table 2.1). For more information on the flow conditions that prevailed at the sampling sites during sampling, please refer to Table 5.17.

Table 2.1: Dates of field visits to the Seekoei River by the specialists for the various specialist fields included in the study.

Date	Purpose	Disciplines involved
2005		
21-22 November	Reconnaissance and site-selection	Geohydrology, fluvial geomorphology, water quality, aquatic macroinvertebrates, and fish
2006		
27-31 March	Data collection and full team discussions	Water quality, aquatic macroinvertebrates, and fish
23-25 May	Data collection	Water quality, aquatic macroinvertebrates and fish
27-29 June	Data collection	Water quality, aquatic macroinvertebrates and fish
3-7 July	Data collection	Catchment geomorphology
15-17 August	Data collection	Water quality, aquatic macroinvertebrates and fish
25-29 September	Data collection and full team discussions	Hydrology, geohydrology, fluvial geomorphology, water quality, aquatic macroinvertebrates, and fish
13-15 November	Data collection	Water quality, aquatic macroinvertebrates and fish
11-12 December	Hydraulic cross-sections and data collection	Hydraulics, water quality and fish

Table 2.1 continued: Dates of field visits to the Seekoei River by the specialists for the various specialist fields included in the study.

Date	Purpose	Disciplines involved
2007		
30 January-2 February	Data collection	Water quality, aquatic macroinvertebrates and fish
20-22 March	Data collection	Water quality, aquatic macroinvertebrates and fish
12-14 June	Data collection	Water quality, aquatic macroinvertebrates and fish
9-11 October	Data collection	Water quality, aquatic macroinvertebrates and fish
2008		
28 March-11 April	Data collection	Water quality, aquatic macroinvertebrates and fish

2.3.2 *Sampling sites*

Four sampling sites were selected for study on the Seekoei River: EWR1 in the upper part of the catchment, EWR2 in the middle part and EWR 3 and 4 in the lower catchment (see Figure 2.1). Site-selection was primarily based on a macro-reach analysis which divided the river into distinct geomorphological reaches based on the river's longitudinal profile, a habitat integrity assessment which evaluated the physical condition of the in stream channel and riparian zones of the river, and information obtained during a recognisance visit to the river. Based on this information it was decided to select four sampling sites located in macro-reaches 2, 4 and 5. The site-selection process, including the macro-reach analysis and habitat integrity assessment, is discussed in more detail in Chapter 5 and will not be duplicated here. Reports outlining the macro-reach analysis by Dollar (2005) and the habitat integrity assessment by Watson and Barker (2006) are included on the CD and will provide further details on the methods followed and the results obtained.

The location and physical characteristics of the four sampling sites are described below.

2.3.2.1. *EWR1*

EWR1 is situated southeast of Hanover on the main stem of the Seekoei River (D32E), about 20 km upstream of the confluence of the Seekoei and the Klein Seekoei Rivers. In this reach (macro-reach 3), the river meanders over alluvium which is underlain by mudstone and sandstone. The dominant channel type comprises isolated pools and dry linear distributary channels. Both the in-stream and riparian zones are largely natural (Instream Habitat Integrity, IHI, Class B; Riparian Habitat Integrity, RHI, Class B) with flow regulation being the major impact in the reach.

The site is dominated by a persistent, but isolated, pool of approximately 90 m long, 7.4 m wide and approximately 70 cm deep (at the deepest point; see Plate 1). The pool's substrate consists mostly of sand to very fine sediment covered by extensive organic matter deposits and is fringed by sedges. The active channel is overgrown with sedges.

2.3.2.2. *EWR2*

EWR2 is located downstream of the confluence of the Seekoei and the Klein Seekoei Rivers in Macro-reach 4 (D32F), east of Hanover (Figure 2.1). The river channel consists mainly of a single thread channel flanked by reeds, and broken occasionally by pools and distributary channels (Dollar, 2005). The in-stream and riparian habitats of the river is moderately modified in this reach (IHI Class C), mainly due to flow regulation (24 weirs and 1 dam wall) and reed encroachment in and along the riverbed.

The sampling site comprises a large pool (approximate pool length: 75 m; width: 12.92 m at the widest point) surrounded by reeds (*Phragmites australis*; see Plate 2). The pool has a shallow section of about 30 m long, which dried up several times during the study period[2]. The pool has a sandy bottom with decomposing reed material. The channel at the site is very uniform with extensive reed growth on the terraces, benches and in-channel (Petersen and Dollar, 2008).

The site is situated about 2 km downstream of a large weir (D3H001 – once used for measuring flow) which is not ideal due to the impact the weir might have on the natural flow patterns. The pool is, however, fairly natural. Although a number of large pools occur downstream of EWR2, the water levels of these pools are artificially managed for agricultural purposes, making them unsuitable for EWR assessments.

2.3.2.3. *EWR3 and 4*

Sampling sites EWR3 and 4 are both situated in macro-reach 5 in the lower part of the Seekoei River (D32J). This lower section of the catchment is characterised by a much steeper topography, where the river flows over dolerite and shale, siltstone and sandstone. The river channel comprises mainly of alternating pools and rapids with

[2] The shallow part of the pool was dry when the site was visited in November 2005 for site-selection.

riffles occurring only towards the upper end of the reach (Dollar, 2005). The channel form (and hydraulics) is strongly controlled by local bedrock intrusions. Flow regulation as a result of the Vanderkloof Dam and several other impoundments, has a major impact in this reach of the Seekoei e.g. decreasing the variety of geomorphic features. The instream habitat is, therefore, considered to be largely modified (IHI Class D; Watson and Barker, 2006). The riparian zone was rated as moderately modified (RHI Class C). Approximately 39% of the reach has reeds along the river, which could have a large impact on the flow, bed and channel of the river in this reach.

Available habitats at EWR3 comprise a large pool (1 173 m long, 100-180 m wide, and 2.36 m deep at the deepest point when full) with a capacity of 32 517.46 m^3 (when full[3]) and when the river is flowing, a run of 30 m and a riffle/rapid of about 70 m length (see Plate 3). The bottom of the pool consists mostly of coarse to fine sand, while the bed material of the run and riffle/rapid is typically coarser, consisting of cobbles and boulders (Petersen and Dollar, 2008).

The channel form at EWR4, which is situated approximately 2 km downstream of EWR3, is dominated by bedrock. The site is dominated by a large shallow pool with a sandy, gravel bottom (Plate 4). Several bedrock pools, rapids and a few riffle areas are present when the river is flowing.

The pool at EWR4 initially appeared to be fed by ground water, in contrast to the pool at EWR3 which appeared to be fed by surface runoff water. EWR4 was added as an extra site in order to investigate possible differences between pools fed by surface water and those maintained by sub-surface water.

2.4 *Ecological functioning of the Seekoei River*

2.4.1 *Overview of the present understanding of the Seekoei River's ecological functioning*

The upper part of the Seekoei River catchment is steep with floodout type channels, resulting in surface water becoming dispersed very quickly on the flat plain immediately downstream. The lower reaches of the river, where sites EWR3 and 4 are located, is situated in a gorge extending approximately 8 km and starts a few km upstream of the gauging weir at the outlet of quaternary catchment D32J. This high topography area occupies 20 to 30% of the total area of D32J (1112.5 km^2) and is

[3] Volume surveys of the pools done by Mr. J. Le Grange of DWAF, Free State region.

drained by 12 major tributary streams. Although this area covers a small area of the total catchment, most of the flow recorded at the measuring weir, is generated here, and proved to have a major influence on the flow regime. For example, while surface flow was lacking in the upper catchment in August 2006, flow records at the gauging station suggest that a flow event with a peak of 2 m^3s^{-1} occurred in the lower parts.

The existence of prolonged flow (after events) only in the lower part of the catchment is attributed to unsaturated zone drainage from the high topography area in the vicinity of the gorge. Whether this represents concentrated outflow at the base of a perched aquifer or more distributed lateral flow (interflow) through fracture zones is difficult to confirm. The results, however, should be quite similar. It is postulated that after major rainfall events the quantity of this flow could be quite substantial, either because of a greater head caused by additional recharge, or because a larger number of springs are active.

One of the most critical issues that has potential to impact on ecological functioning in non-perennial rivers systems is the dynamics of pool storage. Pools in the Seekoei River occur mostly upstream of hydraulic controls: In the upper part of the catchment the controls tend to be sedimentary features, and in the lower parts dolerite intrusions. Under drying conditions, the dynamics of the pool storage in the lower part of the catchment seemingly depends upon the balance between spring discharge and pool evaporation, which will differ between seasons. In the upper parts of the catchment, where there is little evidence of spring flow, it is possible that small contributions to pools are made through connections with the ground water, but these are expected to be relatively small due to the low hydraulic gradients. Most of the pools in the upper part of the catchment are therefore expected to dry out relatively rapidly, depending on the evaporative demand.

Water quality at the four sampling sites differed not only in salt concentrations, but also in ion dominance. Salt concentrations at Site EWR1 (>1000 mg/ℓ) were consistently higher than at the three downstream sites (average of 450 mg/ℓ). Salt concentrations at EWR sites 3 and 4 showed an increase with a decrease in pool depth, mainly as a result of evaporation and/or evapotranspiration. Na and Cl were the dominant ions at all EWR sites, except EWR2 where Ca, Na and Mg were dominant, indicating a strong geological effect. Ca, Sulphate and Mg were the dominant ions at the two interflow springs monitored. This high variability between sites makes it difficult to predict the expected water quality of pools/reaches not sampled.

The influence of the steep topography in the lower part of the river was also evident in the distribution of riparian plant species. Riparian vegetation at EWR sites 1 and 2 was restricted to sedges, rushes and a few hygrophilous grasses. The absence of trees and shrubs from the flat lying plain are mainly as a result of the occurrence of severe frost in winter. The hills and ridges at sites EWR3 and 4 provides a more protective environment for these growth forms, and several indigenous trees and shrubs are found here. Even though similarities exist between EWR1 and 2, distinct differences between the plant communities of these sites were noted.

Invertebrate and fish composition at sites EWR1 and 2, comprising isolated pools, differed from sites EWR3 and 4 with pools and riffle biotopes, even when EWR3 and 4 were left with isolated pools after a long dry period. The macro-invertebrate community was more diverse at sites EWR3 and 4 with 36 and 33 families compared to the 21 and 23 families sampled at EWR1 and 2 between March 2006 and October 2007. The presence of the invertebrates appears to be related to the hydrological phase (pool, onset or flow) at the site, as well as, biotope availability. No clear pattern of invertebrate presence could be ascertained from the period of sampling (March 2006 to June 2007).

The fish community of the Seekoei River is naturally species poor, and consists of hardy generalist species. Fish species richness and diversity increased downstream with one minnow present at EWR1 and seven species (including two exotics) sampled at EWR4. Shallows play a major role in protecting young fish from predation by larger fish which are more common in deeper water. When pools dry out, young fish are forced from the extensive flat shallow vegetated areas into steeper-sided deeper pools where they are more vulnerable. The high number of weirs restricting flow and upward migration of fish creates concern; only during major flow events can fish circumvent weirs.

The socio-economic profile of the population utilizing the Seekoei River is made up of established commercial farmers and their workers. General farming activities are game and stock farming, or a combination of livestock, game and limited opportunistic irrigation agriculture (predominantly fodder for livestock). The large number of dams and weirs in the river course have been erected for irrigation abstraction, stock watering and for recreation.

2.4.2 *Specialist studies*

In order to save space, the specialist studies are included on compact disc (CD; see Table 2.2). They include a literature study providing some background and perspectives of the specific discipline in a non-perennial setting, the methods followed by each specialist, the results obtained and a discussion.

Table 2.2: A list of the specialist reports produced for the Seekoei River, indicating which are available on a CD attached to the report.

Reports	Authors	Included on CD
Supporting reports		
Macro-reach analysis	Dr. Evan Dollar	X
Habitat Integrity Assessment	Ms. Marie Watson and Dr. Charles Barker	X
Site-selection report	Marinda Avenant	X
Specialist reports		
Hydrology	Prof. Denis Hughes[4]	Published separately
Geohydrology	Prof. Gerrit van Tonder	X
Catchment geomorphology	Dr. Charles Barker	
Fluvial geomorphology • Sediment surveys • Methodology applied for the fluvial geomorphological component	Dr. Evan Dollar and Ms. Chantel Petersen	 X X
Water quality	Ms. Linda Rossouw	X
Riparian vegetation	Prof. Johann du Preez	X
Aquatic macroinvertebrates	Ms. Marie Watson	X
Fish	Ms. Marinda Avenant	X
Socio-economics	Dr. Jack Armour	X
Hydraulics	Dr. Evan Dollar	X

Summaries of the main findings of the specialist studies done for the Seekoei River are given below.

[4] The hydrology report has been published as a separate report by the WRC, see Hughes (2008).

2.4.2.1. *Geohydrology and hydrology*

A conceptual model of the interaction between surface and ground water, based on data obtained from boreholes and springs, was developed for the Seekoei River.

The movement of water to the river channel is considered to occur within the perched water table associated with weathered dolerite, as well as within the hardrock aquifer. The colluvium beneath the channel bed is also considered to play a role in the sub-surface movement of water in the direction of the channel. Contributions to the channel are expected to be highly localized (in springs) due to structural differences and the occurrence of more transmissive fracture zones and weathered material. These contributions are expected to contribute to pool storage, support riparian vegetation and be lost to evaporation. The exact water balance in any specific part of the channel system will largely depend on the balance between the seepage contributions and the evaporative losses.

The low gradients in the side slopes, even far away from the channel, suggest that seepage rates would be very slow. The low gradient topography and shallow, stony soils suggest that there is a substantial opportunity for recharge during rainfall events due to surface pondage and vertical drainage through macropores.

With respect to anthropogenic affects, there are many farm dams and main channel weirs within these catchments. The aerial recording of the river channel suggests that some of the main channel weirs are little more than low walls at the end of natural pools (which are unlikely to increase the channel pool storage by a large amount), although there are also several quite substantial earth dams that will increase in-channel storage and affect downstream runoff during small to moderate sized runoff events. It is very difficult to speculate on the impacts of the many farm dams that are remote from the channel system in an area with such low gradient topography.

An issue that is worth noting is that if the conceptual model (see Figure 5.7 in Chapter 5 for an illustration of the concept) is realistic then channel losses to ground water are likely to be a negligible component of the overall water balance. This is because the model assumes that the water table is close to the channel bed. There may be parts of the channel system that are losing water during surface runoff events, while other parts of the channel system are gaining water through ground water discharge. However, on balance the losses are expected to be small.

The two most important mechanisms that therefore influence pool sustainability (in terms of not drying up) in the lower part of the Seekoei River, are the number and flow rate of springs situated upstream of where the pools are located and the flux of ground water towards the pools in the channel aquifer. Of these, the contribution from the interflow springs was considered to play the most important role in sustaining the pools in the river channel. Flow from the hard rock aquifer adjacent to the pools was very low, with most of this flow being used by the riparian vegetation.

2.4.2.2. *Fluvial geomorphology*

The Seekoei River is defined as a typical dryland river, characterised by its flow variability receiving flow 10-80% of the time as described by Young and Kingsford (2006). It has a hydrological index value 66, making it one of the most hydrological variable systems in South Africa (see Dollar, 2005). Dryland rivers are characterised by their hydrological variability, spatially or temporally. This is due to the highly variable effective rainfall and low rainfall to runoff ratios (Puckridge et al., 1998; Thoms and Sheldon, 2000; Kingsford and Thompson, 2006). Rainfall is often localised and of short duration so that runoff is variable in both years and storms within a year (Peel et al., 2001). As a consequence, runoff can be localised so that flows can occur in small tributaries or sections of the main stem river, while a large percentage of the channel system remains dry (Jacobson, 1997). Extended periods of time can pass with little hydrological connection, which creates intermittently connected habitats with exceptions occurring during large floods (Young and Kingsford, 2006). These characteristics have been displayed by the Seekoei River where the intermittently connected habitats consist predominantly of pools. The dynamics of pool storage and the frequency of pool connection in the Seekoei system have been identified as important issues (see Hughes, 2006), which drives the ecology and their dependent ecosystems (Young and Kingsford, 2006).

A number of additional key hydrological characteristics are evident in dryland rivers (after Young and Kingsford, 2006), which are also relevant to the Seekoei River:

- limited water availability;
- high rates of evaporation;
- low rainfall runoff ratios;
- frequent periods of zero flow;
- irregular floods;
- downstream reductions in peak discharge per unit area is more pronounced

- relative flood magnitudes are more variable in dryland rivers than humid rivers (ratio of mean annual flood to 50-year flood can be 10:1 in dryland rivers, as opposed to 2:1 or 3:1 for many perennial systems). This hydrology acts on a physical template which both influences and is influenced by sediment and vegetation (Dollar et al., 2007). The physical template of the Seekoei River is described by Partridge et al. (in press), who note that for the majority of the its path, the Seekoei River traverses the Upper Karoo and Lower Vaal and Orange geomorphic provinces. The Upper Karoo geomorphic province is characterised by the flat-lying sedimentary rocks of the Karoo Supergroup which have been intruded by sills and dykes of dolerite. This extensively planed landscape has resulted in ephemeral rivers which occupy broad, open valleys, and have braided floodplains and concave longitudinal profiles. The Lower Vaal and Orange Rivers geomorphic province represents an area where the rivers are incised in the Post-African I cycle (cf. Partridge and Maud, 1987). Accordingly, within this province, the Seekoei River valley is more incised and the slope steeper (than the Upper Karoo geomorphic province). The hydrology acting on these two (different) physical templates results in different channel types and assemblages of geomorphic units; in particular,
- unique features can occur (floodouts and waterholes – large isolated pools).

Geomorphological variability in the Seekoei River is provided by the in-channel/riparian vegetation and the geology. The geology plays a significant role in the shape of the longitudinal profile (through hydraulic controls, breached/unbreached sills and dykes and knickpoints) and influences the channel type and the location of pools. Two types of pools have been identified in the Seekoei River; 1) intrusions of dolerite and incision into the Karoo bedrock create hydraulic controls and 2) sedimentary hydraulic features create hydraulic controls.

Our understanding of dryland river systems in southern Africa is in its infancy. It is clear that there is significant work to be done, particularly in understanding sedimentary hydraulic features creating hydraulic controls.

Compound channel morphologies commonly occur in dryland systems, with an active channel nested within a broader ‘macro-channel’ (cf. Graf, 1987; Thoms and Walker, 1992; Wende and Nanson, 1998; Moon et al., 1997; Makaske, 2000; Tooth, 2000). The within-channel morphology is dynamic, with longitudinal variations in sediment supply, hydrology and channel boundary conditions producing variable channel morphologies and morphological units which represent adjustments to different dominant flow regimes and result in varying biotic assemblages. Another common feature in dryland rivers are in-channel benches; these are depositional features that are often flat, elongated and crescent-shaped in planform, and are formed by suspended load deposition (Thoms et al., 2006). These features were also observed in the Seekoei River channels and more detail regarding the macro-reaches, cross-sections and physical sediment analysis can be found in Dollar (2005), Dollar (2007) and Petersen and Dollar (2008) respectively.

It is likely that these are highly variable in space and time in the Seekoei River, which could result in equilibrium, non-equilibrium or 'patchy' equilibrium conditions, depending on the scale of observation, as was found by others (e.g. Tooth, 1999; Nanson et al., 2002; Thoms et al., 2006). It can also be reasonably assumed that large infrequent disturbances are the most "effective discharges", responsible for sediment transport and channel formation. Although other flow regimes such as freshes/flash floods, low flows and no flows are also important as shown by authors (e.g. Graf, 1987; García, 1995; Petts, 1996; Thoms and Sheldon, 2000, Holdt, 2005; Sheldon and Thoms, 2006), the significance compared to large infrequent floods are not known. It is also likely that as the Seekoei River is so infrequently connected hydrologically, any disruption to this connectivity (e.g. through impoundments, diversions, abstractions) is likely to have significant implications for fluvial processes.

2.4.2.3. *Water quality*

Historical water quality data for the Seekoei River were only available at Gauging Station D3H015-Q01. The data contain a long term water quality record from 1980 to the present and sampling is ongoing. This station is located downstream of EWR4 at the lower end of the catchment and is more perennial than the upper parts of the river. Only salinity and nutrients will be discussed.

- The trend appears to be a small decrease in the TDS/EC over the long term. TDS concentrations range from about 300 mg/ℓ to almost 800 mg/ℓ.
- Sodium and chloride are the dominant ions.
- A strong seasonal trend is evident in TDS/EC, with elevated TDS concentrations occurring during the drier winter months.
- There does not appear to be a definite trend in the Dissolved Inorganic Nitrogen (DIN) or Phosphate (DIP) concentrations.
- Nutrients show a seasonal trend. The DIP decreases over the winter months whereas the DIN shows an increase and then a decrease before increasing again during the warmer summer months. The concentrations range from 0,023 to 0,050 mg/ℓ for DIP and 0.05 to 0.120 mg/ℓ for DIN.

The water quality situation assessment of the Seekoei River is based on the present day data that were collected over 18 months. The study period was from November 2005 to June 2007 and samples were taken at the EWR sites.

- The water temperature typically follows a winter low, summer high temperature profile at all the EWR sites.
- The dissolved oxygen concentrations were generally higher during the colder winter months.
- The turbidity was generally low. Light limitation has a low probability of being a limiting factor of algal growth.
- The pH had a neutral to alkaline profile at all the EWR sites.
- EWR 1 had a much higher TDS concentration than any of the other sites (Table 2.3). EWR 2 had the lowest concentration, whereas EWR 3, 4 and 6 had very similar concentrations as was expected. The TDS concentrations in the springs differed from those at the EWR sites.

Table 2.3: **A summary of the TDS concentrations measured at the four EWR sites on the Seekoei River.**

TDS in mg/l	EWR1	EWR2	EWR3	EWR4	EWR 6	Spring1*	Spring2*
Median	1968	365	741	675	746	466	456
Min	968	206	307	366	311	455	453
Max	2582	671	865	1103	2450	477	458
5% Conf	1203	224	345	367	401		
95% Conf	327	125	141	166	612		

* Only two samples were taken

- Different ions dominated at each of the different sites. At EWR1 sodium, chloride and sulphates dominated. EWR 2 was different from the others in that calcium, sodium and then chloride and magnesium were the dominant ions. EWR 3 to 6 were mainly dominated by sodium and chloride with some sulphates and magnesium forming part of the TDS at EWR 3 and some sulphates at EWR 6. At the two springs, calcium, magnesium and sulphate were dominant. This indicated that the local geology and sources of water at the EWR sites play an important role in the chemical footprint of a particular site.
- The depth of the pools at the EWR sites also plays an important role in the TDS concentrations. The pool depth was more or less constant over the study period at EWR1. However, the TDS concentration varied from a minimum of

968 mg/ℓ in March 2006 to a maximum of 2582 mg/ℓ in June 2006 even though the water level was constant. This may imply that the pool is ground water fed, and that insufficient "fresh" water enters the pool to dilute the high TDS concentrations. It is assumed that the high TDS occurs naturally due to the local geology. White areas were found around the pool where salts had precipitated. This may be a natural process as salt-affected soils of primary origin result from the long term influence of natural processes accumulating salts in a particular region.

- At EWR 2 to 6, as was to be expected, the TDS concentrations increased as the water level dropped due to evaporation and evapotranspiration.
- At all the sites the algal species diversity was higher during the warmer months. At EWR2 the algal species diversity remained the same during the colder months, probably because it was a smaller, shallower pool compared to the other sites and experienced higher temperatures (warmed more quickly) that supported algal growth in the winter.
- In the samples taken from the Seekoei River it was found that for most of the sampling periods N was probably the limiting factor (N:P ratio <10). P was the limiting factor at all the sites during November 2007 when the water levels at all the sites were low. There was no flow at sites EWR3 and EWR4 during the August 2006 and January 2007 medians. In January 2007 the water levels at sites EWR3 and 4 were very low and there was no flow out of the pools. Conditions were the same as during November 2005. It can thus be concluded that P is limiting during drier cycles.

There are water quality and flow data at D3H015-Q01 from 1980 to the present. Hughes (2008) made some observations using the TDS data from the gauging station and the surface and spring data collected by the project team based on several assumptions:

- "The initial ground water investigation report suggests that the ground water spring flow that sustains pools during periods of zero flow has a TDS of approximately 400 mg/ℓ.
- The observed runoff at D3H015 has TDS values ranging from less than 100 to over 1500 mg/ℓ.
- The highest TDS values occur after prolonged periods of base flow or at the start of flow events that have very low flows."

The water quality and flow relationship still requires further investigation.

2.4.2.4. *Riparian vegetation*

In the upper reaches including EWR 1 and 2, a well-developed tree and shrub community are absent. The riparian vegetation consists mainly of grasses, sedges and a number of forbs.

The pools are surrounded by typical hydrophilous species such as the reed *Phragmites australis,* the grass *Agrostis lachnantha* and the sedges *Pseudoschoenus inanis* and *Cyperus longus*. The areas further away from the pools as well as between the pools are dominated by more hygrophilous species such as the sedge *Cyperus marginatus*, the forbs *Cirsium vulgare*, Veronica anagalis-aquatica*, *Sonchus oleraceus**, *Pseudognaphalium oligandrum, Mentha longifolia* and the grasses *Helictotrichon turgidulum and Bromus catharticus*.* (The asterisks denote exotic species).

Closer to the Orange River between the dolerite hills and where the springs supply a more constant flow of water the character of the riparian vegetation is more that of a perennial river. The riparian vegetation is restricted to the channel and channel banks. Zones in the lower and marginal zones are relatively well-defined.

A well developed tree and shrub zone occurs with trees such as Common Karee (*Rhus lancea*), Sweet Thorn (*Acacia karroo*), and White Stinkwood (*Celtis africana*). Prominent shrubs present *are Diospyros lycioides, Rhus pyroides,* and *Lycium hirsutum*. The only exotic tree in the riparian zone is the Weeping Willow (*Salix babylonica**).

In the marginal zone, the hydrophilic grass *Paspalum distichum* and the cosmopolitan reed (*Phragmites australis),* forms dense homogenous stands in the water. Other hygrophilous plants present in this zone are the woody hydrophyte *Gomphostigma virgatum*, sedges such as *Cyperus marginatus*, and *Pseudoschoenus inanis,* the forbs *Cirsium vulgare*, Veronica anagalis-aquatica*, *Sonchus oleraceus**, *Pseudognaphalium oligandrum,* and the grasses *Agrostis lachnantha*, *Bromus catharticus** and *Helictotrichon turgidulum*. These plants grow mainly on gravel bars, riffles, cobbles and boulder beds.

2.4.2.5. *Aquatic macroinvertebrates*

The intrinsic differences between a perennial and non-perennial river led to an investigation into the community structure of macro-invertebrates and the applicability of using the present ecological status (PES) methods in South Africa to determine the state of the river/reach/site in an Environmental Water Assessment (EWA). Various authors (Boulton and Suter, 1986; Chutter, 1998; Uys, 1997 and

Dallas, 2000) have indicated that methods developed for perennial systems and the understanding of the ecology of these systems should not be extrapolated without consideration to non-perennial rivers.

The Seekoei River in the Northern Cape, South Africa, is an interesting example of a non-perennial river as its upper reaches (sites EWR1 and 2) consist mostly of pools that are only connected during floods, and the lower reaches (EWR3 and 4) consist of riffles, rapids, runs and pools that usually flow after rainfall events.

The abiotic factors contributing most to the difference between sites was the higher conductivity (109-271 mS/m) measured throughout the study at site EWR1 and the difference in substrate (coarser sand to very fine sediment at site EWR1 and 2 and bedrock, boulders, cobbles, pebbles and gravel at EWR3 and 4) as well as the variability in flow (no-flow at site EWR1 and 2 and high to no-flow at sites EWR3 and 4).

Data collection using the standard SASS5 (South African Scoring System for Invertebrates version 5) method spanned a dry and a wet year (2006-2007) and all four seasons at four sites (EWR1 to 4) in the Seekoei River. All available biotopes were sampled across a range of hydrological phases (onset, pool, no-flow and flow).

The 41 families sampled at the four sites in the Seekoei River from March 2006 to October 2007 indicate that the river has a low family level diversity. Studies (Boulton and Lake, 1992; Uys, 1997) on other non-perennial rivers in Australia and South Africa have found a high species level diversity of macro-invertebrates. A total of 64 species were identified from all four sites sampled in March 2006 suggesting that the species diversity in the Seekoei River could also be high if more samples were identified to species level. Site EWR3 was the most diverse and EWR1 the least diverse at family level throughout the study period. This was expected as site EWR3 had more biotopes and flow available than site EWR1. At species level, the highest abundance was recorded at site EWR3 in March 2006, although site EWR4 had the highest species richness. The lowest abundance recorded in March 2006 was at site EWR2, also being the site with the lowest species richness.

The invertebrate fauna of the Seekoei River was dominated by insects (88%). Hemiptera (mostly facultative taxa that are able to occupy lentic or lotic habitats) and Diptera (comprising resident taxa adapted to and often restricted to temporary rivers as well as opportunistic taxa that are permanent stream forms not particularly adapted to temporary rivers) were the dominant orders in the Seekoei River. The most diverse order was Diptera being represented by nine families. The majority of families sampled in the Seekoei River were facultative and macro-invertebrates present were either predators or collectors. Facultative taxa generally remain in the river as conditions deteriorate due to drying (Uys, 1997). Agnew (1986) and Palmer (1996) suggest that the arid conditions surrounding the middle and lower Orange River (which is similar to conditions at the Seekoei River) isolates the river biogeographically. Most species present in these systems are resilient, hardy and temperature tolerant taxa.

Macro-invertebrate abundance data analysis indicated that there was a significant difference between macro-invertebrate communities at sites EWR1 and 3 ($r=0.765$, $p<0.001$). The three combined variables that contributed most ($r=0.593$, $p<0.001$) to the structuring of the macro-invertebrate community in biotopes were maximum velocity, percentage silt and percentage stones. Macro-invertebrate communities (using family data) in marginal vegetation out of current differed significantly ($p<0.001\%$) from the stones in current with some difference between the macro-invertebrate communities from stones in current and stones out of current. The Pool and Flow hydrological phase were significantly different ($r=0.612$ and $p<0.001$) with regards to the macro-invertebrate community composition.

Macro-invertebrate family abundance and presence/absence data from all sites combined indicated that there was no significant difference between months ($p<0.053$), between seasons ($p<0.01$) or between years ($p<0.008$). There was however a significant difference between years at sites EWR3 and 4 ($r=0.618$, $p<0.001$). Results showed that macro-invertebrates that characterized samples taken at sites EWR3 and 4 during 2006 (wet year) were Simuliidae, Gyrinidae, Corixidae and Chironomidae and during 2007 (dry year) were Corixidae, Pleidae, Dytiscidae, Chironomidae and Notonectidae.

The species composition at all four sites on the Seekoei River in March 2006 was determined and although it was not possible to test for significant differences between sites due to the small sample size, combining sites EWR1 and 2 as pool sites and sites EWR3 and 4 as flow sites did result in some difference between the flow and pool biotope sampled ($r=0.5$; $p<0.3$). The flow biotope had a larger (34) species specific richness than the pool biotope (15) in March 2006. Site EWR4 had the most (15) species unique to the site and sites EWR1 and 2 had the least (7).

2.4.2.6. *Fish*

The Seekoei River is an ephemeral southern tributary of the upper Orange River. The Orange River system, with its sixteen indigenous fish species, is relatively species-poor compared to the rivers systems situated to the north, such as the Limpopo with 50 indigenous species and the Zambezi with 134 species (Skelton, 2001). Four endemic species are known to occur in the upper part of the Orange River (upstream of its confluence with the Vaal River), namely *Labeobarbus kimberleyensis* (Vaal-Orange largemouth yellowfish), *L. aeneus* (Vaal-Orange smallmouth yellowfish), *Labeo capensis* (Orange River mudfish), and *Austroglanis sclateri* (rock catfish).

During this study, five indigenous species, *L. aeneus*, *L. capensis, Labeo umbratus* (moggel), *Barbus anoplus* (chubbyhead barb) and *Clarias gariepinus* (sharptooth catfish), and two exotic species, *Cyprinus carpio* (carp) and *Micropterus salmoides* (largemouth bass), have been recorded.

Species richness and diversity increased in a downstream direction with only one species sampled at EWR1 (in the upper Seekoei) and seven species recorded at EWR4 (in the lower section of the river). Four and six species were recorded at EWR 2 and 3 respectively.

In the upper reaches only *Barbus anoplus*, a tolerant and widespread pioneer species (Cambray and Bruton, 1985; Skelton, 2001), was found in the isolated pool at EWR1. Considering the site's location in the catchment, the natural low degree of surface water connectivity and the natural high concentration of electrical conductivity, *B. anoplus* was also the only species expected to occur there.

At EWR2 four of the five expected indigenous fish species were recorded, namely *B. anoplus*, *L. capensis*, *L. umbratus* and *C. gariepinus* – *L. aeneus* was never found at this site. One exotic species, *Cyprinus carpio*, was also recorded. Species composition varied markedly between samples. *B. anoplus* was the species with the highest frequency of occurrence, found during eight of the eleven sampling visits. Two of the species, *L. capensis* and *C. gariepinus*, were only found once.

Five indigenous and one exotic species were recorded at EWR3. Two of the species expected at this site, endemics *L. kimberleyensis* and *A. Sclateri*, was never found. Species richness varied between one (in October 2007) and six (in September 2006).

EWR4 had the highest species richness (n = seven), the added species being the exotic *M. salmoides.* The lowest species richness and abundance at this site was recorded in October 2007 when only one *B. anoplus,* one *L. aeneus,* and one *C. gariepinus* individual were sampled. This followed a six month period during which most of the available habitats at the site were dry. During the June 2007 survey fish were already isolated in a few shallow pools with sandy bottoms. It is most likely that only the largest of these still persisted when flow resumed in October 2007.

River conditions and habitat diversity differed profoundly between sites EWR1 and 2 (situated in the upper and middle sections of the catchment) and EWR3 and 4 (both located in the lower part of the catchment). In the upper and middle catchment surface waters are connected for less than 10% of the time (Hughes, 2008; pers. obs.), resulting in the river mostly being a series of isolated pools. Especially in the upper and lower reaches the numbers of species is negatively impacted by the many impoundments which reduce surface water connectivity and restrict fish movement. Available habitat at these sites, therefore, comprised of only two velocity-depth classes (slow-deep and slow-shallow), compared to the four classes (slow-deep, slow-shallow, fast-deep and fast-shallow) present at EWR3 and 4 during periods of flow. Habitat diversity at EWR3 and 4 is, however, reduced when surface flow stops and isolated pools form as drying continues.

In conclusion: the fish community of the Seekoei River is dominated by cyprinid species and consists of hardy, tolerant species adapted to the unfavourable environmental conditions prevalent in the river. The river typically exhibits high degrees of hydrological variability and natural disturbance. It experiences a low degree of flow predictability and surface water connectivity, mainly as a result of unpredictable and variable rainfall, high rates of evaporation and flow modification due to weirs and small dams. The river is further characterised by frequent floods and droughts, marked fluctuations in water temperature and rather homogenous habitats, especially in the upper and middle parts. It is therefore not strange that most of the fish are opportunistic generalist species.

Variability of flow was found to have a large impact on the availability and diversity of fish habitat at the various sites, and therefore also, fish species distribution and richness. Species composition varied markedly between samples, especially at sites where pool persistence was low. This large variation in species richness and composition, together with the natural low number of species, the generalist nature of species and the absence of historical data, impeded the mere use of fish indices.

2.4.2.7. *Socio-economics*

The role of the socio-economic analysis in an environmental reserve determination of non-perennial rivers is to calculate the:

- direct economic impacts of proposed / possible changes and subsequent secondary economic effects,
- value of environmental goods and services provided based on the ecological analysis,
- induced impacts on society through measures such as changes in the levels of safety, health, food security, employment, etc.
- The combination of the economic, social and environmental dimensions in a logical framework / a common unit of measurement for comparison between projects / scenarios.

The determination of socio-economic impacts of changes to non-perennial systems is not very widely published. The basic socio-economic methodology however remains unchanged; it is just based on a slightly different set of bio-physical and social indicators due to the generally more arid nature of non-perennial rivers.

Based on the experience in the Seekoei River, the project team observe that most of the environmental goods and services used in perennial system analysis are based on the flow of the river whereas with non-perennial rivers the services rendered are based mainly on the function of the pools, with a strong emphasis on ground water recharge.

Compared with perennial rivers, for the socio-economic assessment of non-perennial systems there may be a greater focus on *inter alia*:

- The management and use of river course vegetation as a grazing resource
- The importance of other water sources (bore holes/springs) that are used for human and agricultural water and the impact of these withdrawals on normal river functioning
- The recreational and settlement value of non-perennial rivers
- The proportional value of ecosystems goods and services provided per local inhabitant along the river

Involvement of the socio-economic team in the public participation and technology transfer process is important to gather qualitative and quantitative data that would not readily be available in the scientific and public media. As a guiding statement for the way forward, in CSIR (2000), the author, Alex Weaver, states regarding the integration of the ecological assessments and environmental impacts with economics, for ultimately, political action: *"We need a common currency that we can use to compare impacts in different media (e.g. atmospheric impacts versus using stack filters and disposing the pollutants in the aquatic environment), we need to be able to express the impacts we identify in a way that decision makers can understand so that they can support or defend their decisions, we need robust methods so that we can feel comfortable in and remain accountable for the data we put on the decision makers table."*

2.5 ***References***

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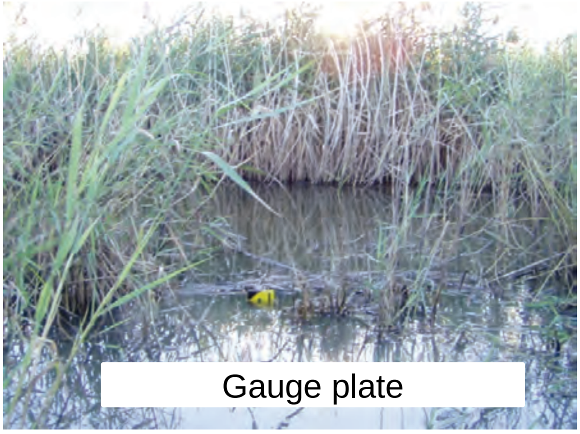
Plate 2: EWR2

March 2006 / March 2007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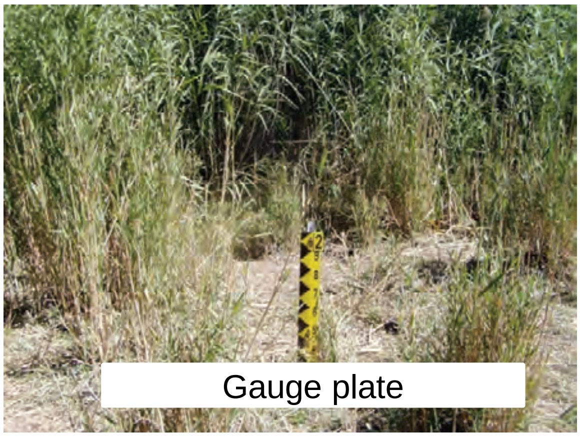
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Downstream view


Downstream view


Upstream view

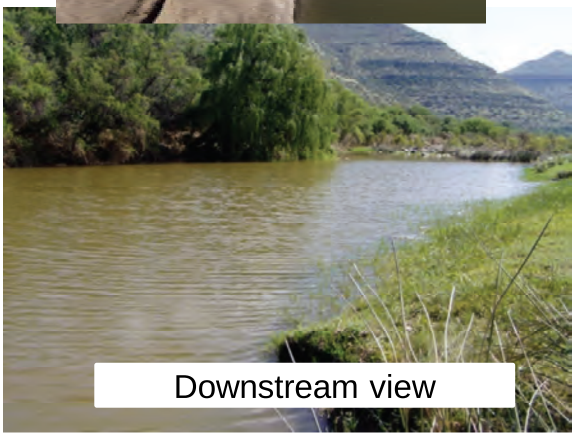

Upstream view

Plate 3: EWR3

March 2006 | March 2007


Upstream view


Upstream view


Downstream view


Downstream view


Start of rapid


Start of rapid

Plate 4: EWR4

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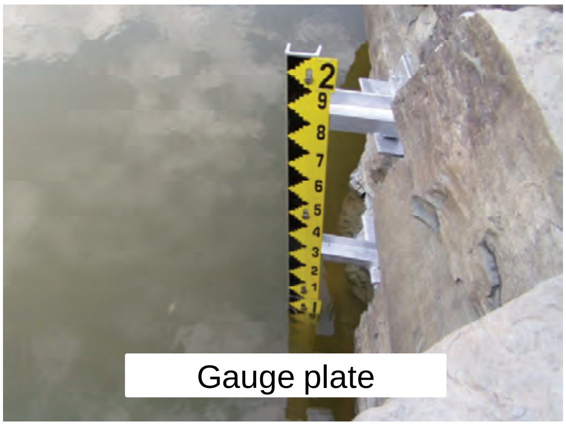
Gauge plate


Gauge plate


Downstream view


Downstream view


Upstream view


Upstream view

CHAPTER 3
CONSTRAINTS AND CHALLENGES OF WORKING IN NON-PERENNIAL RIVERS

"The Orange River is a wild and unpredictable river…" (Shahin, 2002).

3.1 Introduction

Non-perennial rivers present water scientists and resource managers with a range of challenges. Not only are these rivers subject to a high degree of hydrological variability (Davies et al., 2006; Kingsford and Thompson, 2006), but the paucity of hydrographic data (Costelloe et al., 2003) and poor knowledge about their ecological functioning (Kingsford and Thompson, 2006) further complicates matters. Non-perennial rivers are generally located in arid and semi-arid areas receiving less than 500 mm of rain annually (Davies et al., 1994). The low annual rainfalls, which are often unpredictable and spatially variable, together with high evaporation rates, contribute to water scarcity in these areas. Notwithstanding this scarcity, population growth is on the increase in these dryland ecosystems of the world (Millennium Ecosystem Assessment, 2005). Together with a changing climate, this may put further pressure on these river systems. Despite the challenges, and maybe because of these challenges, we need to improve our understanding of the special features of these systems in order to improve the basis on which predictions are made for them (Bull and Kirkby, 2002). Although these types of rivers are quite common worldwide, they are generally not well understood – first because of the dominance of research in perennial systems for which there is a significant amount of existing data (Williams, 1988; Alcácer, 2004; Sheldon, 2005), and second due to the difficulty in predicting the occurrence of hydrological events complicating research planning (Davies and Day, 1998). A number of studies on both the ecological impacts of droughts and on environmental water requirements in arid zones have been published recently (for example Puckridge et al., 1998; Sheldon et al., 2002; Costelloe et al., 2003). It is important to consolidate existing knowledge of these systems in order to provide a basic framework for the ecological understanding of non-perennial rivers (Kingsford and Thompson, 2006).

3.2 South Africa's climate and rivers

Southern Africa's climate ranges from semi-arid to hyper-arid, with only a few relatively humid parts towards the south and east coasts where the rainfall greatly exceeds 500 mm per year (Davies and Day, 1998). The rainfall patterns include a winter-rainfall area at the southwestern tip of Africa, and a cool, dry winter along the east coast and central plateau (Davies et al., 2006). According to Davies et al. (2006) this implies an eastern area of summer rainfall, a south-western winter-rainfall belt, a southern coastal belt of a less specific nature, and an arid central and western region. Although South Africa has a mean annual rainfall (MAP) of 452 mm/year, evaporation exceeds rainfall for most of the country, resulting in a very low MAP/MAR ratio of 8.6%, compared to 9.8% for Australia and 65.7% for Canada (Davies et al., 2006). This, together with a highly seasonal rainfall pattern which could vary erratically between and within years, result in highly variable stream flows, as well as unpredictable periods of droughts and flood. It therefore comes as no surprise that the rivers draining the sub-continent have been described as "variable" and "unpredictable" (Davies et al., 2006).

Intermittent flow is common in a large proportion of South Africa's rivers – according to Davies and Day (1998) about 40% of our total river length is subjected to natural interruptions of flow. A large proportion of South Africa's rivers is event-driven and is considered to be amongst the most variable in the world (Poff et al., 2006). For example, the coefficient of variance (CV) of flow varies between 0.33 in the generally predictable Western Cape rivers and 2.58 in the generally unpredictable rivers of the northwest (King et al., 1992 quoted in Uys and O'Keeffe, 1997). This hydrological variability is believed to play an important role in establishing heterogeneity within South African rivers and has been included as one of three descriptors used to characterise rivers as part of the river component of the South African National Spatial Biodiversity Assessment (SANSBA). The other two physical descriptors used, were the geomorphological template and sediment transport (Nel et al., 2005). Within this assessment, the hydrological index of Hughes and Hannart (2003), which expresses the ratio of flow variability compared to base flow, was used to characterise hydrological variability. For South African rivers, a hydrological index value of close to 1 indicates rivers with low flow variability (referred to as perennial rivers) and an index value of more than 50 indicates rivers with high variability in flow. Rivers with an index value higher than 50 would therefore be non-perennial rivers that experience intermittence of flow (Nel et al., 2005). For the SANSBA quaternary catchments were grouped into eight classes based on their hydrological index values (represented in Table 3.1) and are illustrated in Figure 3.1. Based on these classes, about 15.9% of quaternary catchments have a hydrological index of more than 53, indicating non-perenniality. From Figure 3.1 it is clear that the non-perennial (periodic and ephemeral) rivers are concentrated in the central and western part of South Africa, the only exception being the Orange River which is mainly sourced from the Maluti Mountains and upper Orange area.

Table 3.1: The eight hydrological index classes derived from the hydrological index of Hughes and Hannart (2003) by Nel et al. (2005) for all South African quaternary catchments.

Hydrological index	Class	Percentage quaternary catchments in each class
0 to 5	1	16.5
5.1 to 8	2	19.8
8.1 to 17	3	24.8
17.1 to 37	4	10.8
37.1 to 53	5	12.2
53. to 65	6	8.1
65.1 to 95	7	7.2
95.1 to 110	8	0.6
		100

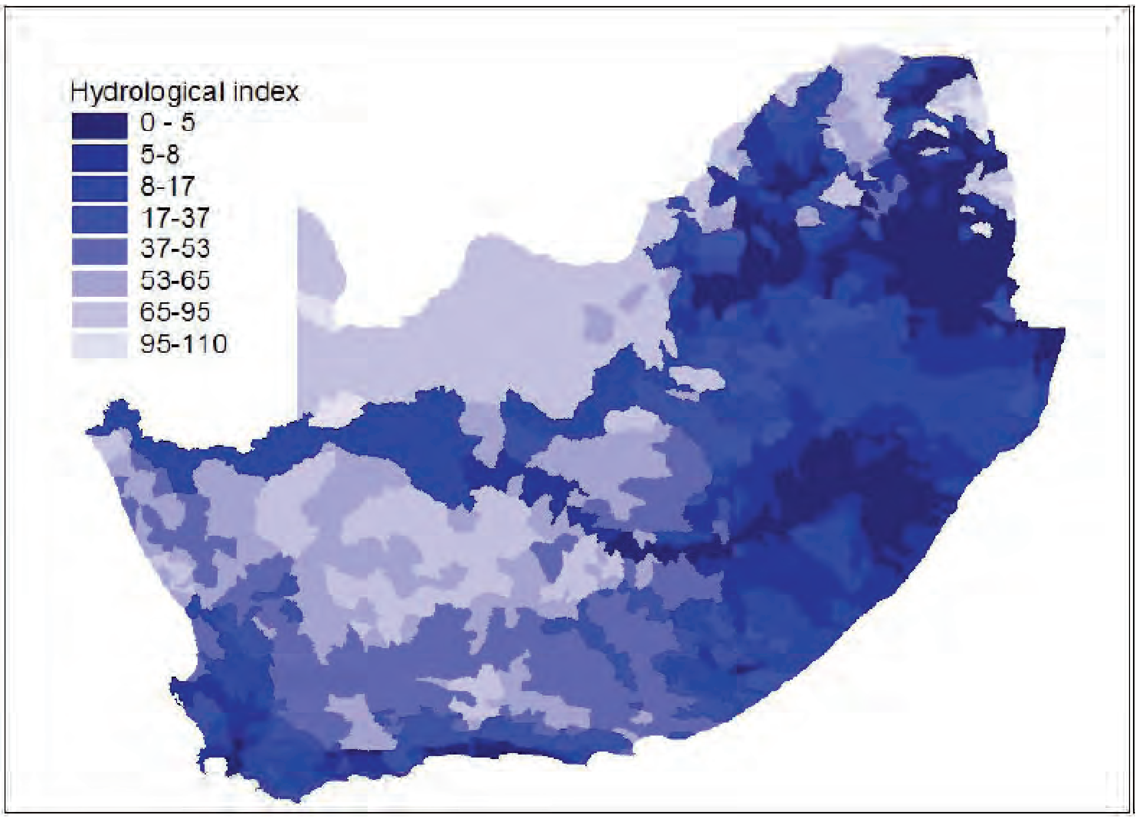

Figure 3.1: The hydrological index classes for South African quaternary catchments based on the hydrological index of Hughes and Hannart (2003) which expresses hydrological variability as a ratio of flow variability to base flow in a river (after Nel et al., 2005).

The SANSBA concluded that the majority (45%) of mainstem rivers in South Africa are “moderately modified”, with 29% considered to be still “intact” and 26% to be “transformed” (Nel et al., 2005). As expected, mainstem rivers closer to the larger urban areas are more heavily utilized and very few intact mainstem rivers are found the in Western Cape, Eastern Cape and Free State, and none in Gauteng (Nel et al., 2005). Mainstem rivers of the Northern Cape, with the exception of the Orange River, and KwaZulu-Natal were the least impacted. Rivers in the drier western parts of the country often have very unreliable and variable surface flow, constraining communities to the use of ground water resources. It may seem, in a way, as if these rivers' hydrological unpredictability and variability are protecting them from over-utilization. The important link that exist between surface and ground water in these systems, as well as the fact that these interactions are not fully understood, imply however the careful use of ground water resources in these areas.

3.3 Classification and terminology in an South African context

Hydrological conditions in river ecosystems form a continuum of variability (Uys and O'Keeffe, 1997; Nanson et al., 2002; Hughes, 2005). While it is often useful and necessary to divide rivers into categories such as perennial, intermittent (temporary, seasonal, semi-permanent, or dryland rivers) and ephemeral (or episodic) for management purposes, the boundaries between these are vague. It is indeed a complex task to categorise rivers considering the great diversity in their hydrological and ecological characteristics, not only between perennial and non-perennial rivers, but also within non-perennial rivers (McMahon et al., 1992). Although some hydrological characteristics are more common in non-perennial rivers than in perennial (e.g. large-scale transmission losses, large flood magnitudes), other characteristics are shared with perennial rivers (e.g. strong channel-floodplain flow interactions; Nanson et al., 2002). Hughes (2005) also noted that non-perennial systems may exhibit the characteristics of perennial rivers during extended wet periods, while perennial systems may experience intermittence and assume the characteristics of non-perennial rivers during severe drought periods.

Uys and O'Keeffe (1997), in an attempt to present a conceptual framework illustrating the range of temporary flow regimes in South Africa's non-perennial rivers, proposed a continuum based on the following gradients (see Figure 3.2):

- The degree that abiotic or biotic processes control ecological community structure,
- The connectivity of surface aquatic habitat,
- The degree of flow predictability,
- The degree of flow variability, and
- The degree of natural disturbance.

Two important hydrological state changes are recognised within this framework: (1) when surface flow disappears but surface water is still present in the river channel and (2) when surface water disappears from the majority of the river channel.

Uys and O'Keeffe's (1997) framework therefore imply three "categories" or hydrological states: the first where surface flow is continuous, referred to as **perennial** systems, the second where surface flow disappears but some surface water remain as refugia in the channel, referred to as **intermittent**, and the third where surface water disappears from most of the channel, referred to as **temporary** systems. Each of these categories is further divided into sub-categories, giving an indication of seasonality. Two types of temporary rivers are recognized, namely "ephemeral" rivers that flow for less time than they are dry and support a series of pools in parts of the channel, and "episodic" rivers that only flow in response to extreme rainfall events, usually high in their catchments. Although different disciplines may prefer different definitions and frameworks, for example Costelloe et al. (2003), from a hydrological perspective, describe ephemeral and intermittent rivers as those rivers that are characterised by a decreasing discharge in the lower reaches due to transmission losses, common categories and definitions accepted by all are urgently needed. This is especially true for multi-disciplinary studies such as Environmental Water Assessments.

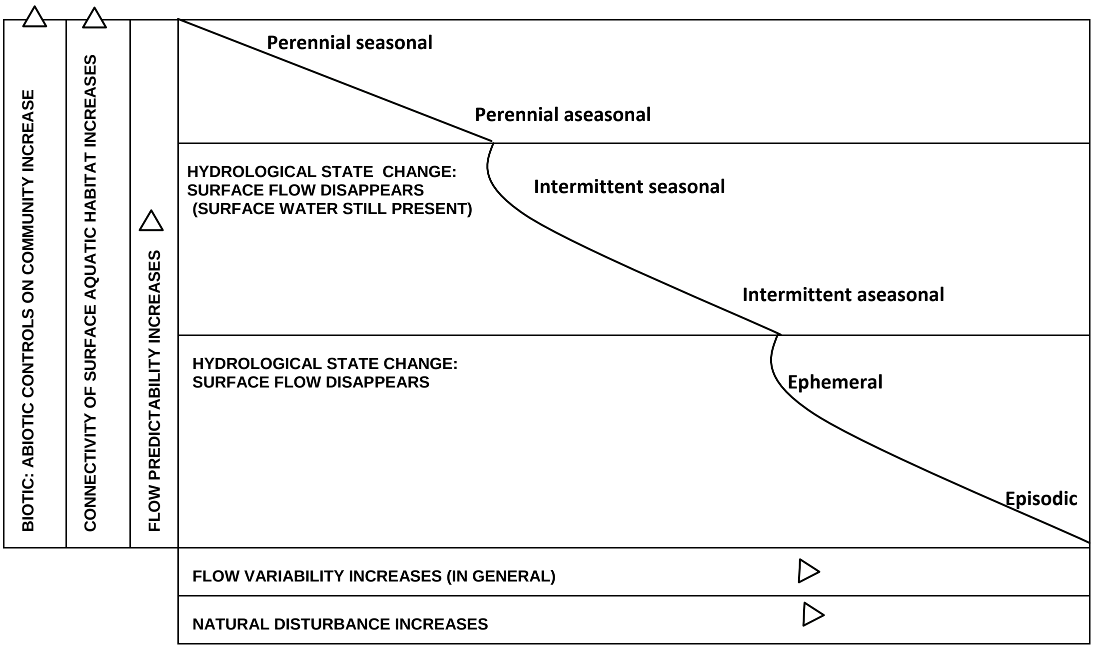

Figure 3.2: A conceptual illustration of the continuum concept (after Uys and O'Keeffe, 1997).

In the first phase of this project on non-perennial rivers (see Rossouw et al., 2005), two main categories of rivers based on flow persistence were recognized, namely perennial, referring to rivers that flow continually except during extreme droughts, and non-perennial, referring to rivers that do experience intermittence (or disruption) of surface flow. Non-perennial rivers were then further subdivided into three sub-categories: (1) semi-permanent – rivers that experience no flow for between 1% and 25% of the time (up to three months per year); (2) ephemeral – rivers that experience no flow for between 26% to 75% of the time (up to nine months per year); and (3) episodic – rivers that flow briefly (less than three months per year), usually only after rain (Figure 3.3).

These categories, which were arbitrarily chosen by the team after extensive discussion aided by interactive GIS technology, unfortunately contrast with the framework proposed by Uys and O'Keeffe (1997). (There are some resemblances between the categories of Rossouw et al. (2005) and Uys and O'Keeffe (1997) – episodic rivers are for example similarly defined). A tradeoff between the use of categories and a continuum is therefore indicated, depending on user requirements. Uys and O'Keeffe's (1997) framework strongly emphasizes the continuum concept and does not give exact cut-off points between the various sub-categories. This approach, which certainly plays a very useful role in developing a conceptual model of the nature of hydrological variability and ecological functioning, may however present water managers with uncertainty as to where "their" river falls within the framework. The decision to define the "boundaries" between the different categories of non-perennial rivers therefore serves the specific goal of assisting water managers "classifying" or "categorizing" a non-perennial river (Figure 3.4).

The question could be asked whether it is really necessary to know in which non-perennial category a river falls. Is it not enough to know that flow in this river is intermittent and therefore corresponds to a non-perennial flow regime? Knowing where a river is situated on the continuum of flow variability can indeed provide a water manager with very useful information about the community processes influencing the community structure of that system. Inevitably, though, a manager might prefer simple categories.

For the purpose of this report, the categories of Rossouw et al. (2005) have been used. Also to ensure continuity between the first and the second report that are part of the programme, the team has decided to stick with the terminology used in the first report.

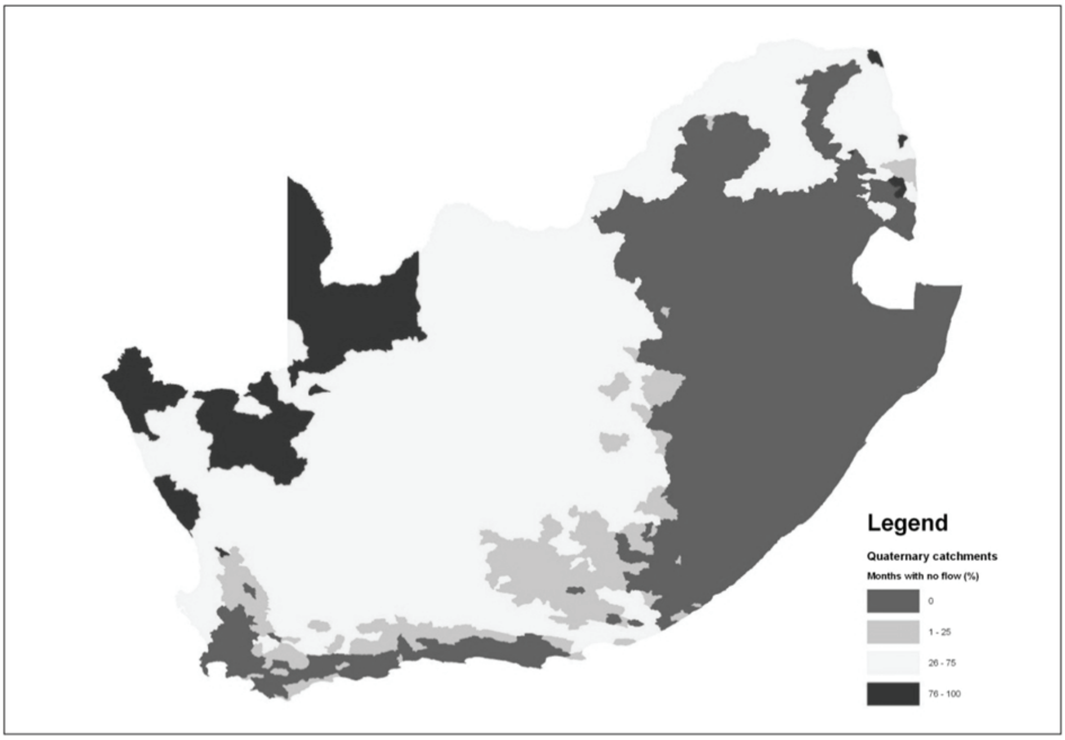

Figure 3.3: South African quaternary catchments categorized into four sub-categories based on the relative period of no-flow during each year.
(Black, catchments that do not experience flow >75% of the time; very light grey, catchments experience no-flow for 26%-75%; light grey, catchments that experience no-flow for <25% of the time; dark grey, catchments that only experience flow intermittence during times of severe drought).

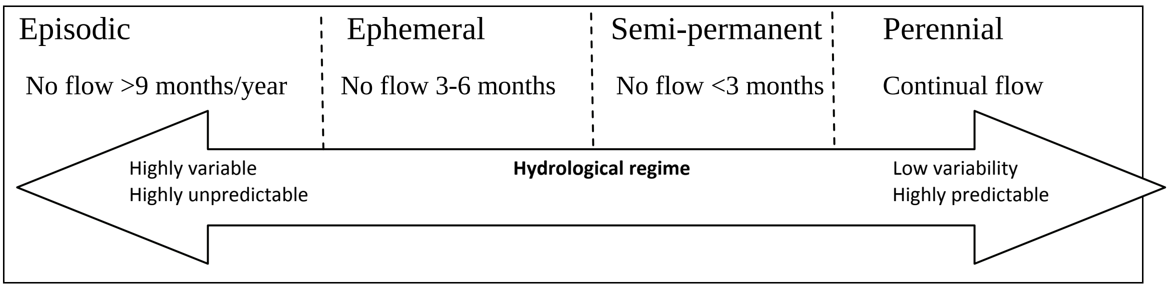

Figure 3.4: A reconciliation of the four categories and the hydrological continuum in rivers. Boundaries were defined in order to assist management decisions, but the dashed lines indicate that these boundaries are not fixed, but only an indication.

3.4 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.

3.5 Challenges facing EWAs for non-perennial rivers

3.5.1 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 drivers 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 model the movement of water through the catchment satisfactorily. 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 ground water 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.

3.5.2 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.

3.5.3 *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.

3.5.4 *Surface water and sub-surface water interactions*

Much of the nature of non-perennial rivers and their pools are 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.

3.5.5 *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.

3.5.6 *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, 2007) 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.

3.6 Challenges facing specialist studies in non-perennial rivers as part of EWAs – based on the Seekoei River experience

What remains uncertain in ephemeral and episodic systems is how to measure their vulnerability. It is often difficult to determine their ecological integrity as many of the methods commonly used for this have been developed in perennial systems and do not always recognize the fact that these systems are subjected to high levels of variability and disturbance. An important question regarding these rivers is then, "how much change can they absorb before reaching a tipping point in other words, how resilient are they? The biota of these systems have had a long evolutionary exposure to this disturbance regime and are adapted to rapidly recover from even quite severe droughts (Sheldon, 2005). Other factors that may be important in community assemblage and structure are factors such as the presence and persistence of pools or waterholes acting as refugia and the connection/disconnection regime. Not only for repopulation after a period of isolation (intermittence), but also the energy cycles – in other words energy cannot come from upstream, but needs to be added locally.

Below follows a discussion of the specific constraints and challenges as experienced by the various specialists during their studies on the Seekoei River.

3.6.1 *Geomorphology*

It is prudent to recognise that limited knowledge exists on the physical functioning of dryland rivers, especially with respect to the effects of floods, droughts and flow variability on channel form and process. An earlier review of the geomorphology of dryland rivers (Petersen and Dollar, 2007) highlighted the limitations of our current understanding, and identified a number of characteristics unique to dryland rivers that can be used to guide future work and method development. In summary, the salient points were:

- Although distinct systems, dryland rivers do not have unique landforms (except water holes and flood-outs). Dryland rivers are, however, characterised by their hydrological variability (Nanson et al., 2002) which occurs both spatially (the predominantly disconnected nature of the flow in a catchment other than during extreme events) and temporally.

- Unlike perennial rivers which have relatively close links between form and process because of frequent adjustments of channel form; in dryland rivers process-form adjustments are often variable in space and time so that equilibrium, non-equilibrium or ‘patchy’ equilibrium conditions occur, depending on the scale of observation (Tooth, 1999 and 2000).
- The most ‘effective’ discharges in dryland rivers are the large infrequent disturbance (LID) events such as floods with a >10 year return period. These events are responsible for most of the sediment transport over the medium- to long term and are the dominant channel-forming events. Other ‘components’ of the flow regime are considered significant (e.g. freshes/flash floods, low flows) by some authors (e.g. Graf, 1987; García, 1995; Petts, 1996; Thoms and Sheldon, 2000; Holt, 2005; Sheldon and Thoms, 2006), although their importance relative to LIDs are unknown.
- Currently there are no bespoke methods or tools available for setting the geomorphological component of environmental flows for dryland rivers.

3.6.2 *Water quality*

Non-perennial rivers are different from perennial rivers in that river flow is much more variable and unpredictable in non-perennial rivers. Water quality is also more difficult to predict as the Seekoei River results clearly indicated huge differences between the different EWR sites, not only in concentrations but also in the ionic composition of the water. This implies that extrapolation of results within the same catchment must be used with extreme caution.

This exacerbates the hunt for reference conditions. Reference conditions are generally required in the use of the existing water quality ecological reserve determination methods. This is seldom available and the use of substitute site data only increases the inaccuracies.

No single water quality reserve method has been accepted as the best, and the selection of a methodology will vary according to management objectives, the resources and amount of data available.

The mismatch between daily hydrology data and monthly water quality data remains an issue as the hydrology model currently used, presents the results on a daily basis whereas the water quality, if it is a good water quality record, only have data on a monthly basis. This implies that extrapolation of the water quality data will be needed, enhancing inaccuracies.

Methods and tools are available to determine the water quality Ecological Reserve, however, the focus has been on perennial rivers and the methodology as tested on the Seekoei River study indicated that issues such as the amount of data required in these methodologies remain an issue. Limited chemical, nutrient or bacteriological data are generally available for perennial rivers, even less to no data are available for the non-perennial rivers, making the use of the methodologies even more problematic.

One major gap in the current available methodologies is still linking water quality with flow as the existing methods, the Q-C model (Malan et al., 2003) and the Simple Water Quality Model (Hughes, 2008), have a number of limitations and it is expected that even more shortcomings will be found if this is implemented on other non-perennial river. Water quality modelling where water quality and flow are linked is an area that needs to be further developed in future.

The existing water quality methodology used to determine the water quality reserve for perennial rivers can be applied to non-perennial rivers depending on the management objectives, the resources and amount of data available and the accuracy required.

3.6.3 *Riparian vegetation*

The riparian vegetation of non-perennial streams and rivers is an important indicator and tool to assess these rivers because in most cases aquatic insects, fish and water quality cannot be used to evaluate the integrity of these types of rivers.

The riparian vegetation communities along a non-perennial river are, like in the case of a perennial river, still linear but in most cases not continuous. The zonation in the riparian vegetation is also notable in most places. It is most obvious around areas with standing water such as pools. Here, the vegetation is the best developed in terms of structure and species diversity because of higher water availability. Between the pools are stretches where water flows only when the river or stream is in flood. Here, the riparian vegetation is usually different. The variability of the hydrological regime of the non-perennial river is a key determinant of species composition and plant community structure in time and space (Bornette et al., 2001). The variation in the vegetation along a non-perennial river can be attributed to the extreme variability in their natural hydrological regimes. Floods and droughts occur unpredictably, expanding and contracting across the landscape and altering the size, shape and connectivity of aquatic habitats (Ward, 1988). Differences in the frequency and duration of hydrological disturbances can also change spatial patterns of plant community composition and structure, among and within habitats (Brock et al., 2006). Thus the character of the riparian vegetation along a non-perennial river usually differs significantly from pool to pool as well as those sections between pools.

The constraints are:

- the hydrological variability causes variation in the vegetation between the areas around pools and those areas linking the pools,
- the upstream areas may also vary significantly from those further downstream,
- the character of the riparian vegetation also varies from stream to stream in the same catchment,
- the species composition and structure of the riparian vegetation of no two rivers can be regarded as similar. Therefore to compare two non-perennial rivers is almost impossible,
- to set reference conditions for a non-perennial stream is almost impossible because of the variation along a stream and between streams.

The greatest challenge is to develop methods which are adaptable to the variation in and among rivers.

3.6.4 *Aquatic macroinvertebrates*

Intrinsic differences between perennial and non-perennial rivers are the main reasons why methods developed as part of EWAs in South Africa (and internationally) are difficult to apply in non-perennial rivers. Variability in the contribution of runoff generated, ground water, length of inundation period and timing of floods all contribute to the unpredictability of flow, habitat and water quality available to macro-invertebrates at a particular site or river section in a non-perennial river.

Invertebrates in non-perennial systems are adapted to the harsh conditions and are specialized in the sense that they are able to reproduce and survive in extremely variable conditions. Chutter and Heath (1993) stated that the fauna in non-perennial rivers have evolved life histories to cope with the droughts and floods. Any change in this “unpredictable” environment could have an influence on the invertebrates present. The change may not be in a loss of a species or family from the system but it could be a change in the community composition or abundance of specific species or families.

Species that are sensitive to flow and water quality changes are not often present in non-perennial systems except in the case of seasonal non-perennial rivers or sections of rivers where flow does occur. These species however are able to utilize the flow period and then move on to another river when flow ceases. A change in the flow duration of these rivers could have an influence on which species are present but this would be difficult to predict as the historical duration of flow, length of inundation, velocity and water quality all contribute to their presence.

Knowledge of the specific period of flow needed to survive and for species to complete their life cycles is not always available. Data on species-specific preferences in perennial rivers are often not applicable to non-perennial rivers.

Due to the scarcity of long term data on non-perennial systems throughout the world, the functioning of the system is difficult to understand and the presence of biota and other physical and chemical parameters are difficult to predict. In perennial systems, long term studies have led to a basic understanding of the functioning of the system and methods to determine the health of the system have been developed. These methods have been used on non-perennial systems but various constraints and challenges have been identified.

Constraints:

- As very little long term data are available on non-perennial rivers and almost no data was available on the Seekoei River, it was not possible to predict, with confidence, what the historical record of the river was and therefore which macro-invertebrates would be present under certain circumstances. No extrapolation of data was possible as no other rivers with data could be located in the same ecoregion, geomorphological zone and degree of non-perenniality. Data available was for perennial rivers and could not be used with confidence. The seasonal as well as yearly variability in hydrology complicated the setting up of a reference (expected) list.
- Sampling pools and predicting which macro-invertebrates would be present was complicated by the fact that the pool species composition could vary between neighbouring pools depending on which species recolonised each pool first.

- The complexity of the non-perennial river system in terms of flow variability made sampling of invertebrates difficult as habitat was either dry or had 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. The high flow period in non-perennial rivers implies flooding, when most invertebrates are swept downstream or occur after a dry period when invertebrates have not yet had time to recolonise. Low flow periods occur as stream is drying out and invertebrates have started to leave the system. Sampling during these periods gives a distorted view of the present condition of the system.
- Very little data on life history strategies of macro-invertebrate species in non-perennial rivers are available. General life history strategies of families were not helpful as various species in each family have different strategies. To predict which species would be present under certain circumstances (as pools dry out or when marginal vegetation starts disappearing) more specific life history strategy data is needed.
- No method was available to determine the PES (present ecological state) of the macro-invertebrates in the Seekoei River. SASS (South African Scoring System for macro-invertebrates) and MIRAI (Macro-invertebrate Assessment Index) do not make provision for the natural variability in flow and habitat. Using the SASS method is not recommended in non-perennial rivers and wetlands (Dickens and Graham, 2002; Bowd et al., 2006), but at present no other standard sampling method is available.
- SASS sampling only requires identification to family level. It is time consuming to identify to species or even genus level. It appears (from the study on the Seekoei River) that identification to species level or at least genus or morpho-species level is necessary if small changes (due to pollution, abstraction, etc.) in the community structure of macro-invertebrates at sites in a non-perennial river are to be investigated. Different species have different life history strategies and although the family may still be present at the site after a disturbance, some of the species may have disappeared.
- The questions in the MIRAI method used to determine the impact of flow, habitat and water quality changes were difficult to answer. To determine a rating for the presence of taxa with a preference for very fast flowing water, a flowing habitat is needed and if only a pool habitat is available then this question has to be ignored. If all the questions regarding high flow, diverse habitat (SIC) and high water quality have to be ignored then the class determined is based on one or two questions, which carry all the weight and if answered incorrectly could influence the final class.

Challenges:

- Research on non-perennial rivers needs to incorporate biota-hydrological phase (dry, no-flow, pool, onset of flow, flow) relationships rather than just biota-flow relationships. Data on invertebrates in non-perennial rivers needs to include accurate flow data (in each available biotope sampled) and habitat descriptions. The unpredictability of flow makes it difficult to assess the requirements of macro-invertebrates, as they are already adapted to harsh conditions. We need to determine what amount of change is critical. The challenge is to understand and interpret the large spatial and temporal variations in the natural condition.
- Data is needed on seasonality (including wet and dry years) and macro-invertebrate presence in non-perennial rivers as this influences time of sampling and interpretation of data.
- Specific data on recolonisation tempo, cues required before colonization, temperature and other water quality preferences, length of inundation required, habitat and flow preferences, are needed before accurate (high confidence) predictions of the expected species at a site can be made.
- Setting up reference conditions for non-perennial rivers would have to include time of year, hydrological phase, ecoregion, characteristics of site such as pool or riffles or combination, substrate type and distance from nearest refugia. This would result in a different reference condition for practically each reach/site of each river. A less complicated method is needed which would incorporate all these aspects. It could be possible, after more long term studies in non-perennial rivers, to set up reference conditions for a particular biotope type (including habitat, flow, substrate type, inundation period) per ecoregion rather than a site/reach reference condition.
- A standard sampling method needs to be developed for non-perennial rivers where pools (no-flow) as well as flowing sections of a river could be sampled and the data used to determine the PES of macro-invertebrates in the system. It is proposed that biotopes be sampled separately (SIC, SOOC, MVIC, MVOOC, AVIC, AVOOC, POOL, GSM) which would make comparisons between sites possible. This would however be time consuming and probably not suitable for a rapid assessment.
- The results obtained from SASS and MIRAI in non-perennial rivers often reflect the natural decline in condition associated with hydrological fluctuations and not necessarily the level of pollution or degradation present. The tolerant generalist species (low scoring SASS taxa associated with pollution and degraded sites in other systems) are present during the drying period in non-perennial rivers resulting in a poor class when the SASS score or MIRAI class is determined. A method, which could distinguish between natural and anthropogenic degradation, is needed.

Deciding which taxa are sensitive in non-perennial systems is also a challenge 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. 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 adapted species disappear?

3.6.5 *Fish*

Fish are considered to be very useful biological indicators of catchment conditions due to their longevity and mobility (Karr et al., 1986). They have been included as a key indicator in environmental water assessments, also in the South African context. According to Louw (2003), fish are often the critical indicator used to define flow objectives in EWAs for perennial rivers due to factors such as their larger body size (compared to macroinvertebrates) and their more critical flow requirements (unlike some insects they cannot leave when a pool dries out). The question could however be asked how relevant (important) an indicator are fish in EWAs for non-perennial rivers?

For rivers towards the episodic side of the continuum (see Figures 1.2 and 1.4) that lack sufficient surface water to naturally support fish (e.g. Kuiseb), the answer is clear. For ephemeral rivers, that could experience intermittence of surface flow for up to six months per year, it is not so clear. These rivers present aquatic biota with very harsh environmental conditions, like variable and unpredictable flow, catastrophes such as large floods and long droughts, high turbidity, large fluctuations in water temperatures, being confined to isolated pools, etc. and fish communities in these rivers are often species-poor and dominated by tolerant, generalist or opportunistic species (Bowmaker et al., 1978; Gaigher et al., 1980; Allanson et al., 1990). The nature of the Seekoei River fish community, which is naturally low in species richness and consist of species tolerant to changes in surface flow (e.g. although *Labeobarbus aeneus* prefers to spawn during high flow conditions, they are known to produce young in dams and pools) and habitat availability and condition, made it difficult to apply existing indices (see Kleynhans 1999, 2003 and 2008). Bramblett and Fausch (1991) in their studies on prairie streams in the US have found that the Index of Biotic Integrity did not detected a degradation of biological integrity after artificial disturbances, mainly due to the fact that the fish community was naturally adapted to disturbances like floods and droughts. This does not mean that fish should not be included as a biological indicator for such systems, but it does mean that further thinking regarding suitable methods is needed.

Some of the specific constraints and challenges experienced during the study on the Seekoei River are listed below:

<u>Constraints</u>

- The low species richness and generalist nature of the fish community impeded the effective use of the existing Fish Response Assessment Index (FRAI; Kleynhans, 2008) commonly used for biomonitoring and EWA studies in South African rivers (River Health Programme, 2006; Kleynhans and Louw, 2008). Specifically, the following were problematic:
    - The relative absence of historical information on species composition and distribution made it difficult to determine the expected vs. observed species ratio in the form of Frequency of Occurrence (FROC) scores for each river section.
    - The low number of species adds to the problem as one species expected but not found, or vice versa, could change scores considerably and impact negatively on the conclusions drawn from the fish assessment.
    - The low degree of surface water connectivity and homogenous nature of available habitats in the upper and middle parts of the Seekoei River made it difficult to sample the minimum number of points required by FRAI.
    - Habitat diversity decreased markedly when surface flow stopped, reducing the number of sampling points per site to one or two.
    - The few and generalist nature of fish species present in the Seekoei River further makes it almost impossible to make use of the presence or absence of indicator species as a reference for biological integrity.
- This study had the advantage that routine fish assessments were conducted every six weeks. Sampling success (CPUE) varied to such a degree between corresponding months and seasons as a result of unpredictable and variable flow that it is difficult to recommend a most suitable time for sampling.
- The relatively high natural electrical conductivity at EWR1 hindered effective sampling at this site. New sampling gear (a SAMUS 725G backpack-electroshocker) was acquired halfway through the study to correct for this.
- Fish habitat in the upper and middle reaches, and for a large part of the year in the lower reach, comprise mainly of isolated pools of varying depth. Due to the absence of beach areas from where to launch seine nets, we found it difficult to effectively sample the larger pools. Gill nets were used twice, in March and September 2006, at the two downstream sites in order to determine

species composition. This is not an ideal method of sampling in an isolated pool which could be an important refuge area and we are investigating the use of fyke nets in future.

Challenges

- Sampling fish communities in the Seekoei River has shown how difficult it will be to apply any scoring method on ephemeral rivers in the drier interior and western parts of South Africa where communities consist of relatively few, hardy, species. The high degree of environmental variability, and consequently the continuous, but irregular, loss and gain of habitats, has contributed to the low diversity of indigenous species. The natural formation of isolated pools and man-made weirs further prohibit the frequent and immediate re-colonisation of the upper, middle and lower stretches of the Seekoei from the important refugia. Although A more generalised approach was used to determine the PES of the Seekoei River fish communities a more formal and structured approach should be investigated. It is important to note that even though FRAI is not ideally suited for the Seekoei and possibly other rivers in the Orange River system, it could be suitable for non-perennial rivers in other system with higher species richness.
- The relationship between water level (including the effect of water being pumped from isolated pools) and the biological integrity of fish communities should be further investigated. It is most likely that management objectives could be set in future to regulate the quantity of water that could be pumped from a pool regarded (by way of a standardised protocol) as an important refuge area for fish within a catchment.

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CHAPTER 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 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; see 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

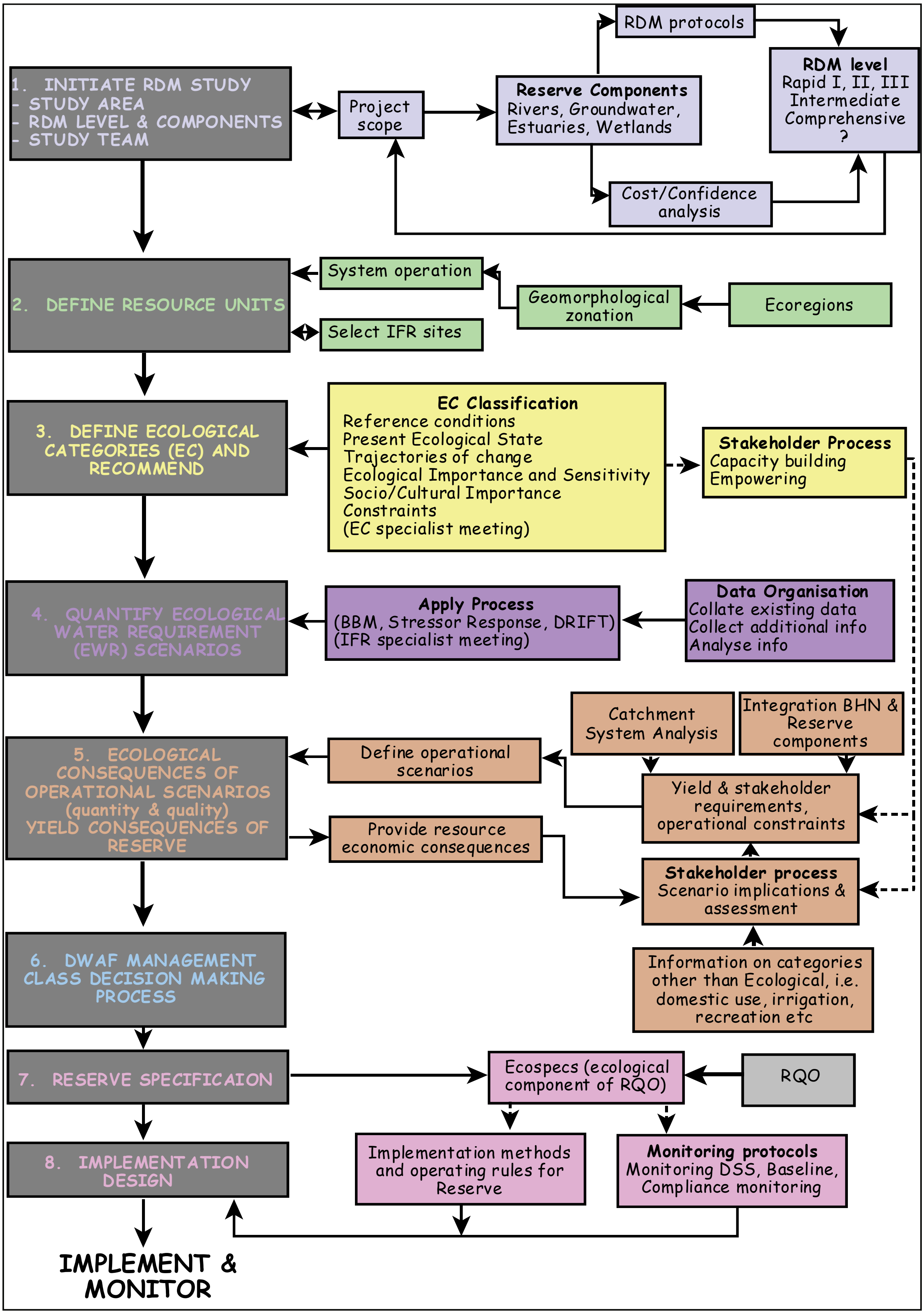

Figure 4.1: The EWA process for perennial rivers (adapted from DWAF, 2002).

rainfall data, complications in hydrological modelling, 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.

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

Several assumptions were made at the start of the Seekoei River 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 licensing stage in order to assess the possible impact on specific pools or reaches.

4.4 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).

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

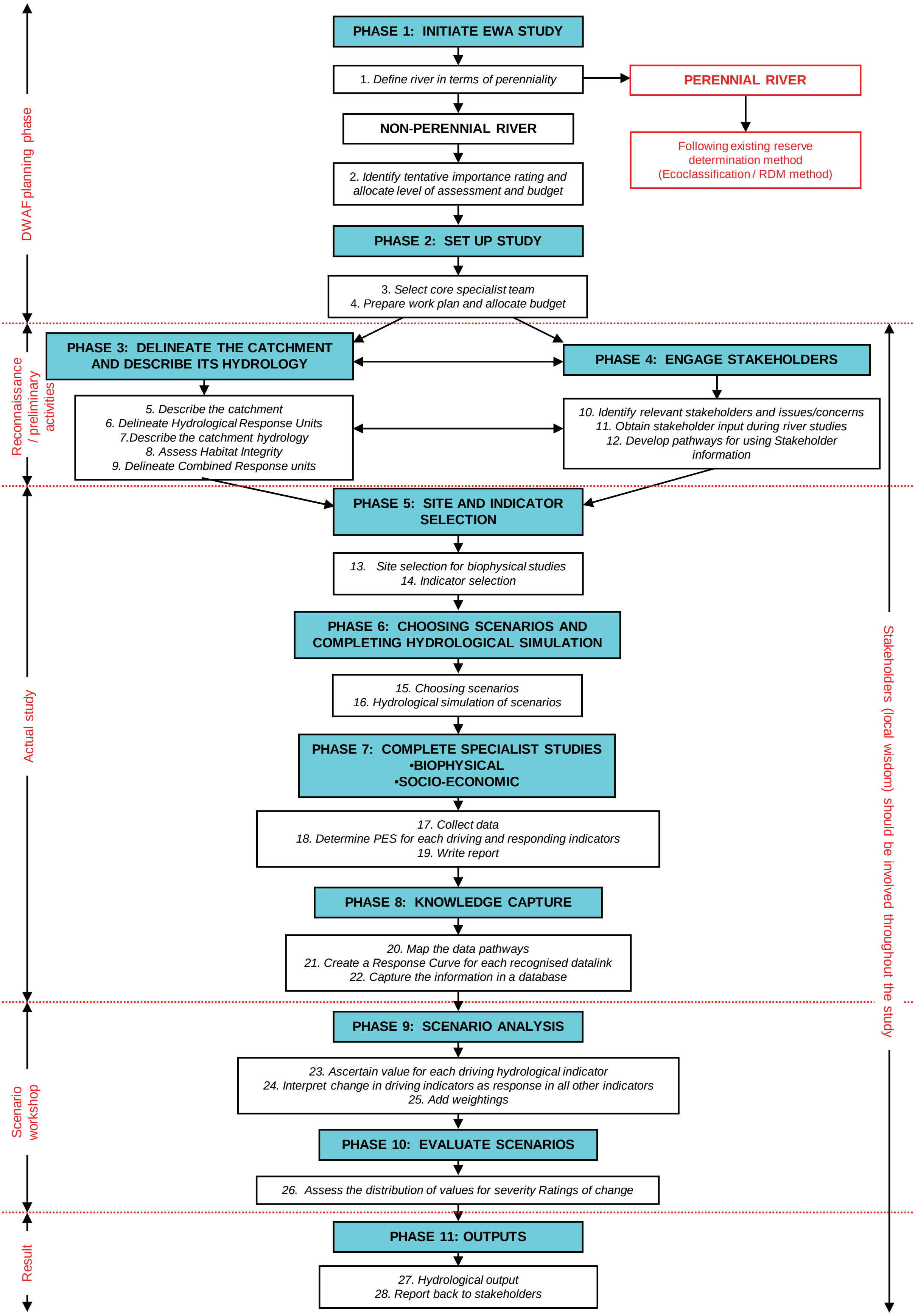

Figure 4.2: The 11-phase process proposed for EWAs for non-perennial rivers.

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.

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

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 (2007), 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.

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 additional layers such as catchment, slope, infiltration rate, vegetation cover, rainfall intensity and flow accumulation, are also included in the determination.

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 2002 or latest)	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 and 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

It is the contention of the catchment geomorphologist that information from the whole catchment, and not just instream areas, should be used in river delineation and determining the location of sampling and 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 A 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 were 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 evapotranspiration, 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 assessment 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 a 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

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 B. 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 B. 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; land use)			
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 B). Of relevance here is the need to ensure that the information from Activities 10 and 11 is used when planning the selection of indicators (Activity 14) 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

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 C).

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

  - quantitative socio-economic indicator
  - qualitative socio-economic indicator

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

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

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.

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 (Figures 5.18-5.20).

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 are 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).

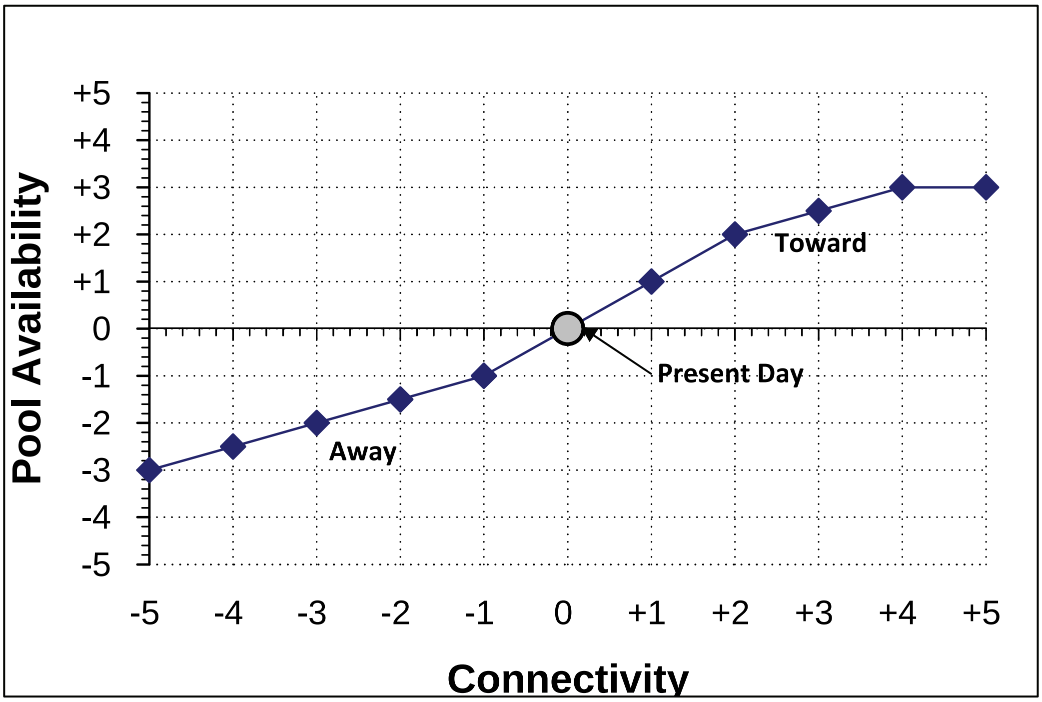

Figure 4.3: Hypothetical response curve showing changes from Present Day in Pool Availability as a result of changes in Connectivity. The direction of change is also identified as a move toward or away from natural.

The shape of the Response Curve is then completed, using the Severity Ratings 1 to 5 as guides (Table 4.2). 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

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 Table4.3).

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 4.3). 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.

Phase 10. Evaluate the scenario in terms of ecological condition

The values emanating from a table of responses (e.g. Table 4.3) 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 4.3 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.

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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CHAPTER 5
APPLICATION OF THE PROTOTYPE METHODOLOGY FOR THE SEEKOEI RIVER

5.1 Introduction

The prototype methodology proposed in Chapter 4 was based on the experience and knowledge gained during two years of field studies on the Seekoei River. The various phases and activities described in the previous chapter have been formulated and sequenced retrospectively during method development workshops during the last year and a half of the project. This obviously implies that the exact sequence and activities proposed under the prototype methodology have not been followed for the Seekoei River study. The prototype methodology has, however, been tested on the Seekoei in order to determine the practicability of the method. The latter phases (Phases 8-10: knowledge capture, scenario analysis and scenario evaluation) were tested at a workshop in March 2008, while the initial phases (Phases 1-7) have been applied retrospectively using both the data accumulated and experience gained during the field work.

This chapter reports on the test application of the prototype methodology. The phases and activities will be discussed in sequence, reporting on the actions taken to satisfy the requirements of each activity, presenting the results obtained for the Seekoei River and noting where problems were experienced with application. Where the approach followed for the Seekoei River study deviates significantly from the proposed prototype methodology, explanations were given in order to allow the reader some insight into the reasoning behind these changes, as well as to put the proposed prototype into better perspective.

5.2 Test application of the prototype methodology on the Seekoei River

The phases and activities outlined in Chapter 4 were followed with the results reported below.

Phase 1. Initiate the EWA study

The main focus of Phase 1 is to decide whether the perennial or the non-perennial approach should be followed. This decision is based on the outcome of the first of two activities under Phase 1, namely to define the river in terms of its perenniality. The second activity comprises identifying river importance, as well as the level at which the EWA would be conducted.

Activity 1: Define the river in terms of perenniality

Data availability

The Seekoei River is situated in the D3 sub-drainage region in the south western parts of the Northern Cape Province. Three river gauging stations have been operated by the Department of Water Affairs and Forestry (DWAF) in die Seekoei River since 1911: D3H001 (Seekoei River at Haasfontein, D32E), D3H007 (Seekoei River at Welbedacht, D32F) and D3H015 (Seekoei River at De Eerstepoort, D32J; see Figure 3.2). Of these, only D3H015 was still in operation at the start of the project (Table 5.1).

Data accuracy

An assessment of the available hydrological records for the three stations revealed that the data for D3H001 and D3H007 were of poor quality (see Table 5.1) [5]. About 75% of D3H001's data record was unreliable due to problems with river sediment and unreliable observations. D3H007's data record consisted of gauge plate readings taken once a day when low flow occurred, and more readings per day during floods. Although the manually recorded data were considered to be accurate, it was not as accurate as continuous automatic water level readings would have been, especially with regards to low flows or when floods passed the station at night.

The third gauging station, D3H015, which is situated in the lower section of the river (D32J), consisted of a Crump Weir with six notches specifically designed and constructed for accurate flow monitoring. The station, therefore, had an accurate record of flow and stage data spanning 25 years (22/06/1980-10/03/2005[6]). Although submergence was identified as a possible problem, the weir could operate at submergence levels as high as 75% to 90% allowing accurate flow calculations up to the structural limit of the weir. The hydrological assessment showed that only four flood peaks in 25 years were above the rating table limit.

[5] Done by Ewald Stëyn, a DWAF hydrologist based in Kimberley.
[6] The study commenced in 2005.

Table 5.1: Quality assessment of hydrological records for the gauging stations on the Seekoei River (adapted from Stëyn, 2005).

Gauging station	Coordinates	Period of available data	Type of data recording	Quality of data records	Reason
D3H001 Seekoei River at Haasfontein	31°10’34” Lat 24°35’43” Long	01/10/1911-29/01/1918	Automatic recorder	Unreliable	Siltation
		01/05/1935-31/10/1942	Private observer – stage readings	Unreliable	Unreliable observer
D3H007 Seekoei River at Welbedacht	31°03’52” Lat 24°34’22” Long	01/11/1959-04/03/1974	Stage plate readings	Low accuracy	Low accuracy i.t.o. low and high flows
D3H015 Seekoei River at De Eerstepoort	30°32’03 Lat 24°57’43” Long	22/06/1980-present	Automatic stage and flow data	Good, up to structural limit of 1.5 m	

Flow duration curve

Flow duration curves were produced for the three gauging stations and are presented in Figure 5.1. The curves indicated that surface flow in the Seekoei River occurred between 12% (at D3H007) and 45% (D3H015) of the period covered by each station’s data record. The discrepancy in the period of flow calculated for the two stations was explained by the way the data were measured. Gauge plate readings recorded by human observers clearly underestimated the percentage of time flow occurred in the river when compared to automatic recorded water levels. The percentage of time flow occurred in the Seekoei River increased four to tenfold when automatic water level recorders were used (Table 5.2), which emphasised the shortcomings of a flow record based on gauge plate readings.

Based on the continuous data record, it was concluded that the Seekoei River is a non-perennial river with flow occurring about 45% of the time. According to categories of flow persistence identified by Rossouw et al. (2005; Table 4.1), the Seekoei River can be described as an ephemeral river.

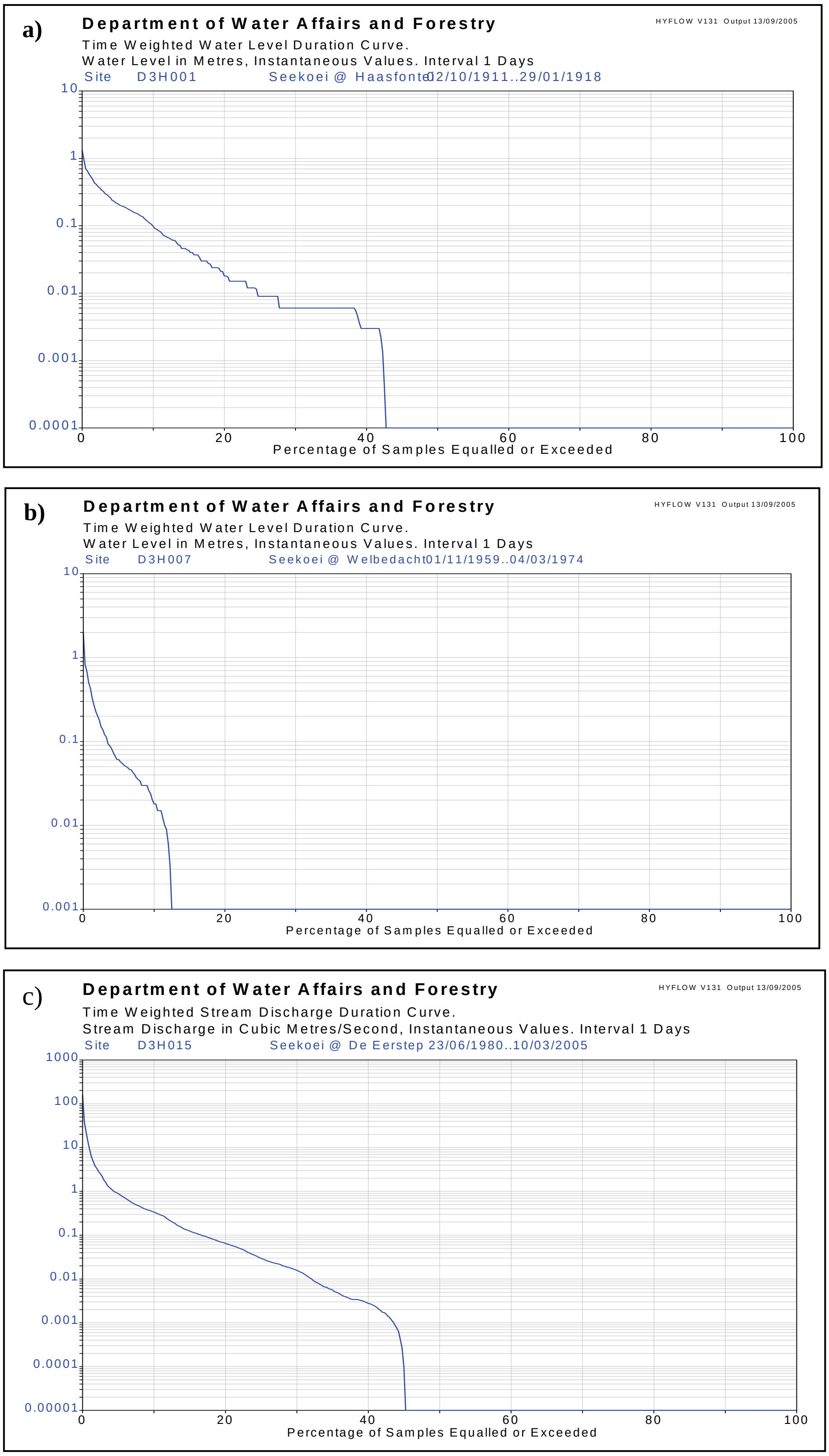

Figure 5.1: Flow duration curves for D3H001 (a), D3H007 (b) and D3H015 (c) (after Stëyn, 2005).

Table 5.2: Different percentages of time the Seekoei River flowed calculated for continuous water level readings measured automatically and gauge plate readings recorded by human observers (after Stëyn, 2005).

Gauging station	% of time flow has occurred during the period of flow monitoring at the station			
	Period with continuous water level recording	%	Period with only gauge plate readings taken	%
D3H001	02/10/1911-29/01/1918	42	01/05/1935-31/10/1942	4
D3H007			01/11/1959-04/03/1974	12
D3H015	23/06/1980-10/03/2005	45		

Seasonality and flow variability

Based on the mean monthly discharges as recorded at D3H015, which is the most complete and reliable data record for the Seekoei River, flow was most likely to occur in late summer i.e. February to March (Figure 5.2).

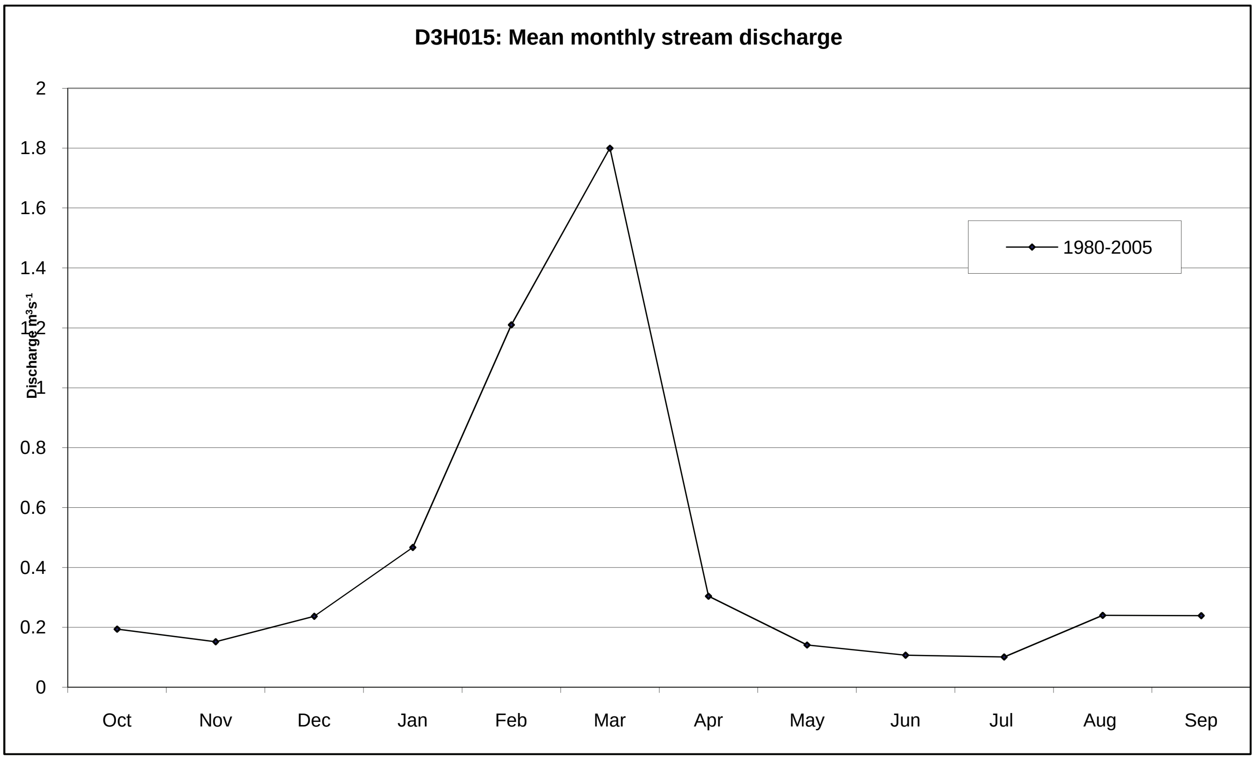

Figure 5.2: Monthly average stream discharge for gauging station D3H015 (Seekoei at De Eerstepoort) for the period 01/071980 to 01/06/2005 (after Stëyn, 2005).

Flow in the Seekoei River proved, however, to be highly variable. While wet conditions prevailed during the first year of field studies, dry conditions characterised the second (Figure 5.3). Based on the Hydrological Index (HI; Hughes and Hannart, 2003), which indicates flow variability, the Seekoei River was in the top 5 to 15% of all rivers in South Africa in terms of flow variability with HI values varying between 55 (D32B) and 75 (D32E; see Table 5.3).

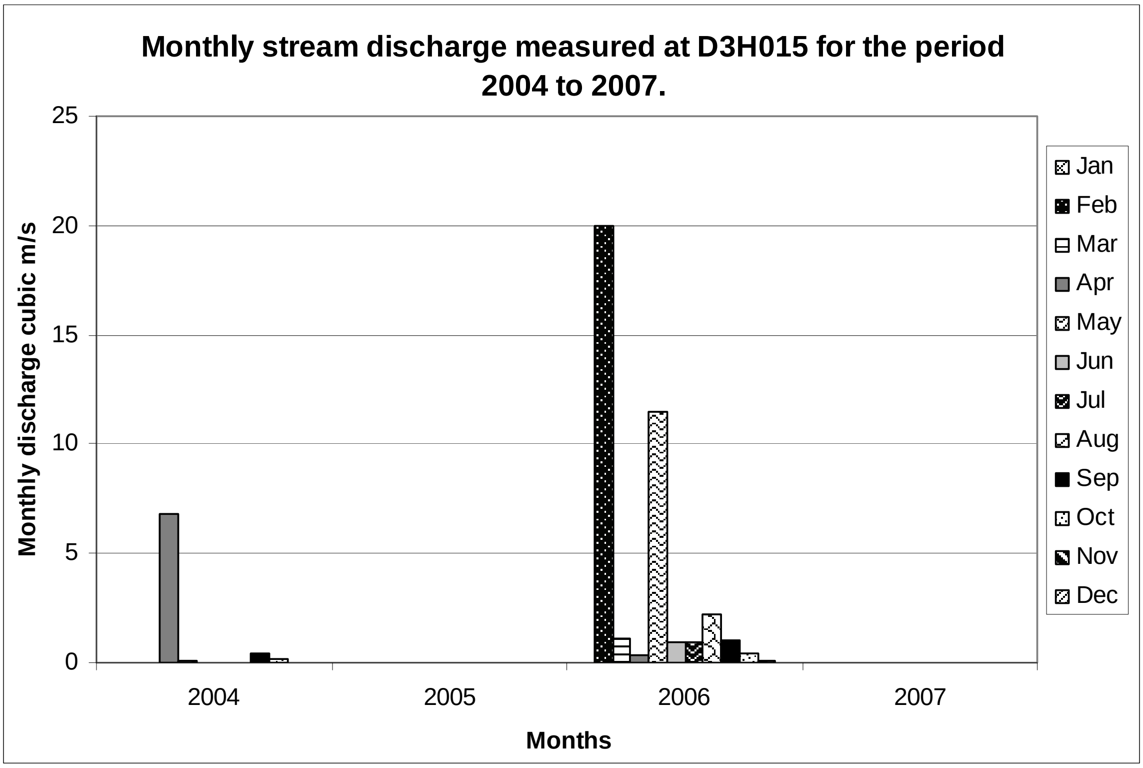

Figure 5.3: Monthly stream discharge in cubic metres per second for gauging station D3H015 (Seekoei at De Eerstepoort) for the period 01/01/2004 to 31/12/2007 (data obtained from www.DWAF.gov.za).

Table 5.3: Quaternary catchment information for the Seekoei River (taken from Dollar, 2005). (MAE, mean annual evaporation; MAP, mean annual precipitation; MAR, mean annual runoff; CV, coefficient of variance of runoff; Hydrological Index after Hughes and Hannart, 2003).

Quaternary catchment	Area (km^2)	MAE (mm)	MAP (mm)	Gross MAR ($10^6 m^3$)	CV	Sediment yield (1000 t/a)	Sediment yield ($t/km^2/a$)	Hydro-logical index
D32A	716	1925	314	3.2	1.871	58	81	56
D32B	582	1925	341	3.7	1.860	47	81	55
D32C	850	1925	316	3.9	1.871	69	81	73
D32D	851	1925	312	3.7	1.871	69	81	56
D32E	1157	1925	274	3.0	1.821	93	80	75
D32F	1443	1925	305	5.8	2.273	111	77	72
D32G	1045	1925	330	5.7	2.297	84	80	71
D32H	572	1925	328	3.0	2.298	46	80	56
D32J	1041	1925	315	5.1	2.292	80	77	72
D32K	824	1925	325	4.2	2.298	53	64	73
D32	**9081**		**313**		**2.0**		**78**	**66**

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

The DWAF is responsible for commissioning EWA studies in the South African context. The importance and sensitivity rating of a river system determined during the first step would be one of the considerations playing a role in deciding the level at which the EWA would be conducted.

Importance rating

A desktop estimation of the ecological importance and sensitivity (EIS) of South Africa's river ecosystems was carried out by the DWAF in 1999 as part of the Provincial Water Resources Assessments for the National Water Balance (NWB; Kleynhans, 1999a). The ecological importance and sensitivity of each quaternary catchment were determined by selected local experts based on their local knowledge and experience. A summary of the desktop estimations for the Seekoei catchment are presented in Table 5.4. These estimations were used to give an early indication of the EIS status of the Seekoei River.

Table 5.4: Estimated ecological importance and sensitivity classes for the Seekoei River catchment (adapted from Kleynhans, 1999a).
(EIS scores are based on a number of biotic and habitat determinants that are scored on a scale of "0" = "low" to "4" = very high. The EIS categories can be interpreted as follow: Category A = 4, very high sensitivity; category B = 3, high sensitivity; category C = 2, moderately sensitive system; category D = 1, low sensitivity; category E = 0, very low sensitivity).

Quaternary catchment	River	EIS score	EIS Category	Description
D32A	Elandskloof	2	C	Moderately sensitive system
D32B	Klein Seekoei	2	C	Moderately sensitive system
D32C	Klein Seekoei	2	C	Moderately sensitive system
D32D	Seekoei	2	C	Moderately sensitive system
D32E	Seekoei	2	C	Moderately sensitive system
D32F	Seekoei	2	C	Moderately sensitive system
D32G	Noupoortspruit	2	C	Moderately sensitive system
D32H	Tributary	2	C	Moderately sensitive system
D32J	Seekoei	2	C	Moderately sensitive system
D32K	Seekoei	2	C	Moderately sensitive system

The Seekoei River and its major tributaries were all considered to be moderately sensitive (category C). This implied that the catchment was considered to be unique on a provincial or local scale in terms of its biodiversity in terms of habitat diversity, species diversity, and unique, rare or endangered species. According to the general description for this category, the biota and habitats of the Seekoei River were not expected to be very sensitive to flow modifications and the river could have a substantial capacity for use (Kleynhans, 1999a).

Allocation of level for EWA

Due to the fact that the EWA on the Seekoei was not commissioned by DWAF in response to a water-use application or planned development, this step was not completed in full. The research nature of the project however implied that the study was conducted at a level similar to a comprehensive reserve determination.

Comprehensive reserve determinations, which could be linked to EcoStatus Level 4 assessments (see Kleynhans and Louw (2008) for further discussion on the EcoClassification process), usually comprise extensive field data collection of 8 to 12 months by various specialists in order to provide answers of relatively high confidence (DWAF, 1999). These studies typically include the following specialist studies or river components: geomorphology, water quality, hydrology, hydraulics, riparian vegetation, aquatic macroinvertebrates and fish.

Phase 2. Set up study

Phase 2 comprises two activities, namely selecting a core team of specialists and preparing a workplan and a budget for the EWA.

Activity 3: Select core specialist team

Background

It was not clear at the start of the study which ecosystem components, or specialist fields, would be the crucial ones to include in EWA assessments on non-perennial rivers. Not all disciplines were expected to play an equally important role. Fish, for example, are absent from many ephemeral and episodic rivers. Uncertainty also existed about whether to include hydraulic modelling in the Seekoei River study, as well as the value this discipline could contribute to EWAs in intermittent rivers – especially when considering the limited resources that are usually available. It was also highly likely that a different combination of disciplines would be required for seasonal, ephemeral and episodic rivers, respectively. It would, therefore, be more cost-effective to start out with a core team comprising of key disciplines and to add the additional specialists required for the study later on in the project. It was proposed that the core team consists of a study leader, hydrologist, geohydrologist, geomorphologist/GIS specialist, an instream ecologist and a socio-economist. All of these should have local knowledge of the river system and/or experience of working in intermittent systems. This core team would then identify additional expertise needed for the completion of the study, after the initial assessment of the catchment and important issues raised by the stakeholders had been completed.

For the Seekoei River study, it was decided to include as many of the disciplines used in comprehensive perennial reserve determinations as practically possible. Each discipline's contribution, usefulness and practicality (within the context of ephemeral systems) would then be evaluated towards the end of the project. The present study, therefore, deviated from the proposed method in that the whole team was involved in the study from the start.

Select core team

It was decided to include the following ten disciplines in the Seekoei River study: hydrology, geohydrology, hydraulics, catchment geomorphology, fluvial geomorphology, water quality, riparian vegetation, aquatic macroinvertebrates, fish and socio-economics. Specialists in these fields were therefore appointed (see Table 3.1 in Chapter 3), together with Dr. Jackie King to assist with method development. Most of the specialists were associated with the University of the Free State and have previous experience and knowledge of local systems and conditions in the Free State and Northern Cape. Due to the fact that land use in the catchment and along the river banks consisted almost exclusively of commercial and game farming, an agricultural economist (instead of a sociologist and economist) was included in the project team.

Activity 4: Prepare workplan and allocate budget

The workplan and budget prepared for the Seekoei study referred to the wider research project running over three years and are not included here.

Phase 3. Delineate the catchment and describe its hydrology

The main focus of Phase 3 is to develop a basic understanding of physical catchment processes, based on a thorough desktop description of the catchment, as well as catchment hydrology. This understanding is then applied to delineate the river into Combined Response Units (CRUs). CRUs can be described as river reaches that are relatively similar in terms of their natural features and land use, and would play a pivotal role in guiding the site-selection process which follows in Phase 5. Phase 3 comprises five activities, namely describing the catchment, delineating the runoff potential units (RPUs), describing the catchment hydrology, assessing the habitat integrity and finally, delineating the CRUs.

It should be noted, that a different approach was followed for the Seekoei River study. The Seekoei River was delineated into geomorphologically similar units, or macro-reaches, based on the river's longitudinal profile. These macro-reaches then formed the basis for site-selection and the subsequent specialist studies. This approach was, however, later in the project found wanting for a number of reasons, and an alternative approach was proposed.

The new approach was tested on the Seekoei River retrospectively during the final year of the study.

Below, the steps followed for the initial approach are briefly described and the results presented. Second, results from the new approach are presented, and third a comparison of the two approaches is provided.

Initial approach followed for the Seekoei River
(A description of the process that we followed in the Seekoei, and how this gave rise to the new approach proposed here).

Site-selection in the Seekoei River was mainly based on geomorphologically distinct segments. The river's longitudinal profile continuum was used to delineate the river into distinct segments, hereafter referred to as macro-reaches, by means of a macro-reach analysis.

Hierarchical river classification systems are often used to divide rivers into similar segments or reaches in an attempt to deal with the complexity of these systems. Delineating rivers into similar reaches based on their broad geomorphological characteristics or longitudinal profiles, have been found useful in river management (Kleynhans et al., 1998; Roux et al., 1999), ecological reserve determination studies (DWAF, 1999; Rowntree, 2000) and freshwater ecosystem planning (Dollar et al., 2006). Geomorphological river segments are often used as ecological management units for which benchmarks conditions can be defined (Roux et al., 1999) and can be of considerable use in choosing representative study sites in a river (Dollar, 2005).

The delineation of macro-reaches is an expert-driven process that is especially useful in situations where there is limited information, or where a regional- or national-scale approach is required (Nel et al., 2005). Recently, an automated desktop procedure aiming to produce repeatable and statistically defensible results was developed by Dollar et al. (2006).

Steps followed for the Seekoei

A four step approach, presented in Table 5.5, was followed to delineate the Seekoei River into macro-reaches in preparation for site-selection. Although the first three steps contributed directly to macro-reach determination, the fourth step, "assessing the integrity of the riparian and instream habitats", provided important information and insight into river condition, which was considered during site-selection.

Table 5.5: Comparing the activities followed for the initial approach for the determination of homogenous river reaches in the Seekoei River study to those proposed by the prototype method.

Activity	**Initial approach:** Actions followed to determine macro-reaches	**New approach:** Actions proposed to determine CRUs
1	Delineate catchment boundaries	Describe catchment
2	Complete aerial survey of the river	Delineate RPUs
3	Analyse macro-reaches	Describe catchment hydrology
4	Assess habitat integrity	Assess habitat integrity
5		Delineate CRUs
Outcome	**Macro-reaches**	**CRUs**

Delineation of study area

The main stem of the Seekoei River was divided into 51 segments of 5 km each (using 1:50 000 maps), starting at the upstream end, in preparation for the aerial survey of the catchment. Background information on the catchment's physical (e.g. geology, topography, rainfall, land use, etc.) and biological characteristics (vegetation types, ecoregions, etc.) were gathered from maps, GIS databases and literature sources.

Aerial survey

An aerial survey comprising a low-level video survey and an aerial assessment of river impacts (noted for each 5 km segment) was conducted on 13 October 2005 from a R44 type helicopter (a more detailed description is included under Activity 8). The video recording was used as a basis for the macro-reach analysis, as well as the Habitat Integrity Assessment (see Activity 8), which followed later.

Macro-reach analysis

The main objective of the macro-reach analysis was to divide the river into geomorphologically distinct macro-reaches as a basis for the selection of representative sampling sites in the Seekoei River.

Two approaches were applied on the Seekoei River, a statistical approach and a desktop approach[7]. The approaches are explained in Dollar (2005) and Dollar et al. (2006), and only a brief summary on each approach is included:

[7] The report on the macro-reach analysis by Dollar (2005) is included on the accompanying CD.

i) The statistical approach (see Dollar et al., 2006) used an adaptation of the Worsley Likelihood Ratio Test (WLRT) (for a successively bifurcated sample set) to find the most likely position of a change in mean in the data set (chainage and elevation values for the longitudinal profile). The WLRT method calculated a sum of deviations from the mean and weighted them according to their position in the series. The partial sums were rescaled and adjusted by dividing through by the sample's standard deviation. The advantage of the WLRT method was that it could determine the position of the change point whereas a Student t-test could only test whether the hypothesis of a change point is true if the position of the change point is known. The test is therefore statistically defensible.

ii) The desktop approach used 1:50 000 topographical maps to generate longitudinal profiles for the main stem Seekoei River. The Cumulative Summation (CUSUM) technique (see Dollar et al., 2006) was used to identify breaks through plotting the cumulative standard deviations of slope. Major breaks of slope could easily be identified from the plot. This, together with the geological information and classification of 'channel type' from the aerial survey video provided the basis for defining macro-reach boundaries.

Macro-reaches

Five macro-reaches were identified for the Seekoei River (see Figure 5.4). The macro-reaches reflected the influence of the underlying geology and sediments, dolerite intrusions and slope. These three factors have imposed high level constraints on the channel type, which in turn influences lower level forms and processes. Climatologically and hydrologically, the catchment was fairly uniform, and therefore these factors were considered as constants in delineating the macro-reaches.

Macro-reach 1 (~1855 to 1595 mamsl; see Figure 5.4) represented the upper section of the Seekoei River. It was underlain by dolerite in the upper sections, and by alluvium and mudstones and sandstones of the Adelaide Subgroup in the lower sections (Table 5.7). The macro-reach was steep, with a slope of 0.01905. No helicopter survey was available for this short, concave section of the profile, but evidence from the 1:50 000 topographical maps suggested 'floodout' type channels, a channel type common in dryland Australia (Tooth, 2000).

The second macro-reach (~1595-1538 mamsl; see Figure 5.4) represented an alluvial, meandering channel with isolated pools. The channel flowed in alluvium underlain by mudstones and sandstones of the Adelaide Subgroup (Table 5.7). Heterogeneity was imposed, in part, by discontinuous linear swathes of in-channel vegetation.

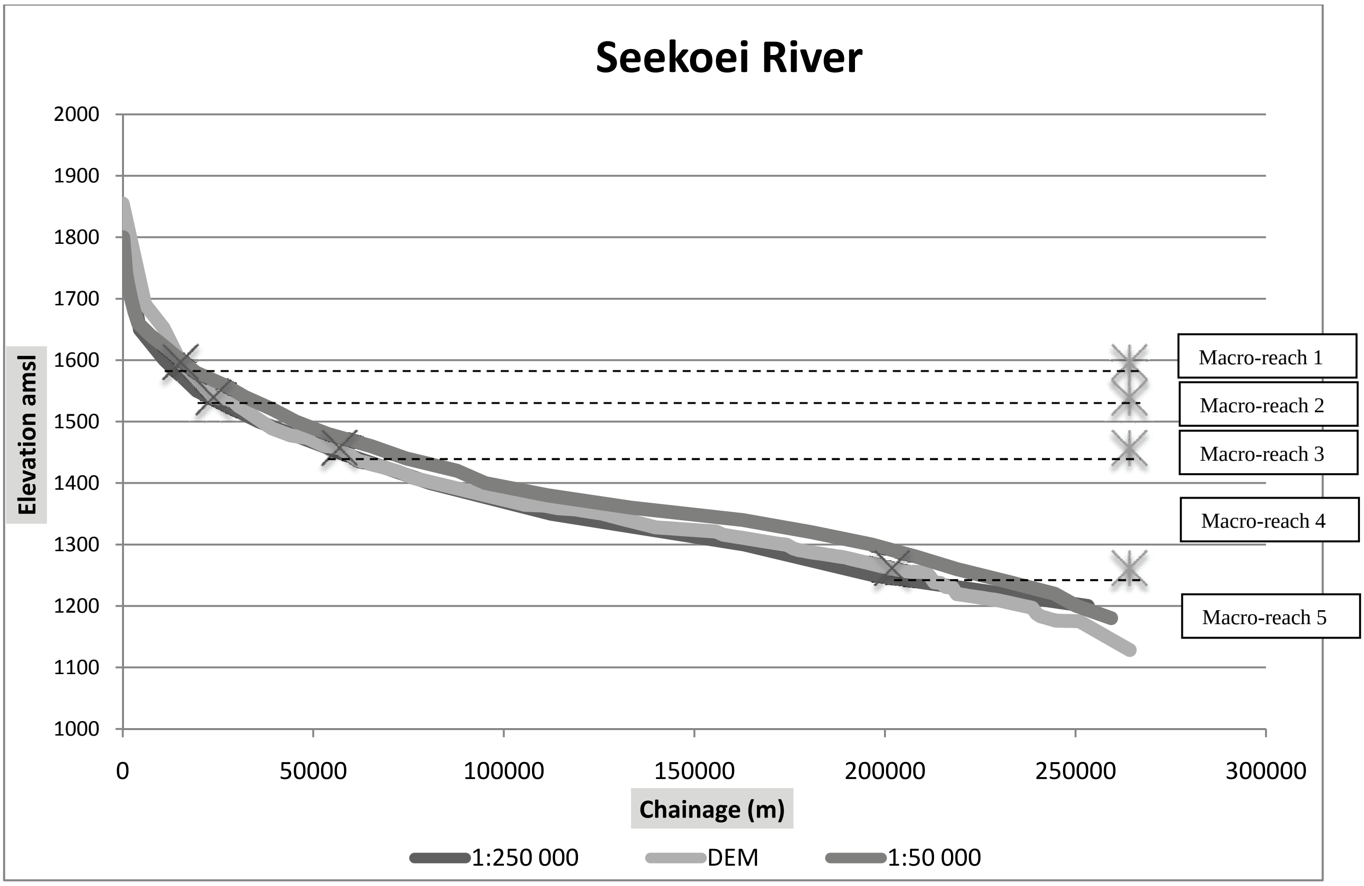

Figure 5.4: The longitudinal profile of the Seekoei River, showing the five macro-reaches (after Dollar, 2005).

Two types of pools were evident in macro-reach 2, both of which were determined by downstream hydraulic controls. First, intrusions of dolerite and incision into the Karoo bedrock in places created hydraulic controls, with pools forming upstream of the bedrock. Second, sedimentary hydraulic features created hydraulic controls, with pools forming upstream of them. In places, coarse bed material occurred. Approximately 22 artificial impoundments influenced this macro-reach.

Macro-reach 3 (~1538 to 1473 mamsl; Figure 5.4) was very similar to macro-reach 2, but with two important distinguishing features. First, the slope was approximately half of macro-reach 2, and second, coarse bed material was absent. Approximately five artificial impoundments occurred in this macro-reach.

Macro-reach 4 (~1473 to 1260 mamsl) was the longest and the flattest of the five macro-reaches. It was underlain by alluvium, and unlike macro-reaches 1 to 3, the shape of the profile was convex (Table 5.6). The channel type was mainly single thread, and was strongly influenced by reed encroachment. Occasional isolated pools occurred, as well as linear swathes of in-channel vegetation, which created distributary channels in short anastomosing section of the channel. The large impact that the approximately 34 artificial impoundments had on this river section made it difficult to assess the ‘pre-impact’ channel type.

Table 5.6: Macro-reach analysis for the Seekoei River main stem using adapted Worsley Likelihood Ratio Test (WLRT) approach from the 20 m Digital Elevation Model (after Dollar, 2005).

Change point chainage (km)	**Elevation** (mamsl)	**Reach length** (km)	**Average slope** (m/m)	**Shape**
15.3	1595*	15.30	0.01905	Concave
23.8	1538*	8.5	0.00465	Concave
56.9	1473+	33.1	0.00278	Concave
201	1260+	144.1	0.00134	Convex
	<1260	62.3	0.00203	Convex

Macro-reach 5 (~1260 m to 1180 m a.m.s.l.) represented a significant change from macro-reach 4. Here, the convex macro-reach was influenced strongly by dolerite and the shales, siltstones and sandstones of the Tierberg formation, so that the valley form was more confined, and the valley slope steep (slope of 0.00203; Table 5.7). Significant intrusions of dolerite and incision into bedrock created a pool/rapid channel type, although pool/riffle sequences were absent from the upper sections of the macro-reach. As with macro-reach 4, the Vanderkloof Dam and approximately 17 other artificial impoundments had a large impact on the channel form.

Although it would have been ideal to select a sampling site within each of the five macro-reaches, this was not possible due to financial and resource constraints. It was proposed that representative sampling sites should be selected in macro-reaches 2, 4 and 5.

Table 5.7: Summary table of the macro-reaches for the Seekoei River main stem (after Dollar, 2005).

Macro-reach	Length (km)	Amsl (m)	Slope (m/m)	Dominant channel type	Lithology	Comment
1	15.3	1855	0.01905	Floodouts?	Dolerite, alluvium over mudstone and sandstone	No video tape for analysis, but evidence from topographical maps would suggest floodout type features. alluvium over mudstone and sandstone
2	8.5	1595	0.00465	Isolated pools and linear (dry) distributary channels. Meandering.	Alluvium over mudstone and sandstone	Alluvial reach. The channel planform is meandering, with occasional pools. Of significance is the existence of sedimentary hydraulic controls. These unreported and unexplained features warrant further investigation. Occasional bedrock outcrops create diversity locally and also form upstream pools. Occasional linear distributary channels occur. Coarse bed material in places. Where riparian vegetation is reeds, limited diversity, where in-channel and riparian vegetation ‘not’ reeds, considerably more diversity. ~22 impoundments.
3	33.1	1538	0.00278	Isolated pools and linear (dry) distributary channels. Meandering.	Alluvium over mudstone and sandstone	Alluvial reach. The channel planform is meandering, with occasional pools. Sedimentary hydraulic controls. Occasional bedrock outcrops create diversity locally and also form upstream pools. Occasional distributary channels. Where riparian vegetation reeds, limited diversity, where in-channel and riparian vegetation ‘not’ reeds, considerably more diversity. ~5 impoundments.
4	144.1	1477	0.00134	Single thread and pools. Limited distributary channels.	Alluvium over mudstone and sandstone	Alluvial reach. The influence of impoundments (~34) in this macro-reach makes it difficult to assess the channel type. The influence of reed encroachment (assumed) is considerable. The channel consists mainly of a single thread channel flanked by reeds, broken occasionally by isolated pools and distributary channels. Occasional bedrock outcrops create some diversity. Hydraulic controls are created by bedrock and sedimentary features. Additional diversity is created by in-channel and riparian vegetation which form/impact occasional distributary channels.
5	62.3	1260	0.00203	Pool/riffle/rapid	Dolerite, and shale, siltstone and sandstone	The influence of the Vanderkloof Dam and other impoundments (~17 impoundments) is considerable. The impounded water creates a homogenous environment; there is limited geodiversity (variety of geomorphic features) and the lack of in-channel and riparian vegetation which plays such a significant role in imparting diversity to the channel in non-impounded reaches creates an almost featureless channel. At some locations, dolerite sheets have been breached, in others, breaching process is ongoing. The channel is mainly pool/rapid, although towards the upper end of the macro-reach (>1240 m amsl), riffles occur. The channel form (and hydraulics) is strongly controlled by local bedrock intrusions. Where reeds have encroached into the channel, a single thread channel occurs. Sedimentary hydraulic controls.

Habitat integrity assessment

An assessment of the condition of the riparian and instream habitats for the Seekoei River is a component of both approaches and is discussed under Activity 8.

Shortcomings of the approach initially followed for the Seekoei River

A number of shortcomings of the approach followed in the Seekoei River became apparent as the study progressed. Of these, the most significant was the realisation that the available hydrological record only reflected conditions in the quaternary catchment immediately upstream of the gauging station. The hydrological analysis revealed that most of the surface-flow (measured at the gauging weir) is generated within quaternary catchment D32J where the gauging weir is situated, presenting a skewed view of surface-flow in the rest of the catchment. This presented the hydrological modeller with some challenges. Although the hydrological models produced information for sites EWR3 and 4 (situated in D32J) on how the connectivity of surface flow and the flood regime could change for the various scenarios, only connectivity could be modelled for the two upstream sites, EWR1 and 2. Introducing the hydrological analysis and modelling into the river delineation process, as proposed by our new prototype method, could alert the study team to such anomalies earlier in the process. This would allow the team to include these issues into their project planning and the selection of sampling sites.

In retrospect, the initial Seekoei River approach, which focused mainly on the river channel and adjoining riparian areas as a basis for site selection, appeared too narrow-minded. The need for comprehensive assessment of the whole catchment became apparent. Although the initial approach included a desktop reconnaissance of the catchment in preparation for site selection, a comprehensive catchment assessment only followed later as part of the specialist studies – the result being that river delineation did not consider a wide enough range of catchment characteristics. Broadening the scope of the river delineation process to include a wider assessment of the catchment's characteristics and processes (including a description of the catchment hydrology) could, therefore:

- Increase the understanding of the catchment and catchment processes before sampling sites are selected.
- Guide the selection of indicators for the various river sections/units, as well as the expertise needed for the EWA.
- Assist with the development of relevant scenarios. For example, gradient proved to be quite an important factor in the Seekoei catchment. Due to a low gradient throughout the biggest part of the catchment, land use was not expected to have a large impact on river condition. The hydrological model, indeed, predicted very insignificant changes to the hydrological regime as a result of changes in land use and catchment cover.

- Enhance project planning, thereby reducing costs and increasing efficient use of time.

The alternative approach proposed in the prototype methodology

Aquatic scientists know that rivers are intricately linked to their catchments or watersheds and they cannot be effectively managed in isolation without considering human impacts within their catchments. Still, they often tend to dislocate a river from its catchment in research studies and only concentrate on the parts interested in. Being confronted, however, with a dry empty channel, forces one to turn one's focus sideways to the catchment. The idea that landscape or catchment processes plays an important role in the ecological functioning of non-perennial rivers is by no means novel.

It is very clear that the drier an area or catchment is, the greater the variability in rainfall, runoff and river flow is, not only temporally but also spatially. Some systems, closer towards the episodic end of the continuum, only experience surface flow once every few years. This implies that ideal sampling opportunities (for some disciplines) become very rare as you move towards the episodic end. It is also understood that water use licence applications cannot be put on hold indefinitely in order to allow field sampling. EWA methodologies for non-perennial rivers should, therefore, acknowledge this limitation and provide a means to gather suitable information to allow and support decision-making.

Recognising the need for a wider approach and considering the lessons learned from the Seekoei River study, two activities were added to the river delineation process, a rather comprehensive desktop assessment of the catchment, as well as a mechanism to incorporate these characteristics into the delineation process, and a description of the catchment hydrology (see Table 5.5). Five activities were, therefore, proposed for river delineation: (i) describing the catchment, (ii) delineating the hydrological response units (RPUs), (iii) describing the catchment hydrology, (iv) assessing the habitat integrity and (v) delineating the CRUs.

Activity 5: Describe the catchment

A detailed description of the Seekoei River catchment, accompanied by the relevant maps, is presented in Chapter 3 and only a concise summary is provided here.

The Seekoei River catchment is situated in the Nama Karoo Ecoregion (26.03; Kleynhans et al., 2004) between 1 300-1 700 meter above sea level in the dry central parts of South Africa. The river originates in the Sneeuberge and joins the Orange River at Vanderkoof Dam after flowing for approximately 220 km through a flat landscape of sandstones, shales and mudstones interbedded by dolerite intrusions. These dolerite intrusions play an important role in the shaping the river’s longitudinal profile, channel type and the location of pools. Pools in the Seekoei River are often formed upstream of dolerite acting as a hydraulic control.

The daily and seasonal temperatures show large fluctuations – summers are hot (mean daily maximum temperature for January is 32.3°C), and winters cold (average daily minimum temperature for June, the coldest month, is 0.6°C). Frost occurs frequently between May and October (Venter et al., 1986). Mean annual precipitation (MAP) ranges between 300 and 340 mm (Hughes, 2008a) and occurs mainly in late summer to autumn**.** Potential mean annual evaporation (MAE; average of 1911 mm/a) exceeds MAP (average of 313 mm/a) resulting in a low gross mean annual runoff (MAR) and high coefficient of variation (CV; Dollar, 2005). The Seekoei therefore has a highly variable hydrological regime, with hydrological index scores varying between 55 and 75 for the various quaternary catchments (Dollar, 2005). The Hydrological Index (HI) was developed by Hughes and Hannart (2003) to express flow variability.

The catchment is located in the Nama Karoo Biome, and the two main vegetation types are described as Besemkaree Koppies Shrubland and the Eastern Upper Karoo (Mucina and Rutherford, 2006). Land use in the catchment comprise mainly of agricultural activities and no major towns situated within the river’s catchment. The major impacts in the river are flow, bed and channel modifications as a result of the large number of impoundments (59 weirs, 7 concrete dam walls and 22 earth dam walls) on the river – mostly related to agricultural activities (Watson and Barker, 2006).

Activity 6: Delineate Runoff Potential Units (RPUs)

Twelve fifth order RPUs were identified for the Seekoei River based on the method described in Appendix A. The RPUs are illustrated in Figure 5.5 and their respective runoff potential indicated. Four classes of runoff-potential have been are identified, high, high to medium, low to medium and low, based on a number of variables e.g. erodibility, slope, drainage area, etc.

Four units, RPUs 1, 5, 7 and 11, are classified as having a high runoff potential and another three units, RPUs 13, 14 and 16, as high to medium. It is, therefore, expected that the highest potential runoff in the Seekoei catchment will be generated in basins 1, 5, 7, and 11, together with the three basins in the south-eastern part of the catchment.

RPU 11 is also the largest unit with respect to surface area and runoff-potential (flow accumulation; see Table 5.8). This indicates that the unit could be responsible for the largest amount of flow in the catchment.

The current delineation of quaternary catchments (as used in hydrological modelling) does not follow natural catchment boundaries and therefore gives an unnatural view of processes in individual catchments. The delineation of RPUs could result in a more natural representation of catchment processes in investigations.

As the proposed delineation of RPUs is based on ratings of vegetation cover, infiltration rate, slope and precipitation, future research should be conducted to investigate the links between this classification based on fifth order catchments and the hydrological models simulating the processes in the catchment. Application of fifth order catchment classification in EWA studies could, therefore, result in more effective project planning and site-selection.

Table 5.8: Drainage area and flow accumulation for fifth order basins in the Seekoei River catchment. RPU 11 produces the highest runoff in the catchment and is indicated in bold. (RPU; Runoff potential unit).

				Flow Accumulation (cells)	
RPU	**Area (ha)**	**MIN**	**MAX**	**MEAN**	**STD**
1	68 607.300	0.000	274 475	842.335	11 763.200
4	57 069.500	0.000	228 289	583.013	8 431.660
5	26 647.200	0.000	106 625	372.291	4 586.810
7	34 427.800	0.000	137 674	487.837	6 144.200
9	31 479.000	0.000	125 915	374.045	4 505.350
11	**116 853.000**	0.000	**467 328**	**855.512**	14 071.000
13	105 099.000	0.000	420 455	761.307	13 166.700
14	34 096.200	0.000	136 396	453.803	5 850.790
15	32 667.500	0.000	130 656	422.244	5 149.990
16	7 703.500	0.000	30 820	161.446	1 306.120
17	94 156.700	0.000	376 628	728.413	12 196.200
18	38 127.800	0.000	152 527	405.243	5 522.400

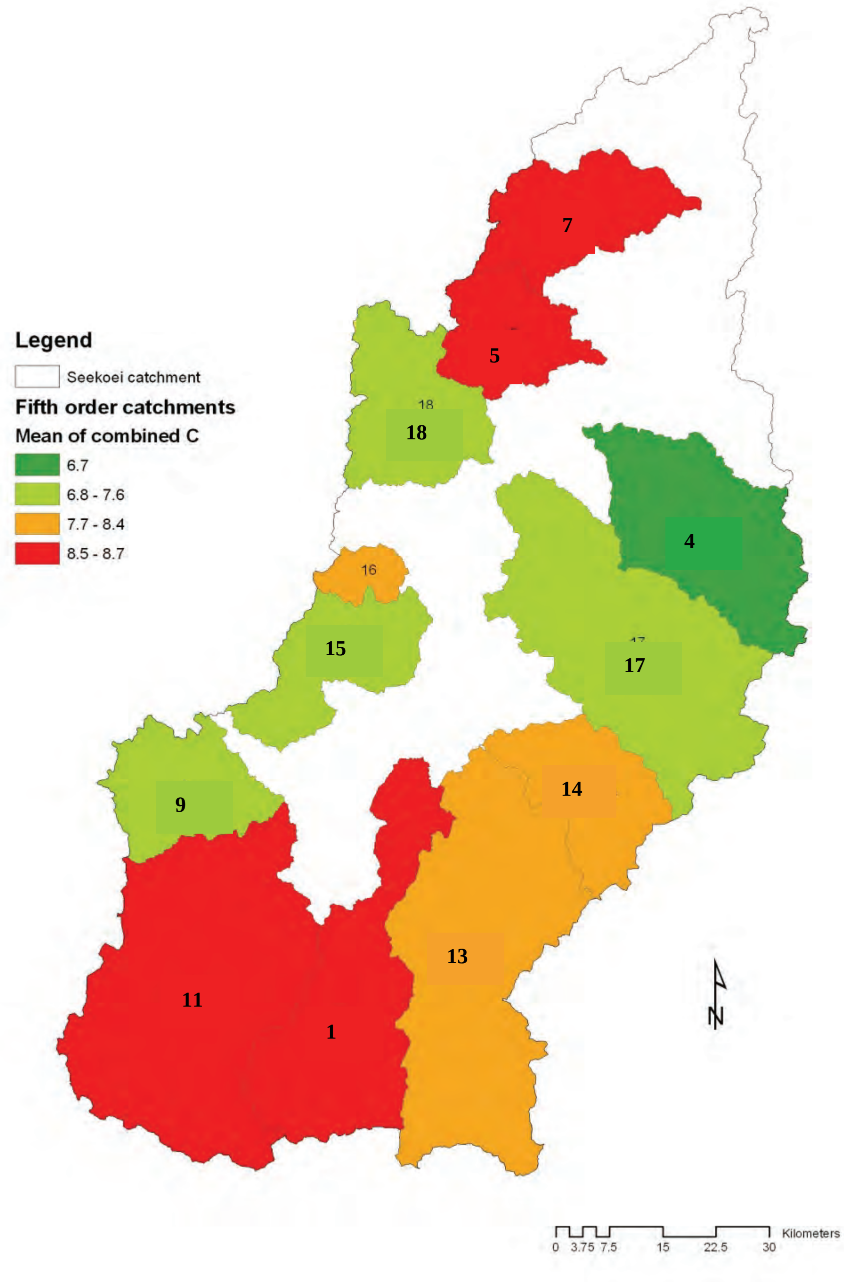

Figure 5.5: Run-off Potential Units identified for the Seekoei River catchment.
Four runoff-potential classes are indicated: red, high runoff potential; orange, high to medium runoff potential; light green, low to medium runoff potential; dark green, low runoff potential. (Note: only fifth order basins are indicated).

Activity 7: Describe the catchment hydrology

The hydrological data analysis and modelling for the Seekoei River was done as a consultancy project to the main project by Prof. Denis Hughes. Results from the study were published in a separate report to the WRC entitled "Hydrological information requirements and methods to support the determination of environmental water requirements in ephemeral systems" (WRC report no. KV 205/08). The hydrological study was done in four steps.

The first step was to identify the hydrological issues that could be of ecological importance within an EWA for the Seekoei River. The dynamics of pool storage and the frequency of pool connection were identified as the two components of the flow regime that are likely to have the most impact on the river's ecological functioning.

During the second step an appropriate hydrological model was established and calibrated. The initial calibration was based on assumed pool dynamics, some observations of ground water and surface water interactions, and the observed flow data at the gauging station.

The third step focused on the interpretation of additional field observations and project team discussions, and the incorporation of this information into revised model calibrations. The models used were the monthly time-step Pitman model, the daily time-step VTI model and a simple water quality (TDS) mass balance model that used the flow outputs from the hydrological models.

The fourth step evaluated the use of the models to simulate various development scenarios.

According to Hughes (2008a), a crucial step in setting up a hydrological model is the development of a conceptual model of the river system, based on an understanding of the flow processes innate to that system. Although knowledge of the climate, topography, geology, soils, vegetation and drainage pattern can provide a great deal of information about possible active processes, site specific investigations over an extended period of time are needed to infer hydrological processes within a specific catchment. Extended site investigations have not been done for the Seekoei River but observations made during a field visit to the river in September 2006 contributed to the development of a conceptual understanding of flow processes in the system.

Two hydrological models, the Pitman monthly model (Pitman, 1973; Hughes, 2004) and the daily VTI model (Hughes and Sami, 1994), were applied on the Seekoei River. Both these models were, according to Hughes (2008a), set up in a manner that was able to replicate the necessary complex conceptualizations of catchment runoff patterns based on the conceptual model for the catchment. Two assumptions were made to address the uncertainties that existed due to the fact that the only observed data were at the catchment outlet, as well as, the large spatial variations in the characteristics of the runoff response:

- D32J was the only sub-catchment in which sustained baseflows were assumedly generated. These were assumed to be generated largely from spring flow, or discharge from perched aquifers, with relatively minor contributions from the regional ground water body.
- In all other sub-catchments the main inputs of water to the channel would be from short-duration surface runoff during high rainfall events. Contributions from ground water were assumed to be very minor.

For the purpose of this chapter, the relevant catchment processes and conceptual model developed for the Seekoei River are presented under Activity 7, while the results from the hydrological modelling (simulations) are presented under Activity 16. More details on the availability and suitability of hydrological models, the setting up, calibration and application of these models for use in ephemeral systems can be found in Hughes (2008a), and will not be discussed here.

Description of the flow processes specific to the Seekoei River

The area experiences summer rainfall with a mean annual total of some 300 to 340 mm with a monthly coefficient of variation of about 1.1, suggesting quite high variations. Mean annual potential evaporation is greater than 1900 mm. The topography is quite flat having a mean catchment slope of 1 to 4%. The video of the river indicated that the near channel environments are typically very low gradient and steeper valley side slopes are mostly experienced a long way from the river, close to the catchment boundary. However, there is one exception to this general rule and that occurs in the lower part of the catchment (within quaternary catchment D32J – see Figures 2.1 and 2.3). Figure 5.6 shows two Google Earth images of the catchment, the left hand side being the area within D32J, while the right hand side illustrates the characteristics of the area further upstream, which is more representative of the catchment as a whole. The left hand image of Figure 5.6 clearly shows steeper topography where the river passes through a gorge related to the occurrence of a dolerite ridge. This area was expected to have very different hydrological response characteristics to the rest of the catchment.

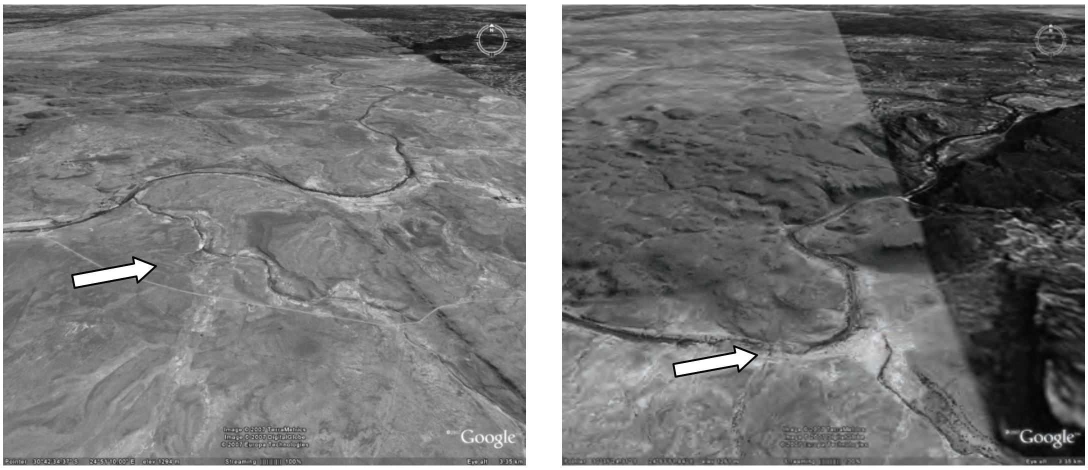

Figure 5.6: Google Earth images (altitude of 3.4 km) of the Seekoei River upstream in the flatter part of the catchment (left) and at the start of the gorge (right). The direction of flow is indicated by the white arrow.

The geology consists of interbedded sandstones, shales and mudstones of the Beaufort Group with relatively frequent dolerite intrusions, some of which can be highly weathered. It appears that shallow colluvial (weathered material) aquifers can be found below the river channel in some areas, while in others the channel is clearly developed on solid rock. Soils are mostly stony and thin, although they can be deep close to the river channels. Vegetation cover is very sparse except on some channel margins where presumably there is improved access to sub-surface water. Drainage densities are low, largely due to the low gradients and this implies that surface runoff processes will be dominated by surface sheet and shallow gulley flow during heavy rainfall.

The only gauging station still in operation within the catchment, D3H15, is at the outlet of quaternary catchment D32J and downstream of the gorge area. The gauged records suggest that flow is quite frequent, even under present-day conditions that are affected by a large number of in-channel weirs and dams. The records also indicate that extended periods of baseflow occur after wet periods. However, field visits indicated that these flow characteristics do not extend very far upstream of the gauging station and that while there is flow in the channels of the lower part of the catchment, the upstream channels do not experience flow. This observation is consistent with the low topographic gradients in the upper parts of the catchment.

A close inspection of the 1:50 000 topographic maps suggests that the high topography area occupies some 20-30% of the total area (1112.5 km^2) of D32J and is drained by 12 major tributary streams. In this area, the river is flanked by koppies rising to about 200 m above the channel bottom. This is quite steep in comparison to other parts of the catchment where a slope of only 20 m occurs. Several of the tributaries that were visited during the field trip in September 2006 were flowing and it is apparent that the source of this flow is spring flow that originates a relatively short distance from their confluence with the main channel. In some cases this spring flow appeared to come from a very concentrated source, while in other cases it originated in a more distributed manner. While geological contact zones could be identified at the spring sources they were not very clear. The current DWAF flow records at D3H015 suggest that a flow event with a peak of about 2 m^3 s^{-1} occurred at the end of August 2006 such that the flow experienced during the September 2006 field visit would have been the recession after that event.

Figure 5.7 illustrates the conceptual concepts of subsurface flow contributions to the channel within the gorge area, developed by the geohydrologist based on initial site visits and test boreholes. The movement of water to the channel is considered to occur within the perched water table associated with weathered dolerite, as well as within the hardrock aquifer. The colluvium beneath the channel bed is also considered to play a role in the sub-surface movement of water in the direction of the channel. Contributions to the channel are expected to be highly localized (in springs) due to structural differences and the occurrence of more transmissive fracture zones and weathered material. These contributions are expected to contribute to pool storage, support riparian vegetation and be lost to evaporation. The exact water balance in any specific part of the channel system will largely depend on the balance between the seepage contributions and the evaporative losses.

The low surface and ground water gradients in the majority of the catchment suggest that sub-surface contributions to channel flow or pool storage will be relatively small in all the other quaternary catchments. However, observations from boreholes close to the river channel suggest that the regional ground water level is very close to the bed of the river and that exchanges do take place between the ground water and pools. The low gradients suggest that these exchanges will be very slow.

With respect to anthropogenic affects, there are many farm dams and main channel weirs within these catchments. The river channel video suggests that some of the main channel weirs are little more than low walls at the end of natural pools (which are unlikely to increase the channel pool storage by a large amount), although there are also several quite substantial earth dams that will increase in-channel storage and affect downstream runoff during small to moderate sized runoff events. It is very difficult to speculate on the impacts of the many farm dams that are remote from the channel system in an area with such low gradient topography.

One issue that is worth noting is that if the conceptual model represented by Figure 5.7 is realistic then channel losses to ground water are likely to be a negligible component of the overall water balance. This is because the model assumes that the water table is close to the channel bed. There may be parts of the channel system that are losing water during surface runoff events, while other parts of the channel system are gaining water through ground water discharge. However, on balance the losses are expected to be small.

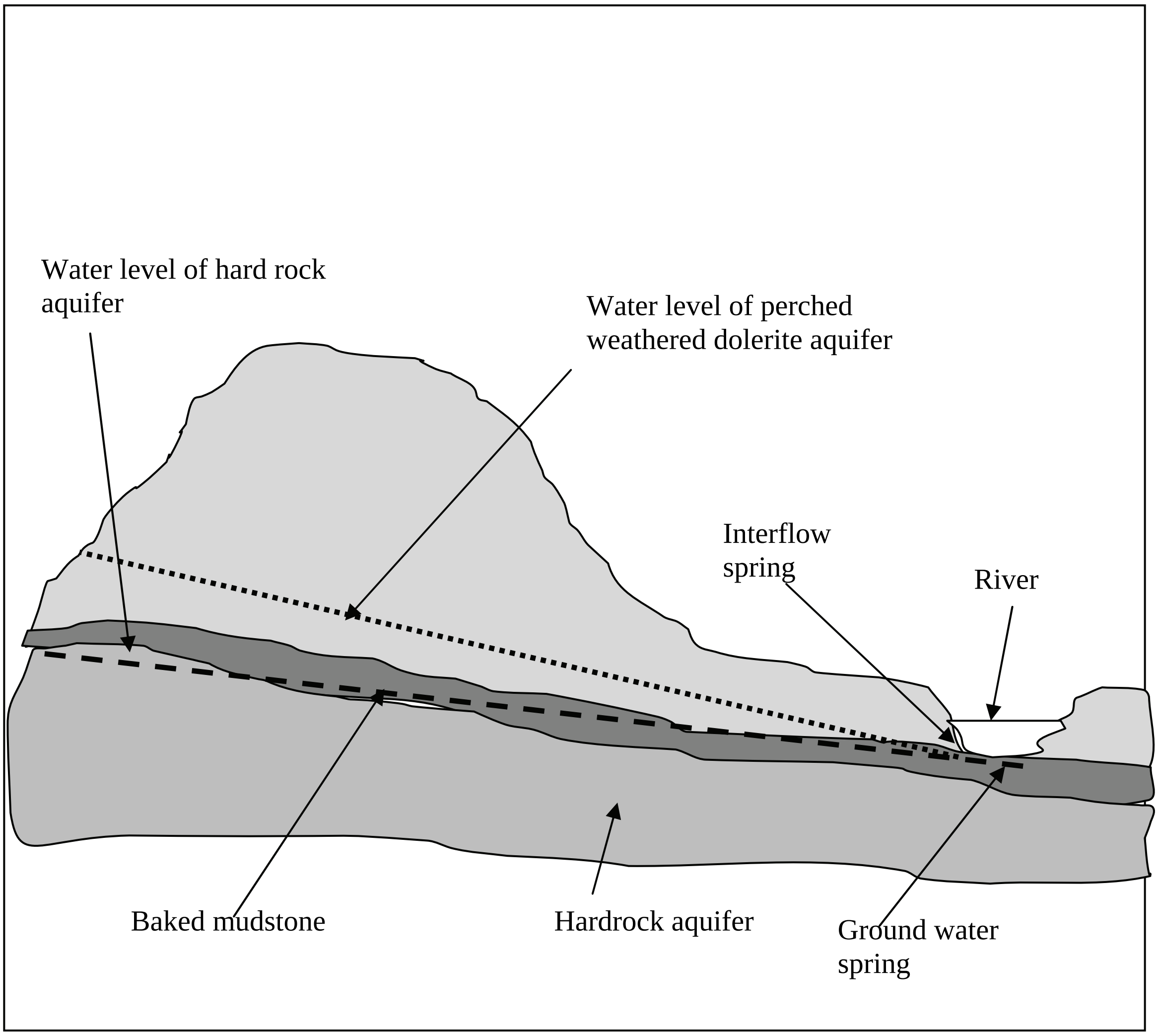

Figure 5.7: Conceptual model for interflow and ground water springs (after van Tonder et al., 2007).

Table 5.9 presents a summary of the estimated natural pool characteristics in the different quaternary sub-catchments, as well as the extent to which the storage has been increased with the development of weirs and dams. The approach adopted for the natural pools assumed that 40% of the total channel length would be 'pooled' at the point when channel flow starts and that the maximum effective surface area (allowing for the effects of seepage into the non-pool areas of the channel) would occupy some 60% of the total channel. The channels were assumed to be 20 m wide on average and between 1 and 2.5 m deep, depending on the upstream catchment area and therefore the channel size. It was further assumed that the surface area for evaporation loss purposes would remain quite large even as the pool dried out (allowing for evaporation from a larger area than simply the visibly wetted area).

Table 5.9: Reservoir (natural and present day) parameters for the 10 sub-catchments (after Hughes, 2008a).[8]

Catchment	Channel length (km)	Max. pool volume (m^3 $*10^6$)		Abstractions
		Natural	Present Day	(P.Day – m^3 $*10^6$)
D32A	53	0.76	5.5+0.76 = 6.26	1.65
D32B	33	0.30	0.5+0.3 = 0.80	0.15
D32C	22	0.32	0.4+0.32 = 0.72	0.12
D32D	31	0.28	18.0+0.28 = 18.28	5.40
D32E	45	0.65	0.6+0.65 = 1.25	0.18
D32F	49	0.98	5.5+0.98 = 6.48	1.65
D32G	52	0.75	2.5+0.75 = 3.25	0.75
D32H	31	0.28	0.1+0.28 = 0.38	0.03
D32J	34	0.75	0.4+0.75 = 1.15	0.12
D32K	22	0.66	0.5+0.66 = 1.16	0.15

Water quality and flow relationships

It is possible that the relationships between water quality and flow could provide some further insight into the runoff processes that are dominating within the Seekoei River catchment. There are water quality and flow data at D3H015 (outlet of D32J) for the period of about 1980 to the present day, while Table 5.12 provides a summary of collected water quality data. While there are a number of apparent gaps in the water quality data, some interesting observations can be made using the TDS data:

- The initial ground water investigation report suggests that the ground water spring flow that sustains pools during periods of zero flow has a TDS of approximately 400 mg l^{-1}.
- The observed runoff at D3H015 has TDS values ranging from less than 100 to over 1500 mg l^{-1}.

[8] *Note: The natural volume estimates are based on the discussion in Chapter 3 of Hughes (2008a), while the additional volumes for the present day scenario are based on information contained within WR90. The abstraction estimates are very approximate and largely based on the volume of storage.*

- The highest TDS values occur after prolonged periods of baseflow or at the start of flow events that have very low flows.
- Several assumptions can be made about flow processes based on the previous bullet point.

  If the start of an event has very low flows, most of the runoff at D3H015 will be displaced pool water that has very high TDS values due to the concentrating effects of evaporation.

  If the start of an event has quite high flows the TDS will be more a reflection of surface runoff water quality, which appears to have low (±100 mg l^{-1}) TDS values.

  The quite rapid increases in TDS during the baseflow recession period suggest an additional mechanism apart from the spring flow and surface runoff already identified. This may be related to the storage of salts within the pools and adjacent soils which is incremented during pool drying and gradually released after pools have been re-filled.

- Relatively simple mass balance modelling of the system using assumed pool storage volumes, evaporation rates and TDS values for different water sources could provide a possible method for simulating the general trends of pool water quality under different flow conditions.

Table 5.10: Summary of observed TDS (mg l-1) data. (Springs 1 and 2 are located in small tributaries that flow into the Seekoei River upstream of EWR3).

Site	Boreholes	Sampling pools			
	July 2006	March 2006	May 2006	June 2006	August 2006
EWR1	1064	968	1490	2582	2224
EWR2	644	205	251	277	347
EWR3	653	451	391	635	767
EWR4	626	369	365	614	719
Spring 1	483	455			
Spring 2	459	458			

Conceptual model of flow processes in the Seekoei River

A conceptual picture of the hydrological processes that occur within the Seekoei catchment during a major rainfall event, as well as through the recession period and into a period of dry weather, is described below. The assumption is made that the rainfall event occurs after a prolonged dry period.

During the rainfall event it is assumed that surface runoff will be generated predominantly from the near-channel margins, where a ‘channel’ includes the main river channel as well as many tributary channels. The assumption that the runoff will be generated mostly from the near channel margins is based on the generally very low topography of the catchment surface and that infiltration excess surface water will largely exist as ponds over much of the catchment. The exception will be where the topography is locally steeper, such as in the lower parts of D32J, as well as in the headwaters of the total catchment. Some of this runoff is likely to be lost to transmission losses where there are colluvial and alluvial deposits with high infiltration rates under and adjacent to the channel. These losses are expected to occur during the early part of the event. A part of the initial runoff will also be used to fill up both natural pools and man-made storage (weirs and dams).

The rainfall event will also generate input to the unsaturated zone, particularly in those areas where the surface soil conditions are thin and stoney (such as the dolerite ridges). This input contributes to both ground water recharge as well as additions to either perched water tables and/or water stored in the unsaturated zone fractures. The latter are assumed to be the source of the relatively rapidly responding spring water that is evident in certain parts of the catchment, mainly those with steep topography. The ground water recharge process will be much slower and any changes in ground water levels are expected to be small and substantially delayed relative to both the surface runoff response and the spring flow.

The addition of water to the unsaturated zone and the consequent increase in spring flow is assumed to account for the relatively long recessions experienced at the D3H015 gauging station. This is also related to the fact that the source of the spring water appears to be dominantly in the lower part of the catchment. These long recessions and the maintenance of a baseflow component is not thought to be representative of the catchment as a whole, but is assumed to occur only in the lower parts of the catchment. It is possible that small spring flow contributions exist in the middle and upper parts of the catchment, but these may be too small to overcome evaporation from the channel pools and are not expected to result in prolonged low flows after major rainfall events. It is suspected, but not confirmed, that this process may be the cause of the low salinity at site 2, despite the fact that the TDS values in this pool are below the TDS of the spring water in the lower parts of the catchment (Table 5.12).

As the catchment dries out it is assumed that the combined discharge from the springs in the lower part of the catchment will decrease (either due to lower discharge from individual springs, or because fewer springs remain actively discharging), such that the inflows to the channel are lower than the evaporative losses. The result will be a cessation of flow at the gauging station. The dynamics of the pool storage will then depend upon the balance between spring discharge and pool evaporation, which will clearly depend upon the season and the evaporative demand. In the upper parts of the catchment, where there is little evidence of spring flow, it is possible that small contributions to pools are made through connections with the ground water, but these are expected to be relatively small due to the low hydraulic gradients. Most of the pools in the upper part of the catchment are therefore expected to dry out relatively rapidly depending on the evaporative demand. While there is certainly evidence from the October 2005 video (after approximately 1 year of no flow at the gauging station) that there are fewer pools in the upstream areas, there were also some pools that had been maintained over a long dry period. The implication is that these are being partially sustained by some source of sub-surface inflow. Without additional monitoring sites it is difficult to speculate about the source of that water.

Activity 8: Assess the Habitat Integrity

The habitat integrity of the riparian zone and instream channel of the Seekoei River was assessed in 2005[9] according to the method of Kleynhans (1996) and Kleynhans and Hill (1999)[10]. The assessment was based on three data sources: a video recording made during a low-level helicopter survey, a database of impacts observed from the air during the helicopter survey, and any additional literature sources relevant to the study (e.g. the Upper Orange Internal Strategic Perspective reports produced by the DWAF). **Note that the habitat integrity assessment was based on the macro-reaches and not the RPUs as the assessment was done at the beginning of the Seekoei River study before the new approach was established.**

A helicopter survey was conducted in October 2005 in an upstream direction at an altitude of approximately 80 to 100 m. In preparation for the assessment, the Seekoei River was divided into 5 km segments from its origin near Richmond to where it flows into the Vanderkloof Dam – a total of 51 segments. Observations regarding bank erosion, alien vegetation and developments in the riparian zone were captured on the video recording, as well as, electronically on a Handspring Visor that contains a palm operating system and which is connected to the GPS of the helicopter. Cybertracker software (originally developed to be used during game counts and veld monitoring) was used for data input. Captured data were afterwards downloaded into an Excel spreadsheet.

The video recording was then watched and all impacts regarded as primary causes of degradation of the riparian and instream habitats were noted for each 5 km segment. The observed impacts were also rated for severity according to the scale provided in Kleynhans (1996).

[9] The Habitat Integrity Assessment report by Watson and Barker (2006) is available on the CD.
[10] Note that the new method of Kleynhans (2008), recommended in Chapter 4, was not available in 2005 when this study started.

Information from the relevant sources was used to complete the required scoring sheets for each segment in Excel format. These were then used to determine a Riparian and Instream integrity class for each segment. In order to calculate an overall IHI class for instream and riparian habitats for each of the five macro-reaches, the average integrity scores of the segments present in a macro-reach were used (Table 5.11).

Habitat integrity of the instream and riparian habitats

The overall condition of the Seekoei River's instream and riparian habitats were found to be **moderately modified** (Class C; see Table 5.11). Flow regulation was identified as the major impact in the catchment, and the presence of a large number of dam walls, earth dams and weirs resulted in rather serious channel, bed and flow modifications – especially in the upper and lower reaches of the river (Figure 5.8). Reeds were found to be widely present in the river bed and riparian zones and are considered to have a serious impact on habitats in the middle and lower reaches of the river.

Integrity of the instream habitats

The most prominent modification to the instream habitats of the Seekoei River is the presence of Vanderkloof Dam and the large number of weirs, broken weirs, dam walls and earth dams causing channel, bed and flow modifications. Various impoundments are also present in the runoff channels to the river, affecting runoff reaching the river. Larger dams and weirs have a serious impact on non-perennial rivers, especially on those with a highly variable hydrological regime. Although they do not have a major impact on the high flows, they do reduce the frequency and duration of low flows throughout the catchment, which has an impact on the ecological integrity of the river system. The refugia (pools) in the river are reliant on the low flows to provide connectivity and to reset water quality. This then maintains viable populations in these pools between larger flow events (Sheldon, 2005).

The habitat integrity assessment also revealed that reeds are present in approximately 27% of the river bed. It is uncertain to what extent the reeds influence flow and contribute to river bed and channel modifications, but the impact is considered to be considerable.

Instream Habitat Integrity (IHI) categories for the Seekoei River varied from a category D in macro-reach 2, category B in macro-reach 3 and category C in macro-reach 4 to category D in macro-reach 5 (Table 5.11). The poor IHI in macro-reaches 2 and 5 was due to the presence of a large number of in-channel structures resulting in flow, channel and bed modifications. Again, the improvement in habitat integrity in macro-reach 3 was mainly as a result of the lower presence of weirs and dams in this reach. The overall IHI of the Seekoei River was a **Class C (Moderately modified).**

Integrity of the riparian habitats

The inundation of the riverbanks by Vanderkloof Dam and the numerous weirs, dams and earth dams was the largest modifier of riparian habitats in the Seekoei River. The presence of reeds in the riparian zone excluded natural riparian vegetation and was regarded as an impact in this study. It was assumed that the reeds were not naturally present in the river and along the banks as farmers are planting reeds, as well as burning reeds to stimulate growth, as food for their livestock.

Overgrazing and trampling were visible along the river. The added sediment to the river as a result of the erosion was not considered a serious impact in the Seekoei River. The river flows over alluvium for approximately 80% of its length, so that the added sediment did not have the same effect as it would in a river with riffles and rapids present. In an alluvium river the biota are already adapted to the sediment and the effect of added sediment is not as serious.

The Riparian Habitat Integrity (RHI) for the Seekoei River varied from a category D in macro-reach 2, category B in macro-reach 3 to a category C in macro-reaches 4 and 5 (Table 5.11). The poor condition of the riparian zones in macro-reach 2 was again contributed to flow and channel modifications resulting from the presence of in-channel structures. The overall RHI of the Seekoei River was a **category C (Moderately modified).**

Table 5.11: Average Habitat Integrity categories for the five macro-reaches of the Seekoei River (modified from Watson and Barker, 2006).
IHI, Index of Habitat Integrity; Category A, unmodified/natural; Category B, largely natural with few modifications; Category C, moderately modified; Category D, extensive loss of natural habitat, biota and ecosystem functions; Category E, complete modification and loss of natural habitat and biota.

Macro-reach	Segments	Reach length (km)	Ins-tream IHI Class	Ripa-rian IHI Class	Major impacts
1					No assessment done
2	1-4	20	D	D	Flow regulation (3 dam walls; 14 earth dams; 11 weirs)
3	5-11	35	B	B	Flow regulation (2 dam walls; 8 earth dams; 7 weirs; reeds in river bed)
4	12-39	120	C	C	Flow regulation (31 weirs; reeds in river bed)
5	40-51	60	D	C	Flow regulation (Vanderkloof Dam; 10 weirs)
Over-all	**1-51**	**235**	**C**	**C**	

Activity 9: Delineate Combined Response Units (CRUs)

Combined Response Units (CRUs) are created by superimposing the RPUs with information from the Hydrological Models and Habitat Integrity Assessment.

Due to the fact that the hydrological modelling was done at a quaternary catchment level, the hydrological data could not be integrated into the RPUs to create Combined Response Units. This important issue of incompatibility needs urgent attention.

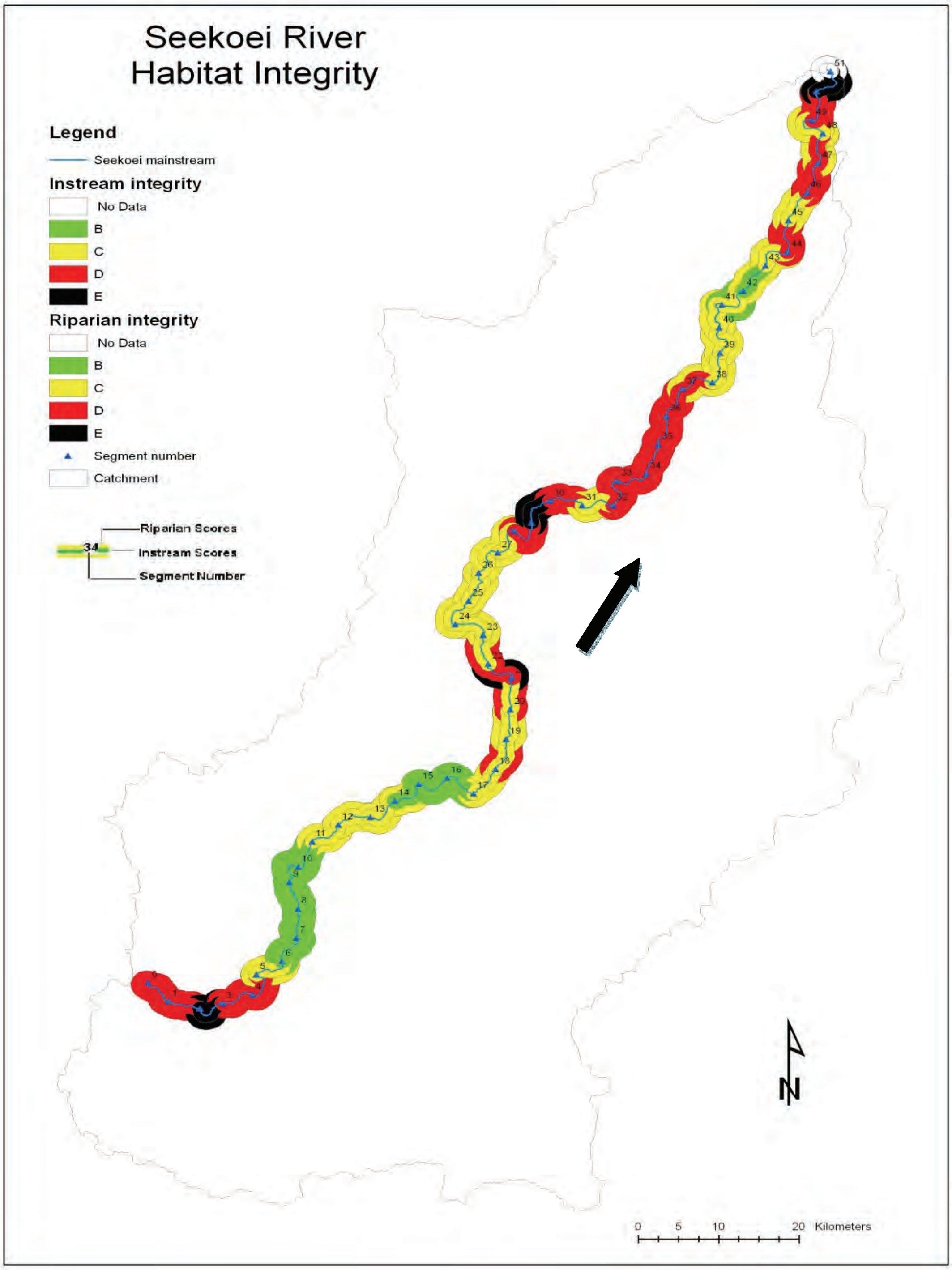

Figure 5.8: Map indicating the Habitat Integrity categories for each river segment of the Seekoei River (after Watson and Barker, 2006).
Habitat integrity categories after Kleynhans (1996): Category A, unmodified/natural; Category B, largely natural with few modifications; Category C, Moderately modified; Category D, Extensive loss of natural habitat, biota and ecosystem functions; Category E, Complete modification and loss of natural habitat and biota.

Phase 4. Engage stakeholders

(Note: Phase 3 and 4 runs parallel to each other).

Including the stakeholders early on in EWA assessments might add much value to the process. Timely identification of the most important issues and concerns for a catchment would allow the:

- inclusion of these matters into the future scenarios to be considered for the catchment.
- biophysical team to specifically address these issues (if related) in their specialist studies.
- appointed specialists to tap into local knowledge available for the system.

This would all contribute to create a better understanding of the relationships between the flow regime, ecological condition of river ecosystem and the social use of river components. Increased understanding would again result in more accurate predictions being made of how catchment changes could impact river use. This is especially important in the light that Society (including political decision-makers) as a whole should decide upon the future use and management options for the catchment. The role of the biophysical team is, therefore, not to decide upon a suitable management option, but to use their understanding of the relationships between the flow regime and ecological condition, and the relationship between ecological condition and river use or social well-being to inform Society about the costs involved with each future management option.

Three activities are proposed in Chapter 4 under this phase: first identifying the stakeholders and their concerns and issues; second, obtaining input from the stakeholders on the nature of the river and its users; and third, developing pathways for the information obtained from the stakeholders to be included into the later phases of the EWA process.

Formal stakeholder engagement was not done for the Seekoei River study. No provision was made in the initial planning and budget of the project to include a formal process to involve stakeholders. Although stakeholders were not formally identified, informal contact was kept with several riparian farmers, officials from the regional and national Government departments (notably DWAF and DEAT), members of the aquatic science's community and consultants.

From a social welfare perspective no contact was made with the riparian farm workers and their families to ascertain their relationship with the river. It was assumed that the river did provide recreational value and some natural resources such as grasses for weaving and clay. Food provided by the non-perennial river is assumed opportunistic and thus the dwellers are not dependant on this as a food source.

Many deductions as to the socio-economics of the region can be made in a desk top study using maps (including Google Earth) and public statistics.

Activity 10: ***Identify stakeholders and their issues/concerns***

In order to integrate the biophysical units with the economic units, the quaternary catchments were superimposed on a map showing the municipal boundaries (see Figure 5.9). Clearly municipal demarcation does not follow quaternary catchment hydrology watersheds. Economic and socio-economic data obtained at Municipal level therefore have to be aggregated at a combined quaternary catchment level.

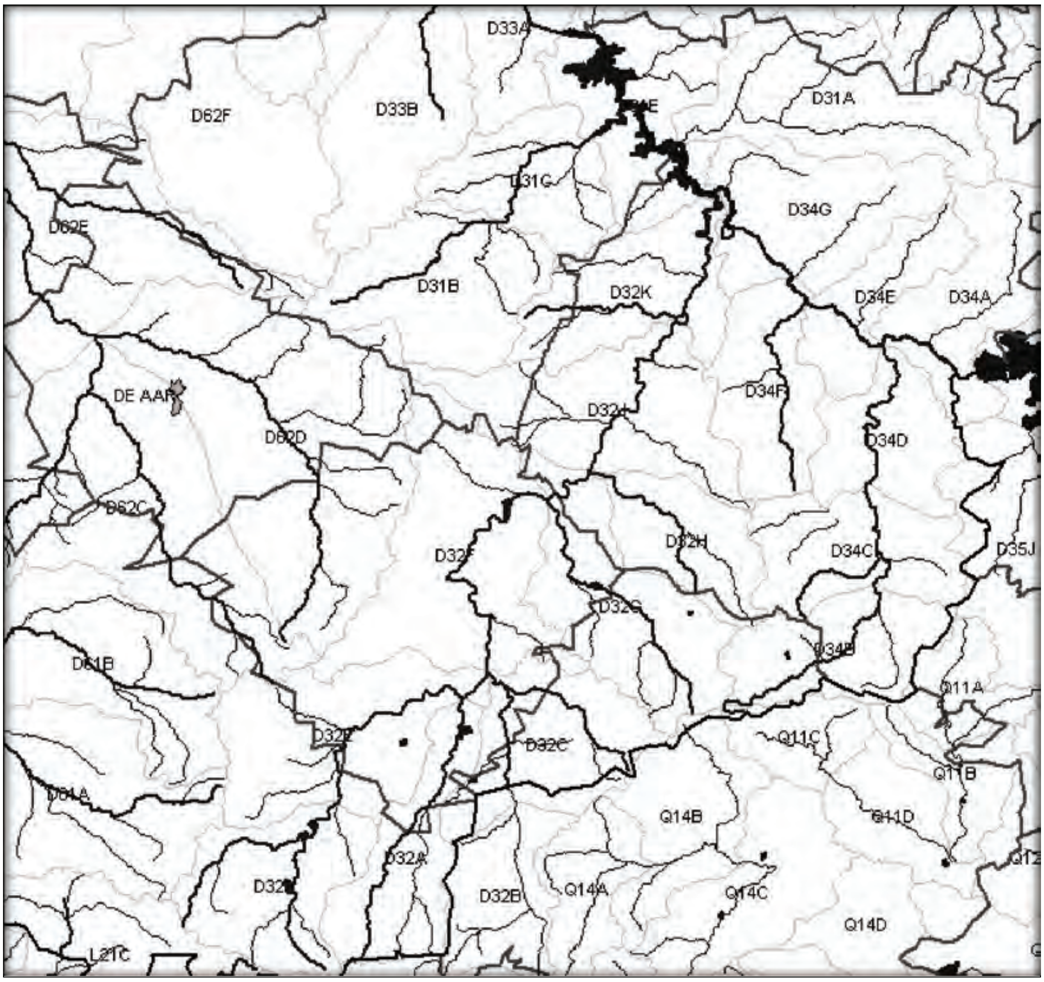

Figure 5.9: The Municipal managerial areas relevant to the Seekoei River catchment (data layers supplied by Charles Barker, UFS, Department of Geography).
(Black lines, rivers; dark grey, regional municipal boundaries; light grey, quaternary catchments; numbers, quaternary catchments).

There are no major towns that have an influence on the river but the river flows through the Richmond, Hanover, Philipstown and Colesberg municipal areas. Hanover and Noupoort are situated on the watershed between the Seekoei and Brak Rivers and the Seekoei and Fish Rivers, respectively and both are using boreholes to supply urban needs. None of the towns draw their water directly from the Seekoei River.

The socio-economic profile of the population utilizing the Seekoei River is made up of established commercial farmers and their workers. General farming activities are game and stock farming, or a combination of livestock, game and limited opportunistic irrigation agriculture. A large number of dams and weirs have been erected in the river course for irrigation abstraction, stock watering and for recreation (Figure 5.10). The crops irrigated are predominantly fodder crops to supplement livestock operations (Figure 5.11). With improved infrastructure and minimum wage labour regulations it is cheaper to buy vegetables at the local town than to try and grow your own. Irrigation is only possible where weir infrastructure has been build to dam up the non-perennial river.

Each farming settlement supports three to six farm-workers and their immediate families, paying them minimum wage salaries, and supplying basic water, health and emergency transportation services.

Small rural transportation node towns serve the farming community, which is generally not more than 30 km from a town, with farmers often travelling further to larger service towns for schooling and major services and supplies.

The group of biophysical experts identified features, activities and attributes of the study river based on their knowledge acquired of system functioning, local knowledge and land use activities. The list is presented below:

River goods:

- Water for stock and game watering.
- Reeds used as cattle fodder, especially during the winter months.
- Fish as an additional food source for local farm workers.
- Large cyprinid fish species for recreational anglers.

Figure 5.10: Google earth analysis at 115 km, indicating all irrigation/potential water-related features (image downloaded 09/03/2007).

Figure 5.11: Google earth analysis at 4 km, showing how irrigation can be detected (image downloaded 09/03/2007).

- Ground water supply for domestic and stock water use.
- Water from surface and/or ground water for irrigation.
- Vegetation on the riverbank, as well as in wetlands/pans, acting as a back-up resource for grazing during dry/winter periods.

River services:

- Reeds acting as bank stabilizers, as migration routes and as habitat.
- Riparian vegetation acting as habitat for birds and smaller mammals.
- Biological control of pest species by invertebrates and fish as part of a healthy ecosystem.
- Floods in the river form part of the migration routes of fish and help in maintaining the biodiversity.
- Pools creating refugia.
- Macrophytes removing nutrients from the water and sediments.
- Surface water recharges the channel aquifer.

Attributes:

- An aesthetic environment provided by a well-functioning river ecosystem.
- Tourism and aesthetics: People come to the area to relax, catch fish, enjoy the tranquillity of the area and view game.

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

Due to the reasons discussed earlier, this activity was not completed for this study. Although a formal stakeholder process was not followed, informal contact was kept with a number of stakeholders such as some riparian farmers, the DWAF (especially the regional offices in Bloemfontein and Kimberley) and the Northern Cape Provincial Department of Nature Conservation. The information and cooperation received from these stakeholders played a pivotal role in the completion of this study.

The farmers, especially, provided the team with very useful information such as fish species composition in the various river sections, small mammal and bird species occurrence along the river, present and past land- and water uses in the catchment, as well as changes that occurred over the past 30 years, past floods and droughts, rainfall and when the river started flowing, etc.

The knowledge they shared with the team greatly facilitated our understanding of the system, and would even be more valuable in projects where field visits are limited.

Activity 12: Develop pathways for the stakeholders to be included in later phases of the EWA

At the initial stakeholder meeting the needs and aspirations/expectation of the stakeholders would have been ascertained and report back could be conducted accordingly. In this project the farmers associations would have played an important role in communicating with commercial farmers and farm workers.

Phase 5. Site and indicator selection

Phase 5 involves two activities, the selection of sampling sites for the biophysical studies and the selection of suitable indicators for the river. At this point in the process, the core team should have a basic understanding of the physical characteristics of the catchment (based on the outcome of Phase 3), as well as a feel for the most important issues and concerns raised by stakeholders during the public participation process (Phase 4). This would guide them towards identifying and appointing additional specialists needed to complete the study.

Activity 13: Site selection for biophysical studies

Site selection in the Seekoei River was mainly based on the macro-reaches identified for the river and therefore differs from the methodology proposed in Chapter 4 (see discussion under Phase 3). Under the new method, sites are to be located in selected RPUs identified by the team, in consultation with DWAF.

Site selection process for Seekoei River

Site selection in the Seekoei River involved seven steps[11]: (i) preparing a desktop overview of the catchment, (ii) delineating the river into 5 km sections, (iii) conducting an aerial survey of the river and catchment, (iv) doing a macro-reach analysis, (v) determining the habitat integrity of the river, (vi) a team meeting, and (vii) a field visit.

The desktop assessment provided the team with information on the catchment's physical (e.g. geology, topography, rainfall, land use, etc.) and biological (e.g. vegetation types and ecoregions) characteristics (see Chapter 3). Next, the main stem of the river was divided into 5

[11] The report on site-selection is available from the accompanying CD.

km segments, using 1:50 000 maps), in preparation for the aerial survey. The aerial assessment, which was conducted in October 2005, formed the basis of the macro-reach analysis and habitat integrity assessment (discussed under Phase 3 and Activity 8). The macro-reach analysis, which identified 5 macro-reaches for the Seekoei River (Figure 5.4 and Table 5.9), proposed that undisturbed and representative sampling sites be found in macro-reaches 2, 4 and 5. A list of potential sites was then identified for each of these reaches from the aerial recording (DVD) and GPS data set, and pinpointed on a map. The potential sites were then considered at a team meeting, taking the results of the habitat integrity assessment into account. A core team, consisting of the fluvial geomorphologist, geohydrologist, water quality specialist and freshwater biologists, visited the river in November 2005 to determine the suitability of the potential sites, which was assessed according to the criteria listed in Chapter 4 (Section 4.4.5), as well as those listed in the BBM (King et al., 2000) and RDM (Kleynhans et al., 2005) manuals. Photographs were taken at each of the potential sites, as well as, water-quality and invertebrate samples where possible.

Difficulties experienced

The field visit to the catchment took place towards the end of a year-long dry period in November 2005. Although flow in the Seekoei River is most likely to occur in late summer (February to March), the last rainfall event in the catchment occurred in November 2004, resulting in the water levels being very low at the time. The dry conditions were not ideal for site selection. The riverbed was mostly dry, leaving a number of isolated pools, with riffle- or rapid-type biotopes being mostly absent. Although it was difficult to assess the presence of critical or flow sensitive habitat types, persistence of pools could be noted. However, two of the pools (at EWR3 and 4) that still persisted in November 2005, dried up in December 2005.

Other factors that hampered site selection in general, were:

Most river segments had several weirs or other structures obstructing flow or causing a backup of flow in the segment. One hundred and seventeen weirs, dam-walls, earth embankments or other structures are present in the 51 segments (approximately 255 km) of the river.

Several of the persisting pools were situated directly upstream or downstream of weirs or dam walls.

Several suitable sites were inaccessible due to prolific reed growth.

No rural communities were present along the banks of the Seekoei River – a requirement set by the project team at the site-selection workshop. The river is bordered almost entirely by commercial farms.

Sampling sites

Four sampling sites were finally selected for the Seekoei River: EWR1 in macro-reach 3, EWR2 in macro-reach 4, and EWR 3 and 4 in macro-reach 5 (see Figure 2.1). Although it would have been ideal to select a site within each macro-reach, this was not possible due to budget (e.g. between three and five boreholes needed to be drilled at each of these sites) and time constraints. Two sites were, however, selected in macro-reach 5 – the reason being that the large pools at sites EWR3 and 4 appeared to be fed by different sources. Based on physical appearance and in-situ water quality measurements, the sandy-bottomed pool at EWR3 appeared to be mainly fed by surface water, while the bedrock pool at EWR4 appeared to be fed by ground water. Including both sites in the study would provide the team with an opportunity to investigate these assumptions and to gain insight into the dynamics of pool storage in the Seekoei River.

The location and physical characteristics of the four sampling sites are described in Chapter 3 and a summary of each site's physical characteristics (based on Dallas, 2005) and suitability, are presented in Appendix D.

Activity 14: Indicator selection

Seventeen indicators, grouped into four categories, (i) hydrology, (ii) physical and chemical, (iii) biological and (iv) socio-economic, were proposed for the Seekoei River:

(i) Hydrological indicators

- connectivity
- floods for channel maintenance and sub-surface recharge
- sediment delivery

(ii) Physical and chemical indicators

- pool size and/or numbers (pool availability)
- channel aquifer recharge
- riparian aquifer recharge
- water quality variable (possibly conductivity)

(iii) Biological indicators

- 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

(iv) Socio-economic indicators

- quantitative socio-economic indicator
- qualitative socio-economic indicator

These indicators were seen as attributes of the Seekoei River ecosystem that could be used to describe change within the ecosystem. By selecting these indicators, the specialists attempted to identify and represent the most important characteristics of this ephemeral river ecosystem, and then to describe/predict how each would respond to changes in the catchment. The chosen indicators, therefore, needed to reflect, or respond to, changes in flow or water levels, as well as be measurable in terms of numbers, areas or concentrations.

A brief motivation for the inclusion of each indicator is given below. More information on the specific methods applied by each specialist to determine the likely degree of change for each indicator as the flow regime changes is included in the various specialist reports (available on the CD).

Hydrological indicators

Three hydrological indicators, acting as ecosystem primary drivers, were selected for the Seekoei River. Information on these indicators is to be produced by the hydrological model prepared for the catchment. For the Seekoei River, information was only available for the first two indicators (connectivity and floods). The models used for the Seekoei River were not able to simulate information on sediment delivery.

Connectivity

The frequency with which connected channel flow occurs was considered to have an important impact on ecological functioning of an ephemeral system, such as upstream and downstream migration, mixing of gene pools, flushing out poor quality water, etc. and should be represented as a driving indicator.

Floods for channel maintenance and sub-surface recharge

Floods play an important role in maintaining the river channel. The frequency with which flood events of geomorphological significance occur was included as a driving indicator.

Sediment delivery

The movement of sediment along the river system plays a crucial role in determining the nature of the channel, banks and river bed, and thus aquatic and riparian habitats.

Physical and chemical indicators

Two ecosystem components were included under this category, namely sub-surface water for which three indicators were selected, and water quality which was represented by one indicator. Sub-surface water is often the dominant water resource in semi-arid and could play an important role in sustaining isolated pools and sub-surface water below the river bed (Hughes, 2005).

Pool size and/or numbers

The importance of including an indicator relating to pools was clear, but its measure was not defined because it could not be defined quantitatively. For the purpose of the Seekoei study it was interpreted as a general indicator of availability of pool-type habitat.

Channel aquifer recharge

The channel aquifer is the main mechanism linking the pools in a river. It is the usual pathway of sub-surface water, providing sub-surface continuity, and feeds the various pools, especially in dry periods when pools are dominant.

Riparian aquifer recharge

The riparian aquifer is an important water resource in non-perennial rivers, in that it provides storage and may feed the channel aquifer during certain times of the year. The riparian aquifer is mainly recharged when the river has surface flow, with water moving from the river to the riparian aquifer, but it can also receive water from the terrestrial aquifer. Abstraction from the riparian aquifer may increase the available storage during cessation of surface flow and would imply that this storage would first need to be satisfied when surface flow resumes. The riparian aquifer further plays an important role in sustaining riparian plant communities with the water level being a critical issue. In addition the vegetation would, during the growing season, tend to remove water from this aquifer via transpiration.

Water quality variable

Although a large number of physical, chemical and biological parameters were considered, and measured, for the Seekoei River, it was decided to suffice with one indicator in order to save time and to limit complexity during the method development stage.

Salinity, expressed as total dissolved solids (TDS), was selected because it not only gives a good indication of chemical water quality, but can also be used to assess the acceptability of the aquatic environment for aquatic biota, fitness for human and animal consumption, and suitability for irrigation. TDS concentration, which can be seen as a measure of the quantity of all compounds dissolved in water, is directly proportional to the electrical conductivity (EC) of water. TDS concentrations were measured during the study and were found to change seasonally and along the length of the river. The fact that TDS concentration is a conservative variable made it a good indicator of water quality in the catchment.

Biological indicators

Two indicators each were included for riparian vegetation, aquatic macroinvertebrates and fish. Two additional indicators were also added: one referring to terrestrial wildlife, and the other to the river's contribution to the parent river with regards to surface flow and biodiversity.

Riparian vegetation cover

The riparian vegetation is directly linked to surface water, ground water, geomorphic processes and land management. This direct and powerful link implies that changes to any one of these, could influence the other (Graf, 1998), making riparian vegetation an important catchment indicator. The riparian vegetation is furthermore an important habitat to terrestrial biota associated with rivers and streams.

Aquatic/marginal vegetation cover

The aquatic and marginal vegetation provide habitat, food and cover to aquatic biota and play an important role in the cycling of energy and nutrient in streams and pools. During periods when surface flow is absent and pools become isolated, phytoplankton and benthic algae become a major primary food source (for example see Bunn et al., 2003; Balcombe et al., 2005). The aquatic and marginal plant communities are mainly influenced by changes in the flow regime, availability of pool habitat, sediment deposition and water quality.

Number of important (unique, threatened, sensitive to flow, habitat or/and water quality) invertebrate taxa[12]

Various indices were considered such as the South African Scoring System for Invertebrates version 5 (SASS5; Dickens and Graham, 2002); Average score per taxa (ASPT; Chutter, 1998); the Macro-invertebrate Response Assessment Index (MIRAI; Thirion, 2008); presence of sensitive invertebrates; percentage Ephemeroptera, Odonata and Trichoptera (% EOT) and the abundance of pest species.

% EOT was not found to be a suitable index as the presence of most Ephemeroptera and Trichoptera are dependent on presence of flow. As non-perennial rivers do not always flow under natural conditions this indicator could not be used.

SASS5, ASPT or MIRAI were not considered suitable indices in a non-perennial river as all of these indices were developed for use in perennial rivers and various problems were encountered when trying to use them in the Seekoei River study. Importantly, the low presence of sensitive (having high flow, habitat and water quality preferences) species in the Seekoei River resulted in low categories of ecosystem health. This was not a true reflection of the present ecological status as most of the sites sampled were relatively natural to moderately modified.

The presence of sensitive invertebrates was also not regarded to be a suitable indicator as very few if any sensitive invertebrates are present in non-perennial rivers. It was difficult to decide which invertebrates should be regarded as sensitive: those that are flow, habitat or water quality sensitive or those that are sensitive to change in the system (residents or other species that require a certain period of inundation to complete their life-cycle). It was decided to change this indicator to presence of important invertebrates. Important invertebrates include all those that are unique, threatened, sensitive to flow, habitat and/or water quality. The presence of important invertebrates in a non-perennial river would provide an indication of the health of the system as important species would decrease in number and abundance if the ecosystem was altered by an unnatural reduction or increase in flow, habitat reduction and/or water quality deterioration. Each species present in the ecosystem is essential to ensuring that the ecosystem can provide the services needed by man.

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[12] A list of important species identified at each site in the Seekoei River is provided in the Macro-invertebrate specialist report.

Deciding on whether the important invertebrates would increase or decrease under various scenarios however requires identification to species level as family level identification is too broad. Only after identifying the observed macro-invertebrates to species level was it found that various species that are threatened in the Orange River were present in the Seekoei River. A particular family could still be present in the system after alteration but an important species within the family could be absent.

Abundance of invertebrate pest taxa[13]

Certain pest macro-invertebrates would increase or decrease in abundance in the system if it were disturbed. These species could also have socio-economic implications as some are regarded as pests to man and animals. Blackflies, mosquitoes and other pest species are mostly present and these species increase or decrease in abundance as flow, habitat and/or water quality is altered. Abundance data are also easy to collect as the abundances can be recorded in categories, for example: 1= 1, A= 2-10 individuals; B= 11-100 individuals and C= >100 individuals.

Status of indigenous fish community

The fish communities of rivers with highly variable flow regimes, high disturbance levels and low habitat diversity are not only species-poor, but also generally tolerant to harsh environmental conditions. These fish communities are therefore often dominated by resilient generalist species, as is the case in the Seekoei River.

In the light of the above, the application of either the Fish Assemblage Integrity Index (FAII; Kleynhans, 1999b), and the Fish Response Assemblage Index (Kleynhans, 2008) was not ideal, as the indices are not considered suitable for rivers with naturally low species richness and a hardy generalist fish community (see Bramblett and Fausch, 1991; Kleynhans, 1999b; Lyons, 2006). The absence of existing fish data on the river, together with the high variability in species composition at some sites, made it furthermore very difficult to predict the frequency of occurrence along the river. Although the FRAI and FAII could be applied to determine the status of more diverse and specialised fish communities in other non-perennial rivers, a more generalised approach was adopted for the Seekoei River (see specialist chapter on fish on CD). For this study, “status” broadly referred in a general way to a number of community characteristics, such as abundance, species richness, species evenness, recruitment and fish health.

[13] All pest taxa identified in the Seekoei River are discussed in the Macro-invertebrate specialist report.

Abundance of exotic fish

The indigenous fish communities of non-perennial rivers are especially vulnerable to exotic fish species. Being confined to isolated pools during periods of flow intermittence, indigenous fish might not escape the pressure exerted by exotic predaceous species. Anthropogenic changes to the flow regime and catchment, such as inundation and flow regulation, may alleviate the natural harshness associated with many of these systems, benefitting introduced species. Careful consideration should, therefore, be given to the impact future developments could have on the abundance and distribution of exotic fish species.

Terrestrial wildlife

Rivers, isolated pools and sub-surface water are important resources for a number of vertebrates in a dry landscape. This association has been well described for species such as vlei rats, water mongoose, otters, riverine rabbit, and elephants. These waterways are often areas of highest primary productivity, highest prey density, and act as important habitats and corridors for survival and dispersal of a number of herbivorous and carnivorous species throughout the year (Avenant et al., 2008). In such areas these taxa are considered to be useful indicators[14] (Avenant, pers. comm.).

Contribution to the parent river

This indicator considers the contribution of the studied system to the parent river in terms of surface water, biodiversity, food (e.g. plankton drift), habitat, etc. For example, the lower part of the Seekoei River just upstream of its confluence with the Orange River at Vanderkloof Dam is an important spawning area for yellowfishes, including the vulnerable largemouth yellowfish.

It is noted that in a catchment with intermittent tributaries such as the Orange not all the tributaries will contribute surface flow to the main stem each year. Due to rainfall variability, different tributaries could contribute surface flow, habitat, biodiversity and food during different years.

Socio-economic indicators

Two indicators were selected to represent social and economic uses of the Seekoei River ecosystem. Both indicators are considered to be comprehensive (all encompassing) indices that cover the quantitative and qualitative aspects of the socio-economic analysis.

[14] Dr. N.L. Avenant, Head of Mammalogy, National Museum, Bloemfontein.

Socio-economics

Two variables were included under this indicator:

- GGP (Gross Geographical Product) – expected changes in the economic product produced in a geographical area, e.g. the change in the economic value of cattle marketed from the area in a years
- Job creation – the change in the value of jobs created

Social well-being

The following were used to give an indication of social wellbeing in the Seekoei catchment:

- Livelihoods indicator – changes in the expected number of livelihoods supported in a specific area over a certain time period;
- Sense of place;
- Peace and quiet;
- Access to safe drinking water and fuel for cooking; and
- Access to natural resources e.g. certain grass for basket weaving, etc.

Activation of indicators for the different scenarios

Not all the indicators were used for each of the sampling sites. Individual indicators were, therefore, de-activated where not relevant. The indicators selected for every site, were however, kept constant for that specific site for all the scenarios considered. For example, only 15 (of the 17) indicators were activated for EWR1 (Table 5.12). Two were left out, namely the "number of important invertebrate species", because no important species were recorded at the site during the study period, and the "abundance of exotic fish species" due to the absence of exotic fish species in the river reach. Because no important invertebrate species were present at EWR2, this indicator was also omitted for EWR2. All indicators were activated for sites EWR3 and 4.

Table 5.12: The indicators activated for each of the sampling sites on the Seekoei River.

Sampling sites	Indicators																
	Hydrological			**Physical and chemical**				**Biological indicators**								**Socio-eco-nomic**	
	Connectivity	Floods	Sediment delivery	Pools	Channel aquifer	Riparian aquifer	Water quality	Riparian veg. cover	Aquatic veg. cover	No. of important inv. sp.	Abundance of inv. pests	Status of ind. fish com	Abundance of exotic fish	Terrestrial wildlife	Contr. to parent river	Socio-economics	Social well-being
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
EWR1	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X
EWR2	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
EWR3 & 4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Phase 6. Choosing scenarios and hydrological simulation

Phase 6 comprised two activities: choosing scenarios and completing the hydrological simulation for these scenarios.

Activity 15: Choosing scenarios

Problems experienced with scenario selection and hydrological simulation

Three different scenarios for future development were initially selected for the Seekoei River catchment. The three scenarios, perceived initially as quite different in hydrological character, were:

***Scenario 1*: Intensification of farming activities and a reduction in farm size.**

The scenario considered a situation where more small scale farmers move into the catchment, with the traditional farms being divided into smaller units or small holdings. This could result in increased pressure on the natural resources and a deterioration in farming practices including over-grazing, loss of bank stability, removal of riparian vegetation, increased sedimentation and erosion resulting from poor land cover.

***Scenario 2*: Increased game farming and ecotourism activities in the catchment**

A switch from stock to game farming with the aim of inviting ecotourism opportunities into the catchment was expected to improve the condition of the veld. However, greater abstraction from ground water sources to cater for tourists could occur.

***Scenario 3*: Increased return flows from towns and settlements**

This scenario considered the possibility of an increase in town development in the region with water being diverted from the Orange River to local towns and settlements and the consequent increase in return flows to the Seekoei River.

The simulation of the hydrology for these three scenarios, however presented the team with several challenges, slowing the project down. The following were problematic:

- Many uncertainties associated with the results produced by the hydrological model existed. These uncertainties were, to a large extent, related to the fact that most of the real observations were taken from the gauging station situated at the outlet of the catchment, while substantial spatial differences in the hydrological processes existed in the catchment. It was, therefore, impossible to verify the results produced by the model for quaternary catchments in the upper and middle part of the Seekoei River.
- The fact that most disciplines collected field data at a smaller spatial scale than the quaternary catchment level used in hydrological modelling, and that these data were not temporally representative due to the short period of sampling.
- The hydrological model was not sensitive enough to reflect small changes in catchment conditions. This was mainly due to the fact that most of the runoff observed at the gauging station was generated in quaternary catchment D32J at the lower end of the catchment, and the fact that this quaternary catchment was unlikely to be subjected to a great deal of development.
- Uncertainty existed with regards to the processes associated with a deterioration of land use in the catchment, lacking observed data.
- Difficulties with converting land use changes into model parameter changes, especially due to the fact most of the catchment is fairly flat and sparsely vegetated.
- The low gradient that prevails for the largest part of the Seekoei catchment lessened the effect of impacts resulting from land use change. Impacts from land use change may have a more profound impact in steeper catchments.

- The scenarios were not expected to have a large impact on the flood regime. Considering the fact that the flood regime is already quite variable (as for most systems in semi-arid regions), it would be difficult to predict and interpret additional change.
- Increased abstraction from boreholes was not expected to have a large impact on the water levels of in-stream pools (unless it was quite intensive and close to the river channel) as the ground water contributes little water to the pools.
- The highly variable distribution pattern (especially for macroinvertebrates) and the robust generalist nature of the biota made it very difficult to predict biotic responses to small changes in pool dynamics.

Of the three scenarios, the intensification of farming activities in the catchment (scenario 1) would most likely have the biggest effect on the catchment, but not in a way that could be accurately simulated by the hydrological models. For example, increased surface runoff, as a result of over-grazing, would lead to an increase in sediment load, while the removal of riparian and in-channel vegetation would result in channel erosion. These effects could, however, not be simulated by the available models. Neither the second (Increased game farming and ecotourism), nor the third (increased flow from the Orange River) scenario were expected to create impacts significant enough to be reflected by the surface hydrology. The hydrological models were, therefore, unable to satisfactorily reflect the type of impacts associated with the scenarios selected by the team.

In order to resolve the situation and to allow the method to be tested, the following decisions were taken:

- To add the “present day” and “natural” situations as separate scenarios because the hydrological modelling for these scenarios were available and were quite distinct from each other.
- To add a scenario where the effect of land use changes in the catchment on the water availability in the river could be considered. The hydrological data modelled for “present day” conditions would be used for this scenario.
- To consider the impacts of increased ground water abstraction due to an increase in game farming and ecotourism activities (scenario 2) for the lower catchment only. The increased baseflow in the lower Seekoei River comes mainly from interflow springs situated in D32J.
- To discard the third scenario.

The final scenarios selected for consideration

The four final scenarios, that were not necessarily realistic, were:

Scenario 1: Present day

The present day situation was taken to represent the baseline development scenario. The main impacts on the natural hydrology were the existence of a large number of in-channel weirs and dams.

Scenario 2: Natural conditions

The second scenario considered, hypothetically, the expected changes in ecosystem functioning if all dams, artificial weirs and in-channel obstructions were to be removed from the river, restoring the natural flood regime.

Scenario 3: Intensification of farming activities and a reduction in farm size.

The third scenario considered the impacts of dividing larger farms into small holdings (especially along the river) resulting in a densification and intensification of farming activities. The expected consequences of this scenario, which focused very much on changes in landscape features, are deterioration in farming practices including over-grazing, loss of bank stability, removal of riparian vegetation, increased sedimentation and erosion resulting from poor land cover. The hydrological simulation for scenario 1 (present day) would be used.

Scenario 4: Increased game farming and ecotourism activities (Increased abstraction from the springs in the lower part of the catchment).

Scenario 4 considered what could happen to the river ecosystem if farmers switched from current farming practices to game ranching in order to encourage ecotourism. For this scenario it was assumed that vegetation cover would increase as the veld recovers, and that water would be extracted from the interflow springs in order to cater for tourist accommodation and activities. It was also expected that river condition would be improved or maintained for the tourists. This scenario focused mostly on the lower part of the catchment (D32J) where water from interflow springs contributes substantially to surface flow in the river.

Activity 16: Hydrological simulation

The hydrological simulation for the four scenarios was done for two of the three hydrological indicators only: the “frequency of connectivity” and the “flood regime”. No data on “sediment delivery” could be produced by the hydrological models used, and further research would be needed in this regard. Data on the "frequency of surface water connectivity" (Indicator 1) were produced for all the sampling sites (EWR1, 2 and 3 & 4) for all the scenarios (Table 5.13). The adjacent sites EWR3 and 4, which are both situated in D32J, were treated as one site because of their similar hydrologies.

Hydrological modelling for the high flow component was done in a parallel modelling exercise using the Nash-Muskingum routing mode (Hughes, 2008a[15]). The areal reduction factor in the model was set to generate results at the outlet of sub-catchment D32J in order to be consistent with the observed flow data at D3H015 and data on the "flood regime" (Indicator 2) were, therefore only available for sites EWR 3 and 4. Modelling was only done for "present" (scenario 1) and "natural" (scenario 2) conditions.

Table 5.13: The availability of simulated hydrological data for the three hydrological indicators for the four chosen scenarios.

Hydrological indicators	Sites	Scenario 1 Present day	Scenario 2 Natural	Scenario 3 Intensification of farming	Scenario 4 Ecotourism
		Simulated data available	Simulated data available	Simulated data available	Simulated data available
1. Connectivity	EWR 1	Yes	Yes	Same as 1	N/A*
	EWR 2	Yes	Yes	Same as 1	N/A*
	EWR 3 and 4	Yes	Yes	Same as 1	Yes
2. Floods	EWR 1	No	No	No	N/A*
	EWR 2	No	No	No	N/A*
	EWR 3 and 4	Yes	Yes	Same as 1	No
3. Sediment Delivery	EWR 1	No	No	No	N/A*
	EWR 2	No	No	No	N/A*
	EWR 3 and 4	No	No	No	No

*Scenario 4 only referred to EWR3 and 4.

Scenario 1: Present day

The hydrological simulation for present day conditions has, to a large extent, already been discussed under Activity 7, which described the present catchment hydrology. This section will, therefore, focus on the hydrological output for the hydrological indicators driving the system.

Flow regulation was identified as the most important impact influencing present day hydrological conditions in the Seekoei River (Watson and Barker, 2006). A large number of in-

[15] See Hughes (2008a) for an in-depth discussion on the effectiveness of the method.

channel weirs and dam walls are present on the river and is expected to have a significant impact on surface water availability in the catchment.

Connectivity

Water storage has greatly increased in all quaternary catchments, but especially in D32D, D32A and D32F (see Table 5.14). The maximum pool volume in D32D, for example, increased from 0.2 $m^3 10^6$ under natural conditions to 18.28 $m^3 10^6$ at present. This, clearly, results in substantial changes in the frequency with which downstream flow occurs. The inflow of surface water into quaternary catchments D32E (EWR1), D32F (EWR2) and D32J (EWR3 and 4) has been significantly reduced by 79.4%, 34% and 39% from natural conditions, respectively (Table 5.17). Downstream outflow from these quaternary catchments has also been reduced by between 20% (D32J) and 75% (D32E).

It is also evident from the above that the impact is higher in the upper and middle parts of the catchment than in the lower part. This is largely an inevitable result of the fact that a large part of the downstream flow in D32J is generated within that sub-catchment even under natural conditions (55.6%). While the results suggest that a substantial volume of water generated upstream reaches the lower part of the catchment under present day conditions, it should be recognized that this occurs during infrequent short duration events representing a relatively short proportion of the total time.

Table 5.14: Reservoir parameters (natural and present day) for the 10 sub-catchments (taken from Hughes, 2008a).

Catchment	Channel length (km)	Max. pool volume (m3 $*10^6$)		Abstractions
		Natural	Present Day	(P.Day – m^3 $*10^6$)
D32A	53	0.76	6.26	1.65
D32B	33	0.30	0.80	0.15
D32C	22	0.32	0.72	0.12
D32D	31	0.28	18.28	5.40
D32E	45	0.65	1.25	0.18
D32F	49	0.98	6.48	1.65
D32G	52	0.75	3.25	0.75
D32H	31	0.28	0.38	0.03
D32J	34	0.75	1.15	0.12
D32K	22	0.66	1.16	0.15

Table 5.15: Simulated pool water balance components for three quaternary catchments for natural and present day conditions (all values in m3 *106 total flow over the 70 year simulation period; taken from Hughes, 2008a).

Component	**D32E** (EWR1)		**D32F** (EWR2)		**D32J** (EWR3 and 4)	
	Natural	**Present day**	**Natural**	**Present day**	**Natural**	**Present day**
Change in Storage	-0.195	0.271	-0.415	0.255	0.252	0.382
Upstream inflow	170.856	35.171	554.988	367.080	933.240	570.192
Downstream outflow	226.632	79.506	695.352	389.088	1930.320	1558.200
Surface flow	93.744	93.744	203.868	203.868	855.204	855.204
Interflow	0.000	0.000	0.000	0.000	192.276	192.276
Ground water flow	0.292	0.292	2.019	2.019	26.712	26.712
Evaporation	38.455	41.689	65.637	97.944	76.860	77.742
Abstraction	0.000	8.283	0.000	85.680	0.000	8.060

The hydrological simulation indicated that the natural frequency of downstream flow in D32E (EWR1) has been reduced from 10% to 5% under present-day conditions (Figure 5.12). This implies that this quaternary catchment presently experiences surface flow for only half of the time it used to under natural conditions. A large reduction in surface water frequency also occurred in D32F (EWR2), where connectivity decreased from 12% to less than 5% of the time (Figure 5.13).

The impact of flow regulation in D32J appeared to be far less than upstream, with only a 2% decrease in the natural frequency of channel flow connectivity (Figure 5.14). This is mainly as a result of a more sustained baseflow due to a large contribution from springs derived from interflow out of dolerite ridges. Simulated data showed that interflow runoff contributes nearly 20% of total runoff in this quaternary catchment, compared to nothing in the quaternary catchments upstream. The contribution from interflow has not changed from natural (See Table 5.17).

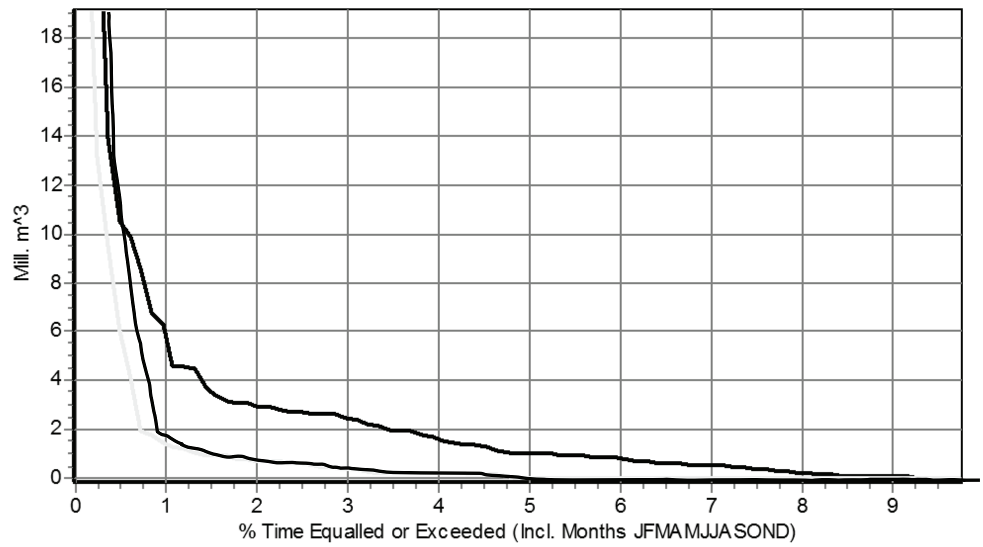

Figure 5.12: Flow duration curve for D32E (EWR1) for Scenario 1 (present day conditions; after Hughes, 2008b). (Upper line, natural; lower line, present day).

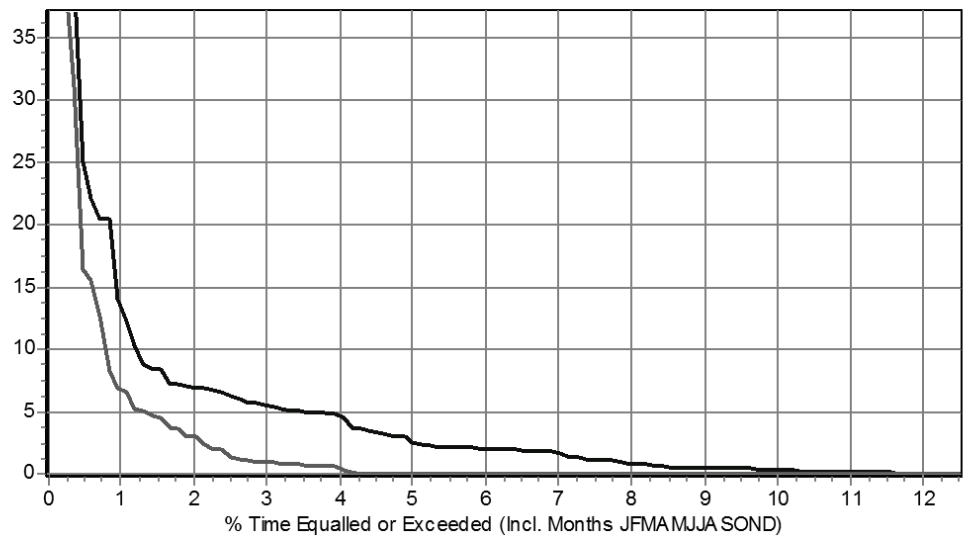

Figure 5.13: Flow duration curve for D32F (EWR2) for Scenario 1 (present day conditions; after Hughes, 2008b). (Upper line, natural; lower line, present day).

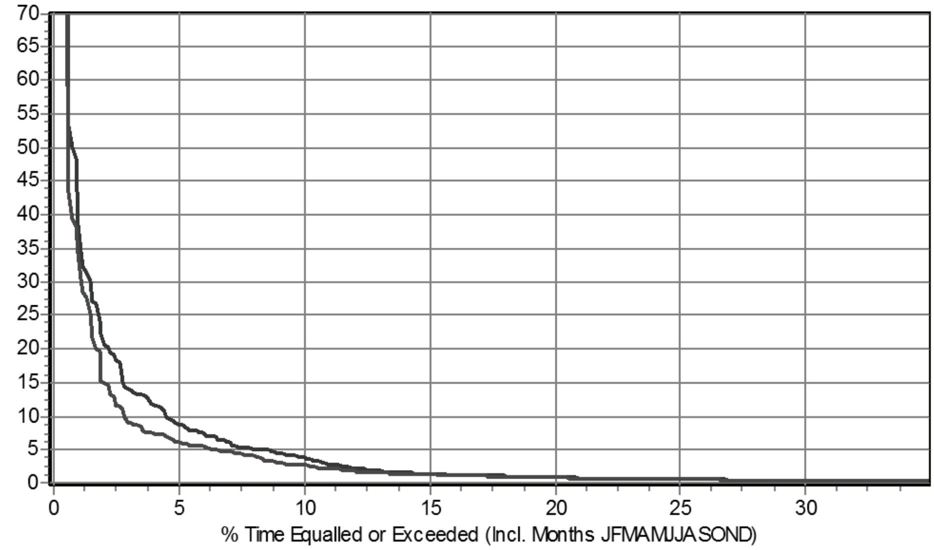

Figure 5.14: Flow duration curve for D32J (EWR3 and 4) for Scenario 1 (present day conditions; after Hughes, 2008b). (Upper line, natural; lower line, present day).

Floods

The differences between the present day and natural flood regime (referring specifically to 1:2 and 1:5 year floods) were larger than expected for D32J (EWR3 and 4). Very little outflow is experienced from sub-catchment D32F (Table 5.17) and the 1:5 year event seems severely curtailed at this point (Table 5.16). Uncertainties, however, still exist around some aspects of the model e.g. the automated estimates, losses and the design rainfalls for the 1:20 and 1:50 year events (refer to Hughes, 2008a for more information on the method and models applied).

Table 5.16: Flood peaks and volumes estimated using the distributed Nash-Muskingum routing model for D32J (taken from Hughes, 2008a).[16]

Return Period	Present Development		Natural	
	Peak ($m^3 s^{-1}$)	Volume ($m^3 * 10^6$)	Peak ($m^3 s^{-1}$)	Volume ($m^3 * 10^6$)
1:2	96	2.9	315	13.6
1:5	265	13.9	620	26.9
1:10	508	24.1	901	39.4
1:20	1275	58.8	1792	78.4
1:50	1222	56.4	1731	76.2
1:100	1676	76.8	2234	98.7

Sedimentation

No simulated data were available for this indicator.

[16] The long term natural MAR simulated by the revised Pitman model is 31.7 $m^3 * 10^6$

Scenario 2: Natural (pre-development) conditions

The greatest influence on the natural hydrology is the presence of in-channel weirs and dams. These man-made structures have greatly reduced the natural inflow of surface water into downstream quaternary catchments, reducing the frequency of surface water connectivity. Surface runoff in the catchment under natural conditions was possibly more localised, with surface inflow from upstream occurring less than 10% of the time in most of the of the catchment. The likelihood also exists that small scale individual thunderstorms did not generate channel runoff – implying that channel runoff would probably only have occurred after large scale events (1:20 or 1: 50 or 1: 100 year floods).

Connectivity

The natural frequency of channel flow connectivity within sub-catchments D32E (EWR1), D32F (EWR2) and D32J (EWR3 and 4) were 10%, 12% and 52% respectively (Figure 5.15). The reduction in surface water connectivity as a result of flow regulation has been especially severe in the upper and middle parts of the catchments.

The study pool at EWR1 (situated in D32E) received, under natural conditions, both local inflow (surface runoff and ground water) and upstream flow (surface flow from upstream sub-catchments). It was estimated that the natural inflow of surface water into D32E was nearly five times what it is at present (Table 5.15), and that channel flow connectivity occurred for twice as long as at present. This large reduction in upstream flow implies that the pool is now mostly replenished by the local sources of flow, surface flow from the sides (which is minimal due to the low topography) and ground water seeping in very slowly, but continually. This implies that the pool habitat was slightly more disturbed (less constant) under natural conditions than at present. The decrease in upstream connectivity could have contributed to the high conductivities measured at the site at present.

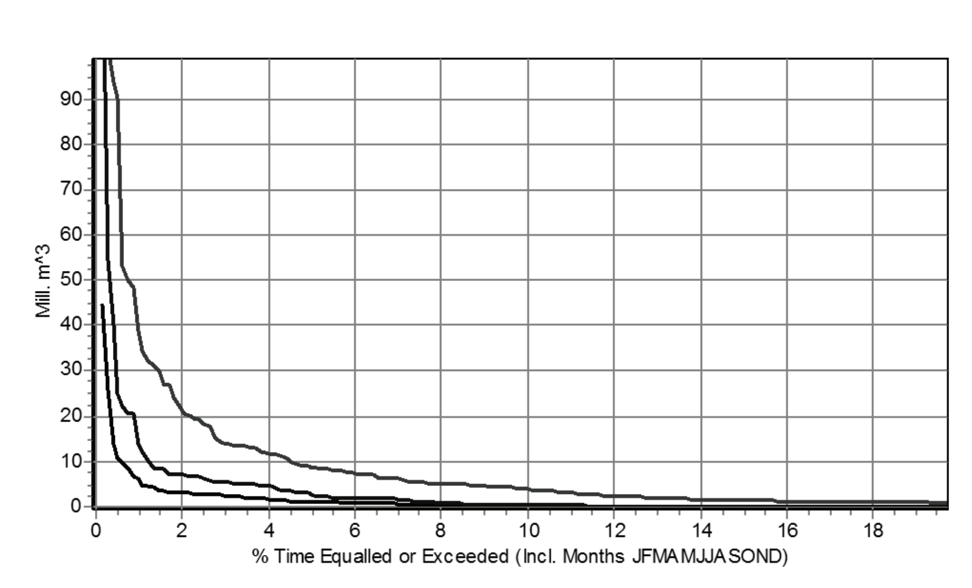

Figure 5.15: Annual 1-month flow duration curves for D32E (EWR1, lower line), D32F (EWR2, middle line) and D32J (EWR3and4, upper line) for Scenario 2 (natural conditions; Hughes, 2008b).

D32F (EWR2) had a natural frequency of channel flow connectivity of 12%. The sub-catchment receives inflow from three tributaries, the Seekoei River (D32E), Elandskloof River (D32A) and the Klein Seekoei River (D32C). The natural inflow from these sub-catchments has been reduced by nearly 34% (from 554.988 $m^3 10^6$ to 367.080 $m^3 10^6$) due to increased upstream storage, resulting in a 7% reduction in the frequency of surface water connectivity (from 12% to less than 5%). The impact of weirs and dams has been very severe on the Seekoei and Elandskloof Rivers. The present maximum pool volume within D32D, D32E and D32A showed a very large increase from natural (65, 2 and 8 fold increase; see Table 5.14). This was, however, not the case for the Klein Seekoei River, where a twofold increase in the natural pool is indicated, so that surface flow from this tributary might reach EWR2 more frequently.

The pool at EWR2, which is underlain by dolerite, is replenished mainly by upstream inflow, but also by local inflow (surface runoff and ground water). Ground water seems to be moving towards the pool from a dolerite ridge situated to the left of the river. As a result of the large reduction in surface water connectivity, it is expected that the pool would be dry more often and for longer periods of time at present than under natural conditions.

Quaternary catchment D32J, where EWR3 and 4 are situated, had a natural frequency of channel flow connectivity of 53% (Figure 5.23). This is the only sub-catchment in which sustained baseflows are assumed to be generated. The baseflow is assumedly generated from spring flow (or discharge from perched aquifers), with minor contributions from the regional ground water body. The hydrological simulations indicated that while the low flows (lower than the flow equalled or exceeded for about 15% of the time) do not seem to be affected very much by the additional storage in D32J and upstream sub-catchments, high flows have been substantially higher under natural conditions.

Floods

Flood hydrographs produced by the hydrological model showed that the smaller, more frequent floods (notably the 1:2, 1:5 and 1:10 year floods) have been severely impacted by the additional storage in the catchment (Table 5.16). The volume and the peaks of 1:2 year floods, for example, were assumed to be respectively 70% and 79% higher under natural conditions than at present. The impact on the larger more infrequent floods appeared to be smaller with the peak of a 1:100 year flood being approximately 15% higher than at present.

Sedimentation

No simulated data were available for this indicator.

Scenario 3: Densification of farms into small holdings

The hydrology simulated for present day conditions (scenario 1) was also used for scenario 3, while considering the consequences of the densification and intensification of farming activities on the catchment at a landscape level. The aim was to see if the method would be able to reflect changes in the landscape.

The major catchment changes that are suggested under this hypothetical scenario relate to land cover, soil erosion and sediment delivery. It is expected that increased surface runoff would lead to increased sediment load, while the removal of riparian and in-channel vegetation could result in increased channel erosion. However, due to the low gradient prevailing in the majority of the catchment, the effects on the quantity of runoff are likely to be very small and very difficult to simulate with the hydrological models that have been used.

If continued and increasing over-grazing were to be the pattern of future farming practice there certainly would be additional soil erosion and possibly somewhat higher volumes of surface runoff. However, the low gradients in the majority of the catchment suggest that the source of additional runoff would be limited to areas quite close to main and tributary channels. The overall impact on water quantity would therefore be to increase the amount of surface runoff during infrequent high rainfall events.

Connectivity

Same as for present day conditions (scenario 1).

Floods

Same as for present day conditions (scenario 1).

Sedimentation

Increased surface runoff would lead to increased sediment load, while removal of riparian and in-channel vegetation would result in increased channel erosion. The models used were, however, not able to simulate these effects.

Scenario 4: Increased game farming and ecotourism in the lower Seekoei catchment

This scenario focused only on the lower part of the catchment (D32J) where flow from the interflow springs made a considerable contribution to baseflow (Table 5.15). The assumption in this scenario is that additional water consumption would be required to account for an increase in tourism and game farming within the catchment[17]. This is expected to be a distributed water requirement that would rely to a large extent upon ground water abstraction from boreholes. This could result in a reduction in baseflow and the duration of connectivity. The hydrological simulation did not consider the effect of an improvement in veld condition.

Connectivity

The hydrological analysis showed, however, that the effect of the increased abstraction of water from the interflow springs would indeed be very small, calculating a reduction of 1% in the frequency of flow. Even when the total abstraction was increased to 0.3 $m^3 10^6$ per year, the impact remained fairly small (Figure 5.16).

Floods

Same as for present day conditions (scenario 1).

[17] See Hughes (2008a) for the specific assumptions on which the hydrological simulation was based.

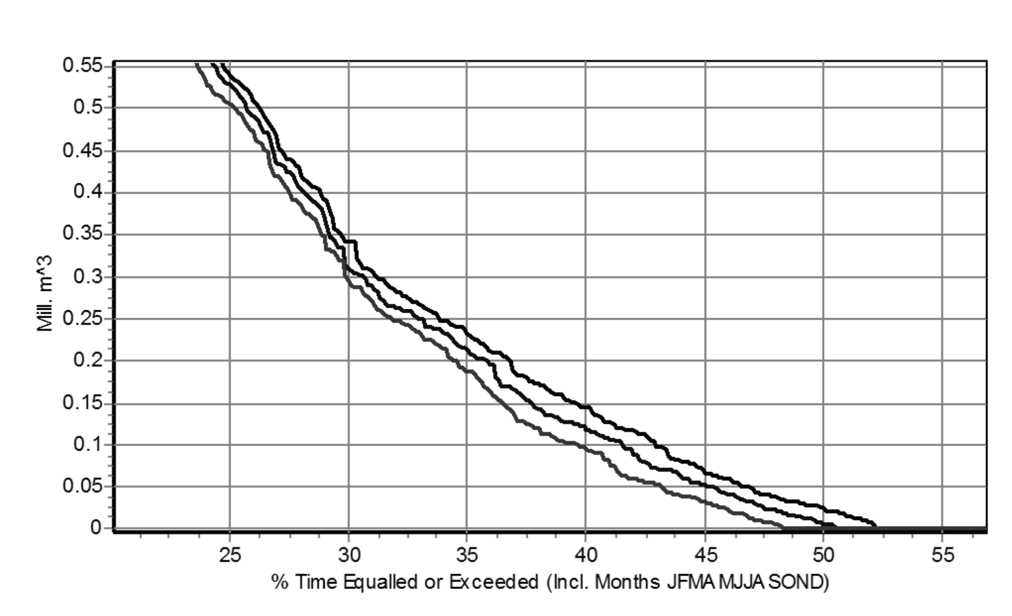

Figure 5.16: Annual 1-month flow duration curves for D32J indicating the natural (upper line), present day (middle line) and Scenario 4 (increased game farming and ecotourism activities; bottom line) (0.3 m3106/yr; red) conditions (taken from Hughes, 2008b).

Sedimentation

Improved vegetation cover and veld condition would lead to a decrease in sediment load. Together with an improvement in the condition of riparian vegetation, this would result in a reduction in channel erosion. The models used were, however, not able to simulate these effects.

Questions regarding the hydrological predictions

A number of points were raised by the some team members with regards to the hydrological simulations used for the scenarios on the Seekoei River. These are discussed in section 6.2.2.2 in Chapter 6.

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

There are three activities under this phase: collecting data, determining the present ecological state (PES) for each driver and response, and writing the reports.

Activity 17: Collect data

Data were collected for ten specialist fields in the Seekoei River over a two year period: hydrology (to a very limited extent); geohydrology, hydraulics (to an extent), catchment geomorphology, fluvial geomorphology, water quality, riparian vegetation, aquatic macroinvertebrates, fish and socio-economic issues (to an extent).

During the planning phase of the project, provision was made for two field-visits by the full team, one during the dry season and one during the wet season. Based on the long term flow record that indicated that the monthly average stream discharge is highest in February and March and lowest in June and July (Figure 5.2), it was decided to do a wet-season visit in March 2006 and a dry-season visit in August 2006. The team also decided to undertake additional field visits to the four sites every six weeks (see Table 5.17 for the dates). Although the main aim of this routine sampling was to acquire additional water quality data, the opportunity was used to also monitor the algal, macroinvertebrate and fish communities. In the light of the limited historical information and records available for the Seekoei at the start of the project (as for most other non-perennial rivers in the central parts of the country), this additional data proved to be very valuable later on in the project.

As expected, the team encountered wet conditions during the March field-visit. The catchment received substantial rain in January and February 2006 and a combined total of 280 mm, 248.5 mm and 221.5 mm were measured for Colesberg, Richmond and Hanover, respectively (see Figure 5.17). This followed on a period of relatively low rainfall that lasted for two years. With the exception of EWR1 where the water level was at its lowest during the study period, the water levels of the sampling pools at the other sites were high, with surface flow occurring in the lower Seekoei River (EWR3 and 4; Table 5.17).

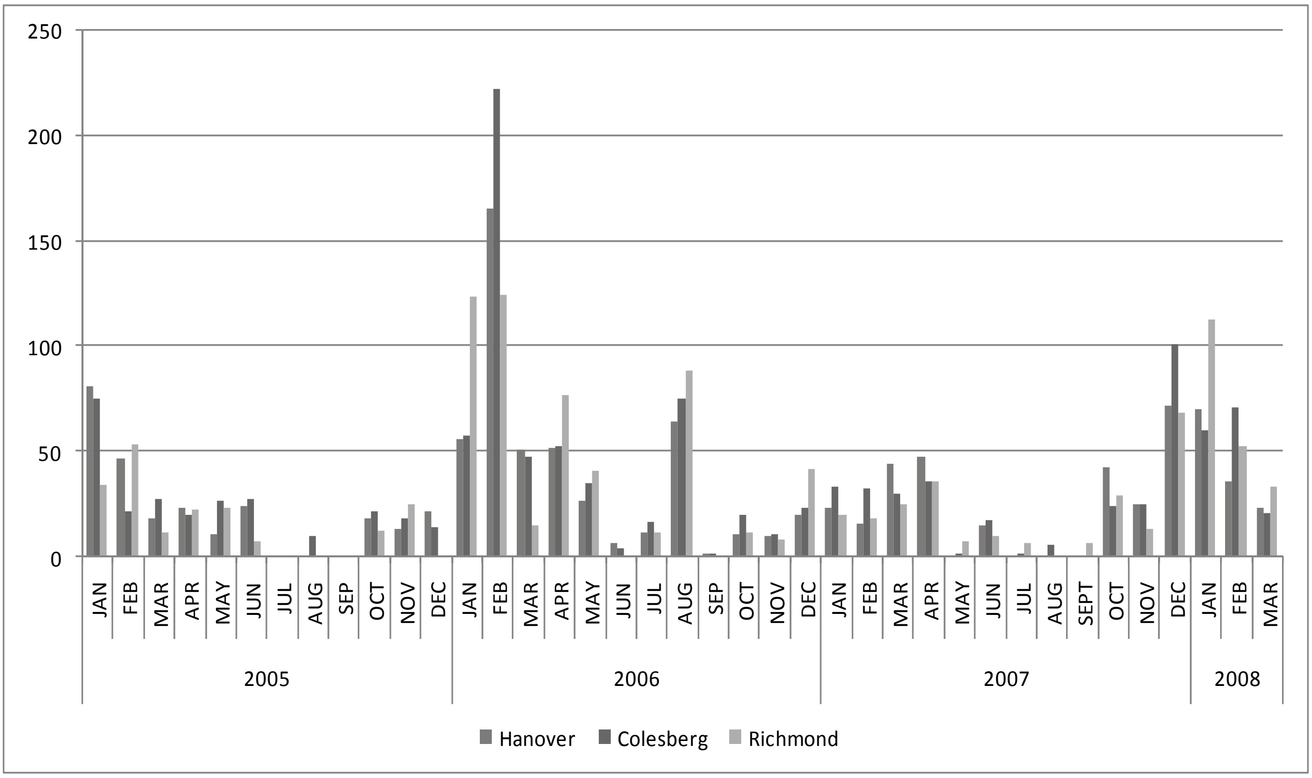

Figure 5.17: Rainfall for the Seekoei River catchment (Colesberg, Hanover and Richmond) for the period October 2005 to March 2008. (Rainfall data obtained from Weather SA).

Wet conditions persisted throughout the winter of 2006, forcing the team to postpone the dry-season visit to the end of September in order to allow some drying. Water levels in the study pools however remained high throughout the winter and spring, with the water level at EWR2 reaching its maximum in September. Results obtained during this field-visit do, therefore, not reflect dry conditions. The river started drying in November 2006 and surface flow in the lower Seekoei River stopped in December of that year. Drier conditions prevailed for the first half of 2007 with surface flow resuming in June. The six-weekly routine sampling proved extremely valuable in capturing this drying period.

Data for the various specialist fields were collected and analysed according to best-practise methods acceptable to each respective discipline. Data collection and analysis methods are described and discussed in the various specialist chapters included on CD (see Chapter 3). Gauge plate readings were noted and fixed-point photographs taken at each site during every field visit, while habitat measurements and assessments were done on most of the field visits.

Table 5.17: Dates when routine sampling was conducted. The water level in the sampling pools and a description of flow are indicated per site.

Dates	EWR1		EWR2		EWR3		EWR4	
	Descrip t-ion of flow	Water level (cm)	Descrip t-ion of flow	Water level (cm)	Descrip t-ion of flow	Water level (cm)	Descrip t-ion of flow	Water level (cm)
2006								
27-31 Mar*	Pool	69	Pool	96	Flow	91	Flow	93
23-25 May	Pool	83.5	Pool	90	Flow	115	Flow	105
27-29 Jun	Pool	83.5	Pool	85	Flow	98.5	Flow	100
15-17 Aug	Pool	84	Pool	96	Flow	100	Flow	103.5
25-29 Sept*	Pool	84	Pool	135	Flow	95.5	Flow	100
13-15 Nov	Pool	85	Pool	100	Flow	83.5	Flow	85.5
2007								
30 Jan-2 Feb	Pool	84.5	Pool	45	Pool	19.5	Pool	10.5
20-22 Mar	Pool	80	Pool	36	Pool	15.5	Pool	0
12-14 Jun	Pool	85	Pool	73	Flow	93.5	Pool	0
9-11 Oct	Pool	81	Pool	65	Flow	81	Flow	76
2008								
28 Mar-1 Apr	Pool	83	Pool	151	Flow	89.5	Flow	80.5

*Field trips attended by the full team.

Activity 18: Determine Present Ecological State (PES) for each driving indicator biophysical response

The present ecological state (PES) for the driving indicators (connectivity, floods and sediment delivery) for the Seekoei River was determined at the scenario workshop, while the PES for the biological responders (Riparian vegetation, macroinvertebrates and fish) were determined beforehand.

Step three of the (perennial) Reserve determination process in South Africa requires that the PES of the driving physical (hydrology, geomorphology and water quality) and responding biological (fish, macroinvertebrates and riparian vegetation) components of a river be determined as part of the Ecological Classification process, also referred to as EcoClassification (Kleynhans and Louw, 2008). The PES concept aims to give an indication of a system’s ecological integrity by comparing the present state of a component to its reference (or natural) state. A number of index models based on a Multi Criteria Decision Making Approach (e.g. Hydrological Driver Assessment Index, HAI; Geomorphology Driver Assessment Index, GAI; Physico-chemical

Driver Assessment Index, PAI; Fish Response Assessment Index, FRAI; Macro Invertebrate Response Assessment Index, MIRAI; Riparian Vegetation Response Assessment Index, VEGRAI) have recently been developed for this purpose (see Kleynhans and Louw, 2008 for further details). These models express each component's PES as an Ecological Category between A to F where A represents "close to natural" and F "critically modified". If a change in the ecological state has been observed, the possible causes, as well as the trend of the change, are indicated. The PES, together with an indication of the ecological importance and sensitivity (EIS; Kleynhans 1999a) of a river or river section, are then used to propose a Recommended Ecological Category (REC) for each component.

The EcoClassification is seen by Kleynhans and Louw (2008) as an integral part of the present Ecological Reserve determination method in that no flow or water quality conditions can be recommended without knowing the Ecological Category. The EcoClassification process, as described by Kleynhans and Louw (2008; including earlier versions), could not be followed as is in the Seekoei River, due to the following reasons:

- A different set of driving indicators were selected for the Seekoei, namely connectivity, channel maintenance floods and sediment delivery compared to hydrology, geomorphology and water quality used for perennial rivers.
- Difficulties with setting reference conditions for river components in the absence of recent and historical information.
- With the exception of the VEGRAI, FRAI and the MIRAI, workable versions of the proposed indices were not yet available for application on the Seekoei River[18].
- The FRAI, MIRAI and VEGRAI were not ideally suited for use in the Seekoei River and have been applied with modifications (see specialist chapters on macroinvertebrates and fish for in-depth discussions on the matter).

The modified approach followed in the Seekoei is described below.

PES for driving indicators

The PES for each driving indicator was based on the simulated hydrological data produced by the hydrological models. Each driver was assessed by comparing the data simulated for present-day conditions to those simulated for natural. This was then expressed as a percentage of change and put into a generic ecological PES class (Kleynhans, 1996 and 1999a; see Table 4.4) using the table of change ratings (see Table 4.5). For example, the hydrological model indicated that

[18] The final versions of the FRAI, MIRAI and Riparian Vegetation Response Assessment Index (VEGRAI) were published at the end of 2008. See Kleynhans and Louw (2008) for further details.

the natural connectivity at EWR1 (D32E) has been reduced from about 10% to less than 5% at present. This represented a 50% loss in connectivity, which implies a moderate change with a severity rating of “3” (based on Table 4.5). The severity rating of “3” was then translated into an ecological PES category C (moderately modified; see Table 4.5). The trajectory of change, causes and sources were also indicated.

The team was, however, confronted with two problems regarding this approach. First, no simulated data were available for the third driving indicator, sediment delivery (see discussion under Activity 16). Estimates by the catchment geomorphologist on the degree of change from natural were used to compensate for the lack of data. Second, simulated data on floods were only available for EWR3 and 4 (situated in D32J) and approximations were made for sites EWR1 and 2, taking connectivity into account.

EWR1 and 2

At sites EWR1 and 2, both the frequency of surface water connectivity and the flood regime were considered to be moderately modified (class C), mainly as a result of flow regulation due to in-channel weirs and dams (Table 5.18). Both these sites are situated in the flat part of the catchment, and sediment delivery was perceived to be largely natural (class B). The drivers were believed to be stable, as no plans existed for future development.

EWR3 and 4

The frequency of connectivity at EWR3 and 4 was still largely natural (class B) as a result of the contribution from interflow springs to baseflow in the lower part of the catchment. Abstraction of surface water from pools for agricultural purposes (mainly irrigation) does occur, and could result in longer periods of intermittence. A downward trend was, therefore, indicated for this driver. The flood regime in this section of the river was considered to be moderately to largely modified (class C/D), again as a result of flow regulation. Sediment delivery was still largely natural (class B) and considered to be stable.

Table 5.18: The present ecological state (PES) and trajectory of change determined for the driving indicators and biological responses identified for the Seekoei River (→, no change; ↓, degrading).

Site	Component	Class	Trajectory of change	Causes
EWR1	**Drivers**			
	Connectivity	C	→	Weirs and dams
	Floods	C	→	Weirs and dams
	Sediment delivery	B	→	Flow regulation
	Responses			
	Riparian vegetation	B	→	
	Macroinvertebrates	B	→	
	Fish	A	→	
	Combined PES	**B**		
EWR2	**Drivers**			
	Connectivity	C	→	Weirs
	Floods	C	→	Weirs
	Sediment delivery	B	→	Flow regulation
	Responses			
	Riparian vegetation	C	→	
	Macroinvertebrates	C	→	
	Fish	C	→	
	Combined PES	**C**		
EWR3and4	**Drivers**			
	Connectivity	B	↓	Abstraction and weirs
	Floods	C/D	→	Abstraction and weirs
	Sediment delivery	B	→	Flow regulation
	Responses			
	Riparian vegetation	B	→	
	Macroinvertebrates	C	↓	
	Fish	C	↓	
	Combined PES	**C**		

PES for biological responses

The PES categories for the biological components riparian vegetation, aquatic macroinvertebrates and fish were determined by expert opinion, supported by collected field data and historical records (if available), and are represented in Table 5.20. More detail on the methods and procedures followed are described in the respective specialist chapters included on CD (see Chapter 3).

EWR1

EWR1 was in good ecological condition. Although only one fish species, *Barbus anoplus,* occurred in this river section, it is believed to be the natural condition (class A). The riparian vegetation and aquatic macro-invertebrate community were still largely natural (class B).

EWR2

All three the biological communities studied at EWR2 appeared to be moderately modified (class C). Changes to the natural community structures were noted for the fish and macro-invertebrate communities, and several exotic species were recorded at this sampling site.

EWR3 and 4

The riparian vegetation community at sites EWR3 and 4 were still largely natural with very few modifications (class B). The macro-invertebrate and fish communities were considered to be moderately modified (class C), mainly as a result of upstream abstraction and in-channel weirs which have altered the natural flow regime and habitats. Two exotic fish species, *Micropterus salmoides* (largemouth bass) and *Cyprinus carpio* (common carp), were recorded in this section of the river.

Combined PES

A combined PES category was determined for each site by following the guidelines presented in Chapter 4, and is represented in Table 5.18.

EWR1

A combined PES class B (largely natural with few modifications) was assigned to EWR1. The drivers were not expected to further change the biota as the trajectory of change was stable. The critical driver class was a C (the frequency of surface water connectivity and flood regime). The combined PES class was, therefore, the same as that of the critical biological components (riparian and macro-invertebrate communities), namely a class B (largely natural with a few modifications).

EWR2

At EWR2, the biological components were in the same class as the drivers. The combined PES class was, therefore, the same as that of the critical biological components, namely class C (moderately modified).

EWR3 and 4

For EWR3 and 4, the class of one driver component (C/D for flood regime) was lower than that of the biological communities. The biological communities were not, however, expected to follow this driver as the driver was considered to be stable. The combined PES class was accordingly placed in the same class as the critical biological component which was a class C (moderately modified).

Activity 19:   Write reports

Ten specialist reports were produced for the Seekoei River study and are included as attachments on CD (see Table 2.2): geohydrology, catchment geomorphology, fluvial geomorphology, water quality, riparian vegetation, aquatic macroinvertebrates, fish and the socio-economic assessment. The specialist report on catchment hydrology has been published as a separate report by the WRC (see Hughes, 2008a) and has not been included.

Phase 8. Knowledge capture

Three activities were included, namely map data pathways, create response curves and capture information in database.

Activity 20:   Map data pathways

A flow-diagram showing possible links between the different indicators was prepared by the specialists at the scenario workshop starting off with the driving (hydrological) indicators, moving on to the physical-chemical and biological indicators and concluding with the socio-economic indicators. These links/relationships, which are an attempt to identify all the drivers that might have an impact on a specific responding indicator, are illustrated in Figures 5.18 to 5.20.

The three driving (hydrological) indicators (represented in the first level of organisation) were not only relevant to the next level of indicators (physical and chemical indicators), but to most other indicators as well (see Figure 5.18). For example, connectivity of surface water directly affects channel aquifer recharge, available pool habitat, and water quality, but it also directly influences fish movement and recruitment (restocking). An interesting development was that, except for the three hydrological indicators which only acted as drivers, most of the remaining indicators acted as both drivers and responders. The physical and chemical indicators (second level indicators), which responded to the hydrological drivers (first level indicators), in turn became drivers to third (biological) and fourth level (socio-economic) indicators. The available pool habitat is, for example, influenced by the frequency of connectivity of surface water, the flood regime and the delivery of sediment (first level indicators). However, the availability of pool habitat in turn might influence the water quality (second level indicator), the abundance and structure of biological communities (third level indicators such as riparian vegetation, aquatic invertebrates, fish and certain terrestrial species) and socio-economic (fourth level) indicators.

A summary of all the links recognised for the Seekoei River indicators is presented in Appendix E.

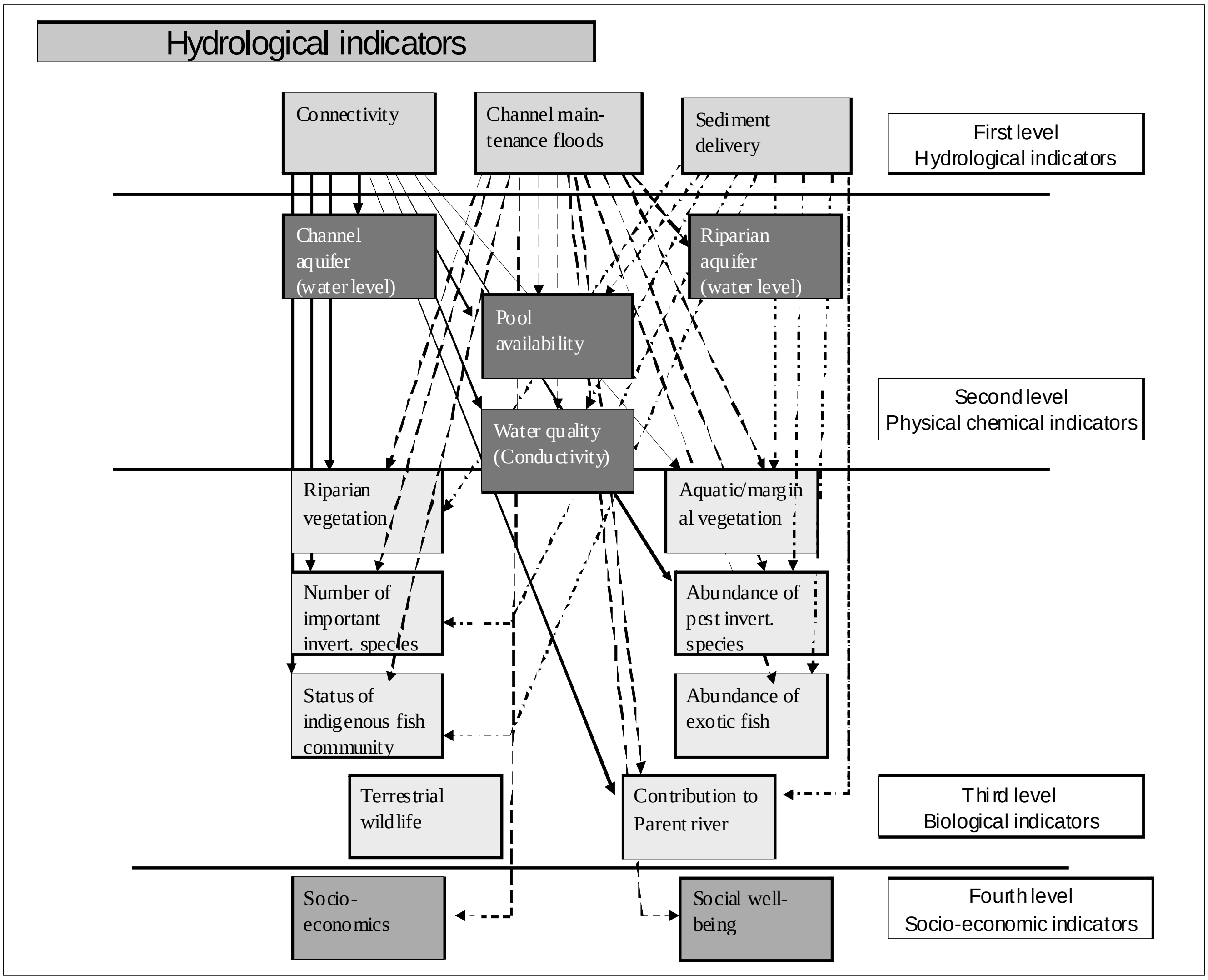

Figure 5.18: Flow diagram representing the links between the three hydrological indicators acting as "drivers" for the various other indicators or "responses".

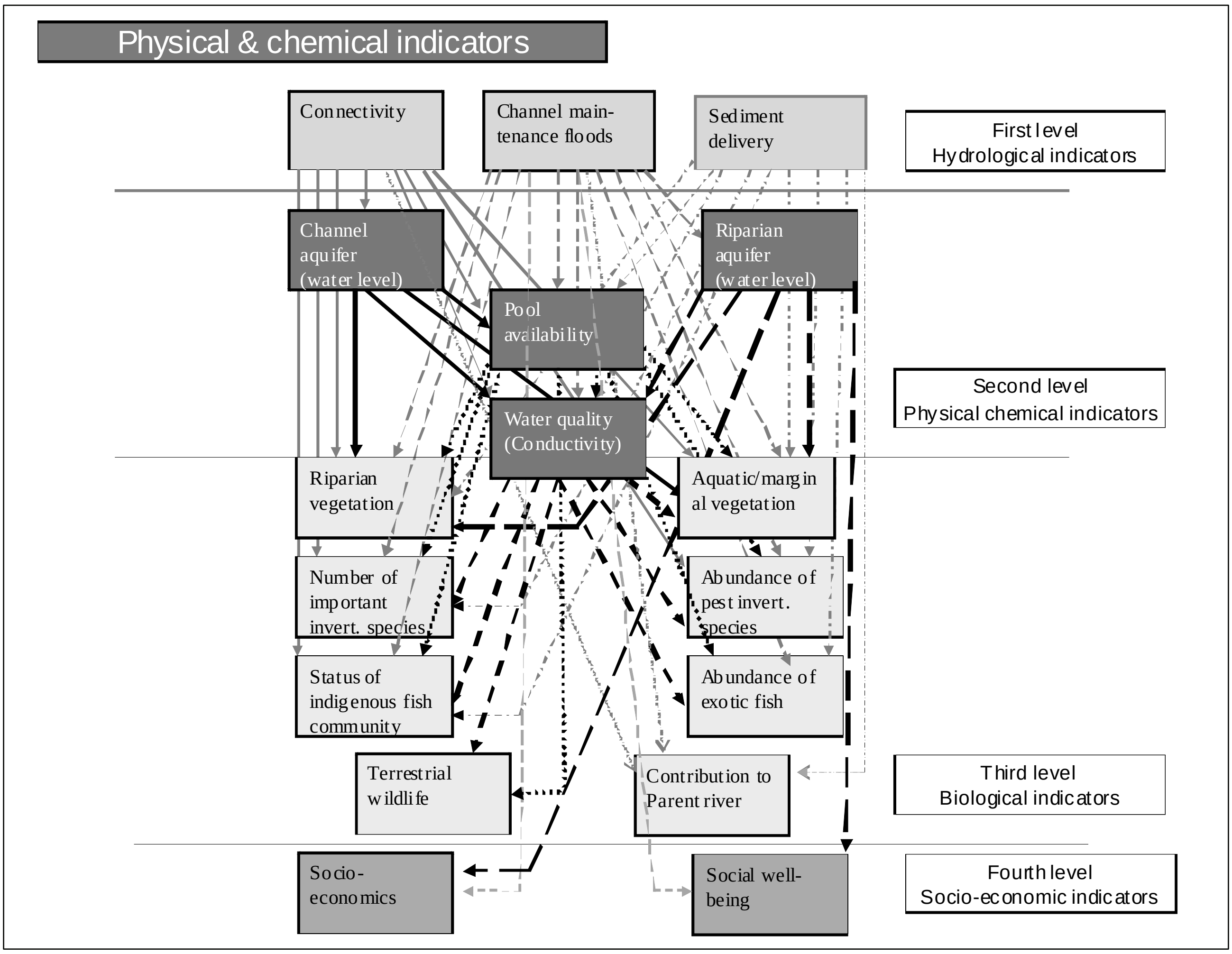

Figure 5.19: Flow diagram illustrating the links between the physical-chemical indicators, now acting as drivers, and those indicators responding to them.

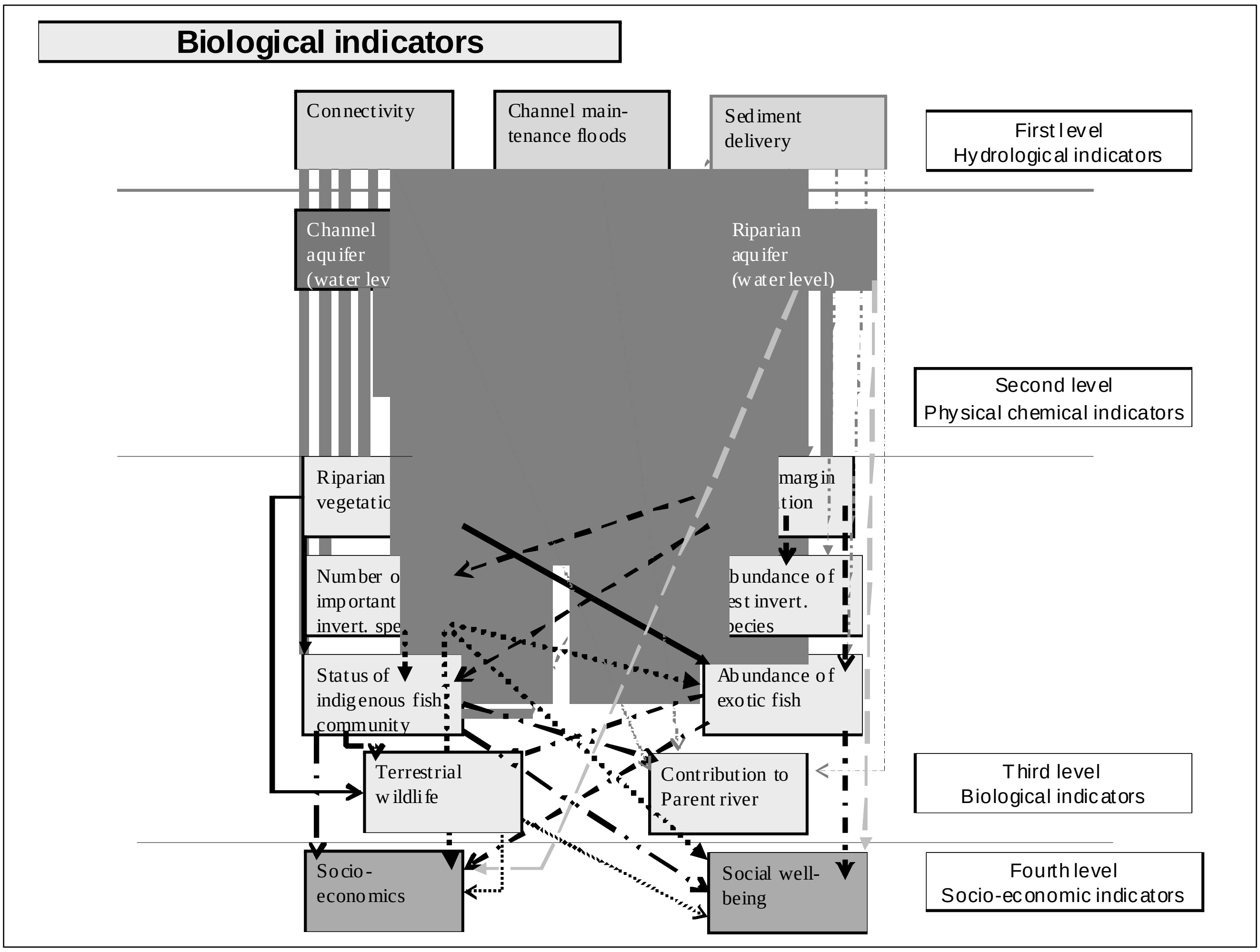

Figure 5.20: Flow diagram illustrating the links between the biological indicators, some of which might act as drivers, and those indicators responding to them.

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

The conceptual relationships behind the links identified for the Seekoei River (presented in Figures 5.18-20) were then described by means of response curves. The response curves showed how present day conditions are expected to change, at each site, for the responding indicators in relation to changes in the driving indicators. Specialists, therefore, used their understanding of the system to predict how the responding indicators would react to changes in the relevant drivers identified earlier. In an attempt to capture these “understandings”, explanatory notes that motivate the specialists’ decisions and reasoning, were added to the response curves. Due to the general lack of long term or historical data in non-perennial systems and the uncertainties of what a river would have looked like under natural or reference conditions, changes were described in terms of change from present day conditions. Response curves were prepared for abundances, area or concentrations only, using ratings of changes (see Table 4.5) to quantify the predicted changes. No response curves indicating changes in ecosystem integrity were drawn for the Seekoei River – mainly to avoid unnecessary complications during the first trial run of the method. This presented the team with difficulties later on in the study, and response curves predicting changes in ecosystem integrity would be included in future studies. Specialists also indicated whether the expected changes were “away” or “towards” the natural condition of the river, which essentially is the response curves of ecological integrity.

As an example, the response curves describing the relationship between connectivity (driving indicator) and electrical conductivity (responding indicator) at EWR1 to 4 are presented in Figure 5.21. It was understood that as connectivity increases, the electrical conductivity (EC) decreases. The EC at a specific site could however also be influenced by upstream EC concentrations. According to the response curve constructed for EWR1, a moderate increase in connectivity would possibly result in a negligible decrease in EC, while a moderate decrease in connectivity would result in a negligible increase in EC. Although the same trend was predicted for EWR3 and 4, the impact of connectivity on the water quality would be much more marked than at EWR sites 1 and 2. A moderate increase in connectivity at EWR3 was therefore expected to result in a moderate decrease in EC, while a moderate loss in connectivity could result in a moderate increase in EC.

All the response curves drawn for the Seekoei River study are presented in Appendix F.

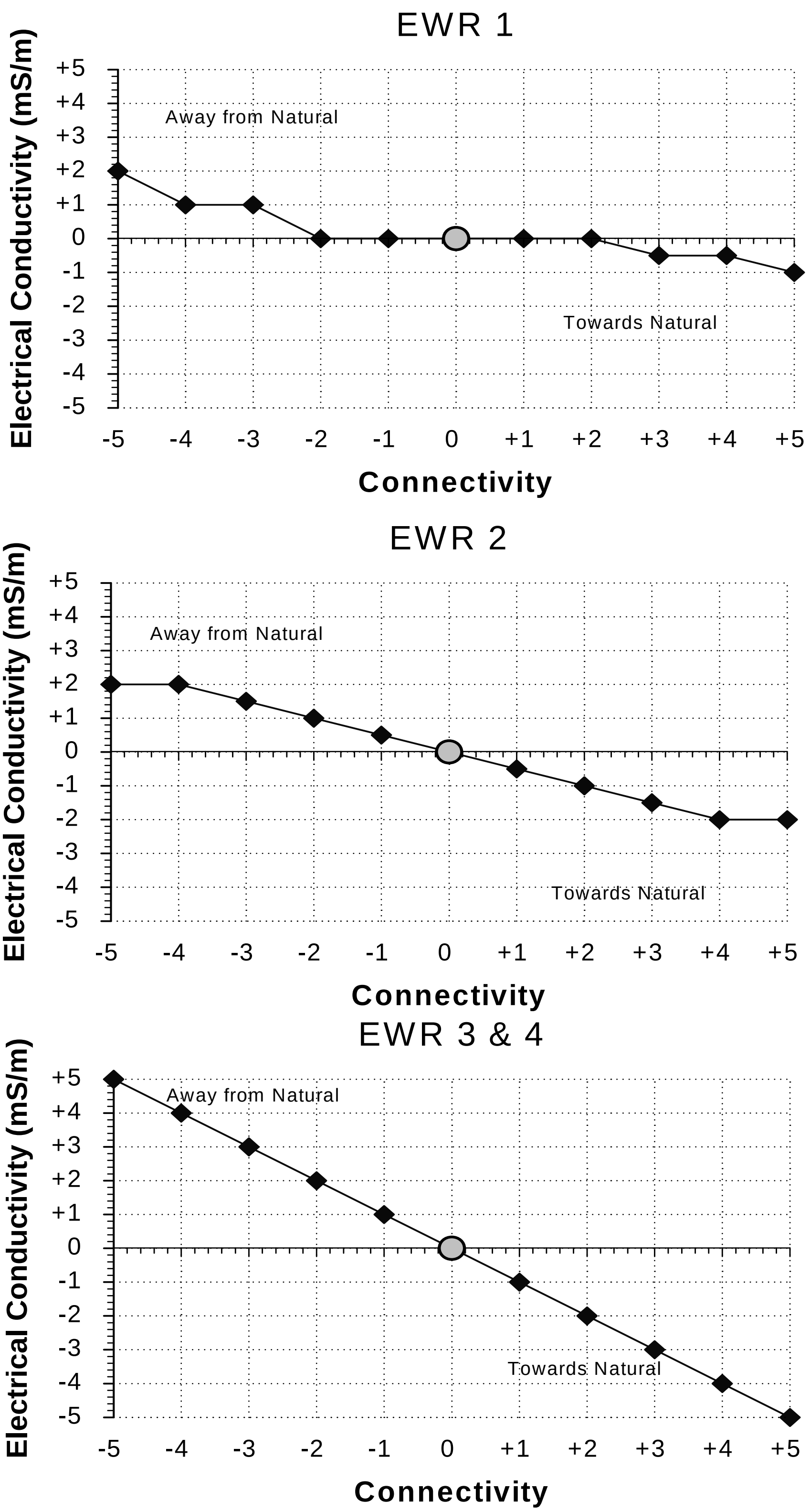

Figure 5.21: Response curves illustrating the relationship between connectivity and electrical conductivity at EWR1 to EWR4 (0 = present day conditions).

Activity 22: Capture the information in database

The Seekoei River project did not, for a number of reasons, attempt to create automated scenarios (used e.g. in DRIFT; King et al., 2004):

- Considering that the development of an EWA-methodology suitable for non-perennial rivers was in a very early stage.
- Uncertainty at that stage of the project of the level of the accuracy and (what could be done) in terms of the hydrological modelling, and how to describe or model the link between surface and ground water.
- The need to go through the process more slowly in order to enhance understanding of existing methods, and to consider the suitability and usefulness of these methods to non-perennial systems.
- A lack of understanding of the inner workings of software and extrapolations and assumptions it makes. The team was also concerned about the automated creation of scenarios, which produced ‘black box’ results that were not easily evaluated using their data and intuitive understanding of the Seekoei system.
- In order for the team to gain ownership and a better understanding of the method development process, they wished to develop their ability to create and evaluate scenarios following a less automated route.
- Acknowledging that the development or adoption of an appropriate scenario-creation tool would follow later on in the process.

Phase 9. Scenario analysis

Three activities under this phase: Ascertain value for driving hydrological indicators, interpret change in driving indicators as response in all other indicators, and add weightings.

Activity 23: Ascertain value for each driving hydrological indicator

The hydrological model constructed for the Seekoei River only provided output for two of the three driving indicators, namely connectivity and floods (see discussion under Activity 16). For floods, data were only available for EWR3 and 4. No simulated data were available on the delivery of sediment from the catchment to the river channel for the various scenarios. In order to allow method application, the gaps were filled with approximations made by the team under the guidance of the catchment geomorphologist. It is clear that the development of a model to supply information on the delivery of sediment in non-perennial river systems is a priority in the further development of the prototype method.

The predictions of change for the hydrological drivers for the four scenarios are summarised in Table 5.19. A short discussion provides background on the reasoning made for each scenario.

Scenario 1: Present day conditions

The present day situation was taken as the point of departure (baseline) for describing how the Seekoei River could change for each scenario. Present conditions were therefore indicated as "0" (see Table 5.19).

Table 5.19: Predictions of change in the three driving hydrological indicators for the four scenarios, using Severity Ratings of change (Table 4.5).

The hydrological/simulated outputs and approximations are indicated ("+" indicates an increase; "-" indicates a decrease).

Hydro-logical indicators	**Sites**	**Scenario 1** Present day		**Scenario 2** Natural conditions		**Scenario 3** Densification of agriculture		**Scenario 4** Ecotourism/Game-ranching	
		Hydro-logical output	Severity rating	Hydro-logical output	Severity rating	Approxi mations	Severity rating	Hydro-logical output	Severity rating
Connec-tivity	**EWR1**	0	0	+>100%	+3		+1		-1
	EWR2	0	0	+>140%	+3		+1		-1
	EWR3&4	0	0	+4%	+1		+1	-1%	-1
Floods	**EWR1**	0	0	+	+2	+	+1	-	-1
	EWR2	0	0	+	+3	+	+2	-	-1
	EWR3&4	0	0	+134%	+3	+	+1	-	-1
Sediment Delivery	**EWR1**	0	0	0	0	++	+3	-	-1
	EWR2	0	0	0	0	+	+2	--	-2
	EWR3&4	0	0	0	0	+++	+4	-	-1

Scenario 2: Natural conditions (pre-development)

The natural condition of the river and the catchment was described in relation to present conditions. The river in its natural condition lacked regulation (in-stream weirs and dams) and abstraction of water.

Indicator 1: Frequency of connectivity

The simulated connectivity values for the sites were reduced to percentages to express the change e.g. +> 100% represented an increase from <5% connectivity (under present conditions) to an estimated 10% under natural conditions. This predicted change was then translated to a severity rating according to the guidelines summarised in Table 4.5.

Indicator 2: Flood regime

Floods (for channel maintenance) were only modelled for sites EWR3 and 4, mainly because observed flood data were only available for one gauging station (D3H015) in the lower catchment. No simulated data were available for the upper catchment (EWR1 and 2) and approximations were made, taking the modelled connectivity into account. The flood for channel maintenance was taken as that with a magnitude of 1:5 year, i.e. between those needed to stimulate fish breeding and significant channel maintenance.

Indicator 3: Sediment delivery

No simulated data on sediment delivery were available for the catchment. It was assumed that the sediment delivered to the river channel would be similar to present conditions.

Scenario 3: Intensification and densification of farming activities

It was assumed that an intensification and densification of farming activities would result in decreased land cover, increased soil erosion and sediment delivery. An estimated decrease of 20% in land cover was assumed by the catchment geomorphologist and vegetation specialist. The simulated hydrology for present conditions was used as departure point in this scenario. Based on this, approximations, taking the landscape changes into account, were made and expressed as rates of change.

Indicator 1: Frequency of connectivity

It was estimated that the catchment changes would result in a negligible (1 to 25%) increase in the frequency of connection between habitats for all the sites (Table 5.19).

Indicator 2: Flood regime

A negligible to a small increase in the volume/ peak/not frequency of 1:5 year floods was expected under scenario 3.

Indicator 3: Sediment delivery

The expected decrease in vegetation cover was assumed to result in a large increase in sediment delivery in the lower part of the catchment, mainly due to the higher topography. A low to a moderate increase was, therefore, predicted for EWR2 and 1, respectively.

Scenario 4: Ecotourism activities

A change from the present commercial agriculture to game-ranching and ecotourism was expected to enhance the condition of the veld and the catchment – a 15% increase in vegetation cover was assumed. It was also assumed that water abstraction from the river and springs would increase to cater for tourists activities.

The simulated data, however, indicated only a very small (1%) reduction in the frequency of connectivity for EWR3 and 4 (D32J). Although the scenario specifically referred to the lower part of the catchment and no simulated data were available for the upper and middle sections, approximations were made for EWR1 and 2 in order to allow method application.

Indicator 1: Frequency of connectivity

The hydrological simulation indicated that increased abstraction from interflow springs for tourism activities could bring about a small reduction in baseflow and the duration of connectivity in the lower catchment. A negligible decrease in the frequency of connectivity was indicated for all three sites.

Indicator 2: Flood regime

No simulated flood data were available for this scenario. It was assumed that the improvement in the condition of the veld could slightly reduce runoff and a negligible decrease in flood frequency/volume/peak was predicted.

Indicator 3: Sediment delivery

Improved vegetation cover was expected to reduce sediment delivery from the catchment to the river channel. A slight decrease in the amount of sediment reaching the river was predicted for all sites.

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

In preparation for scenario building, a spreadsheet was prepared in MS Excel. All the indicators selected for the Seekoei River were added in the first column, with all relevant drivers which might influence them, in the second column (see Table 5.20). If any of these drivers were deemed more important than the others, specialists assigned a higher weighting to these drivers in column five. For example, changes to the riparian aquifer were perceived to be twice as important to the riparian vegetation cover as any of the other drivers (Table 5.20).

Next, the values indicating the predicted changes for the three driving hydrological indicators for the different scenarios (obtained from Table 5.19) were transferred into column three. In column four, an indication was given if the direction of change was towards (indicated by a "T") or away (indicated by an "A") the natural condition of the river. From Table 5.20 it can, for example, be deduced that the frequency of surface water connectivity under natural conditions (scenario 2) was predicted to be moderately higher (based on Table 4.5) than what it is at present. For these first level indicators, it was not necessary to calculate "weighted allocation values" and "weighted sums" and the change values were directly used as final values (see Table 5.20, column 7) to obtain values from the response curves for the second level of indicators (channel aquifer, riparian aquifer, pools and water quality), and so forth.

Table 5.20: Extract from the initial Excel spreadsheet prepared for scenario consideration on the Seekoei River for EWR1, Scenario 2, to illustrate the problems experienced (see discussion under Activity 25).

Scenario: 2_	**Site: EWR 1**					
Responders (Indicators)	**Driver**	**Response curve value**	**Toward/ away**	**Weight-ing**	**Weighted allocation**	**Final value**
Connectivity		3	T	1		**3**
Channel maintenance floods		2	T	1		**2**
Sediment delivery		0	--	1		**0**
Channel aquifer	Connectivity	0.5	T	1		**0.5**
Riparian aquifer	Connectivity	0	--	1	0.50	
	Flood regime	0	--	1	0.50	**0.0**
Pools	Connectivity	1.5	T	1	0.250	
	Flood regime	1.5	T	1	0.250	
	Sediment delivery	0	--	1	0.250	
	Channel aquifer	0	--	1	0.250	**0.750**
Water quality (EC)	Connectivity	-0.5	T	1	0.167	
	Flood regime	-2	T	1	0.167	
	Sediment delivery	0	--	1	0.167	
	Channel aquifer	0	--	1	0.167	
	Riparian aquifer	0	--	1	0.167	
	Pools	0	--	1	0.167	**-0.417**
Riparian vegetation cover	Connectivity	1	T	1	0.143	
	Flood regime	-3	T?	1	0.143	
	Sediment delivery	0	--	1	0.143	
	Channel aquifer	0	--	1	0.143	
	Riparian aquifer	**0**	**--**	**2**	**0.286**	
	Pools	0	--	1	0.143	**-0.286**
Aquatic/ marginal vegetation cover	Connectivity	1	T	1	0.125	
	Flood regime	-3	T	1	0.125	
	Sediment delivery	0	--	1	0.125	
	Channel aquifer	0	--	1	0.125	
	Riparian aquifer	0	--	1	0.125	
	Pools	0.5	T	2	0.250	
	Water quality (EC)	0	--	1	0.125	**-0.125**

Activity 25: Add weightings

During the first trial run, specialists listed all the drivers that might influence a specific response (illustrated in Table 5.20). The water quality at site EWR1, for example, could be influenced by six first and second level indicators (acting as drivers) i.e. the frequency of surface water connectivity, the flood regime, sediment delivery, channel and riparian aquifer recharge. In order to determine what their combined effect would be on the water quality, one final answer or value was needed. This final value was then used to obtain a response curve value for the subsequent indicators. Calculating these final values for responders, however, presented a problem in that the number of drivers affected the final value. [The final value was calculated as the sum of the products of the response curve values (Column 3, Table 5.20) and the weightings rescaled to 1 (Column 6, Table 5.20)]. Those responding indicators with more drivers were biased against as their final value would be lower than if they had fewer drivers. Another concern was that the final value for some responding indicators lower down became so diluted, that it became difficult to interpret them by means of the ratings table. The majority of the final values calculated in Table 5.20 (Column 7) were less than 1, implying that, according to the ratings table, the indicator was expected to exhibit negligible change. It was furthermore problematic to use these small numbers to obtain response curve values for subsequent indicators, as most response values were also less than 1. The final values, also, became increasingly smaller as we went down the list of indicators (responders), resulting in rather meaningless answers.

After much deliberation (including consulting various experts in the EWA field[19]) the following decisions were taken:

- To note this as an important problem to be considered in the next phase of the project which would focus on applying the prototype method on other non-perennial systems.
- To stick with the straight weighted sum for the present study. Although it is true that more drivers (and in a particular instance, some of those are scored 0) would dilute the overall effect, this should still be reflecting what the system of drivers and indicators set up is saying.
- To reduce the number of drivers for responding indicators. Specialists were asked to set up a system of driving and responding indicators that best describe the functionality of the river system, rather than including all the drivers that might have an influence on a particular indicator. The number of drivers originally selected for each site was, therefore, reduced – including only the ones perceived most relevant for that river section. Motivations for these decisions were noted, and are listed in Appendix G. Specialists were not limited to a prescribed number of drivers for this project, and no decision regarding the number of drivers allowed was taken as yet. Once selected, the list of drivers was to be kept constant for each site for the different scenarios. For example, the three drivers “flood regime”, “riparian aquifer” and “pools” were selected for “riparian vegetation cover” for EWR1 (see Table 5.21). The same three drivers were then used, for this responding indicator, at this site for scenarios 2, 3 and 4. A different set of driving indicators were, however, selected for “riparian vegetation cover” for EWR2 and EWR3 & 4, respectively.

[19] e.g. Dr. A. Joubert (Southern Waters) provided very valuable input.

Updated spreadsheet using EWR1 as an example

The updated table of responses for EWR1 under scenario 2 (natural conditions) is presented in Table 5.21[20].

Fifteen indicators were considered for site EWR1. Two indicators were de-activated for this site: the "number of important invertebrate species" (due to the absence of species considered as important) and the "abundance of exotic fish" (no exotic fish species are present in this river section)". The number of drivers per responding indicator was reduced to between two ("water quality") and five ("status of indigenous fish"), compared to Table 5.20. The driving indicators were again weighted (to give prominence to more important drivers) and the "weighted allocation values" calculated. The list of selected driving indicators, as well as the weightings, was kept constant for EWR1 for all the scenarios.

Table 5.21: Example of the updated or corrected Excel spreadsheet prepared for EWR1, Scenario 2 (see discussion under Activity 5.23).
Also note that two indicators were omitted for EWR1, namely the number of important invertebrate species and the abundance of exotic fish.

Scenario: 2_	**Site: EWR1**					
Responding Indicators	**Driver indicator**	**Response curve value**	**Toward/ away**	**Weighting**	**Weighted allocation**	**Weighted sum**
Connectivity		3	T	1		**3**
Flood regime		2	T	1		**2**
Sediment delivery		0	--	1		**0**
Channel aquifer	Connectivity	0.5	T	1	1	**0.5**
Riparian aquifer	Connectivity	0	--	1	0.500	**0.0**
	Flood regime	0	--	1	0.500	
Pools	Connectivity	1.5	T	1	0.250	**0.625**
	Flood regime	1	T	1	0.250	
	Sediment delivery	0	--	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Flood regime	-2	T	1	0.500	**-1.0**
	Channel aquifer	0	--	1	0.500	

[20] Note that the full set of tables for all the sites and scenarios considered are included in Appendix H.

Table 5.21 Continued: Example of the updated or corrected Excel spreadsheet prepared for EWR1, Scenario 2 (see discussion under Activity 5.23). Also note that two indicators were omitted for EWR1, namely the number of important invertebrate species and the abundance of exotic fish.

Responding Indicators	Driver indicator	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Riparian vegetation cover	Flood regime	-2	T	1	0.333	**-0.667**
	Riparian aquifer	0	--	1	0.333	
	Pools	0	--	1	0.333	
Aquatic/ marginal vegetation cover	Flood regime	-2	T	1	0.333	**-0.458**
	Pools	0.625	T	1	0.333	
	Water quality (EC)	0	--	1	0.333	
No. of important invertebrate species						
Abundance pest invertebrates	Flood regime	-1	T	1	0.333	**-0.333**
	Pools	0	--	1	0.333	
	Aquatic/ marg. veg cover	0	--	1	0.333	
Status of indigenous fish	Connectivity	1	T	1	0.167	**0.549**
	Flood regime	1.5	T	1	0.167	
	Pools	0.625	T	2	0.333	
	Water quality (EC)	0	--	1	0.167	
	Aquatic/ marg. veg cover	-0.458	A	1	0.167	
Abundance exotic fish						
Terrestrial Wildlife	Pools	0	--	1	0.250	**0.000**
	Water quality (EC)	0	--	1	0.250	
	Riparian vegetation cover	0	--	1	0.250	
	Status of indigenous fish	0	--	1	0.250	
Contribution to parent river	Flood regime	0	--	1	1.000	**0.000**
Socio-economics	Flood regime	-1	A	1	0.333	**-0.333**
	Riparian aquifer	0	--	1	0.333	
	Pest inv	0	--	1	0.333	
Social wellbeing	Flood regime	-1	A	1	0.333	**-0.444**
	Riparian aquifer	0	--	1	0.333	
	Pest inv	-0.333	T	1	0.333	

Predictions of changes to be expected for EWR1 for scenario 2

Based on Table 5.21, which represents the final set of predictions of how the river ecosystem could change at EWR1 if the natural flow regime was to be restored, the team expected that:

The removal of in-channel structures could increase surface water connectivity by 68 to 250% and flood frequency and volume by between 26% and 67%. Due to the flat topography at EWR1, sediment delivery was not expected to change. Although a negligible gain of between 1-25% was predicted for the channel aquifer recharge, as a result of the higher connectivity and flood frequency and volume, riparian aquifer recharge was not expected to change. The higher connectivity and flood frequency would also increase pool habitat by between 1% to 25%, and lower electrical conductivity by 0% and 20%. Increased floods would also result in a slight loss of riparian and aquatic (including marginal) vegetation cover, while pest invertebrate species is expected to be slightly less abundant than at present. An increase in the floods would flush out organic material and increase disturbance at the site. The gain in connectivity and pool habitat would result in a negligible increase in the status of the indigenous fish population (only one species). No change was predicted for terrestrial wildlife and contribution to the parent river. All the preceding predictions would result in a negligible loss in the socio-economic and social well-being.

The final predictions for the various scenarios for EWR1, 2 and 3 & 4 are presented in Appendix H.

Phase 10. Evaluate the scenarios in terms of ecological condition

This phase include only one activity, namely to assess the distribution of values for severity ratings of change

In order to evaluate the changes in ecological condition predicted for the different scenarios, similar rules to those used in DRIFT (see Brown and Joubert, 2003) were applied.

Using the additional information contained within each Response Curve, indicating if the shifts in ecological condition (i.e. the ratings) are toward or away from the natural state, assessments were made on whether or not the full suite of changes could be further summarised into an ecological class change (B to C, or similar).

This approach, however, did present the team with various problems that need to be addressed in future:

- Because we have only used “abundance response curves” (and not response curves of ecosystem integrity) we had the problem that positive and negative response ratings cancelled each other out in certain instances. For example, an increase in the abundance of exotic fishes is seen as detrimental to the indigenous fish community, and therefore ecosystem integrity. An increase in the abundance of exotic fish would therefore be a change away from natural, and could result in a decrease in the status of the indigenous fish community.

- Ending up with both negatives and positive abundance ratings made it very difficult to apply the 85% rule. For the interim, we cancelled out positive and negative ratings (response curve values) of equal value, and only considered the remaining ratings to determine if a class change occurred.
- Determining the direction of change was complicated by the fact that we had both Toward (Ts) and Away (As) ratings in one column. This made it very difficult to interpret the rules. As an interim measure it was agreed to cancel out Ts and As of equal (or as close to equal as possible) value. The Ts and As of the remaining ratings were then used to determine the final direction of change.

These problems would, however, be resolved by using integrity curves in future applications of the method.

Note that both the quantitative and qualitative socio-economic indicators were not considered in the final analysis of trends for each scenario.

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

A summary of the expected changes under the various scenarios are presented and discussed.

Evaluation of the final predictions for Scenario 2

The second scenario considered, hypothetically, how the Seekoei River ecosystem could change if the natural flow regime was restored by removing all dams, artificial weirs and in-channel obstructions. The vegetation cover in the catchment was kept constant for this scenario. A summary of the expected changes at EWR1 to 4 is presented in Table 5.22 and is discussed below.

EWR1

Description of predicted changes

It is understood that under the natural flow regime EWR1 received mostly localized surface runoff, with inflow from upstream occurring less than 10% of the time. During periods of intermittence, the isolated pool persisted as a result of small amounts of ground water that moved slowly, but continuously, towards the pool. Surface water from the pool was again lost to evaporation.

At present, a large number of small dams and weirs are present upstream of EWR1, making flow regulation the major impact influencing habitat integrity in the upper Seekoei River. The removal of these in-channel structures would increase the connectivity of surface water by between 68% and 250%, as well as restore the natural flood regime by increasing floods (both flood volume and frequency) by between 26% and 67%. Sediment delivery was, however, not expected to change from its present condition, mainly due to the flat topography that prevails in this part of the catchment.

Although a negligible gain (between 1-25%) was predicted for the channel aquifer recharge (as a result of the higher connectivity and flood frequency and volume), riparian aquifer recharge was not expected to change. The higher connectivity and flood frequency would increase pool habitat by between 1% to 25%, and lower electrical conductivity by between 0% and 20%.

Increased floods would also result in a slight loss of riparian and aquatic (including marginal) vegetation cover, while pest invertebrate species are expected to be negligibly less abundant than at present. An increase in the floods would flush out organic material and increase disturbance at the site, having a negative impact on the abundance of pest invertebrates. Increased connectivity would also allow more frequent contact between isolated *B. anoplus* populations persisting in isolated pools, while the restored flood regime would allow migratory movements, more ideal breeding conditions and better water quality. The increase in available pool habitat would result in a negligible increase in fish abundance and condition. No change was predicted for terrestrial wildlife and contribution to the parent river. Although the preceding predictions were expected to result in a negligible loss in the socio-economics and social well-being, these indicators were not included in the analysis.

Table 5.22: A summary of the final set of predictions EWR1, 2 and 3 and 4 for Scenario 2: Natural condition of the river (removal of impoundments and good veld cover). (T) = toward natural. (A) = away from natural. (0) = no change. Where T and A are present for the same indicator, these may cancel out and the final trend shown. Social indicators are not included in analysis of trend. Note that only a summary is presented here for each indicator, whereas the shaded rows refer to the complete set of drivers influencing each indicator as presented in Appendix H.

Indicator	**EWR1**		**EWR 2**		**EWR3 & 4**	
	Expected change	**Direction of change**	**Expected change**	**Direction of change**	**Expected change**	**Direction of change**
Connectivity	3	T	3	T	1	T
Flood regime	2	T	3	T	3	T
Sediment delivery	0	0	0	0	0	0
Channel aquifer	0.50	T	0	T	0	0
Riparian aquifer	0	0	0	0	0.25	T
Pools	0.63	T	1.25	T	1.75	T
Water quality	-1.00	T	-1.50	T	-2.00	T
Riparian vegetation cover	-0.67	T	-1.00	T	-1.00	T
Aquatic/marginal vegetation cover	-0.46	T	-0.44	T	-0.13	T
Number important invertebrate species	N/A		N/A		1.30	T
Abundance of pest invertebrate species	-0.33	T	0.65	T	0.57	T
Status indigenous fish	0.55	T	1.65	T	1.44	T
Abundance exotic fish	N/A		0.3	0	0.42	0
Terrestrial wildlife	0	0	0.125	T	0.09	T
Contribution to parent river	0	0	0	0	0.94	T
River condition	**B to A**		**C to B**		**C to A**	
Number of Response Curve entries (once "+" and "-" cancelled out)	**21**		**27**		**31**	
Number of Response Curve entries (once Ts and As cancelled out)	**12 Ts**		**15 Ts**		**21 Ts**	
85%	**20 (2 or less)**		**25 (2 or less)**		**30 (4 or less)**	
Socio-economics	0		-0.18		-0.60	
Social wellbeing	-0.33		-0.36		-0.85	

Evaluation of the predicted in ecological condition for EWR1

Severity of change

Twenty-one of the thirty-one original ratings remained after the negative and positive ratings (response curve values) of equal value were cancelled out[21] (see discussion under Phase 10). Of these, 20 (95.2%) had a value of 2 or less and no rating was higher than 3. Based on the adopted rules (as explained in Chapter 4), a system change of one category from the present ecological condition was implied.

Direction of change

After ratings with opposite directions were cancelled out, 12 "Toward" ratings remained. River condition should, therefore, improve to a more natural condition.

Final result

If the natural flow regime of the upper Seekoei River is restored, the present ecological condition of this section of the river is predicted to increase from a category B (largely natural) to a category A (natural).

	Category	Description
Present Ecological State (PES)	B	Largely natural
Predicted Ecological State	A	Natural

EWR2

Description of predicted changes

The major impact presently in macro-reach 4, where EWR2 is situated (quaternary catchment D32F), is flow regulation. The large number of in-channel structures present in D32F (as well as those in quaternary catchments upstream of EWR2) has, according to the hydrological model, reduced the frequency of surface water connectivity from 12% of the time (under natural conditions) to less than 5% of the time (at present). The small amount of variable interflow that the pool at EWR2 receives from a nearby dolerite ridge was not sufficient to ensure permanence. The water level in the pool varied, and occasionally dried up, during the study period. The current flow regulation has also greatly increased pool storage in the quaternary catchment. According to the hydrological model, maximum pool volume increased from 0.98 million m^3

[21] Due to the fact that abundances were reflect in the response curves instead of ecosystem integrity, the team ended up with both positive and negative ratings which made it difficult to apply the 85% rules. Opposite ratings of similar value were therefore cancelled out, and the remaining ratings were used to determine if a state change occurred or not (see explanation under Phase 10).

under natural conditions to 6.48 million m^3 at present. About 85.68 million m^3 of water is lost to abstraction in the quaternary catchment.

Based on the values provided by the hydrological model, a severity rating of 3 (moderate; 68-250% gain) towards the natural condition of the river was given to the first two hydrological indicators (frequency of surface water connectivity and flood regime. No change was predicted for the third indicator (sediment delivery). The moderate increase in connectivity and flood regime was not expected to increase channel and riparian aquifer recharge. It was predicted, however, that pool habitat would negligibly increase as a result thereof (see Table 5.22). Water quality was also expected to improve due to the predicted decrease (negligible/low) in conductivity as a result of the improved connectivity and flood regime.

The river channel and pool at EWR2 are presently overgrown by reeds. The high incidence of reeds in the river channel, as well as along the channel, for this macro-reach was identified as a serious impact impairing habitat integrity. The moderate increase in flood frequency and volume, an important control factor for riparian and aquatic plant communities, was therefore expected to increase river condition by slightly reducing the cover of these communities and keeping the channel open.

The negligible increase in pool habitat was, further, expected to benefit invertebrate and fish communities. Pest invertebrates were expected to be slightly more abundant. Under natural conditions these indigenous invertebrates (perceived as pest species by humans) were more abundant than at present, mostly as a result of higher habitat availability. The higher availability of suitable pool habitat would also benefit all indigenous species in this river section, which prefers slow-flowing or standing waters. Increased connectivity and more frequent floods would further enhance the status of fish communities, and a negligible to low increase was predicted. The improved conditions would, however, also be beneficial to exotic fish species. The abundance of exotic fish was predicted to increase slightly, moving the river condition away from natural. Terrestrial wildlife was expected to benefit very slightly from improved river condition, mainly as a result of the higher status of the indigenous fish community. The contribution of this river section to the parent river was not expected to change.

Evaluation of the predicted changes in ecological condition for EWR2

Severity of change

Twenty-seven ratings were left after the negative and positive ratings (response curve values) of equal value were cancelled out. Of these, 25 (95.2%) had a value of 2 or less and no rating was higher than 3. Based on the adopted rules, a system change of one category from the present ecological condition was implied.

Direction of change

The majority of ratings (15 Ts were left after ratings with opposite directions were cancelled out) indicated a change toward natural. The ecological condition of this river section is, therefore, expected to improve toward the natural condition of the river under scenario 2.

Final result

It is predicted that the removal of in-channel structures would improve the present ecological condition of this river section from a category C (moderately modified) to a category B (largely natural).

	Category	Description
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	B	Largely natural

EWR3 and 4

Predicted changes

EW3 and 4 are situated in macro-reach 5 (quaternary catchment D32J) in the lower part of the Seekoei River catchment. Flow regulation was again identified (by the Habitat Integrity study) as the most important impact affecting river condition in this macro-reach. Although flow regulation has some impacts on the frequency and magnitude of high flows and small impacts on low flows, the present day hydrological regime appeared to be largely natural. The hydrological model indicated a 2% decrease in the frequency of surface water connection (from 52% under natural conditions to 50% at present). This lower part of the river, which naturally experiences a longer duration of surface flow (than the upper and middle sections of the river), receives a relatively large contribution from springs derived from interflow out of dolerite ridges. The addition of man-made structures to the river channel, had increased the maximum pool storage from 0.75 million m^3 to 1.15 million m^3. Abstraction from D32J was estimated at 8.06 million m^3.

Based on the information provided by the hydrological model, surface water connectivity is predicted to be negligibly higher (severity rating of 1; see Table 5.19) under natural conditions. The removal of in-channel weirs and dam walls were expected, however, to result in a moderate increase in flood frequency and volume. (According to the hydrological model, the peak and volume of a 1:2 flood is at present respectively 70% and 79% lower than what were expected for natural conditions). Sediment delivery was not expected to change.

Although channel aquifer recharge was not expected to change, riparian aquifer recharge should slightly increase (severity rating of 0.25) as a result of the negligible increase in surface water connectivity. The restoration of the flood regime, together with the higher connectivity, was predicted to increase pool habitat by between 26 to 67%. For the same reason, conductivity was expected to decrease by 21 to 40%, resulting in improved water quality.

The increase in flood frequency and volume would result in a negligible loss (between 0 and 20%) in riparian vegetation cover. Aquatic and marginal vegetation is expected to decrease slightly, gently pushing the river towards a more natural state by keeping the channel open and flushing algae downstream.

The number of important invertebrate species was expected to react favourably (an increase of between 1 and 25% was predicted) to the higher frequency of floods and surface water connectivity. Surface water connectivity was especially important at EWR3 and 4 due to the riffle and rapid habitat present at these sites. Various important invertebrate species found in this habitat type are sensitive to flow, and would be negatively impacted by a reduction in surface water flow. The important invertebrate species were also expected to benefit from the restored flood regime, as channel maintenance floods rearrange and scour clean stone-in-current habitat important to these species. Pest invertebrate species should also slightly increase in abundance.

The indigenous fish community would benefit from the removal of man-made structure from the river channel (a severity rating of 1.44 toward natural condition was predicted). Not only would artificial barriers to fish movement be removed, but longer periods of surface water connectivity would, for example, restore fish movement between pools, allow the utilisation of flow-sensitive habitats (riffles and rapids) for longer periods, allow the young longer periods of stay in shallow nursery areas and increase pool persistence. An increase in flood frequency would, among other things, be beneficial for the breeding of most indigenous fish species present in the river. The predicted increase in pool habitat would, however, result in a slightly higher abundance of exotic species. Both exotic fish species present at EWR3 and 4 are well adapted to pool habitat.

Terrestrial wildlife is expected to slightly increase as a result of the predicted changes, mainly as a result of the enhanced status of indigenous fish. The contribution of the lower Seekoei River to the Orange River is predicted to increase negligibly. Restoring the flood regime would allow a higher volume of surface water reaching the parent river.

Evaluation of the predicted changes in ecological condition for EWR3 and 4

<u>Severity of change</u>

Of the 31 ratings that remained after the negative and positive ratings (response curve values) were cancelled out, 30 (96.8%) had a value of 4 or less. Due to the fact that one rating (response curve value) was higher than 4, the fourth rule (see Activity 26 in Chapter 4) had to be applied which implied that the system changes three categories from the present condition.

Direction of change

The majority of ratings (21) indicated that the system is expected to change toward a more natural condition.

Final result

The present ecological condition of the lower Seekoei River is predicted to increase from a category C (moderately modified) to a category A (natural) if the natural flow regime of the Seekoei River is restored.

	Category	Description
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	A	Natural

Summary of the predicted changes in ecological condition under scenario 2

The ecological condition of the lower section of the Seekoei River (represented by EWR3 and 4) was expected to improve the most as a result of the restored flow regime. The present ecological condition was predicted to increase by two categories from a moderately modified to a natural system (Table 5.23). The ecological condition of the upper (represented by EWR1) and middle (represented by EWR2) sections were also expected to improve. The PES of the upper section was predicted to improve from a largely natural to a natural state and the middle section from being moderately modified to a largely natural state. It can, therefore, be concluded that the removal of the man-made structures from the river channel would move the Seekoei River ecosystem closer to its natural state.

Table 5.23: A summary of the predicted category changes for the three sites for scenario 2 (removal of weirs and dam walls from river channel).

Site	**Category**	**Description**
EWR1		
Present Ecological State (PES)	B	Largely natural
Predicted Ecological State	A	Natural
EWR2		
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	B	Largely natural
EWR3 and 4		
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	A	Natural

Evaluation of the final predictions for Scenario 3

The third scenario considered the impacts of dividing larger farms into small holdings (especially along the river) resulting in a densification and intensification of farming activities. Possible consequences associated with this scenario, which focused very much on changes in landscape features, were the deterioration in farming practices including over-grazing, loss of bank stability, removal of riparian vegetation, increased sedimentation and erosion resulting from poor land cover. The predicted effects these consequences might have on the river ecosystem are summarised in Table 5.24.

EWR1

Description of predicted changes

The deterioration of veld condition as a result of e.g. continued overgrazing could result in higher volumes of surface runoff. Due to low gradient in this part of the catchment, only a negligible increase in surface water connectivity and floods were expected. Increased surface runoff would lead to increased sediment load, and an increase of between 41% and 60% was predicted for sediment delivery. The impacts of these changes were not expected to influence riparian aquifer recharge, while channel aquifer recharge could increase negligibly.

Although the increase in connectivity and floods would contribute to pool volume, the effect of increased sedimentation was perceived to be stronger. A moderate increase in sediment (of between 68% and 250%) was indicated. This resulted in a negligible loss of pool habitat being predicted. The negligible increase in channel maintenance floods, which usually reset the river ecosystem, could result in a very slight decrease in electrical conductivity, especially in the pools.

The physical changes predicted for the river were not expected to have a profound impact on the biological communities. Increased flooding would, together with the small loss of pool habitat, result in negligible loss of riparian and aquatic vegetation cover. No change was predicted for the abundance of pest invertebrate species, while a negligible decrease in the status of the indigenous fish community was indicated as a result of the loss in pool habitat and aquatic vegetation cover. Terrestrial wildlife, contribution to the parent river, socio economic and social well-being were not expected to be influenced by the changes.

Table 5.24: Final set of predictions for EWR1, 2 and 3 and 4 for Scenario 3: Densification of farms. In this scenario, there is a mix of T and A indicators, because the flow regime (although moving away from natural) provides more flow to the river, whilst the sediment delivery is greatly increased, negatively affecting the river. Note that only a summary is presented here for each indicator, whereas the shaded rows refer to the complete set of drivers influencing each indicator as presented in Appendix H.

Indicator	**EWR1**		**EWR 2**		**EWR3and4**	
	Expected change	**Direction of change**	**Expected change**	**Direction of change**	**Expected change**	**Direction of change**
Connectivity	1	A	1	A	1	A
Flood regime	1	A	2	A	1	A
Sediment delivery	3	A	2	A	4	A
Channel aquifer	0.50	T	0.00	0	0.00	0
Riparian aquifer	0.00	0	0.00	0	0.25	T
Pools	-0.50	A	0.50	T	0.00	0
Water quality	-0.25	T	-0.83	T	-1.00	T
Riparian vegetation cover	-0.33	T	-0.67	T	-0.33	T
Aquatic/marginal vegetation cover	-0.50	T	-0.34	T	-0.25	T
Number important invertebrate species	-		-		0.71	T
Abundance of pest invertebrate species	0.00	0	0.30	T	0.00	0
Status indigenous fish	-0.25	A	0.50	T	0.50	T
Abundance exotic fish	-		0.20	A	-0.04	T
Terrestrial wildlife	0.00	0	0.00	0	0.00	0
Contribution to parent river	0.00	0	0.00	0	1.57	A
River Condition	**B to B**		**C to C**		**C to E**	
Number of Response Curve entries (once "+" and "-" cancelled out)	**19**		**28**		**29**	
Number of Response Curve entries (once Ts and As cancelled out)	**5 As**		**4 (3Ts=0.5; 1A=-2)**		**3 (2Ts<0.5; 1A=4)**	
85%	**19 (1 or less)**		**28 (1 or less)**		**28 (3 or less)**	
Socio-economics	0.00		0.029		-0.14	
Social wellbeing	0.00		-0.186		-0.49	

Evaluation of the predicted in ecological condition for EWR1

Severity of change

Nineteen ratings remained after the negative and positive ratings (response curve values) of equal value were cancelled out. All the ratings that remained (100%) had a value of 1 or 0 and no rating was higher than 2. Based on the adopted rules, the system remained in its present ecological condition under scenario 3.

Direction of change

No change is predicted under this scenario.

Final result

The present ecological state at EWR1 is not expected to change if farming activities are intensified and would remain largely natural (category B).

	Category	Description
Present Ecological State (PES)	B	Largely natural
Predicted Ecological State	B	Largely natural

EWR2

Predicted changes

Higher surface runoff as a result of degraded vegetation cover (due to poor farming practices as implied under scenario 3) would result in a negligible gain in surface water connectivity. This would further translate into a low increase in flood frequency and/or volume. Additional soil erosion as a result of the degraded veld cover could increase sediment delivery by between 26% and 67%. These changes were not, however, expected to change the rate of recharge of the channel and riparian aquifers.

Pool volume was predicted to increase negligibly as a result of the higher connectivity and floods. The higher incidence of floods would maintain pools through scouring, as well as, flush out accumulated salts from the pools. A reduction of between 0% and 20% was therefore predicted for conductivity. Increased flooding was further expected to result in a negligible loss in riparian and aquatic vegetation cover.

The abundance of pest invertebrates was predicted to increase negligibly due to the extra pool habitat available under this scenario. Increased pool volume, together with increased flooding, would result in a negligible increase in the status of the indigenous fish community. The higher availability of pool habitat would unfortunately also benefit the exotic common carp, which is well adapted to the slow-flowing conditions that prevail in pools. The terrestrial wildlife associated with the river was not expected to be influenced by the predicted changes, while the contribution of this river section to the parent river was also perceived as not to undergo change.

Evaluation of the predicted changes in ecological condition for EWR2

Severity of change

All 28 ratings that remained after the negative and positive ratings (response curve values) were cancelled out, had a value of 1 or less. This implied that the system would remain in its present ecological condition under scenario 3.

Direction of change

No change predicted.

Final result

The present ecological condition at EWR2 is not expected to change under scenario 3. The river section is therefore expected to remain moderately modified.

	Category	Description
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	C	Moderately modified

EWR3 and 4

Predicted changes

The effects of surface water connectivity and floods on water availability in D32J (where EWR 3 and 4 are situated) are less pronounced than for the rest of the catchment, mainly as a result of the relative large contribution from interflow springs to baseflow. The increased runoff expected to occur under this scenario was, therefore, expected to result in a negligible increase in connectivity and floods only. Reduced veld cover in this part of the catchment with its steeper topography could result in a large increase in sediment delivery and an increase of between 251% and 500% was predicted. Although no change was predicted for channel aquifer recharge, recharge of the riparian aquifer was expected to increase negligibly due to increased connectivity and flooding.

Available pool habitat was not expected to change. Although increased connectivity and floods would contribute to pool volume, this would be neutralised by the increase in sediment accumulating in the pools. Increased flooding would again result in negligibly lower levels of electrical conductivity, improving the general water quality in the pools. Riparian and aquatic vegetation cover was also expected to decrease negligibly as a result of the increased flooding.

The predicted increase in connectivity and floods would benefit both aquatic invertebrate and fish communities. A negligible increase in the number of important invertebrate species and the status of the indigenous fish community was predicted. The abundance of pest invertebrates was, however, not expected to increase. The predicted decrease in aquatic vegetation cover could, however, influence exotic fish abundance by reducing cover for these species which are strongly associated with aquatic vegetation. Again, the terrestrial wildlife was not expected to be influenced by the predicted changes.

The contribution of this river section to the Orange River was expected to increase by between 26% and 67% in terms of surface water, sediment, pest invertebrate species and indigenous fish species. Both the socio-economic and the social well-being indicators could undergo a negligible decrease as a result of the changes predicted above.

Evaluation of the predicted changes in ecological condition for EWR3 and 4

Severity of change

Of the 29 ratings that remained after the negative and positive ratings (response curve values) were cancelled out, 28 (96.6%) had a value of 3 or less, while none was more than 4. The system therefore changes two categories from the present ecological condition.

Direction of change

After the Ts and As of similar values were cancelled out, 3 values remained: 2Ts of 0.5 and 1A of 4. Although the Ts were in the majority, the value of the A was much higher. It could therefore be expected that the direction of change would be away from the present ecological condition.

Final result

The present ecological condition at EWR3 and 4 was predicted to decrease by two categories, from a category C (moderately modified) to a category E (seriously modified), under scenario 3.

	Category	Description
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	E	Seriously modified

Summary of the predicted changes in ecological condition under scenario 3

Although the ecological condition of the upper and middle section of the catchment (represented by EWR1 and 2) was not expected to change under this scenario, a significant decrease was predicted for EWR3 and 4. The upper part of the river was expected to remain in a largely natural state (category B), while the middle part would remain moderately modified (category C; see Table 5.25). The ecological condition of the lower part of the river (represented by EWR3 and 4) was, however, expected to deteriorate from a category C (moderately modified) to a category E (seriously modified). This implied that the changes brought about by this scenario would seriously compromise the ecological integrity of this river section – a situation that is not considered to be sustainable in the long term. It can be concluded that the intensification of farming activities would have a seriously detrimental effect on the lower part of the catchment, while the ecological condition of the rest of the catchment would remain intact.

Table 5.25: A summary of the predicted category changes for the three sites under Scenario 3 (intensification of farming activities and vegetation loss).

Site	**Category**	**Description**
EWR1		
Present Ecological State (PES)	B	Largely natural
Predicted Ecological State	B	Largely natural
EWR2		
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	C	Moderately modified
EWR3 and 4		
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	E	Seriously modified

Evaluation of the final predictions for Scenario 4

Scenario four considered what could happen to the river ecosystem if farmers switched from current farming practices to game ranching in order to encourage ecotourism (see Table 5.28). For this scenario it was assumed that vegetation cover would increase by approximately 15% as the veld recovers, and that water would be extracted from the interflow springs in order to cater for tourist activities. Although the scenario focused mostly on the lower part of the catchment (EWR3 and 4 situated in D32J) which has a great potential for tourism, predictions of change were also made for sites EWR 1 and 2.

EWR1

Predicted changes

Improved ground cover as a result of improved veld management and lower stock densities would possibly result in a negligible reduction in surface water connectivity and flood frequency and volume (see Table 5.28). Improved vegetation cover would further limit sediment delivery from the catchment to the river channel, and a negligible decrease is predicted for this indicator.

The decrease in connectivity could have an impact on channel aquifer recharge, reducing it by between 0% and 20%. Recharge of the riparian aquifer was, however, not expected to be influenced by the changes.

The small reductions in connectivity, floods and channel aquifer recharge could reduce pool volume negligibly but electrical conductivity was expected not to change. The lower levels of disturbance due to reduced flooding would enhance vegetation growth, and both riparian and aquatic vegetation cover could increase negligibly. The abundance of pest invertebrates was not expected to be influenced by these changes.

The loss in pool volume and floods could have a negligible negative impact on the indigenous fish community. The terrestrial wildlife was, however, not expected to be influenced by the predicted changes. This section of the river was not expected to contribute to the parent river.

Evaluation of the predicted in ecological condition for EWR1

Severity of change

All the remaining change ratings (after the negative and positive response curve values were cancelled out), had a value of 1 or less. This implied that the system would remain in its present ecological condition under scenario 4.

Direction of change

No change predicted for EWR1 under this scenario. (9 As remained).

Table 5.26: Scenario 4: Ecotourism; improved catchment cover to 15% increase from PD, and abstraction from springs in the riparian zone at sites 3 and 4.
(T) = toward natural. (A) = away from natural. (0) = no change. Where T and A are present for the same indicator, these may cancel out and the final trend shown. Social indicators are not included in analysis of trend. Note that only a summary is presented here for each indicator, whereas the shaded rows refer to the complete set of drivers influencing each indicator as presented in Appendix H.

Indicator	**EWR1**		**EWR 2**		**EWR3and4**	
	Expected change	**Direction of change**	**Expected change**	**Direction of change**	**Expected change**	**Direction of change**
Connectivity	-1	A	-1	A	-1	A
Flood regime	-1	A	-1	A	-1	A
Sediment delivery	-1	T	-2	T	-1	T
Channel aquifer	-0.50	A	0.00	0	0.00	0
Riparian aquifer	0.00	0	0.00	0	-0.25	A
Pools	-0.19	A	-0.38	A	-0.13	A
Water quality	0.00	0	0.50	A	1.00	A
Riparian vegetation cover	0.33	A	0.33	A	0.17	A
Aquatic/marginal vegetation cover	0.27	A	0.16	A	0.19	A
Number important invertebrate species	N/A		N/A		-0.69	A
Abundance of pest invertebrate species	0.00	0	0.25	A	0.74	A
Status indigenous fish	-0.23	A	-0.48	A	-0.51	A
Abundance exotic fish	N/A		-0.16	T	-0.04	T
Terrestrial wildlife	0.00	0	0.00	0	0.00	0
Contribution to parent river	0.00	0	0.00	0	-0.30	A
River Condition	**B to B**		**B to B**		**C to C**	
Number of Response Curve entries (once "+" and "-" cancelled out)	**25**		**24**		**21**	
Number of Response Curve entries (once Ts and As cancelled out)	**9 As**		**10 As**		**16 As**	
85%	**25 (1 or less)**		**24 (1 or less)**		**21 (1 or less)**	
Socio-economics	0.00		0.00		-0.07	
Social wellbeing	0.00		0.00		0.14	

Final result

The present ecological condition of EWR1 would not change as a result of a increased game farming and ecotourism activities in this part of the catchment. The PEs would, therefore, remain largely natural.

	Category	Description
Present Ecological State (PES)	B	Largely natural
Predicted Ecological State	B	Largely natural

EWR2

Predicted changes

A 15% improvement in vegetation cover was expected to result in a negligible decrease in surface water connectivity and floods (frequency and volume). It could also reduce sediment delivery to the river by between 21% and 40%.

The recharge of the channel and riparian aquifers were not expected to be influenced by the proposed changes. The hydrological simulations indicated that water abstraction from boreholes (for tourist activities) was not likely to have an impact on the river, except where the boreholes are situated close to the river and the impacts could be locally significant. The hydrological model also indicated that pool volume at EWR2 is mainly influenced by upstream surface flow and that ground water contributes very little. A reduction in connectivity and floods could, therefore, result in a <10% loss in pool volume, while electrical conductivity could increase slightly.

A 0 to 20% decrease in channel maintenance floods would further reduce disturbance in this river section (where reed encroachment is already having an impact on habitat integrity), allowing a negligible increase in riparian and aquatic vegetation cover. Reduced flooding, together with a decrease in pool availability would probably lead to a <20% increase in the abundance of pest species as pools become stagnant and predators (not able to survive in low oxygen habitats) decrease. (Mosquito species prefer standing water with little disturbance). Smaller floods play an important role in the reproductive cycles of the indigenous fish and a reduction in these floods, together with a loss in pool habitat, could reduce the status of the fish community negligibly. A very small reduction in the abundance of exotic fish (*C. carpio*) was also predicted, mainly due to the loss in pool volume. The terrestrial wildlife was not expected to be influenced by the predicted changes.

Evaluation of the predicted changes in ecological condition for EWR2

Severity of change

24 ratings remained after the negative and positive ratings (response curve values) were cancelled out. All of these had a value of 1 or 0 and none had a value of more than two. The system is, therefore, expected to remain in the present ecological condition under Scenario 4.

Direction of change

No change predicted for EWR2 under Scenario 4.

Final result

The present ecological condition at EWR2 would remain in a category B (largely natural).

	Category	Description
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	C	Moderately modified

EWR3 and 4

Predicted changes

The hydrological simulation indicated that increased tourism within the lower part of the catchment

As for EWR1 and 2, an increase in vegetation cover could result in a small decrease in surface runoff reducing surface water connectivity and channel maintenance floods by between 0 and 20%. The amount of sediment reaching the river channel could also decrease by <20% as a result of the improved ground cover. Although channel aquifer recharge was not expected to change, recharge of the riparian aquifer could decrease by <5%.

A negligible decrease in pool volume was predicted as a result of the decrease in connectivity and floods. A reduction in the connectivity of surface water also increases the period of time which pools are isolated. This, together with the reduction in floods, could lead to a <25% increase in electrical conductivity. Aquatic vegetation cover would be more abundant under these conditions, and an increase of <5% was predicted. A reduction in channel maintenance floods could also result in a negligible increase in riparian vegetation cover.

The negligible decrease in channel maintenance floods and connectivity would further decrease the flow habitat available, which could reduce the number of important invertebrate species by <20%. The abundance of pest species is expected to increase (<25%) as mosquito species increase in more stagnant pools. The status of the indigenous fish community is also expected to decrease as a result of the reduced connectivity, floods and pool volume. Longer periods of intermittence increase abiotic (e.g. increased water temperature and low oxygen levels at night) and biotic (increased predation) pressures on fish trapped in the isolated pools. The abundance of exotic fish species was also expected to decrease negligibly. Terrestrial species were not considered threatened by the predicted changes and are to remain constant.

A reduction in channel maintenance floods reduces the amount of water delivered by the Seekoei to the Orange River. Decreased connectivity would also limit fish movement between the tributary and the main stem, and could have an impact on fish spawning and restocking.

Evaluation of the predicted changes in ecological condition for EWR3 and 4

<u>Severity of change</u>

All the 21 remaining response curve values (after the negative and positive values were cancelled out) had a value of 1 or 0 and none had a value of more than two. The system was, therefore, expected to remain in the present ecological condition under Scenario 4.

<u>Direction of change</u>

No change was predicted for EWR3 and 4 under Scenario 4.

<u>Final result</u>

Increased ecotourism in the lower part of the catchment should not have a negative impact on the river ecosystem and the present ecological condition was expected to remain moderately modified (Category C).

	Category	Description
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	C	Moderately modified

Summary of the predicted changes in ecological condition under scenario 4

The changes associated with Scenario 4 were not expected to have a significant impact on the ecosystem functioning. The present ecological condition was predicted to remain the same for the upper (EWR1), middle (EWR2) and lower (EWR3 and 4) river reaches (Table 5.27).

Table 5.27: A summary of the predicted category changes for EWR1, 2 and 3and4 under Scenario 4 (Increased ecotourism and game farming activities).

Site	**Category**	**Description**
EWR1		
Present Ecological State (PES)	B	Largely natural
Predicted Ecological State	B	Largely natural
EWR2		
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	C	Moderately modified
EWR3 and 4		
Present Ecological State (PES)	C	Moderately modified
Predicted Ecological State	C	Moderately modified

Comparing the predictions made for the catchment under the three scenarios

EWR1

A summary of the changes predicted for EWR1 under the three scenarios considered for the Seekoei River are presented in Table 5.28.

The present ecological condition at EWR1 was largely natural (category B), and was not expected to change under Scenarios 3 (densification of farming activities) and 4 (ecotourism). For both these scenarios, the driving indicators were predicted to change only negligibly. As a result, only very small changes were predicted for the responding indicators.

Restoring the natural flow regime by removing all dam walls and weirs was, however, predicted to have a significant impact on the river system. The present ecological condition was expected to increase by one category from largely natural (category B) to natural (A/B). Flow regulation was recognised as the major impact influencing ecological integrity in the upper Seekoei River, and by removing these obstructions to flow, the connectivity of surface water could increase by as much as 250%. Together with a 26% to 67% increase in channel maintenance floods, most of the responding indicators were expected to move closer towards natural conditions.

Table 5.28: Comparison of the three scenarios for Site EWR1.
(T) = toward natural. (A) = away from natural. (0) = no change. Where T and A are present for the same indicator, these may cancel out and the final trend shown. Social indicators are not included in analysis of trend. Note that only a summary is presented here for each indicator, whereas the shaded rows refer to the complete set of drivers influencing each indicator as presented in Appendix H.

Indicator	**Scenario 2 Remove impoundments**		**Scenario 3 Densification**		**Scenario 4 Ecotourism plus abstraction**	
	Expected change	**Direction of change**	**Expected change**	**Direction of change**	**Expected change**	**Direction of change**
Connectivity	3	T	1	A	-1	A
Flood regime	2	T	1	A	-1	A
Sediment delivery	0	0	3	A	-1	T
Channel aquifer	0.50	T	0.50	T	-0.50	A
Riparian aquifer	0	0	0.00	0	0.00	0
Pools	0.63	T	-0.50	A	-0.19	A
Water quality	-1.00	T	-0.25	T	0.00	0
Riparian vegetation cover	-0.67	T	-0.33	A	0.33	A
Aquatic/marginal vegetation cover	-0.46	T	-0.50	A	0.27	A
Number important invertebrate species	N/A		N/A		N/A	
Abundance of pest invertebrate species	-0.33	T	0.00	0	0.00	0
Status indigenous fish	0.55	T	-0.25	A	-0.23	A
Abundance exotic fish	N/A		N/A		N/A	
Terrestrial wildlife	0	0	0.00	0	0.00	0
Contribution to parent river	0	0	0.00	0	0.00	0
River Condition	**B to A**		**B to B**		**B to B**	
Number of Response Curve entries (once "+" and "-" cancelled out)	**21**		**19**		**25**	
Number of Response Curve entries (once Ts and As cancelled out)	**12 Ts**		**5 As**		**9 As**	
85%	**20 (2 or less)**		**19 (1 or less)**		**25 (1 or less)**	
Socio-economics	0		0.00		0.00	
Social wellbeing	-0.33		0.00		0.00	

EWR2

The present ecological condition at EWR2 was predicted to improve with one category from being moderately modified (C) to largely natural (B) if the natural flow regime was restored under scenario 2 (Table 5.29). No change in ecological condition was expected to occur under Scenarios 3 and 4.

Both surface water connectivity and channel maintenance floods were expected to increase by between 68% and 250% when obstructions to flow were to be removed from the river channel. The changes brought about by these (e.g. a 25% gain in pool volume and a <30% reduction in electrical conductivity) would benefit the biological communities, moving the system closer to its natural condition. Although an (low to negligible) increase in connectivity and floods was predicted under Scenario 3, this was not significant enough to cause a category change in ecological condition.

The negligible loss in connectivity and channel maintenance floods predicted under Scenario 4 caused only minor changes in the responding indicators (none of the predicted changes were higher than "0.5"). The present ecological condition was, therefore, believed to remain in a moderately modified state if ecotourism activities increase in the middle part of the catchment.

EWR3 and 4

Significant changes were predicted for EWR3 and 4 under scenarios 2 and 3, while scenario 4 was not expected to change the present ecological condition of the river. A summary of the predicted changes are presented in Table 5.30.

Table 5.29: Comparison of the three scenarios for Site EWR2.
(T) = toward natural. (A) = away from natural. (0) = no change. Where T and A are present for the same indicator, these may cancel out and the final trend shown. Social indicators are not included in analysis of trend. Note that only a summary is presented here for each indicator, whereas the shaded rows refer to the complete set of drivers influencing each indicator as presented in Appendix H.

Indicator	Scenario 2 Remove impoundments		Scenario 3 Densification		Scenario 4 Ecotourism plus abstraction	
	Expected change	Direction of change	Expected change	Direction of change	Expected change	Direction of change
Connectivity	3	T	1	A	-1	A
Flood regime	3	T	2	A	-1	A
Sediment delivery	0	0	2	A	-2	T
Channel aquifer	0	T	0.00	0	0.00	0
Riparian aquifer	0	0	0.00	0	0.00	0
Pools	1.25	T	0.50	T	-0.38	A
Water quality	-1.50	T	-0.83	T	0.50	A
Riparian vegetation cover	-1.00	T	-0.67	A	0.33	A
Aquatic/marginal vegetation cover	-0.44	T	-0.34	A	0.16	A
Number important invertebrate spp	-		-		-	
Abundance pest species	0.65	T	0.30	T	0.25	A
Status indigenous fish	1.65	T	0.50	T	-0.48	A
Abundance exotic fish	0.3	0	0.20	A	-0.16	T
Terrestrial wildlife	0.125	T	0.00	0	0.00	0
Contribution to parent river	0	0	0.00	0	0.00	0
River Condition	**C to B**		**C to C**		**C to C**	
Number of Response Curve entries (once "+" and "-" cancelled out)	**27**		**28**		**24**	
Number of Response Curve entries (once Ts and As cancelled out)	**15Ts**		**4 (3Ts=0.5; 1A=-2)**		**10 As**	
85%	**25 (2 or less)**		**28 (1 or less)**		**24 (1 or less)**	
Socio-economics	-0.18		0.029		0.00	
Social wellbeing	-0.36		-0.186		0.00	

The greatest degree of change with regards to ecological condition (at EWR3 and 4) was expected to occur under scenario 2 – the removal of in-channel obstructions to flow. The present ecological condition, which was described as moderately modified (category C), was predicted to improve by three categories to a category A or natural condition. Restoring the flow regime to its natural condition was expected to greatly benefit the aquatic communities, especially the number of important invertebrate species which was expected to increase by more than 25% and the status of the indigenous fish community which could increase by up to 40%.

The ecological condition was predicted to deteriorate by two categories, from a category C (moderately modified) to a category E (seriously modified) if farms were to be divided into smaller units/small holdings (scenario 3). This was a significant reduction in ecological condition and a seriously modified ecosystem is not considered to be sustainable. This reduction in ecosystem integrity was mainly brought about by a 251% to 500% increase in sediment delivery in the catchment due to a loss in plant cover as a result of the densification and intensification of farming activities. Increased sedimentation was specifically predicted to have an impact the available pool volume, flow sensitive habitats (e.g. riffles) and the amount of sediment delivered to the Orange River.

Increased abstraction from the interflow springs to supply water for tourist activities was not expected to have a significant impact on the present ecological condition of the river, and this river section was predicted to remain in a category C (moderately modified).

Phase 11. Outputs

Activity 27: Hydrological output

A hydrological output was not produced for the Seekoei River.

Activity 28: Report back to stakeholders

Formal feedback on the Seekoei River was not done due to the theoretical nature of this project.

Table 5.30: Comparison of the three scenarios for Site EWR3 and 4.
(T) = toward natural. (A) = away from natural. (0) = no change. Where T and A are present for the same indicator, these may cancel out and the final trend shown. Social indicators are not included in analysis of trend. Note that only a summary is presented here for each indicator, whereas the shaded rows refer to the complete set of drivers influencing each indicator as presented in Appendix H.

Indicator	**Scenario 2 Remove impoundments**		**Scenario 3 Densification**		**Scenario 4 Ecotourism plus abstraction**	
	Expected change	**Direction of change**	**Expected change**	**Direction of change**	**Expected change**	**Direction of change**
Connectivity	1	T	1	A	-1	A
Flood regime	3	T	1	A	-1	A
Sediment delivery	0	0	4	A	-1	T
Channel aquifer	0	0	0.00	0	0.00	0
Riparian aquifer	0.25	T	0.25	T	-0.25	A
Pools	1.75	T	0.00	0	-0.13	A
Water quality	-2.00	T	-1.00	T	1.00	A
Riparian vegetation cover	-1.00	T	-0.33	A	0.17	A
Aquatic/marginal vegetation cover	-0.13	T	-0.25	A	0.19	A
Number important invertebrate spp	1.30	T	0.71	T	-0.69	A
Abundance pest species	0.57	T	0.00	0	0.74	A
Status indigenous fish	1.44	T	0.50	T	-0.51	A
Abundance exotic fish	0.42	0	-0.04	T	-0.04	T
Terrestrial wildlife	0.09	T	0.00	0	0.00	0
Contribution to parent river	0.94	T	1.57	A	-0.30	A
River Condition	**C to A**		**C to E**		**C to C**	
Number of Response Curve entries (once "+" and "-" cancelled out)	**31**		**29**		**21**	
Number of Response Curve entries (once Ts and As cancelled out)	**21 Ts**		**3 (2 Ts<0.5; 1A=4)**		**16 As**	
85%	**30 (4 or less)**		**28 (3 or less)**		**21 (1 or less)**	
Socio-economics	-0.60		-0.14		-0.07	
Social wellbeing	-0.85		-0.49		0.14	

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CHAPTER 6
EVALUATION OF THE METHODOLOGY

6.1 Introduction

The ultimate aim of this project was to produce a prototype EWA methodology suitable for use on non-perennial rivers. The first year of the project was used to acquire an understanding of the Seekoei River ecosystem through field research (see Chapter 2), while the second year was spent on developing the prototype method (described in Chapter 4) – drawing on the knowledge and experience gained during the first year. This method was applied on the Seekoei River at a workshop attended by the whole team in Bloemfontein from 10-14 March 2008 (reported on in detail in Chapter 5) in order to test its practicability. Chapter 6 provides an assessment of that test run. It discusses the successes and failures of the proposed methodology, critically assessing the places where we ran into difficulties.

6.2 Evaluation of the proposed methodology

6.2.1 *Background to the method: development, features, constraints and assumptions and applications*

The validity and practicability of the method proposed in Chapter 4 need to be evaluated against the backdrop of the many constraints and challenges facing us in non-perennial rivers and keeping in mind the inherent character of non-perennial systems. It became clear that a new perspective was needed for non-perennial rivers, and it remained a challenge throughout this project not to look at the Seekoei River from an “adjusted” perennial perspective. Trying to make perennial methods fit the Seekoei River wasted a lot of time, and it was only when we put those methods aside and started to focus on the inherent characteristics of this river, that we started to make progress. The key features of non-perennial rivers and the specific challenges that these could bring about in doing EWAs for these rivers, were discussed in Chapter 3.

6.2.1.1. *A short summary of the proposed methodology*

What we have produced for the Seekoei River is a comprehensive approach that 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. This approach, which was explained in Chapter 4 (also see Figure 4.2), was divided into eleven phases:

Phases 1 to 2: dealing with starting and setting up the study;
Phases 3 and 4: focussing on the accumulation of catchment information in order to identify the important catchment processes, components and issues that require further consideration in the study and on which site and indicator selection will be based;
Phases 5 to 7: aiming to choose realistic and applicable future scenarios for the catchment and to gather, document and process the data (on the selected indicators) needed to analyse and evaluate these scenarios during the next phase;
Phase 8: capturing the acquired knowledge in Response Curves and a database;
Phase 9 to 10: considering and predicting the impacts that the chosen scenarios might have on the selected biophysical and socio-economic indicators;
Phase 11: advising the relevant decision-making body of the outcome of the study and providing feedback to the community of stakeholders.

6.2.1.2. *A few of the method's key features:*

The prototype method clearly places an important emphasis on creating an understanding of the nature of the river and its catchment. The method makes provision for a small core team to use available data and information on the physical catchment, together with the issues and concerns pointed out by stakeholders, to develop a preliminary basic understanding of catchment processes which will inform and guide subsequent project planning.

Another important feature of the method is that information on the catchment as a whole, as opposed to the river channel only, is considered in river delineation. It aims to integrate the Runoff Potential Units (RPUs; homogenous units based on soil type, catchment slope, infiltration rate, vegetation cover, rainfall intensity and flow accumulation) with the outcome of the hydrological analysis and the Habitat Integrity Assessment (based on the method of Kleynhans et al., 2008) in order to create Combined Response Units (CRUs), which will serve as a basis for site-selection and specialist studies.

The proposed method uses a number of generic attributes, referred to as indicators, which can be used to describe change in the river and its catchment, such that they would be sensitive to water level and other changes in the catchment. Based on the Seekoei River study, three driving and fourteen responding indicators have been proposed. The method, however, makes provision that any of the indicators can be de-activated where not relevant. Indicators can also be added if needed.

The proposed approach also provides an unbiased way to capture the knowledge, experience and wisdom of specialists by means of Response Curves. These curves can then be used, in a structured way, to predict how the river would change in response to certain scenarios or flow management options.

The method further recognizes the particularly important role that stakeholders could play in EWAs for non-perennial rivers. There is often very little information and data available on these rivers and their users. Involving the stakeholders from early on in the assessment provides a mechanism to obtain information on the past and present nature and uses of the river, and to identify issues and concerns that should be reflected in the scenarios considered for the catchment.

6.2.1.3. *Constraints that should be kept in mind when carrying out the evaluation*

A number of points should be kept in mind when reporting on the testing of the method on the Seekoei River:

The project's focus only turned to method development in the second year of study. The method, as it stands now, gradually crystallized from the group's collective knowledge, ideas and experience. It started to take form, under the guidance of Dr. Jackie King, at a workshop early October 2007. The sequence of the various phases and activities were, however, only finalised at a workshop in March 2008, when part of the method was tested on the Seekoei River. It is obvious that the complete method could not be applied on the Seekoei River, and only Phases 8 to 10 were run at the March 2008 workshop. Phases 1 to 7 were applied retrospectively in a desktop exercise to test the method's practicability. This implied that:

- Phases 1 and 2, for which the responsibility lies mainly with the DWAF, were not carried out,
- The proposed stakeholder process, as set out in Phase 4, was not conducted,
- It was not possible to select alternative study sites based on the new approach,
- The RPUs were not fully integrated with the results from the hydrological analysis and the habitat integrity assessment in order to create CRUs as required by the new approach.
- A final hydrological output was not produced for the Seekoei River.

It should also be kept in mind that the new approach, as applied on the Seekoei River, resembles a comprehensive assessment. Once a comprehensive EWA methodology has been finalised, the process for more rapid assessments will be completed. Because the main emphasis of this project was on method development, more rigorous testing of the method on alternative non-perennial systems will be carried out in a follow-up study approved by the WRC.

The discussion on the evaluation will be split into two parts:

- first Phases 3 to 7 which were tested by means of a desktop assessment after the March 2008 Scenario-workshop, and
- second Phases 8 to 10 that were applied at the Scenario-workshop in March 2008.

Note that Phases 1, 2 and 4 will not be included in this discussion (as explained above) and that a detailed account of the application of the proposed method on the Seekoei River can be found in Chapter 5.

6.2.2 *Discussion of Phases 3 to 7: Desktop application*

The main purpose of the first part of the methodology is to develop an understanding of a particular river system, its users and the most important issues specific to the river and its use. This understanding is then used to divide the river into homogenous units to guide site-selection and specialist studies, to select suitable indicators for the river, to decide on the specific specialist fields needed, and to guide the selection of realistic and relevant scenarios for the catchment.

Three aspects of this part of the methodology presented the team with problems, namely delineating the river (or catchment) into homogenous units, simulating the hydrology for the chosen scenarios and determining the PES for the driving and responding indicators.

6.2.2.1. *Delineation of homogenous river units*

Background

The value of using GIS as a tool to access and integrate existing information sources to develop an understanding of catchments for which information is limited, is clear. If this information could be linked with the data produced by the hydrological analyses and the assessment of the condition of the instream and riparian habitats, it could be even more valuable as a basis for site-selection and specialists studies. The new method, therefore, proposes the use of CRUs.

CRUs are delineated by superimposing the Runoff Potential Units (RPUs), similar to hydrological units that are based on soil type, slope, infiltration rate, vegetation cover, rainfall intensity and flow accumulation, with information from the hydrological models and Habitat Integrity Assessment (see Activity 9). The CRUs can therefore be described as response units that are relatively homogenous in geomorphological characteristics, hydrology, anthropogenic impacts and habitat types. These units could be used to identify high risk areas where the system is under stress, for example where added development could alter river integrity the most, or pristine areas that might contain critical habitat for biota. This would enable the team to select study sites in these critical river sections.

The need for a more integrated approach became evident as the study on the Seekoei River progressed. River delineation in the Seekoei River was mainly based on its longitudinal profile, to produce geomorphologically distinct segments called macro-reaches, and did not consider hydrological data or river condition. As a result, the team only realised later in the project that the hydrological record for the Seekoei (measured at DH015 located in sub-catchment D32J) only reflects flow conditions for about 20 km directly upstream of the gauging weir and not the rest of the catchment.

Problems experienced with the delineation of CRUs

RPUs were created for the Seekoei River (see for example Figure 5.5). The team was, however, unable to superimpose the hydrological data on these units to form CRUs. This was mainly due to an incompatibility of scale – hydrological models makes use of quaternary catchments which are not compatible with the fifth order basin level used for RPU delineation. Even though quaternary catchments do not follow natural catchment boundaries and do not give a true reflection of natural catchment processes (Barker, pers. comm.; also see Figure 8 in Appendix A), the data needed to set up the hydrological models are based on these quaternary catchments. Further research is therefore needed to investigate how fifth order basins could be linked to the hydrological models.

The 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 (2007), and time might prove that these should be harmonized into one concept and one term.

6.2.2.2. *Hydrological modeling*

Background

The hydrological modeling for the study was carried out by Prof. Denis Hughes as a consultancy project funded by the WRC, and a separate report (WRC Report no.K8/679) was produced. The report explains in detail the conceptual model developed for the catchment, how the continuous models (Pitman monthly model and the daily VTI model) used to simulate hydrological data for the Seekoei River were set up and calibrated, the use of simple flood routing models to produce information on flood events, as well as, the development of a simple water quality model. It also discusses the usefulness of the applied models for producing simulated data for the chosen scenarios. These discussions, which mainly relate to the specialist field of hydrology, will not be repeated here. The following discussion would rather focus on the instances where modeling limitations influenced method application.

The new method proposes that the project hydrologist, under Phase 3 (see Figure 4.2), first develops a conceptual model of the main catchment processes before a hydrological model is set up (Activity 7). This model is used later in Phase 6 to simulate data for the three hydrological indicators (Connectivity of surface water, Channel maintenance floods and Sediment delivery) for each of the scenarios chosen for the catchment (Activity 16). In Phase 9 the simulated data produced for the three indicators are used as a point of departure, or driving values, for the analysis of the scenarios (Activity 23).

Problems experienced with producing simulation hydrological data for the hydrological indicators

For the Seekoei River, simulated data were produced for only two of the three hydrological indicators, namely surface water connectivity (for sites EWR1, 2 and 3 & 4) and channel maintenance floods (only for EWR3 & 4; see discussion under Activity 16 in Chapter 5). No simulated data on the delivery of sediment from the catchment to the river channel could be produced by the hydrological models used.

Many uncertainties associated with the results produced by the hydrological model existed. These uncertainties were, to a large extent, related to the fact that most of the real observations were taken from the gauging station situated at the outlet of the catchment, while substantial spatial differences in the hydrological processes existed in the catchment. It was, therefore, impossible to verify the results produced by the model for quaternary catchments in the upper and middle parts of the Seekoei River.

Hydrological modelling for the high flow component was done in a parallel modelling exercise using the Nash-Muskingum routing mode (see Hughes, 2008). The areal reduction factor in the model was set to generate results at the outlet of sub-catchment

D32J in order to be consistent with the observed flow data at D3H015. Simulated data on channel maintenance floods were accordingly only available for sites EWR 3 and 4. Modelling was further only done for two of the four scenarios, namely present (Scenario 1) and natural (Scenario 2) conditions.

The failure to produce simulated data for one of the three driving indicators and only partly for the second, presented the team with a major obstacle. In order to proceed with method application, the gaps were filled with approximations made by the team at the Scenario Workshop (see Table 5.21 in Chapter 5). It is clear that the development of a model to supply information on the delivery of sediment in non-perennial river systems is a priority in the further development of the prototype method.

Problems experienced with the selection of scenarios

Another problem, related to the simulation of the river's hydrology, was the selection of suitable scenarios. Because this study was not done in reaction to a water use application, three hypothetical scenarios were initially selected for the catchment to test the method. The results produced by the hydrological models for these scenarios, however, proved to be very unsatisfactory in that the models did not appear to be sensitive enough to reflect small changes in catchment conditions. Other problems that curtailed hydrological simulation were:

- The fact that most of the runoff observed at the gauging station is generated in quaternary catchment D32J at the lower end of the catchment, and that this quaternary catchment was unlikely to be subjected to a great deal of development.
- The uncertainties that exist with regards to the processes associated with a deterioration of land use in the catchment, lacking observed data.
- Difficulties with converting land use changes into model parameter changes, especially due to the fact most of the catchment is fairly flat and sparsely vegetated.
- The low gradient that prevails in the majority of the Seekoei catchment, lessening the effect of impacts resulting from land use change. Impacts from land use change may have a more profound impact in steeper catchments.
- The fact that the flood regime is already very variable (as for most systems in semi-arid regions), making it difficult to predict and interpret additional change.
- Increased abstraction from boreholes was not expected to have a large impact on the water levels of in-stream pools (unless it was quite intensive and close to the river channel) as the ground water contributes little water to the pools.

- The highly variable distribution patterns and robust generalist nature of the aquatic biota which made it very difficult to predict biotic responses to small changes in pool dynamics.
- The fact that most disciplines collected field data at a smaller spatial scale than the quaternary catchment level used in hydrological modelling, and that these data were not temporally representative due to the short period of sampling. Improved results could be obtained for EWAs if the different disciplines could collect data at the same level of resolution.

To proceed with method application, the team decided to modify some of the existing scenarios in order to magnify the expected impacts and to add two alternative scenarios (see discussion under Activity 15 in Chapter 5).

Further comments on the hydrological models used for the Seekoei River

Simulated hydrological data for the chosen scenarios form the basis of any EWR methodology to predict the ecological and socio-economic effects of physical modifications of the catchment that will affect flow volumes and patterns. For the Seekoei catchment, the hydrological model was based on estimated rainfall and runoff as measured flow data were not available for the upper and middle parts of the catchment. Some of the members of the physical team did not agree with the assumptions made in the hydrological models set up for the Seekoei catchment, and were uncomfortable with models that do not take actual measured flow into account. It was also suggested that the hydrological model would greatly benefit from including a wider range of factors, such as soil permeability.

The consensus was, however, that whatever measurements or lack thereof, or level of accuracy of a model, a predictive model is necessary as a basis from which to predict ecological and socio-economic effects of the hydrology. Therefore the hydrological model could be changed or its accuracy improved, while the methodology (not the accuracy) of the subsequent stages would remain the same – merely the input would change. As the hydrological input improves, the accuracy of the methodologies using the information would improve, but the methodologies could remain the same.

What did, however, came from the study was the development of a conceptual model of the hydrological processes by the combined effort of the geohydrologist and the surface hydrologist. This conceptual understanding proved to be extremely valuable in the setting up the hydrological models for the Seekoei River, so much so, that Hughes (2008) concludes that:

"the usefulness of models rather depend upon how well the hydrological impacts of the scenarios can be conceptualised. This emphasises the need for a sound conceptual

understanding of the hydrology of ephemeral systems, from both surface and groundwater points of view."

6.2.2.3. *Determination of the Present Ecological State (PES) for indicators*

Background

In order to predict how indicators would react to future hydrological and catchment changes, specialists need to understand the present condition of those indicators (specialists need to understand in what condition the indicator is at present). This understanding is usually based on data collected from the river using standard methods (acceptable to each discipline) during field surveys, as well as previous experience in that or similar systems (which is especially valuable for interpreting the acquired data). Specialists are therefore required to make a decision on the present ecological state (PES) of each of the biophysical and socio-economic indicators selected for the river, based on the results of their specialist studies.

Problems experienced with the determination of the PES for indicators

In the perennial Reserve Determination process the PES for each indicator (or river component) is determined by comparing its present condition to its reference of natural condition (see Step 3 in Figure 4.1). The PES is expressed as an Ecological Category between "A" to "F" where "A" represents "close to natural" and "F" "critically modified". If a change in the ecological state has been observed, the possible causes, as well as the trend of the change, are also indicated (Kleynhans and Louw, 2008). A number of index models based on a Multi Criteria Decision Making Approach (e.g. Hydrological Driver Assessment Index, HAI; Geomorphology Driver Assessment Index, GAI; Physico-chemical Driver Assessment Index, PAI; Fish Response Assessment Index, FRAI; Macro Invertebrate Response Assessment Index, MIRAI; Riparian Vegetation Response Assessment Index, VEGRAI) have recently been developed for this purpose (see Kleynhans and Louw, 2008 for more information on the models). The suite of models has, however, not been applied to the Seekoei River due to the following reasons:

- A different set of driving indicators were selected for the Seekoei, namely Connectivity, Channel maintenance floods and Sediment delivery, compared to Hydrology, Geomorphology and Water quality used as driving indicators for perennial rivers.
- Workable versions of the proposed indices, with the exception of the FRAI, MIRAI and VEGRAI[22] were not yet available for application on the Seekoei River.

[22] The final versions of the FRAI, MIRAI and VEGRAI were published towards the end of 2008.

- Difficulties with setting reference conditions for river components in the absence of recent and historical information.
- The FRAI, MIRAI and VEGRAI were not ideally suited for use in the Seekoei River and have been applied with modifications (see specialist chapters on fish, macroinvertebrates and riparian vegetation, respectively, for further discussion).

A modified approach, described in detail under Activity 18 in Chapter 5, was followed for the Seekoei River. For the driving indicators, simulated data for the present and natural conditions were compared and expressed as a percentage of change. This percentage was then put into a generic ecological PES class (Kleynhans, 1996 and 1999; see Table 4.4) using the table of change ratings (Table 4.5). Where simulated data were lacking, for example Sediment delivery, estimates were used. For the biological indicators, PES classes were mainly determined by expert opinion, supported by field data and historical data where available.

This is an area that needs further investigation and development, as it would be ideal to have a standard method or set of rules by which the PES for each indicator could be determined. Each of the proposed Multi Criteria Decision Making Approach models should therefore be evaluated for use on non-perennial rivers by the relevant disciplines as they become available.

6.2.3 *Discussion of Phase 8-10: Workshop application*

Phases 8 to 10 would usually be carried out at a workshop, referred to as a Scenario workshop, attended by the full team. The main purpose of these phases is to use the understanding and knowledge of the specialists to predict how changes to a river's hydrology, as implied by the chosen scenarios, would change the status of the biophysical and socio-economic indicators selected for the catchment, and to try to describe the extent of these changes. These predictions can then be used by the decision-making authority (or Society at large) to better understand the impacts their decisions regarding future development could have on the river and its users. For the Seekoei River study, this part of the method was applied at a five-day workshop held in Bloemfontein from 10 to 14 March 2008.

Three main tasks were completed at the Scenario workshop and is reported on in Chapter 5: first the team members' knowledge were captured into an ecosystem model and the links between the ecosystem components described (Phase 8), second the selected scenarios were analysed by considering how the responding indicators would change in reaction to changes in the driving indicators (Phase 9) and third the overall shift in ecological condition of the river were summarised and evaluated for the various scenarios (Phase 10).

Overall, the team were very satisfied with the results produced by the method and how well the method reflected their intuitive knowledge of the system. The team encountered some problems during the evaluation of the scenarios as a result of their decision not to use integrity Response Curves and a number of interim or bridging rules were made to address the problem (see Chapter 5, Activity 21). A number of steps would also need further development, such as the development of suitable software to capture the information contained in the Response Curves electronically.

A short discussion on each of the main tasks is given below.

6.2.3.1. *Capturing expert knowledge and creating Response Curves (Phase 8)*

Background

Phase 8 of the proposed method provides a way in which the specialists' knowledge of a river, based not only on the data collected during their field studies, but also on previous experience of working in similar systems, can be used to develop a conceptual model of the river ecosystem under study (Activity 15). The conceptual model represents a summary of the team's understanding of how the various physical, biological and socio-economic indicators relate to each other. These relationships or interactions can then be described by means of Response Curves (Activity 16). The Response Curves can be used to predict how responding indicators could react to changes in the driving indicators, and ultimately, how the river could change under certain scenarios. The information and assumptions contained in the Response Curves are quite valuable for systems lacking long term or historical data, and can be tested in subsequent studies. Ideally, this information should be captured and stored in an electronic database (Activity 17).

Comments on the application of Phase 8

The steps (or Activities) under Phase 8 have been successfully completed for the Seekoei River. A flow-diagram showing all possible links between the driving and responding indicators identified for the river was prepared (presented in Figures 5.18-5.20) and Response Curves created for each of the links indicated (see Appendix F for Response Curves). The Response Curves prepared for the Seekoei River used Present Day conditions as a starting point due to uncertainties of what the river looked like under natural conditions (see discussion under Activity 21 in Chapter 5).

The team decided, at the start of the Scenario workshop, to prepare Response Curves for abundances, area or concentrations only, using ratings of changes (see Table 4.5) to quantify the predicted changes – mainly to avoid unnecessary complications during the first trial run of the method. No Response Curves indicating changes in ecosystem integrity were therefore drawn for the Seekoei River and the direction of change was indicated as "away" or "towards" the natural condition of the river. This presented the team with a number of difficulties later on in the study when the scenarios were evaluated. The specifics of these problems and the measures taken to overcome them are discussed in section 6.2.3.3. It is, however, recommended that Response Curves predicting changes in ecosystem integrity rather be used in future studies.

Future development

For the Seekoei River, information on the shape of each Response Curve was captured in a Microsoft Excel spreadsheet. Considering that method development (for non-perennial rivers) was in a very early stage, the study did not attempt to create automated scenarios such as those used by e.g. DRIFT (King et al., 2004; see discussion under Activity 22 in Chapter 5). The understanding is that the development or adoption of an appropriate scenario-creation tool would follow in future.

6.2.3.2. *Scenario analysis and interpreting change in driving indicators as response in all other indicators (Phase 9)*

Background

During this phase the changes predicted for the driving indicators, as described for the chosen scenarios, are interpreted for the responding indicators. The output of the hydrological analysis for the three driving indicators, Connectivity, Floods and Sediment delivery, becomes the driving values to read off the expected (predicted) change from the Response Curves prepared for the responding indicators (Activities 23 and 24). Where more than one indicator feeds into another, their combined influence has to be determined so that a single value can be used as the driving value for the next responding indicator (Activity 25).

Problems experienced with application of Phase 9

In the application of these steps, the team was challenged first by the lack of simulated hydrological data for Sediment delivery and Floods, and second by finding a way to accurately calculate the combined influence of indicators on a responding indicator (in cases where more than one indicator could act as a driver).

The fact that the hydrological model developed for the Seekoei River could not simulate hydrological data on Sediment delivery and only partly for Floods, have been discussed earlier in the chapter (see 6.2.2.2). This was addressed by replacing the missing data with approximations for each chosen scenario (presented in Table 5.21 and discussed under Activity 23 in Chapter 5) in order to proceed with method application. As stated in Section 6.2.2.2, this is an urgent matter that needs to be resolved in the next phase of the project.

For the Seekoei River study, specialists were not at first limited in the number of drivers they could list as having an influence on a specific responding indicator (see discussion under Activity 25 in Chapter 5). This however became problematic when the team needed to determine the combined effect of the listed drivers to provide one final value for the responding indicator. (This final value was needed as an input to obtain a Response Curve value for the subsequent indicator). The final value was calculated as the sum of the products of the Response Curve values (see Column 3, Table 5.22) and the weightings rescaled to 1 (Column 6, Table 5.22). As we progressed down the list of indicators, it became clear that the number of drivers affected the final value in that the final values for responding indicators were lower if they had more, rather than fewer, drivers. This resulted in a situation where the final values for some of the responding indicators lower down became so diluted, that it became difficult to interpret them by means of the Ratings of Change table (Table 4.5). Using these small numbers to obtain Response Curve values for subsequent indicators was problematic in that most response values were less than 1, resulting in rather meaningless answers.

The team noted this as an important problem to be considered in the next phase of the project. As interim measures they decided to:

- Reduce the number of drivers for each responding indicator (see Activity 25, Chapter 5 for further discussion). The number of drivers selected for each site was reduced, leaving only the ones that best describe the functionality of non-perennial systems (motivations for these decisions are listed in Appendix G). It was further decided not to set a limit on the number of drivers for the present study, but this is a matter that should be investigated in future.
- Stick with the straight weighted sum for the present study. Although it is true that more drivers would dilute the overall effect, it should still reflect what the system of drivers and indicators set up is saying.

6.2.3.3. *Evaluating the scenarios in terms of ecological condition (Phase 10)*

Background

In Phase 10 the final values, indicating the severity or extent of the change predicted for each indicator, are considered together with the direction of change to provide an estimate of the overall shift in ecological condition of the ecosystem for each scenario. For these final evaluations or predictions, rules similar to those used in DRIFT (Brown and Joubert, 2003; rules are listed under Activity 26 in Chapter 4 and discussed under Phase 10 in Chapter 5) were applied, except that change was described as either toward or away from Present day.

Problems experienced with the application of Phase 10

The fact that "abundance Response Curves", and not Response Curves of ecosystem integrity, were prepared for the Seekoei had three important implications for the final evaluations of the scenario. First, this implied that we ended up with both positive and negative Response Curve ratings which could cancel each other out in certain instances. Second, determining the direction of change was complicated by the fact that we had both toward (Ts) and away (As) ratings in one column. Third, these two problems made it very difficult to apply the 85% rules of Brown and Joubert (2003).

The problems were addressed for the interim by:

- Cancelling out the positive and negative ratings (response curve values) of equal value, only considering the remaining ratings to determine if a class change occurred.
- Cancelling out the Ts and As of equal (or as close to equal as possible) value and then using the remaining ratings to determine the final direction of change.

These problems would, however, be resolved by using integrity curves in future applications of the method.

6.2.4 *Concluding remarks on method application*

The prototype methodology, which was developed towards the end of this project, was applied in two steps on the Seekoei River. In the first step Phases 8 to 10 were applied at a Scenario workshop in March 2008 in Bloemfontein, while the application of Phases 3 to 7 followed thereafter. Phases 3 to 7 were applied at a desktop level using the results obtained from the study. These applications were evaluated and reported on in Chapter 6.

Overall, the team were very satisfied with the results produced by the method and how well the method reflected their intuitive knowledge of the system. It is however clear from this evaluation that there are some important foundational steps which were not completed satisfactorily and that would need rethinking and/or further development. The most important of these are:

- Finding a way to link the hydrological model/s to 5th order basins in order to allow the delineation of the catchment into Combined Response Units.
- Developing a model that can provide data on Sediment delivery.
- Assessing the suitability of the suite of Multi Criteria Decision Making Approaches proposed in Kleynhans and Louw (2008) for determining the PES of the corresponding indicators (between perennial and non-perennial methods) in non-perennial rivers and to develop new approaches where new indicators have been introduced e.g. Connectivity, Pools, etc.
- Formalise the selection of drivers for each responding indicators and finding a way to integrate the values of these drivers into one final value for the responding indicator.

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CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

In accordance with the study's overarching aim, a prototype methodology for determining the Environmental Water Requirements for non-perennial rivers was developed. The proposed methodology, as it stands now, resembles a comprehensive approach comprising 11 Phases and 28 Activities. It acknowledges and captures (reflects) the most essential characteristics of non-perennial rivers and 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. While some of the method's features are similar to those used in e.g. DRIFT (King et al., 2004) and other South African methods (e.g. Ecoclassification, see Kleynhans and Louw, 2008), it has some unique features e.g. the comprehensive GIS/landscape-based approach to identify integrated units of analysis on which site-selection is based and the fact that change is described from present conditions due to difficulties in setting reference conditions in non-perennial systems.

The key features of the method:

- The prototype method clearly places an important emphasis on creating an understanding of the nature of the river and its catchment. The method makes provision for a small core team to use available data and information on the physical catchment, together with the issues and concerns pointed out by stakeholders, to develop a preliminary basic understanding of catchment processes which will inform and guide subsequent project planning.
- Another important feature of the method is that information on the catchment as a whole, as opposed to the river channel only, is considered in river delineation. It aims to integrate the Runoff Potential Units (RPUs; homogenous units based on soil type, catchment slope, infiltration rate, vegetation cover, rainfall intensity and flow accumulation) with the outcome of the hydrological analysis and the Habitat Integrity Assessment (based on the method of Kleynhans et al., 2008) in order to create Combined Response Units (CRUs), which will serve as a basis for site-selection and specialist studies.
- The proposed method uses a number of generic attributes, referred to as indicators, which can be used to describe change in the river and its catchment, such that they would be sensitive to water level and other changes in the

catchment. Based on the Seekoei River study, three driving and 15 responding indicators have been proposed. The method, however, makes provision that any of the indicators can be de-activated where not relevant. Indicators can also be added if needed.

- The proposed approach also provides an unbiased way to capture the knowledge, experience and wisdom of specialists by means of Response Curves. These curves can then be used, in a structured way, to predict how the river would change in response to certain scenarios or flow management options.
- The method further recognizes the particularly important role that stakeholders could play in EWAs for non-perennial rivers. There is often very little information and data available on these rivers and their users. Involving the stakeholders from early on in the assessment provides a mechanism to obtain information on the past and present nature and uses of the river, and to identify issues and concerns that should be reflected in the scenarios considered for the catchment.

Once method development had been completed towards the end of the study, it was tested on the Seekoei River, an ephemeral tributary of the Orange River. Overall, the team was very satisfied with the results produced by the method and how well the method reflected their intuitive knowledge of the system. A number of foundational steps could, however, not be completed satisfactorily and further development of these steps is needed. The most important of these are:

- Finding a way to link the hydrological model/s to 5th order basins in order to allow the delineation of the catchment into Combined Response Units.
- Developing a model that can provide data on sediment delivery.
- Assessing the suitability of the suite of Multi Criteria Decision Making Approaches proposed in Kleynhans and Louw (2008) for determining the PES of the corresponding indicators (between perennial and non-perennial methods) in non-perennial rivers and to develop new approaches where new indicators have been introduced e.g. Connectivity, Pools, etc.
- Formalising the process of selecting drivers for each responding indicator and finding a way to integrate the values of these drivers into one final value for the responding indicator.

7.2 The way forward

The next step is to verify the prototype methodology on a range of non-perennial systems. The extent to which the methodology, which has been developed on the Seekoei, is universally applicable is unknown. It needs to be tested in other non-perennial systems in order to separate the factors specific to the Seekoei from those generally applicable. Further, it is necessary to understand the variability of systems, which would affect the applicability of the methodology.

In a follow-up study which has been approved by the WRC, the methodology will be tested on three suitable systems in different parts of the country. Ideally, appropriate information will be collected at well-chosen sites for each system, followed by method application. A final assessment would ideally give us a methodology, or rather a set of methodologies, which would then be available for universal application and refinement.

Monitoring of the Seekoei River will continue, at the same time in a parallel phase, albeit at reduced intensity, in order to pick up longer-term variability in the system.

7.3 Suggestions and concerns

- Look into standardizing the general terminology. While Uys and O'Keeffe (1997) proposed a new terminology in an effort to standardize the terminology of temporary rivers in South Africa, we have proposed different categories.
- The lack of skills in certain areas/disciplines needs to be addressed. Some of the specialists are just so in demand that they are fully booked and difficult to get to play a role in a project.
- The huge importance of long term data needs to be stressed. Preservation and expansion of such data is vital.
- The response curves which this study has hypothesised require testing in order to establish confidence in them.
- A workshop should be organised where hydrologists, geohydrologists and geomorphologists from the wider scientific community could discuss the problems experienced with hydrological modelling in non-perennial rivers.

7.4 References

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APPENDICES

Appendix A: 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 5 km 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 Hartbeeshoek '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 (~90 m 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 50 m was used but this can safely be reduced to 20 m (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 / Land use			**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**

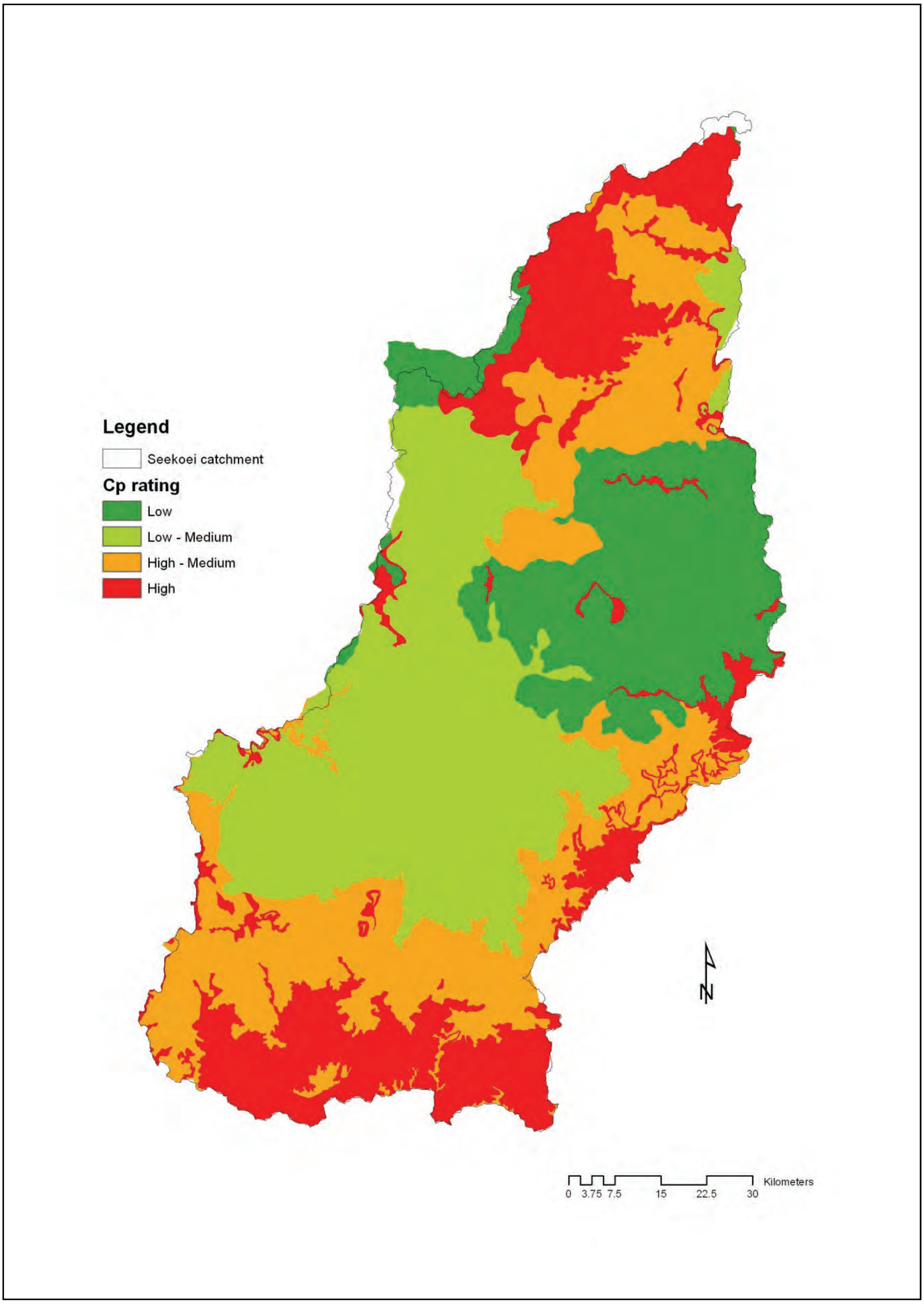

Figure 1 Runoff Potential Rating for landtypes

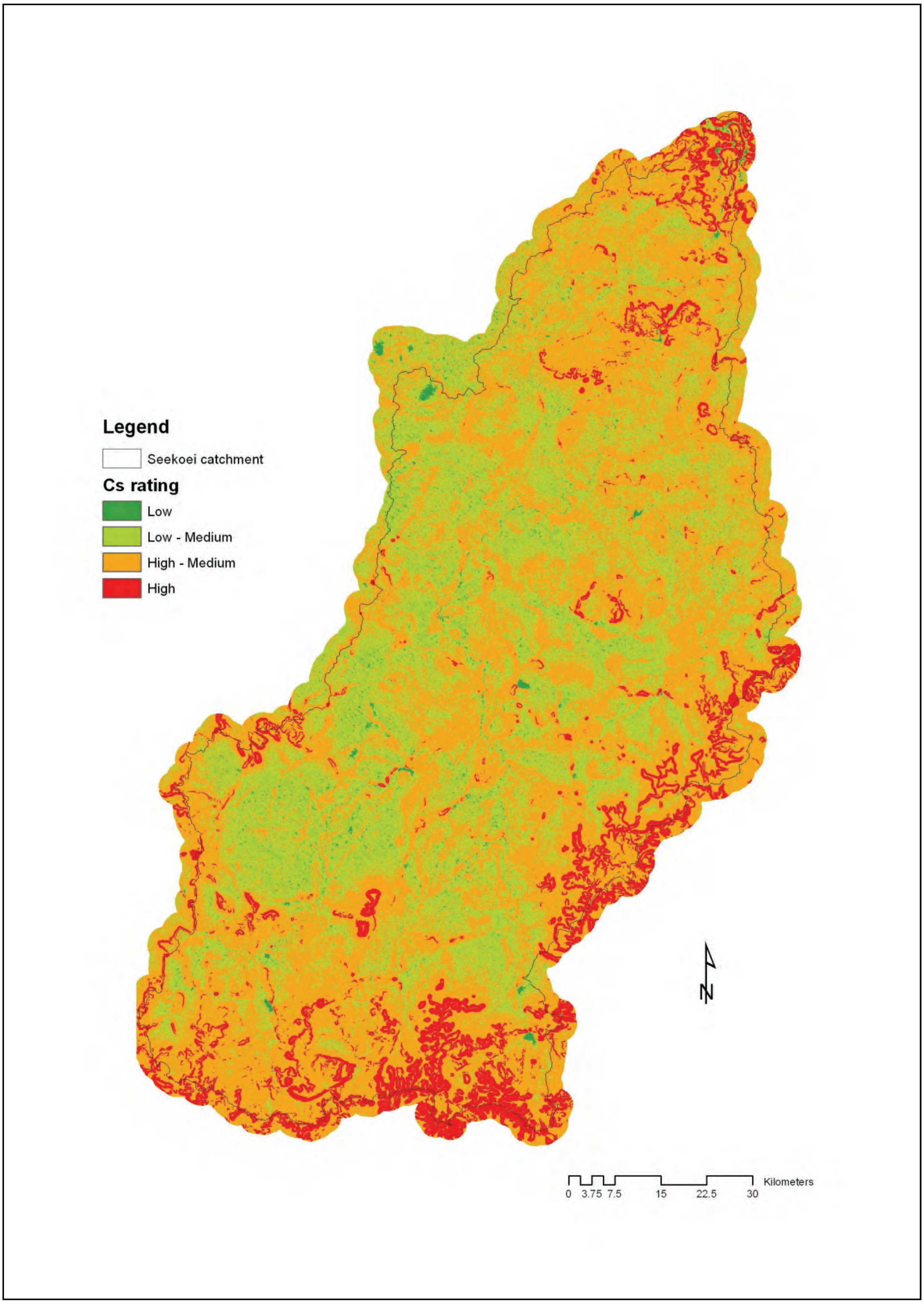

Figure 2 Runoff Potential Rating for Slope

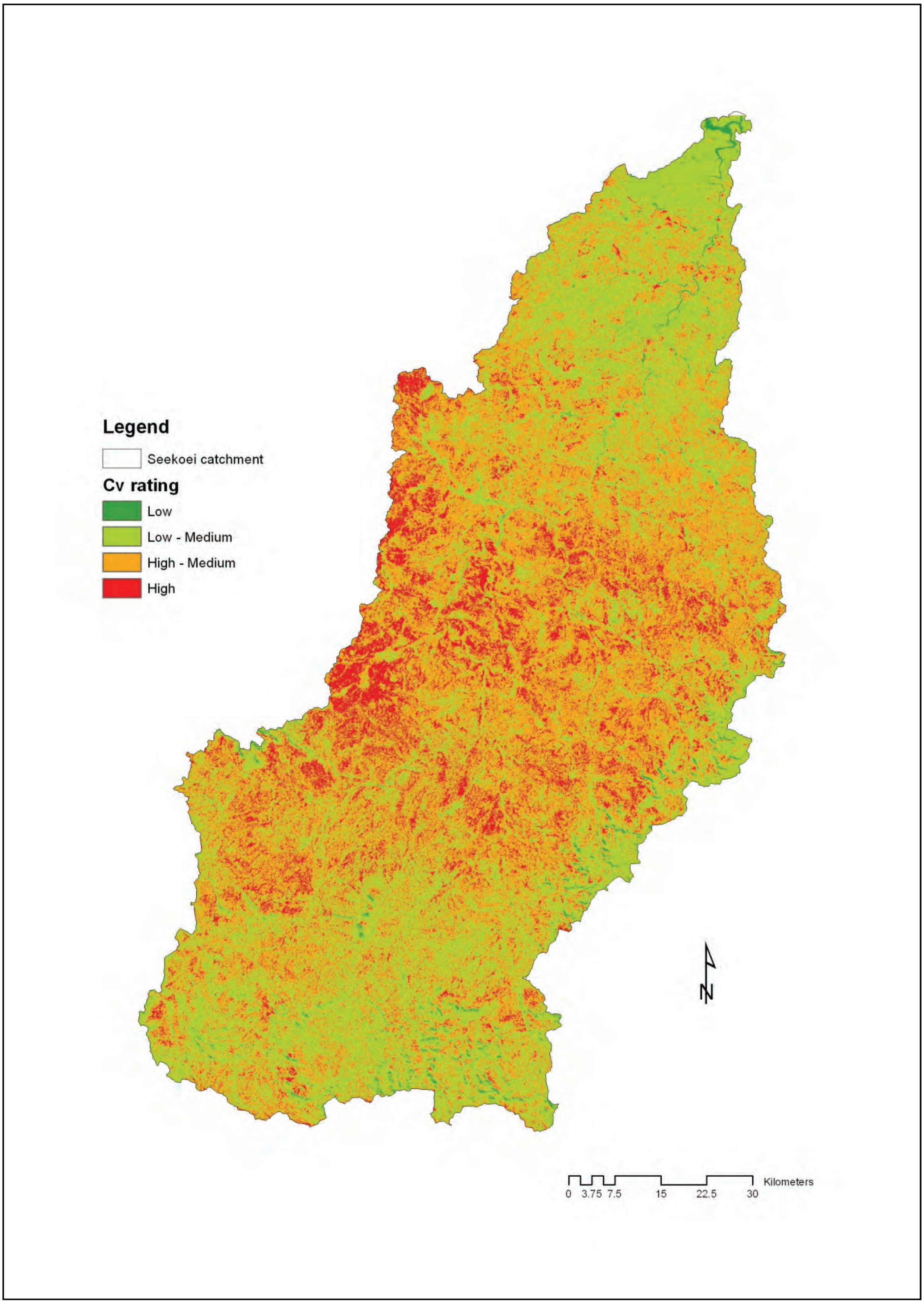

Figure 3 Runoff Potential Rating for Vegetation

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).

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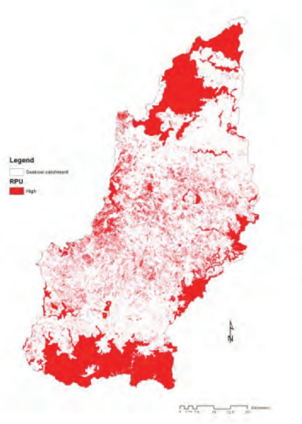


Figure 4 High RPUs

Figure 5 High to Medium RPUs

Figure 6 Medium to Low RPUs

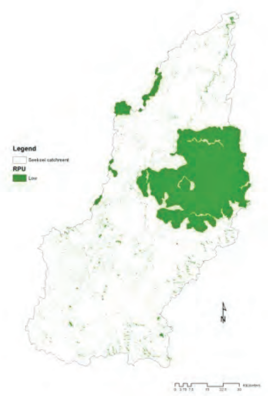


Figure 7 Low RPUs

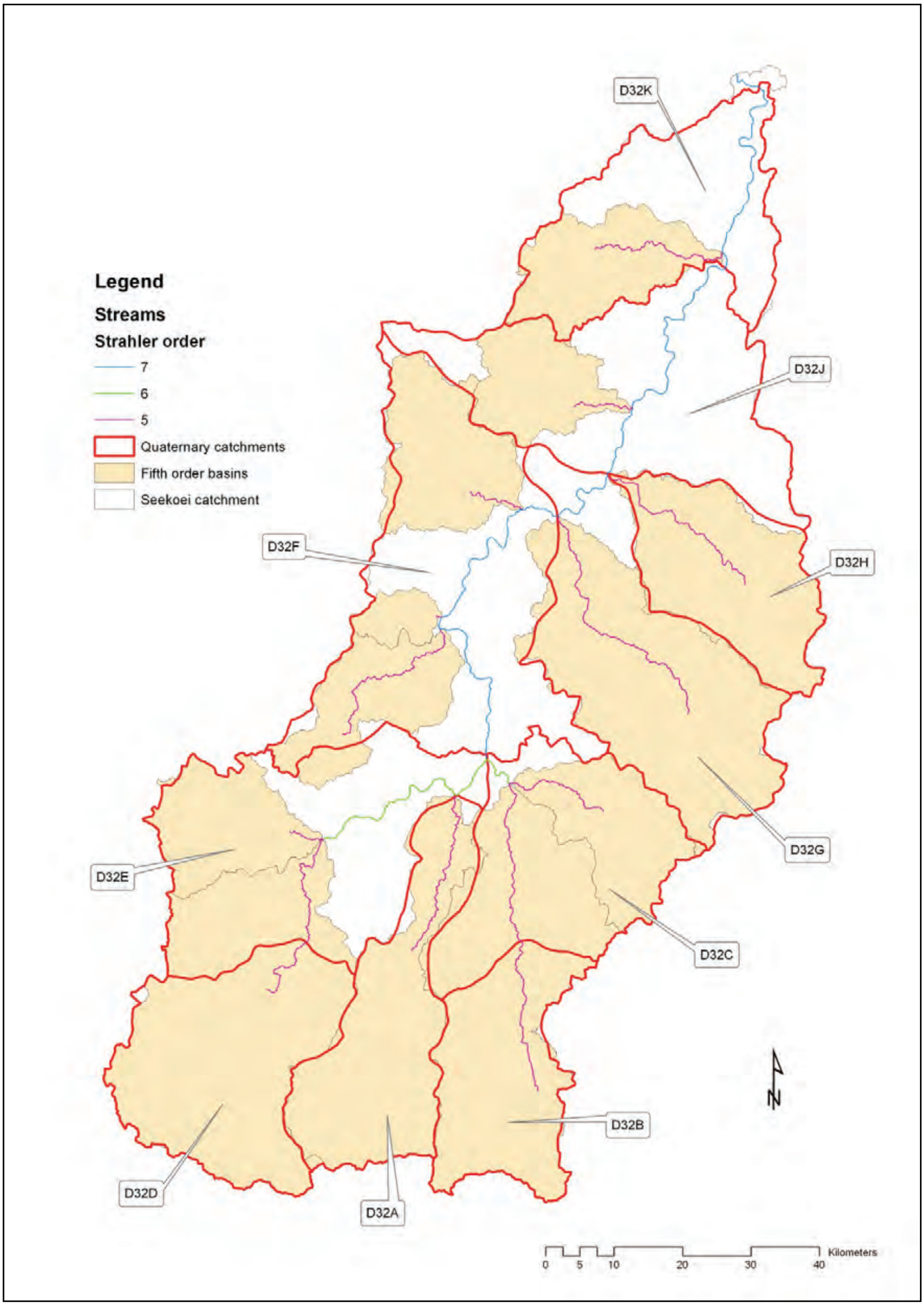


Figure 8 Fifth order basins in the Seekoei Catchment

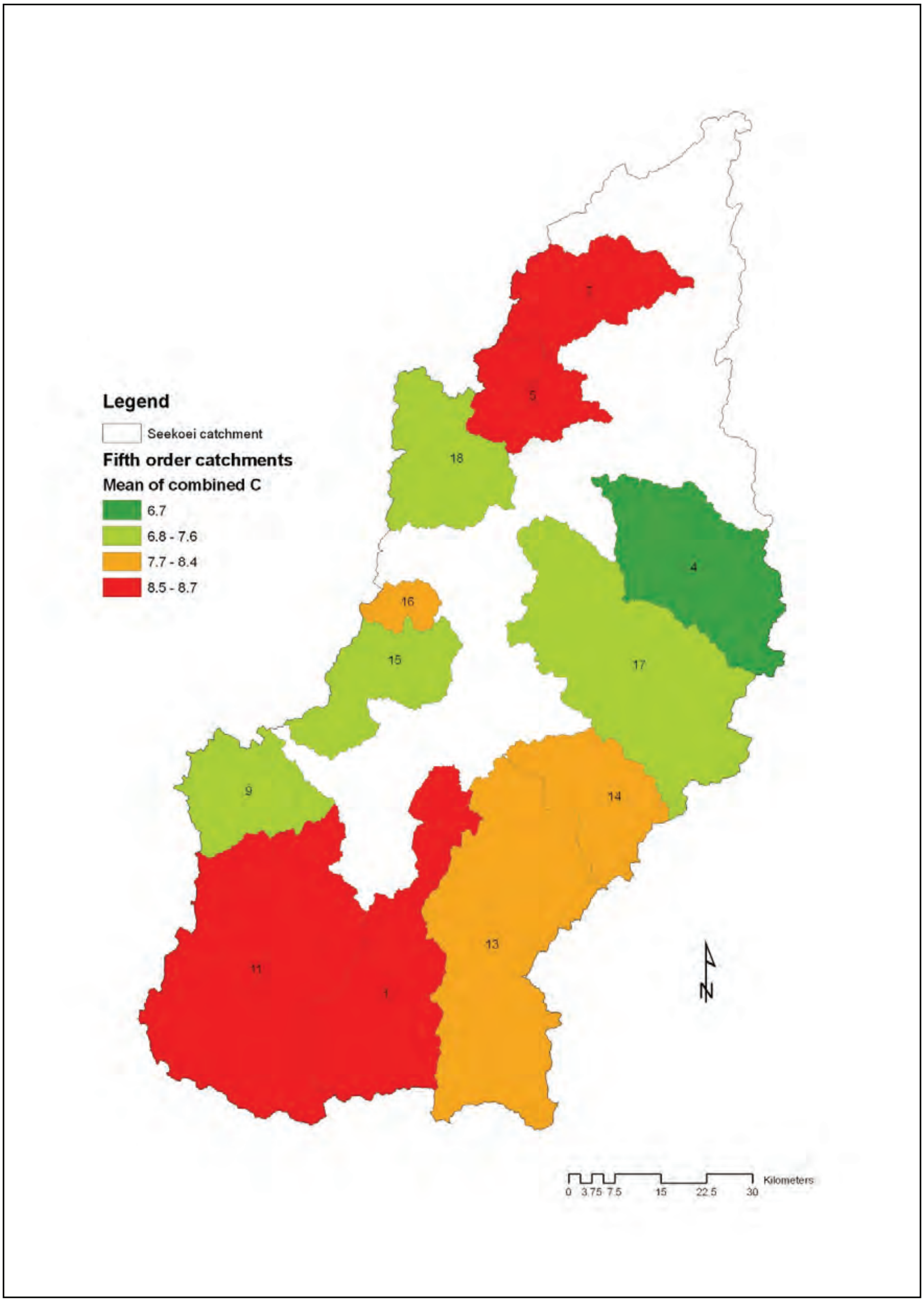


Figure 9 Extracted combined (Cs, Cv and Cp) rating for C per fifth order catchment

Appendix B: The identification of 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 (e.g. 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 C: 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 HBH-94

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:

<table>
<tr><td colspan="5" rowspan="2">Location and Landowner Detail:</td><td colspan="3">Contact No.:</td></tr>
<tr><td>Notify Owner?</td><td>yes</td><td>no</td></tr>
<tr><td>Permit Required?</td><td>yes</td><td>no</td><td colspan="5">Details:</td></tr>
<tr><td>Key Needed?</td><td>yes</td><td>no</td><td colspan="5">Details:</td></tr>
<tr><td colspan="4">Farm Name:</td><td colspan="4">Farm Reg. Code:</td></tr>
<tr><td colspan="8">Comments:</td></tr>
</table>

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).

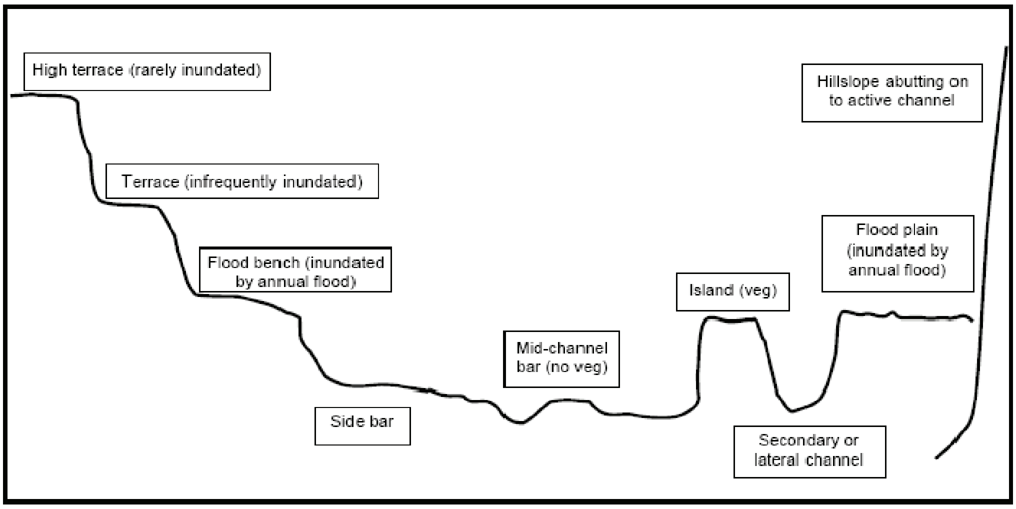
CRITERION	Score	Level of confidence (H,M,L)	Comment
INSTREAM			
Water abstraction (presence of pumps, irrigation etc.)			
Extent of inundation			
Water quality (clarity, odour, presence of macrophytes etc.)			
Flow modifications			
Bed modification (bulldozing of bed)			
Channel modification			
Presence 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	

Appendix D: Advantages and disadvantages of sampling sites selected for the Seekoei River.

Site	Advantages	Disadvantages
EWR 1	Representative of the river macro-reach – alluvial, meandering channel with isolated pools.	Accessibility may be a problem as the road does not go right up to the river. This could mean carrying heavy equipment for approximately 500 m to the river's edge.
	Site relatively natural with few upstream disturbances.	Some cattle trampling present. Some cattle drinking from the pool.
	No formal abstraction evident.	Site is not in close proximity of a gauging weir.
		No rural community present in the river section, only commercial farmers.
Suitability for macro-invertebrate sampling	Pool (water column), Marginal vegetation out of current (MVOOC), Silt, sand and mud biotopes are present. Marginal vegetation in current (MVIC) will be present during flow periods.	Biotopes present are very uniform – MVOOC only reeds, but this is so for most of river and is therefore representative.
		No stones in current (SIC), stones out of current (SOOC) or Aquatic Vegetation (AV) present.
Suitability for fish sampling	Habitat representative of fish habitat of reach.	Very low habitat diversity at time of site-visit (only slow shallow habitat). Fish cover mainly provided by overhanging vegetation.
	Habitat amenable to electro-shocking. Based on the available habitat, this method should be sufficient.	Seine-netting not likely possible.
	Site not in close vicinity of flow limiting structures.	
EWR2	Good accessibility	Pool is silting up probably due to the reeds.
	Representative of reach	Situated downstream of gauging weir D3H001. Due to high silt load recorders silted up, only 7 years of flow records1911-1918 available (Stëyn, 2005)
	Pool is relatively natural – formed by a hydraulic control downstream.	No rural community present in the river section, only commercial farmers.

	No formal abstraction	Sheep drinking
	Some gravel in current habitat could be present during flow.	
Suitability for macro-invertebrate sampling	Biotopes present – MVOOC, Pool and sand (DRG – wet mud where water has retracted). MVIC when flowing.	No SIC, SOOC present but this is representative of river reach.
		MVOOC very uniform – only reeds. The prolific growth of reeds is unnatural.
Suitability for fish sampling	Habitat representative of fish habitat of reach.	Very low habitat diversity at time of site-visit (only slow shallow & slow deep habitat). Fish cover mainly provided by overhanging vegetation.
	Habitat amenable to electro-shocking. Based on the available habitat, this method should be sufficient.	Seine-netting not likely possible.
		Site ± 2 km downstream of large weir.
EWR3	Site situated upstream of gauging station D3H015. Good flow records for 25 years (Stëyn, 2005).	Accessibility – relatively far from where vehicles can be parked
	Representative of river reach – steeper valley slope, incisions into bedrock and dolerite which create pool/rapid channel type (Dollar, 2005).	No rural community present in the river section, only commercial farmers.
Suitability for macro-invertebrate sampling	Biotopes present are MVOOC, AVOOC, Pool, and DRG.	
	Vegetation diverse – not only reeds but some Aquatic vegetation as well as tree roots, etc.	
	Very little disturbance – only cattle drinking	
	Possibly SIC, SOOC available during flow.	
	Sand bottom type pool with deep and shallow habitats.	
Suitability for fish sampling	Habitat representative of fish habitat of reach.	Very low habitat diversity at time of site-visit (only slow shallow & slow deep habitat).
	Large persisting pool[23] habitat with diverse fish cover.	Site ± 3 km upstream of weir.
	Habitat amenable to electro-	

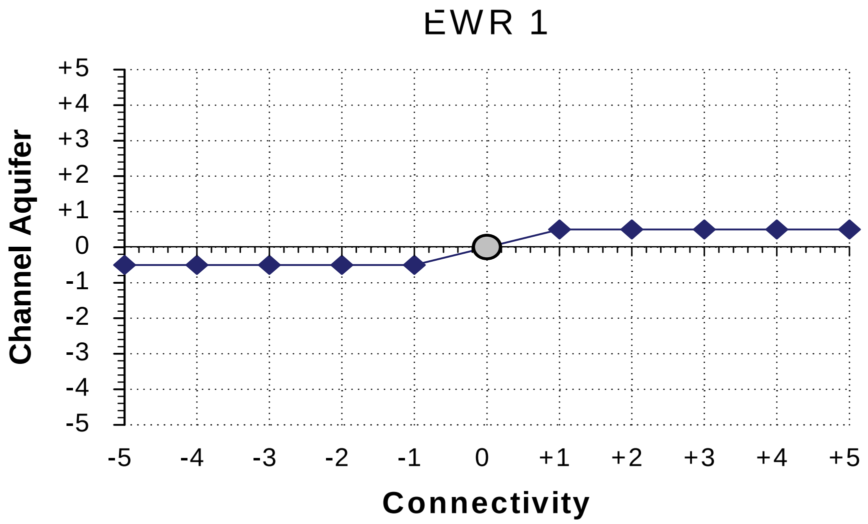
[23] The pool became totally dry in December, 2005 resulting in fish kills (A. Venter, pers. Comm.)

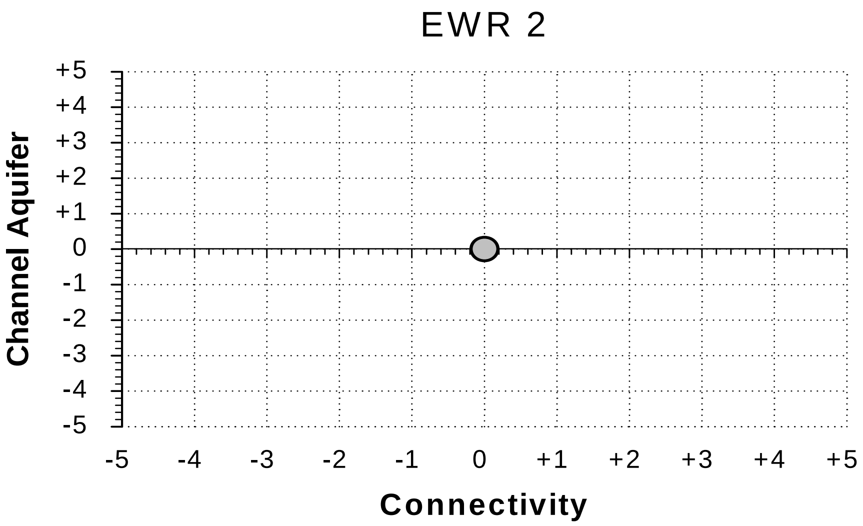
	shocking and seine-netting.	
EWR 4	Representative of reach – bedrock bottom type pool	Accessibility difficult due to distance from place where vehicles can be parked.
	Site situated upstream of gauging station D3H015. Good flow records for 25 years (Stëyn, 2005).	No rural community present in the river section.
Suitability for macroinvertebrate sampling	Biotopes available – MVOOC, AVOOC, Bedrock pool and DRG.	
	Vegetation diverse – not only reeds but Aquatic vegetation, tree roots, etc.	
	Pool with shallow and deep habitats.	
	SIC and MVIC possibly available during flow	
Suitability for fish sampling	Persistent pool habitat.	Only 2 flow-depth classes present at time of site-visit (slow shallow & slow deep habitat).
	High abundance of instream fish cover.	It will be difficult to get fish sampling equipment to river.
	Habitat amenable to electro-shocking.	Site ± 1 km downstream of large weir.

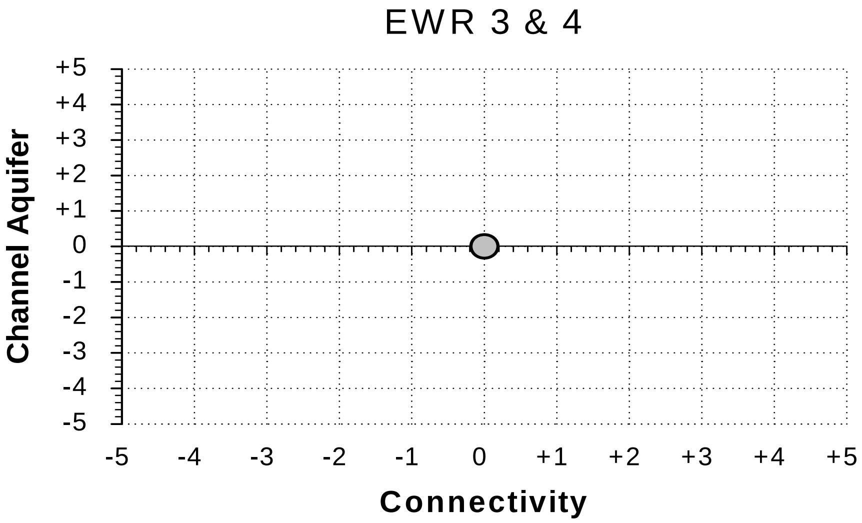
Appendix E: A summary of the links identified for each indicator for the Seekoei River.

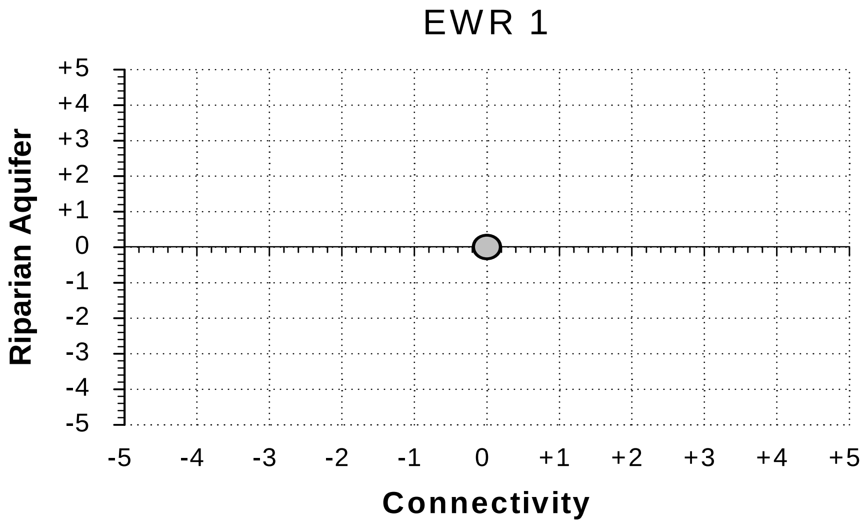
Response / Driver	Channel aquifer	Riparian aquifer	Pools	Water Quality (EC)	Aquatic/ marginal vegetation cover	Riparian vegetation cover	No. of important invertebrate species	Abundance pest invertebrates	Status of indigenous fish	Status of exotic fish	Terrestrial wildlife	Contribution to parent river	Social wellbeing	Socio-economics
Connectivity	X	X	X	X	X	X	X	X	X	X			X	X
Channel maintenance floods		X	X	X	X	X	X	X	X	X		X	X	X
Sediment delivery			X	X	X	X	X	X	X	X			X	X
Pools	X			X	X	X	X	X	X	X	X		X	X
Channel aquifer			X	X	X	X							X	X
Riparian aquifer				X	X	X							X	X
Water Quality (EC)					X		X	X	X	X	X		X	X
Aquatic/ marginal vegetation cover							X	X	X	X			X	X
Riparian vegetation cover									X	X	X		X	X
No. of important invertebrate species									X	X			X	X
Abundance pest invertebrates									X	X			X	X
Status indigenous fish												X	X	X
Status of exotic fish												X	X	X
Terrestrial wildlife													X	X
Contribution to parent river														
Social wellbeing														
Socio-economics														

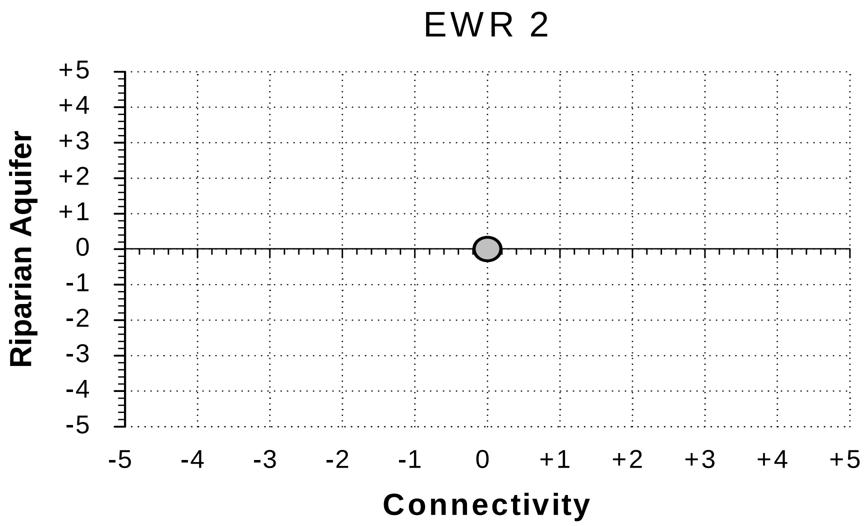
Appendix F: Response curves

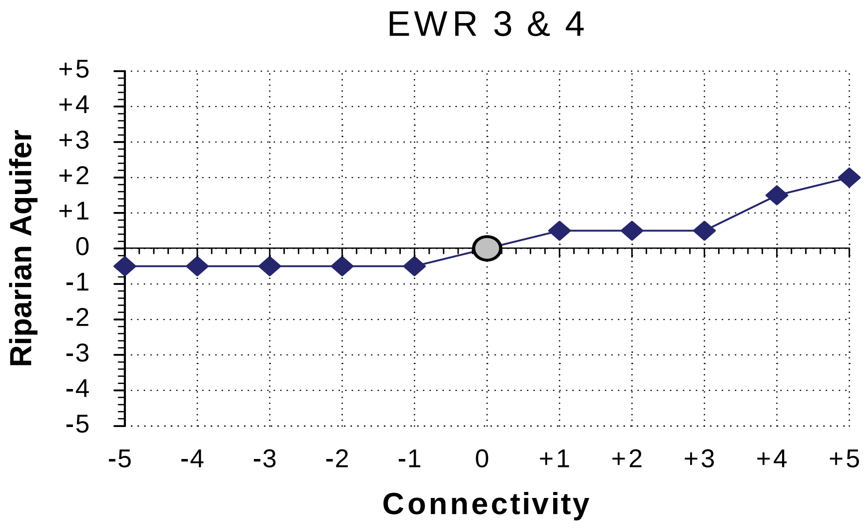


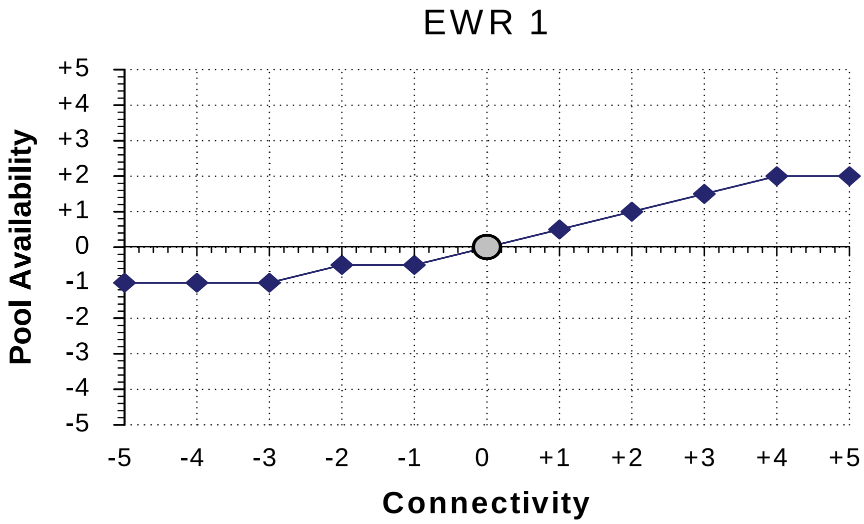


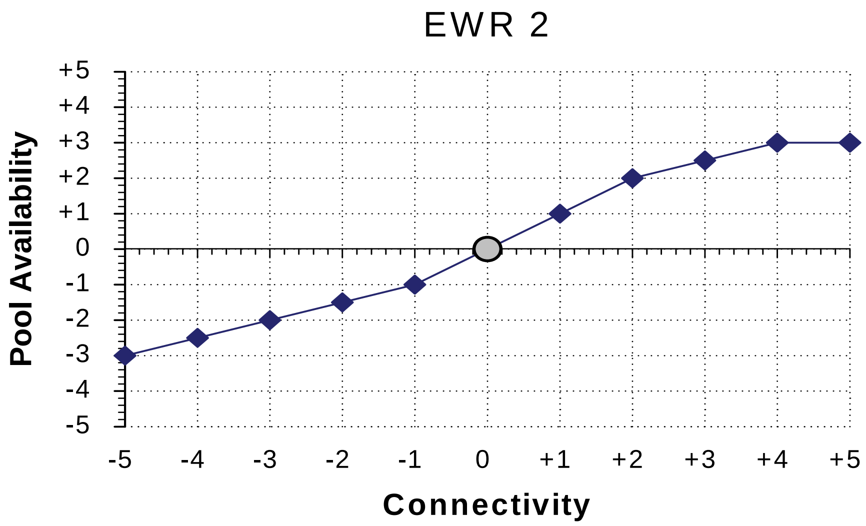


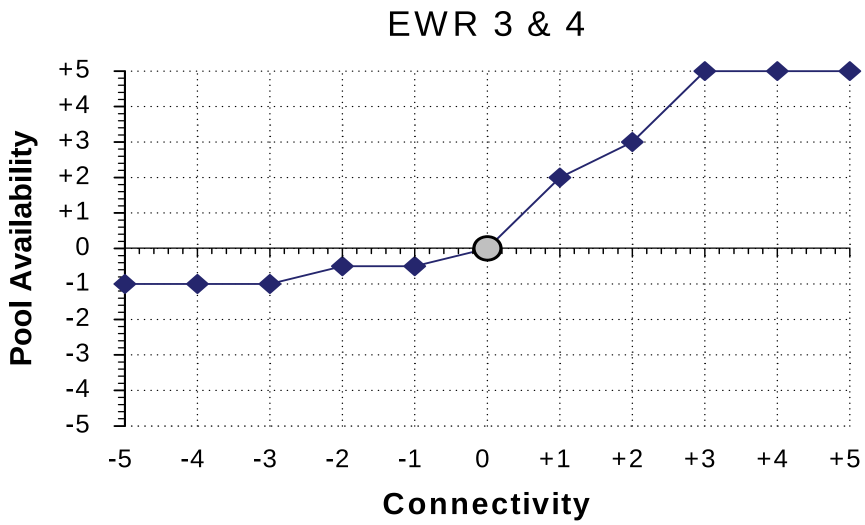

EWR 1
Riparian Aquifer
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity


EWR 2
Riparian Aquifer
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

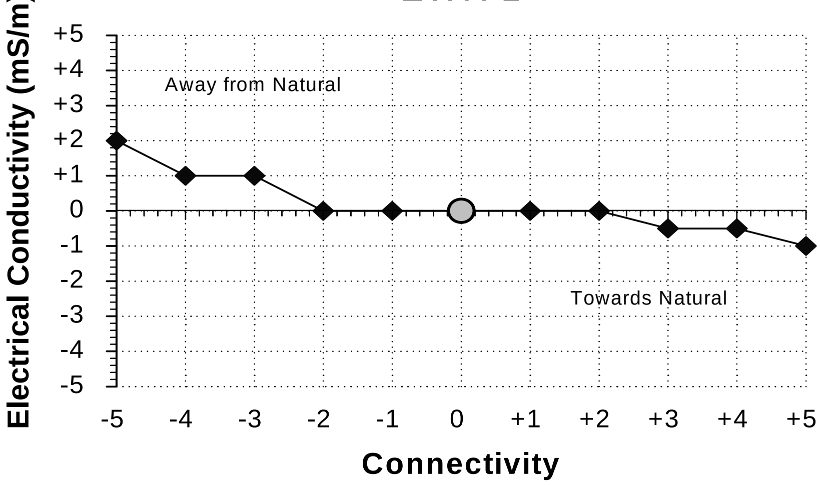

EWR 3 & 4
Riparian Aquifer
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity


EWR 1
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

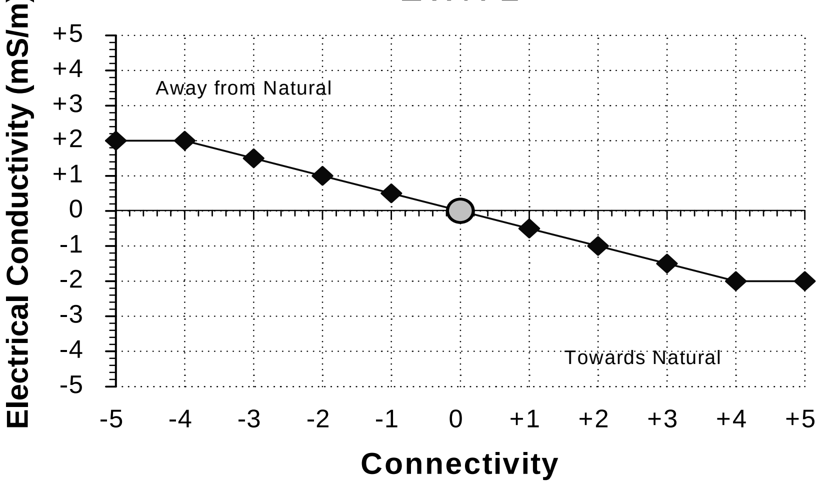

EWR 2
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity


EWR 3 & 4
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

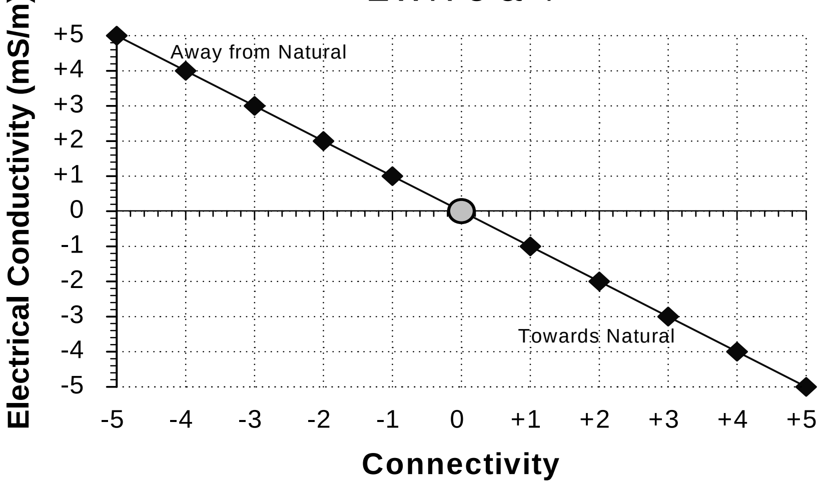
EWR 1

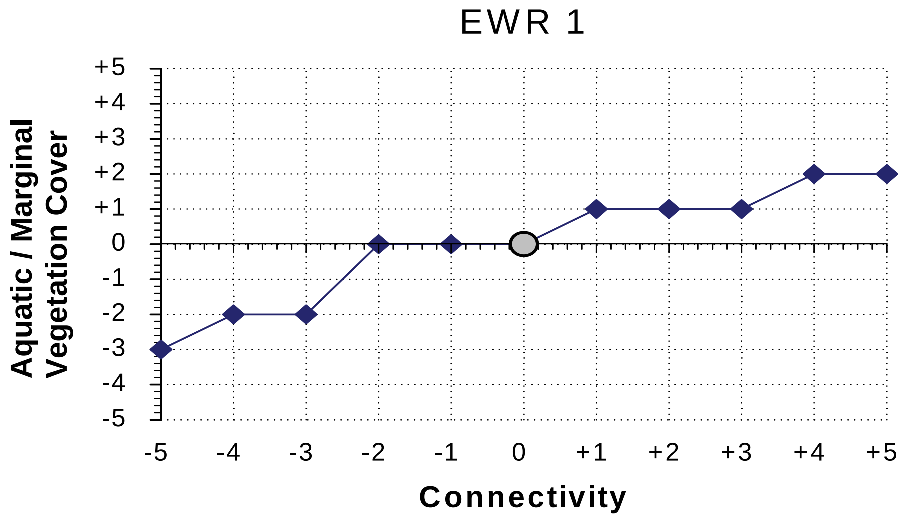


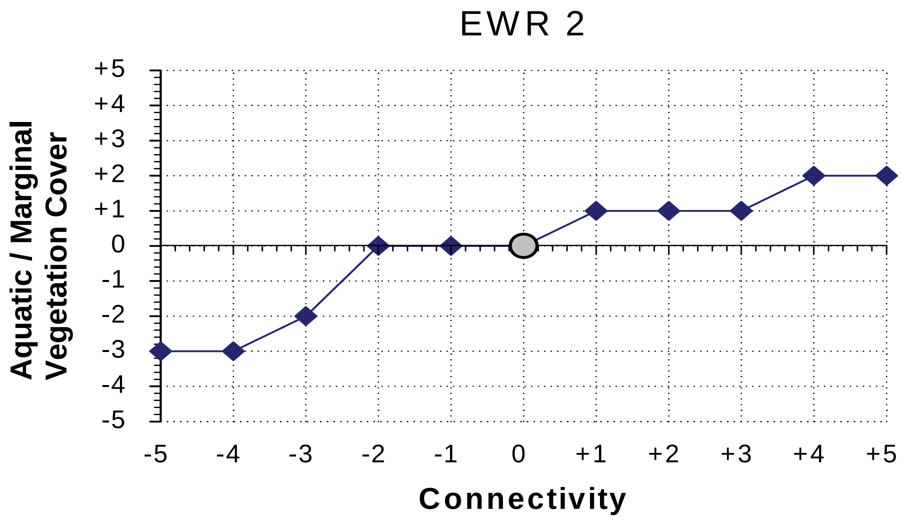
EWR 2

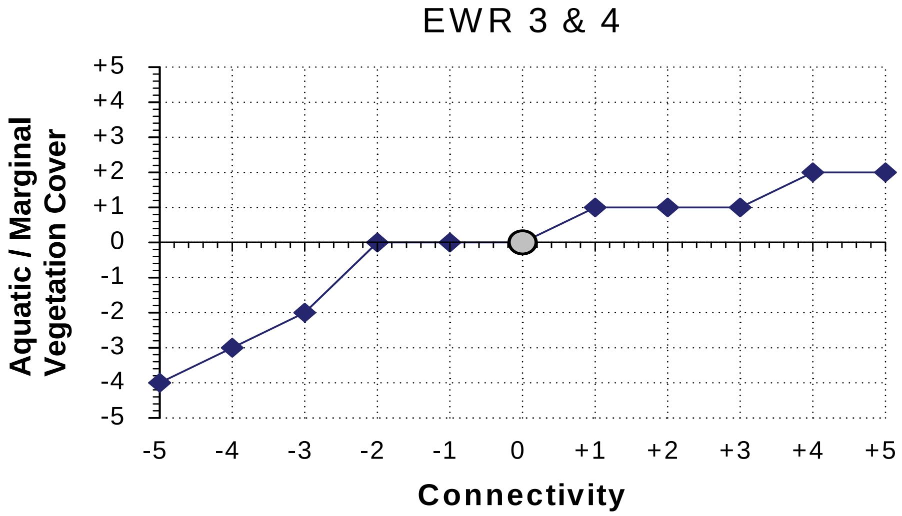


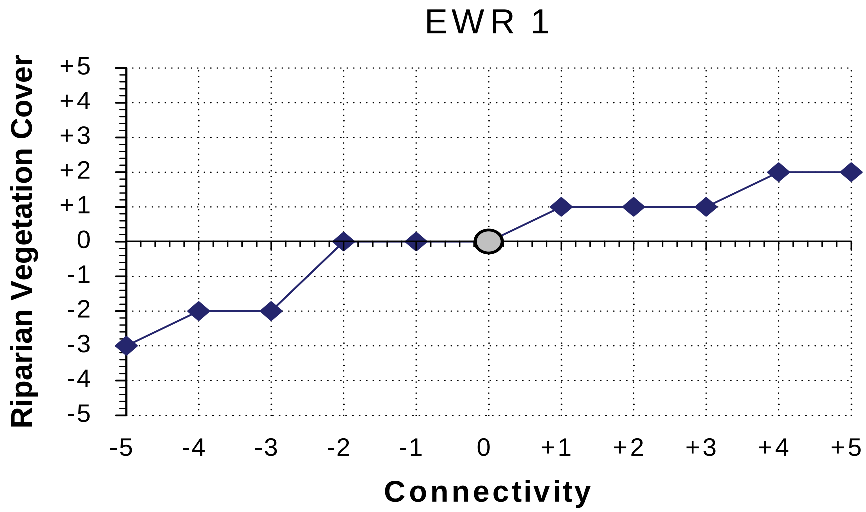
EWR 3 & 4

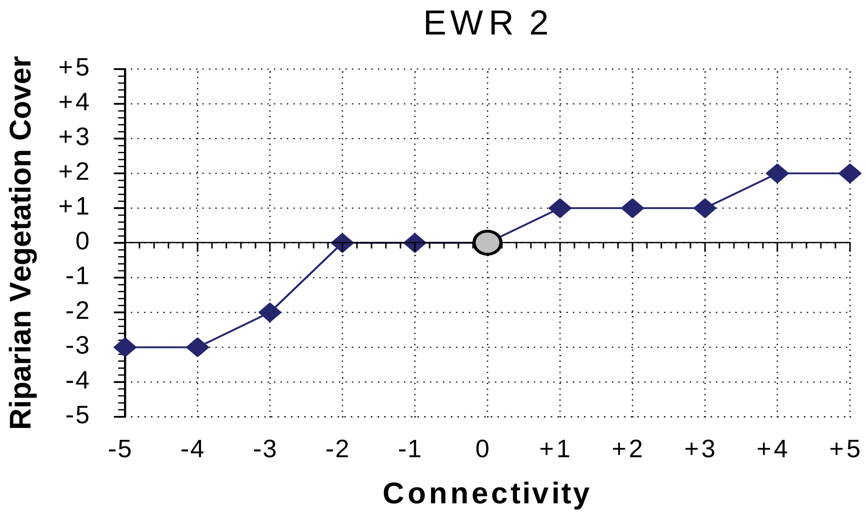


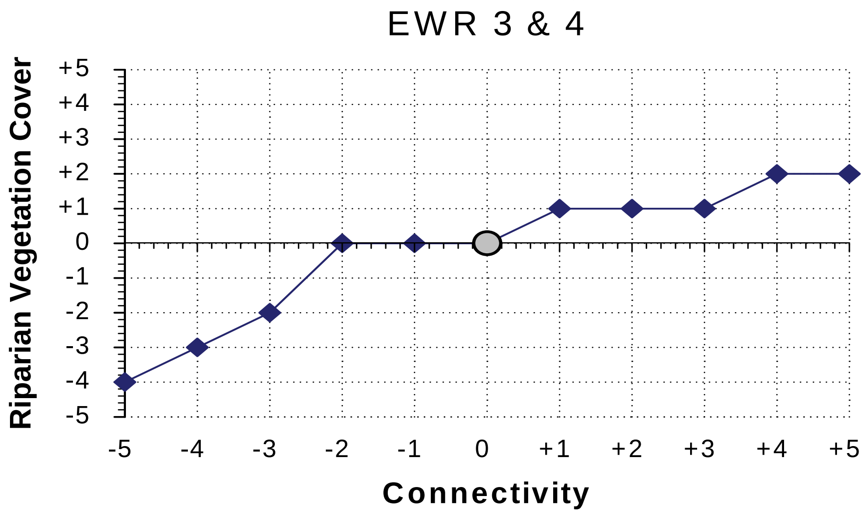

EWR 1
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

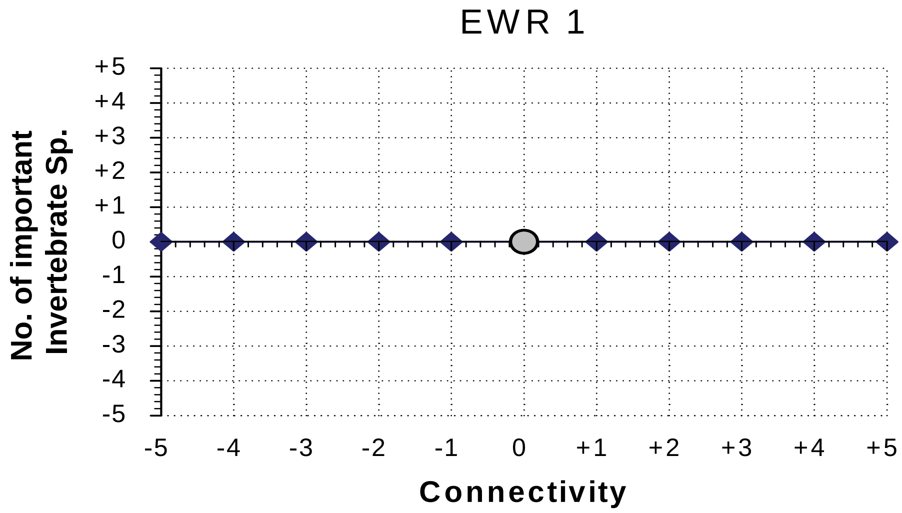

EWR 2
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

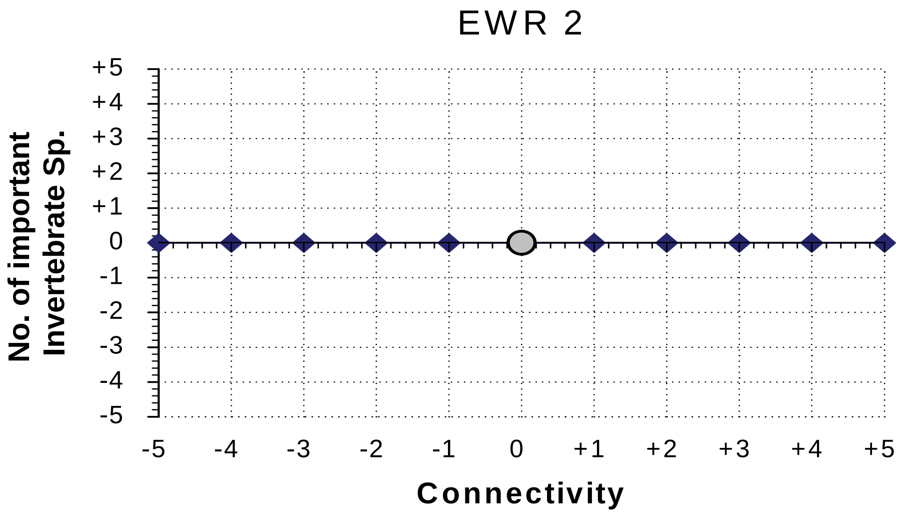

EWR 3 & 4
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

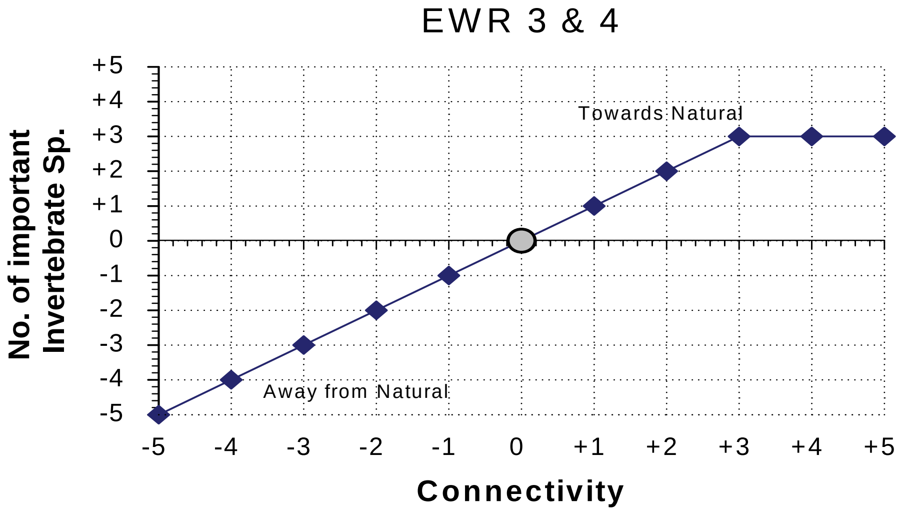

EWR 1
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

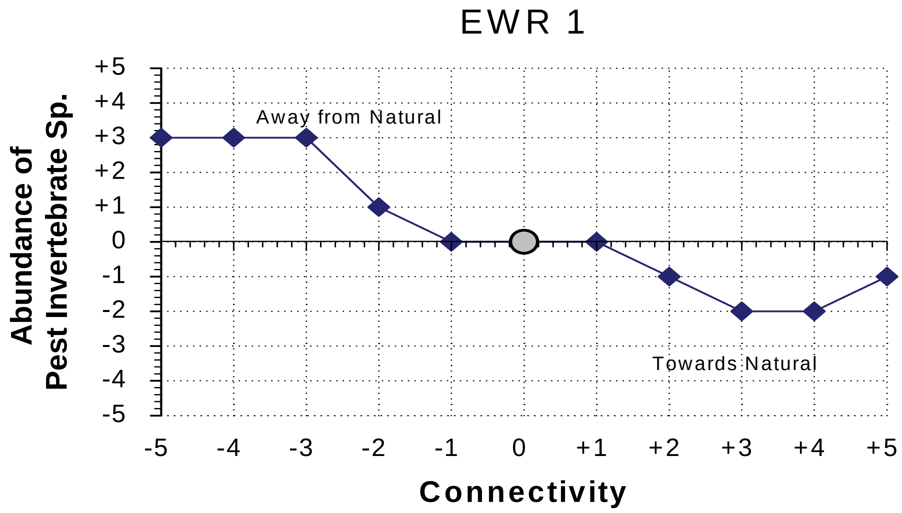

EWR 2
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

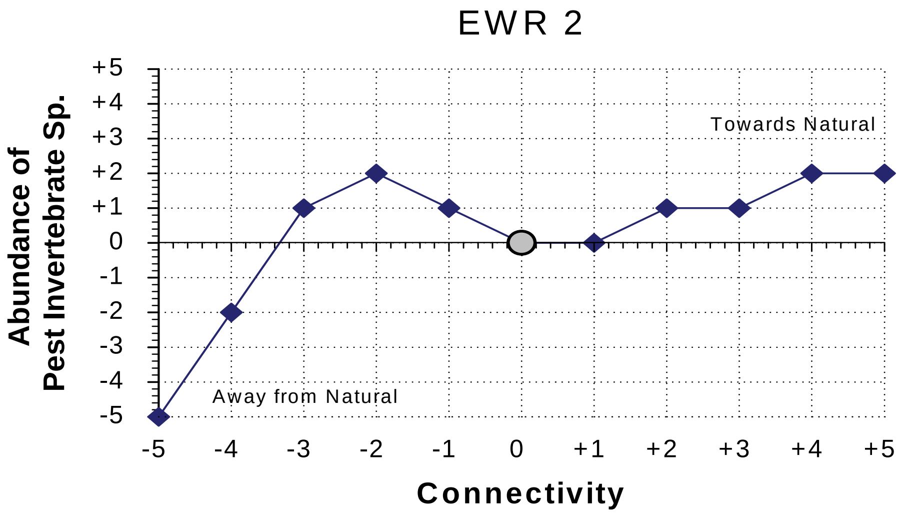

EWR 3 & 4
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

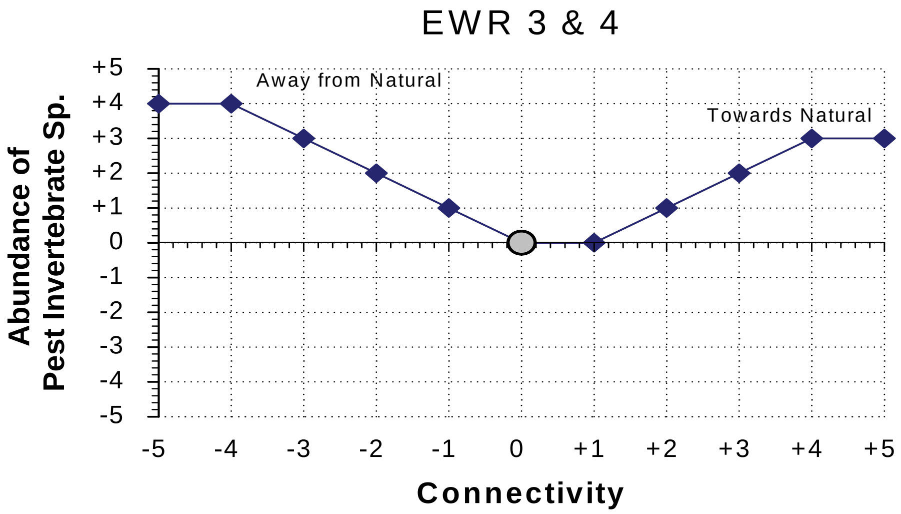

EWR 1
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

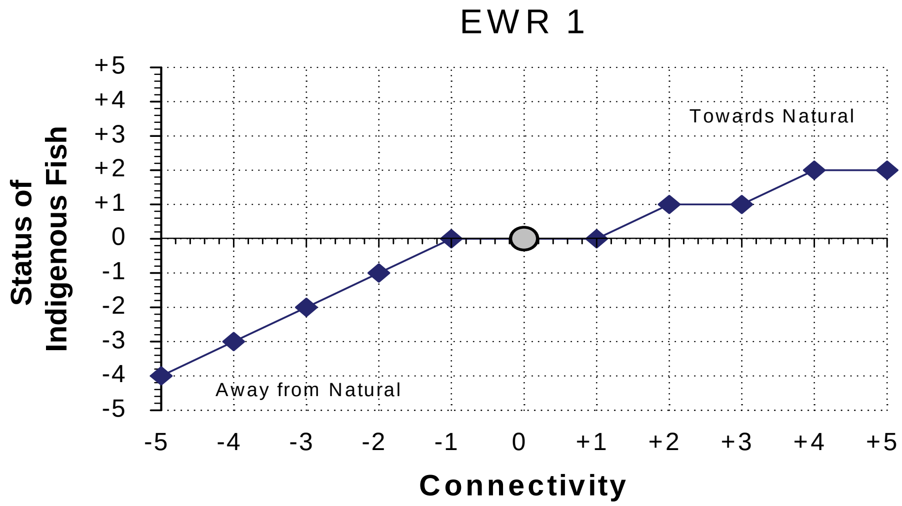

EWR 2
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

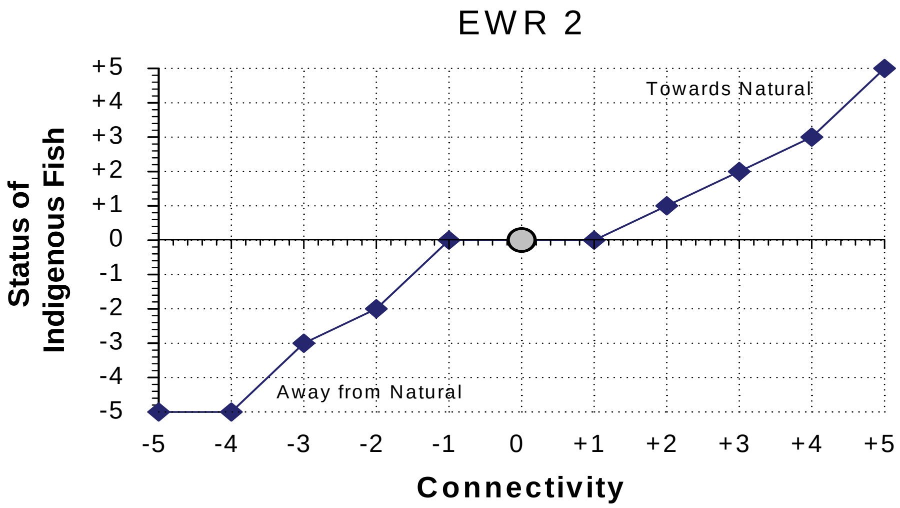

EWR 3 & 4
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

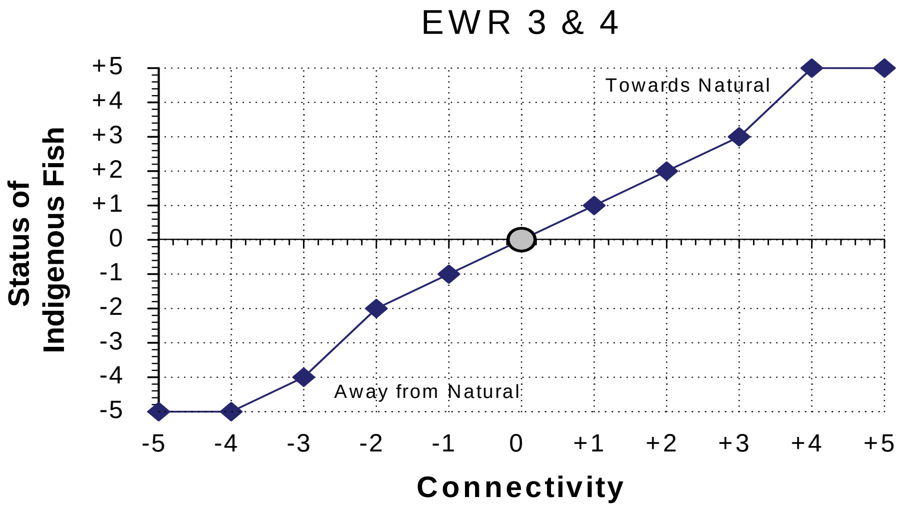

EWR 1
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

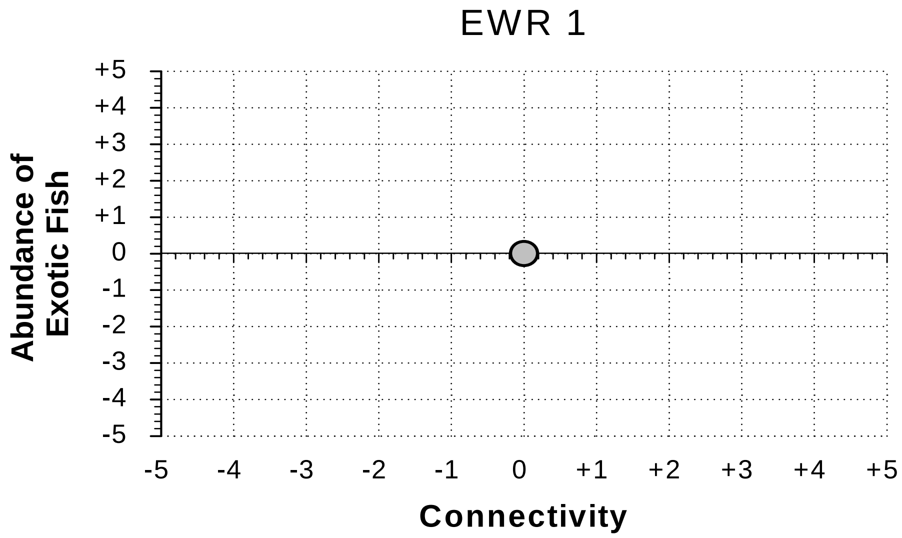

EWR 2
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

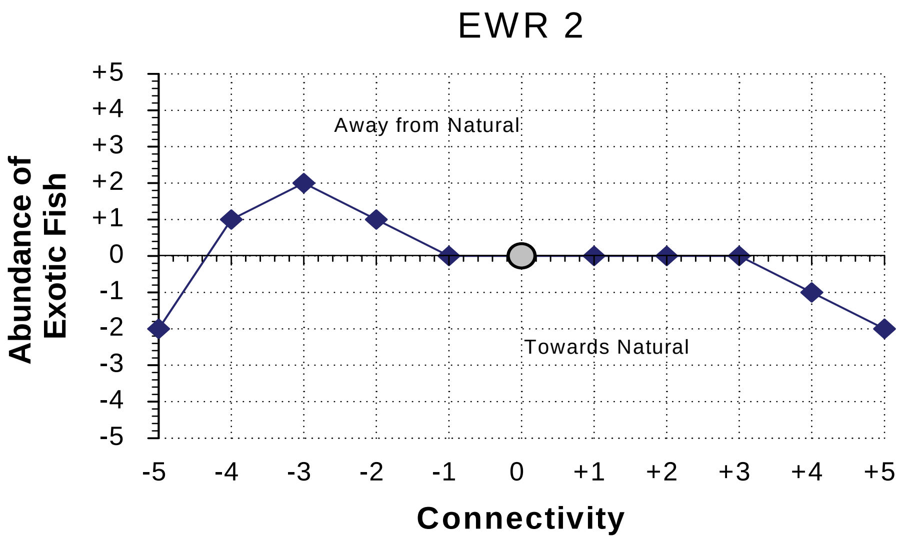

EWR 3 & 4
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

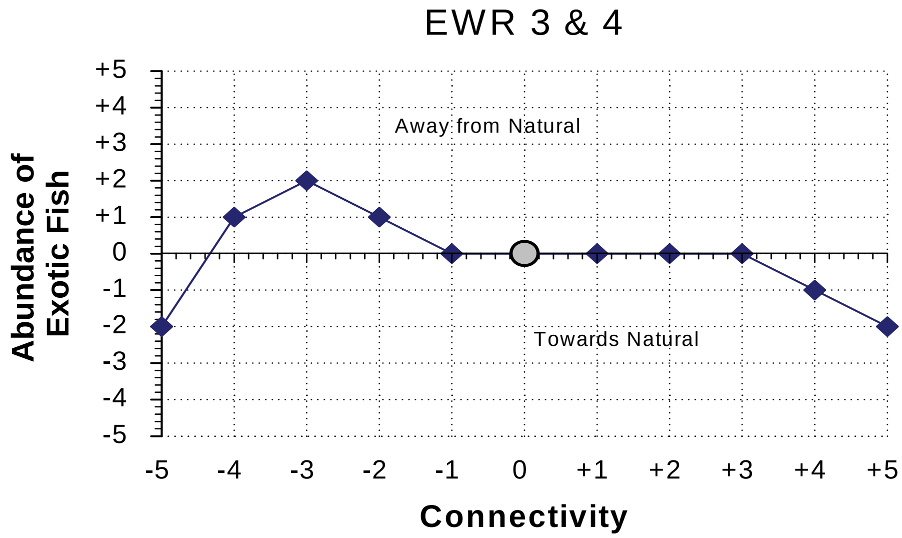

EWR 1
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Connectivity

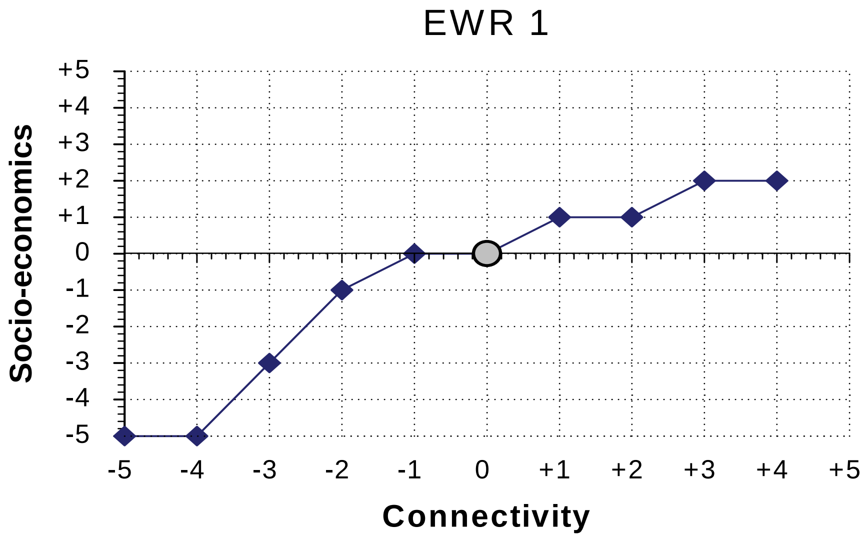

EWR 2
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Connectivity

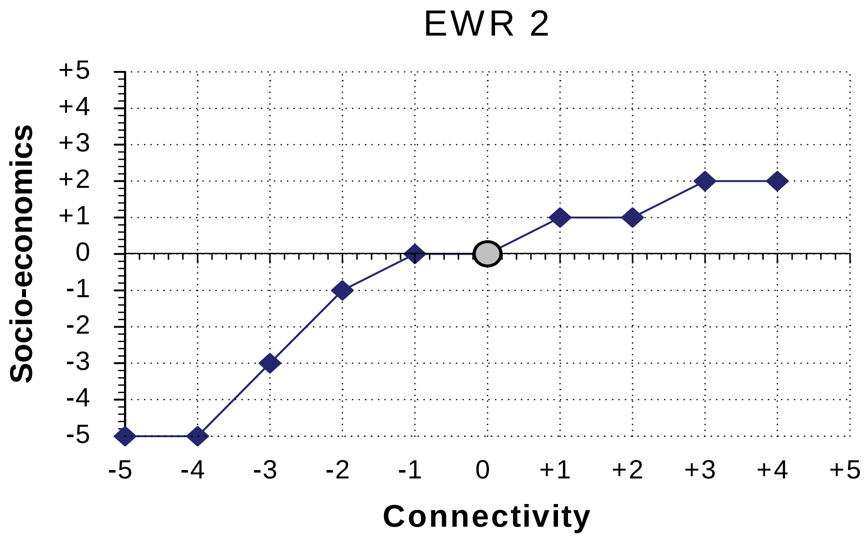

EWR 3 & 4
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Connectivity

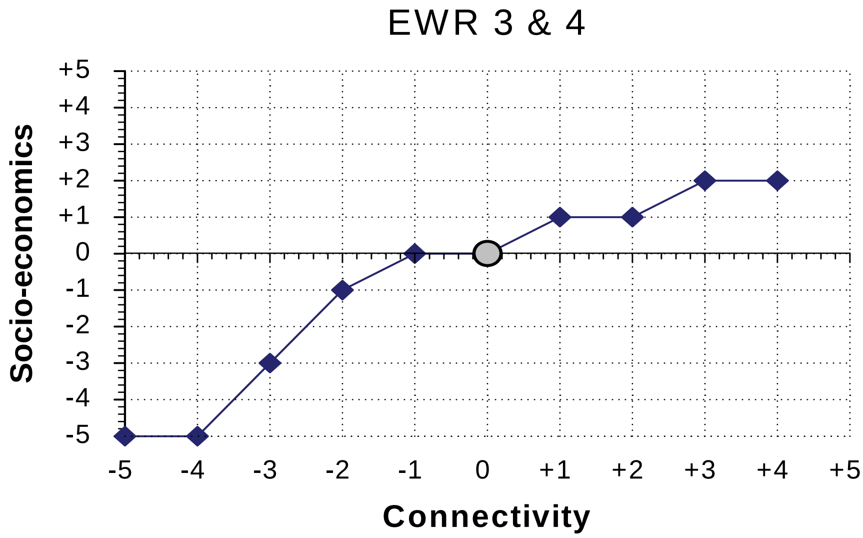

EWR 1
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

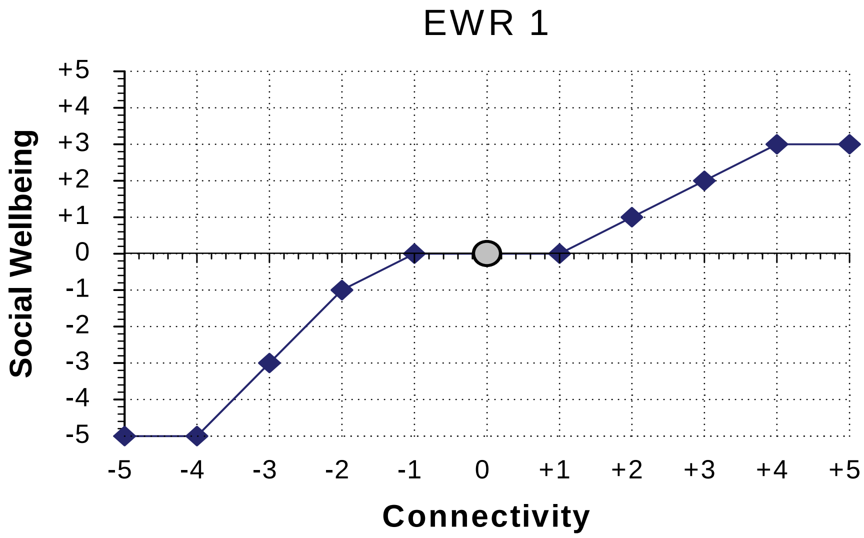

EWR 2
Abundance of Exotic Fish
Away from Natural
Towards Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

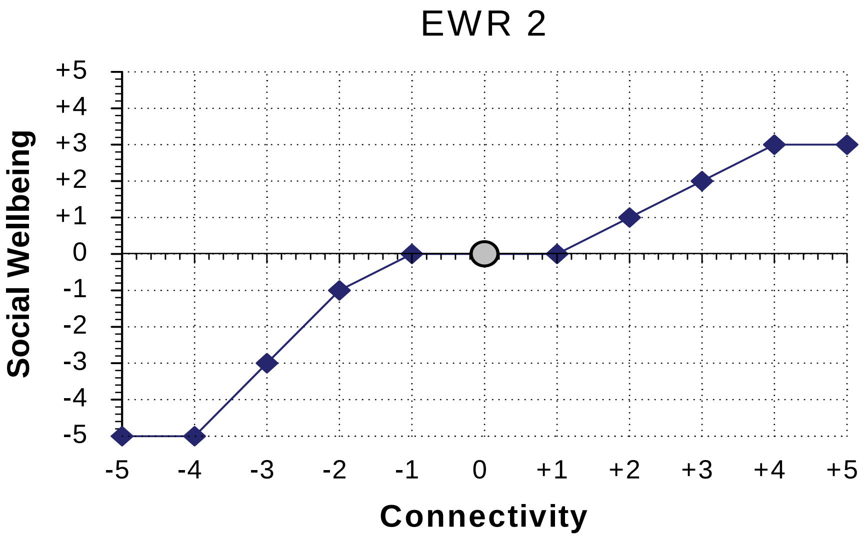

EWR 3 & 4
Abundance of Exotic Fish
Away from Natural
Towards Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

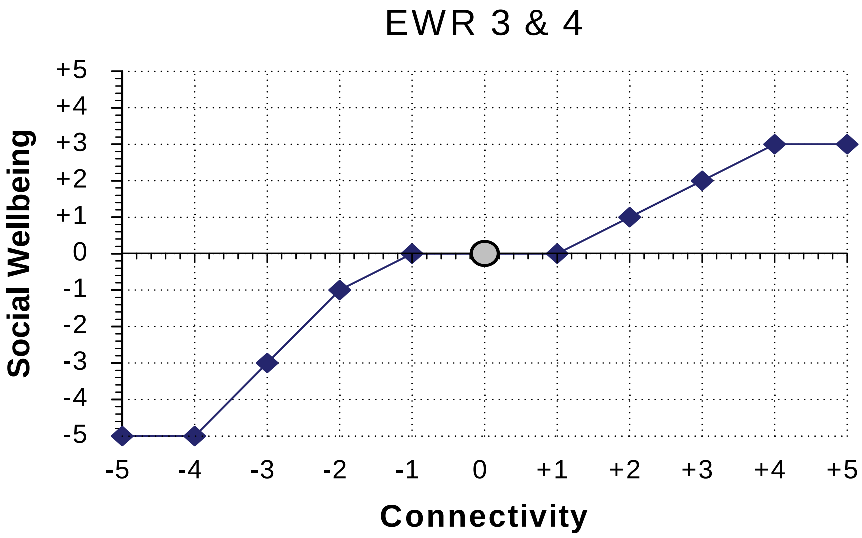

EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

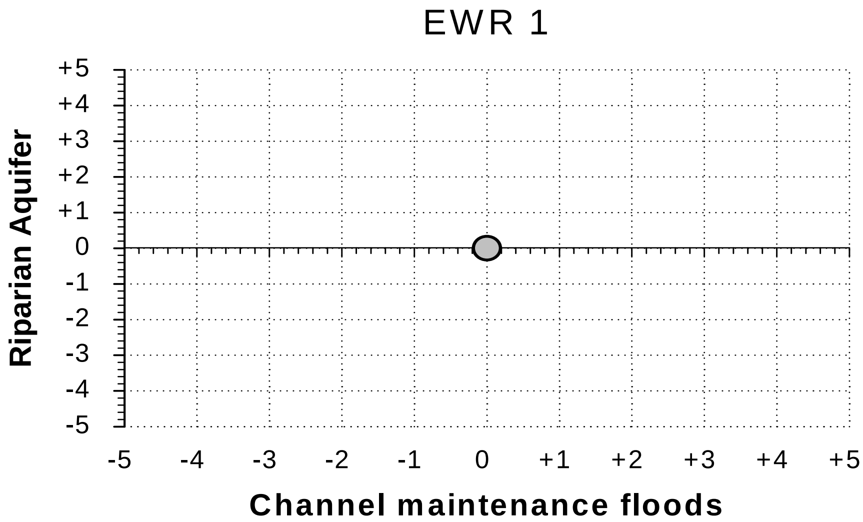

EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

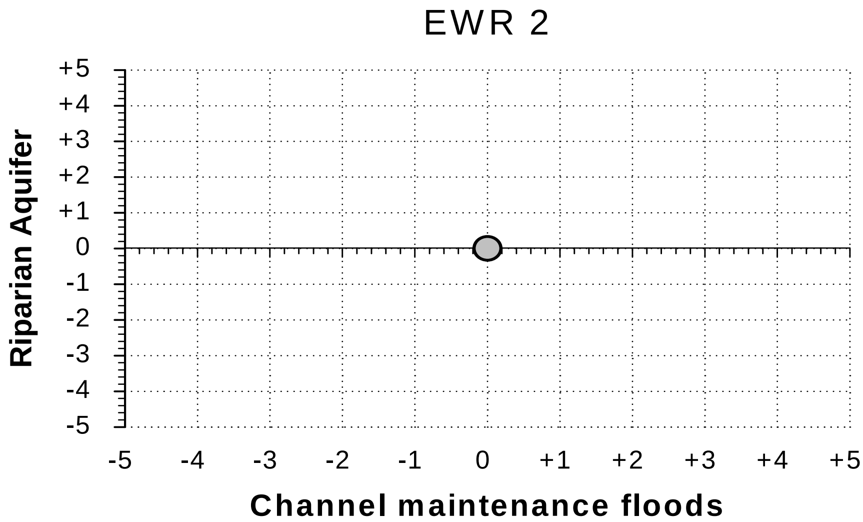

EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

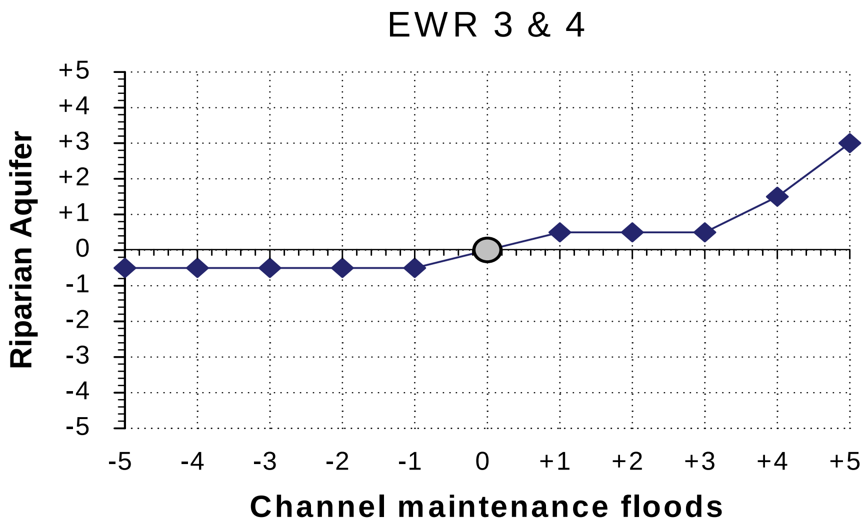

EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

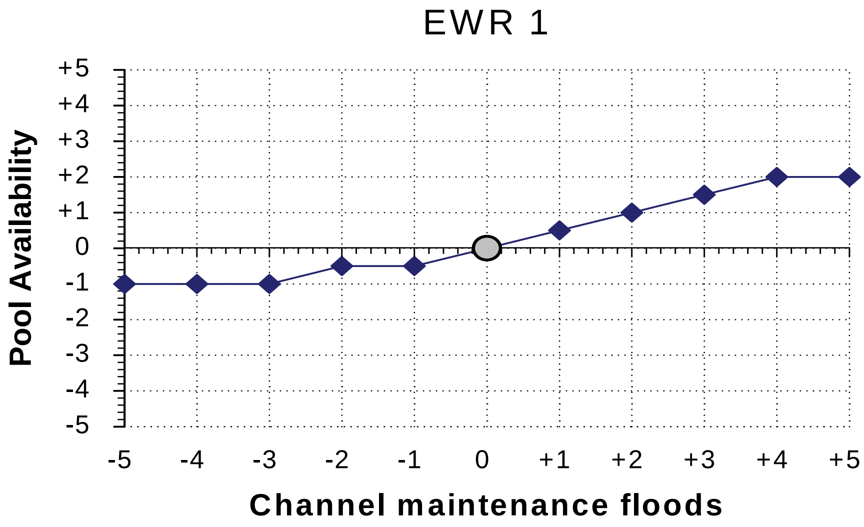

EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

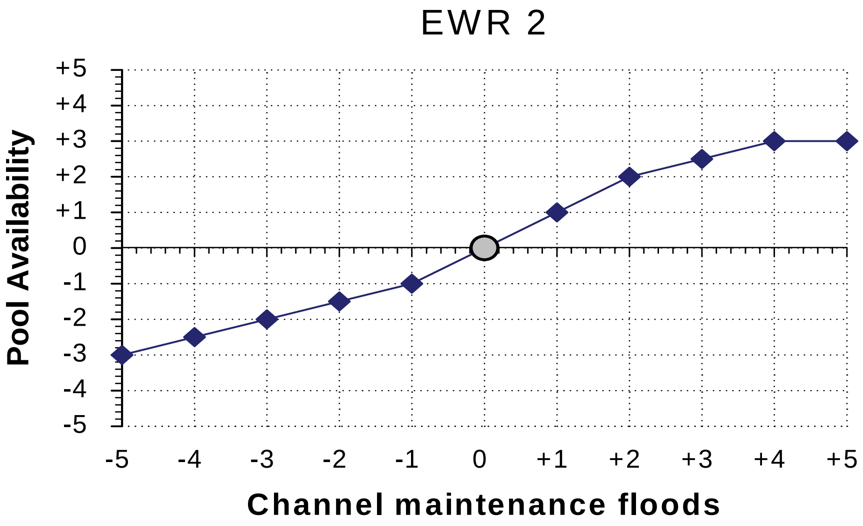

EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Connectivity

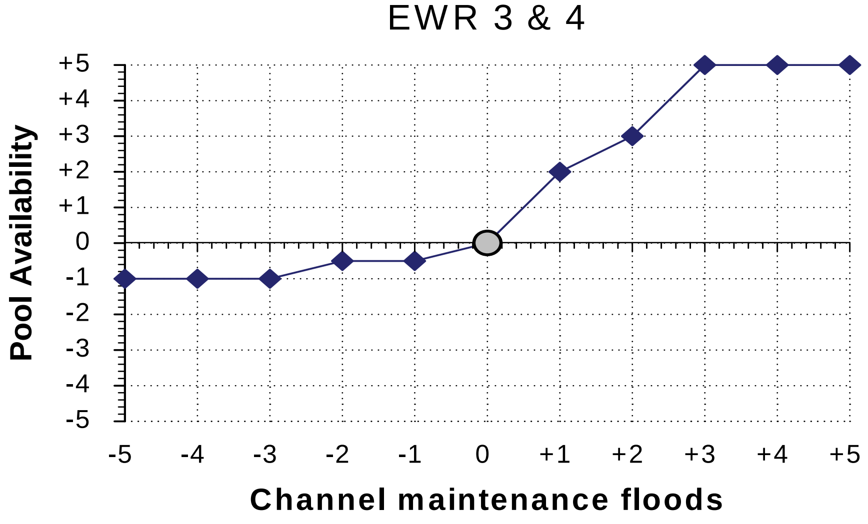

EWR 1
Riparian Aquifer
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

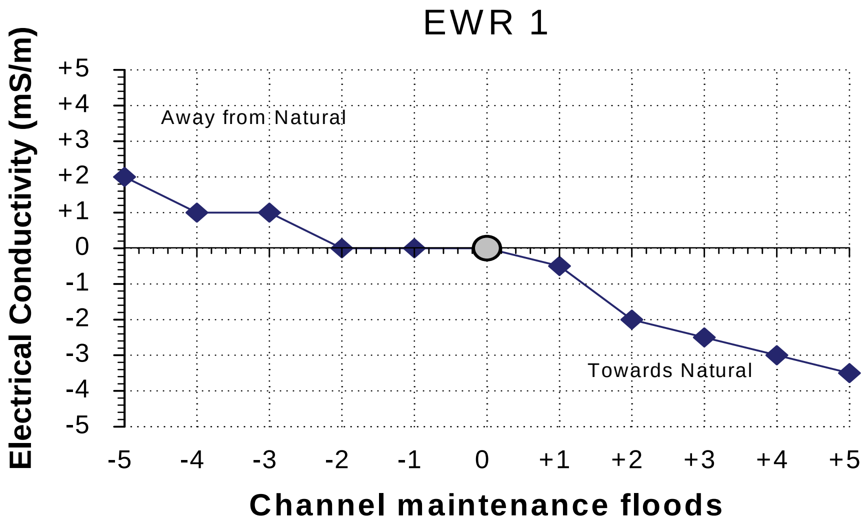

EWR 2
Riparian Aquifer
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

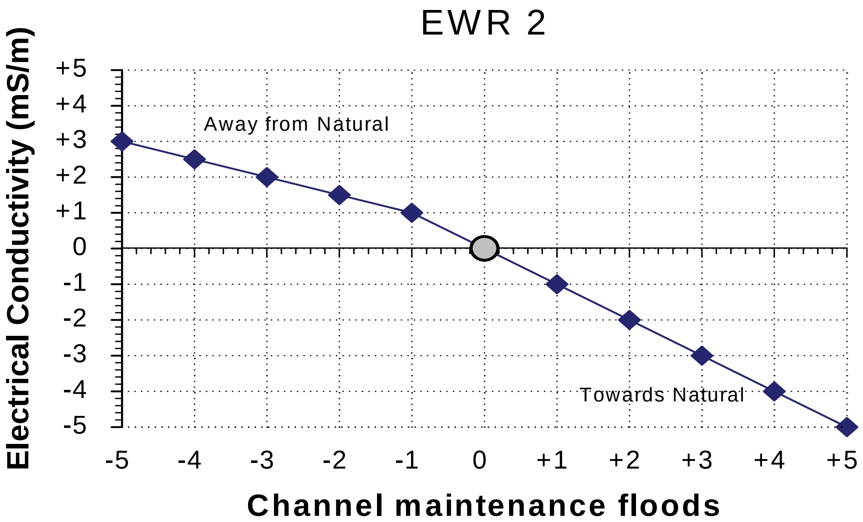

EWR 3 & 4
Riparian Aquifer
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

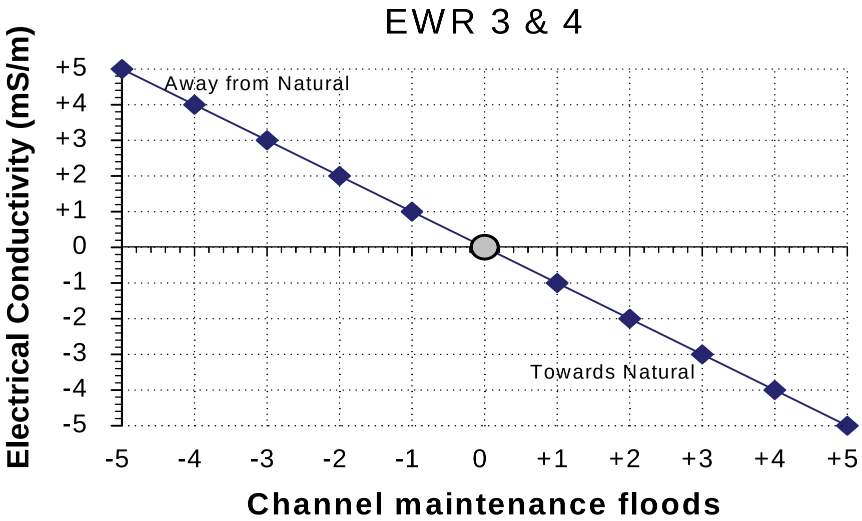

EWR 1
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

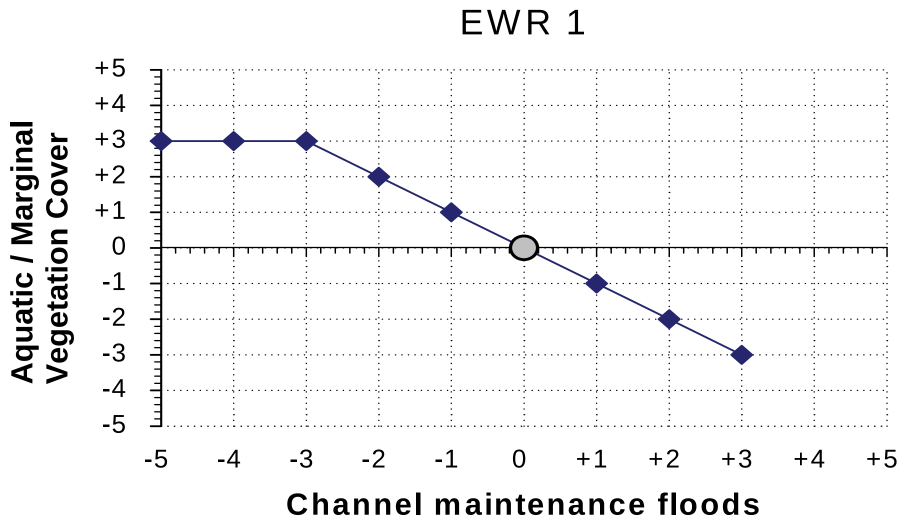

EWR 2
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

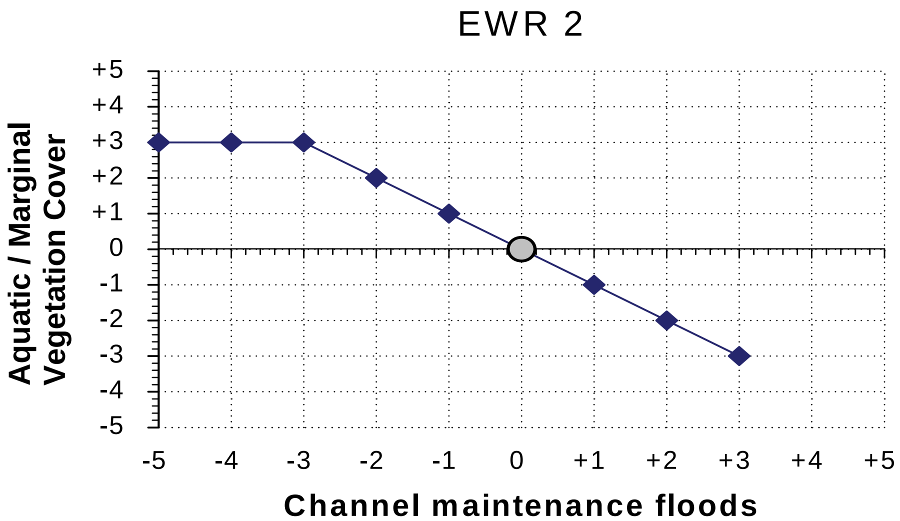

EWR 3 & 4
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

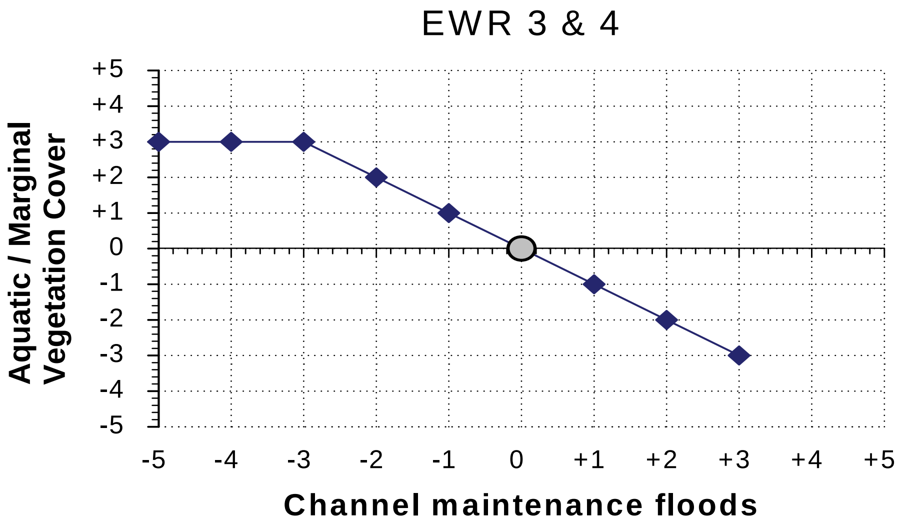

EWR 1
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

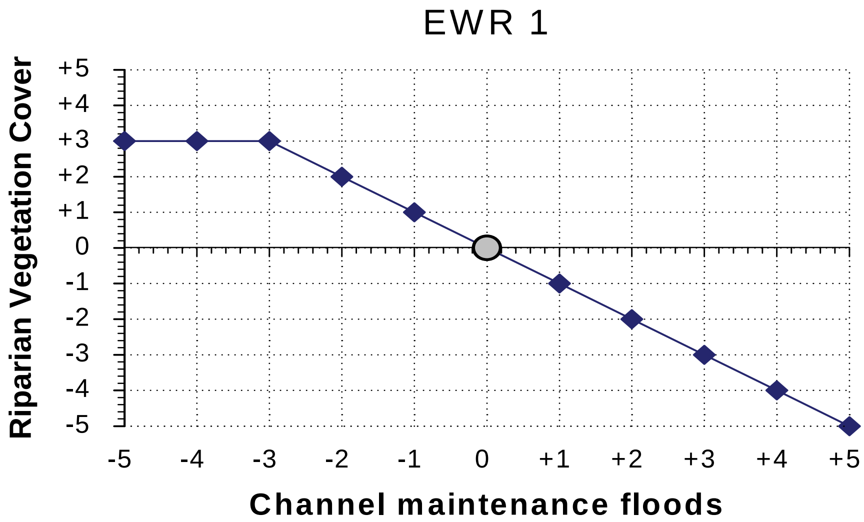

EWR 2
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

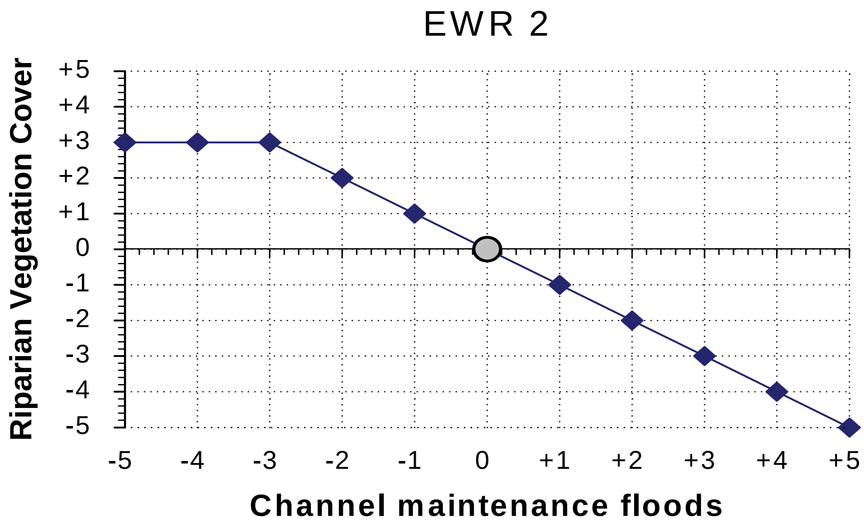

EWR 3 & 4
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

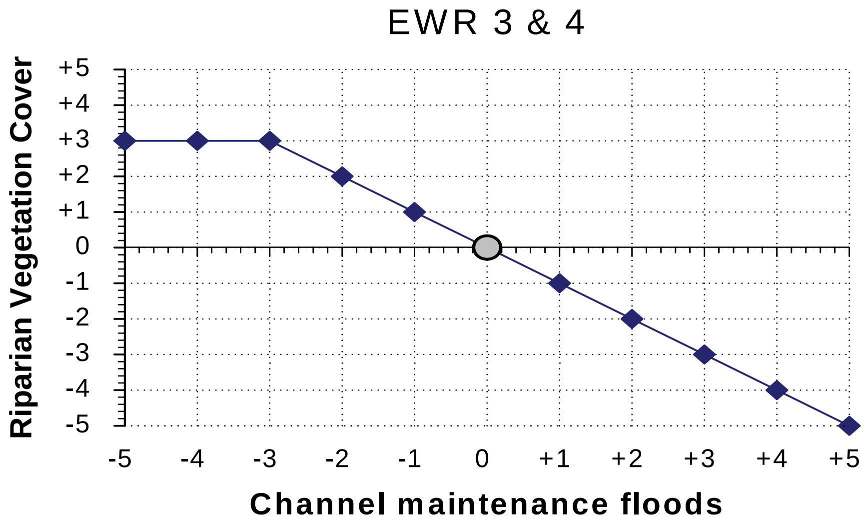

EWR 1
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

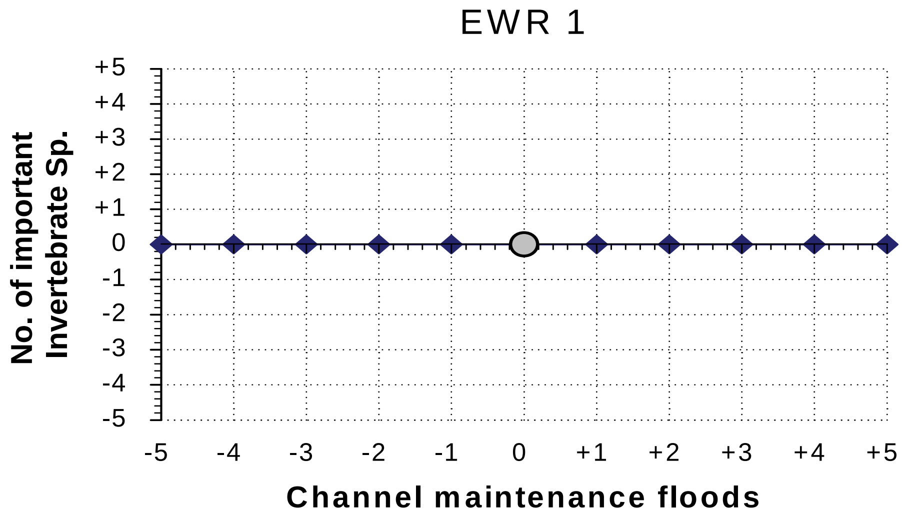

EWR 2
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

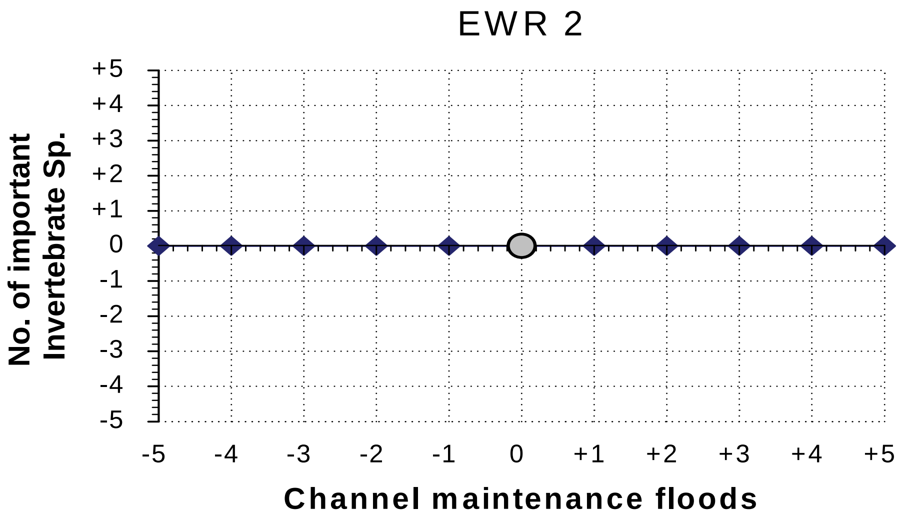

EWR 3 & 4
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

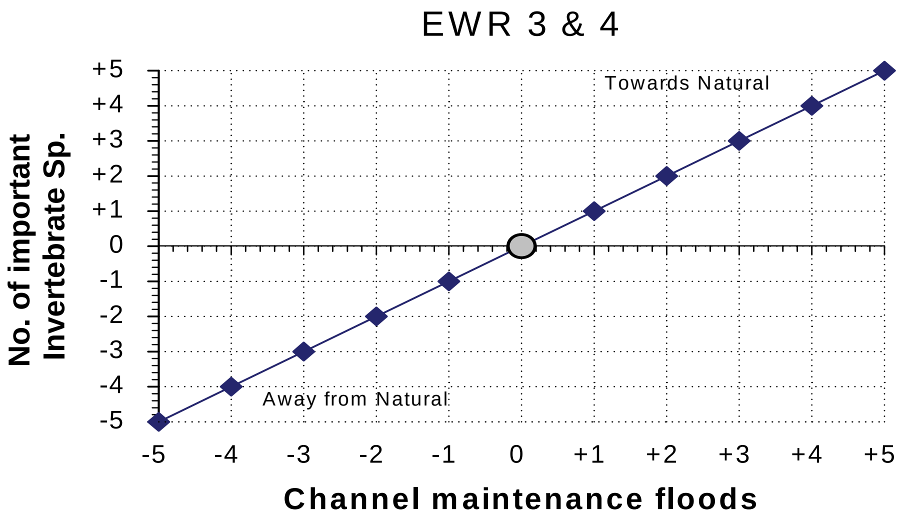

EWR 1
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods


EWR 2
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

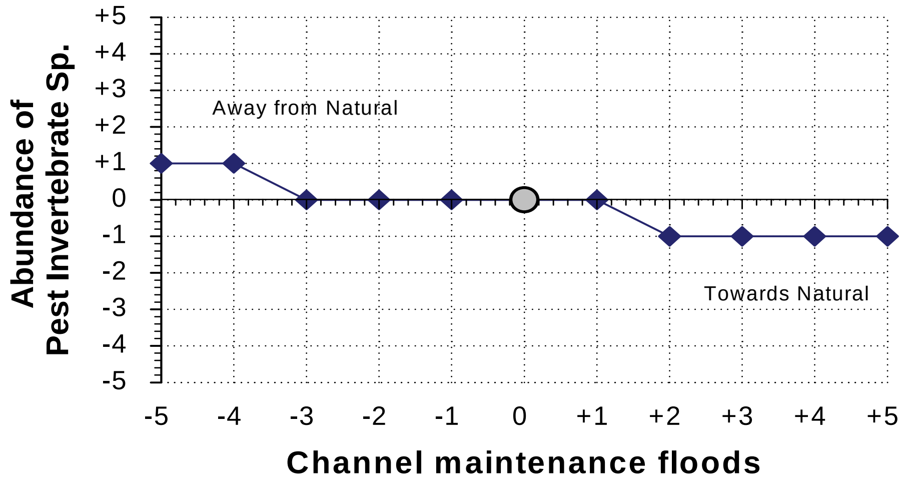

EWR 3 & 4
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods


EWR 1
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

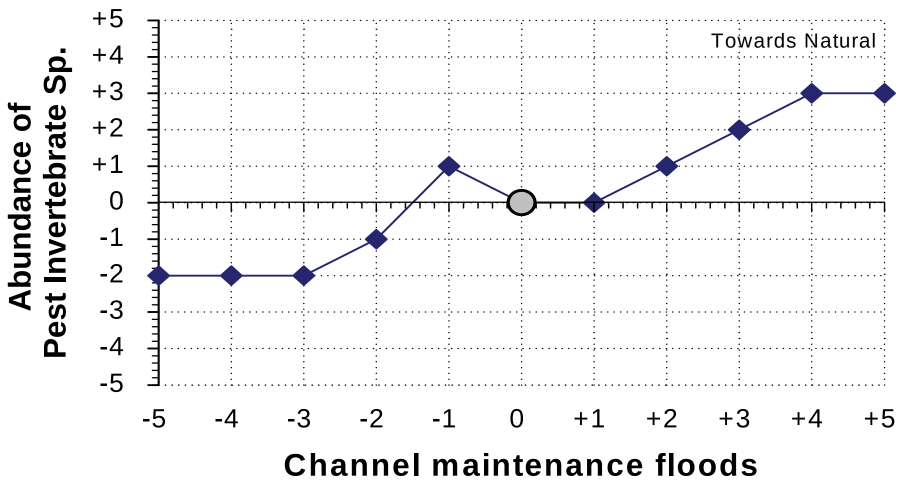

EWR 2
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods


EWR 3 & 4
No. of important Invertebrate Sp.
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

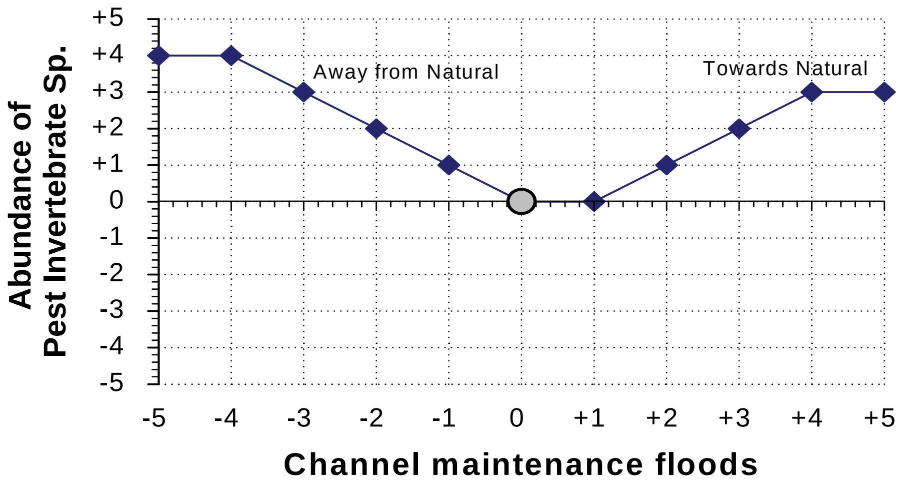
EWR 1

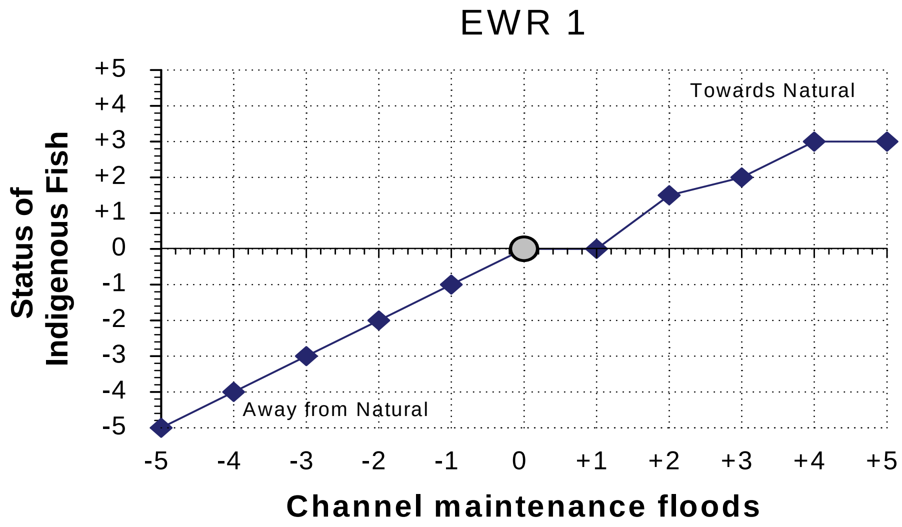


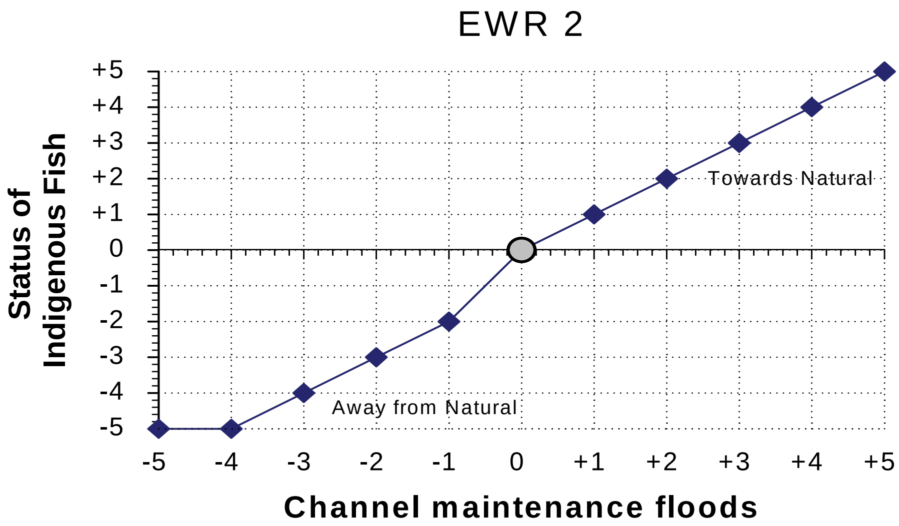
EWR 2

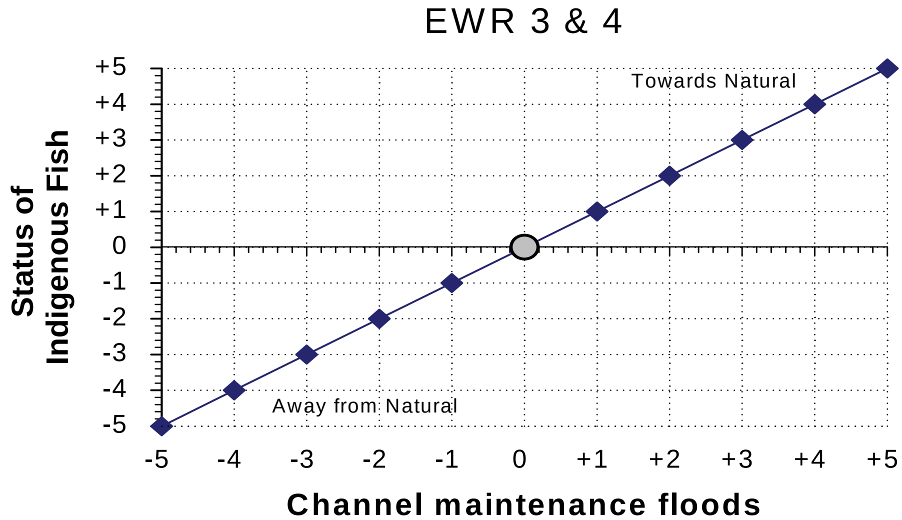


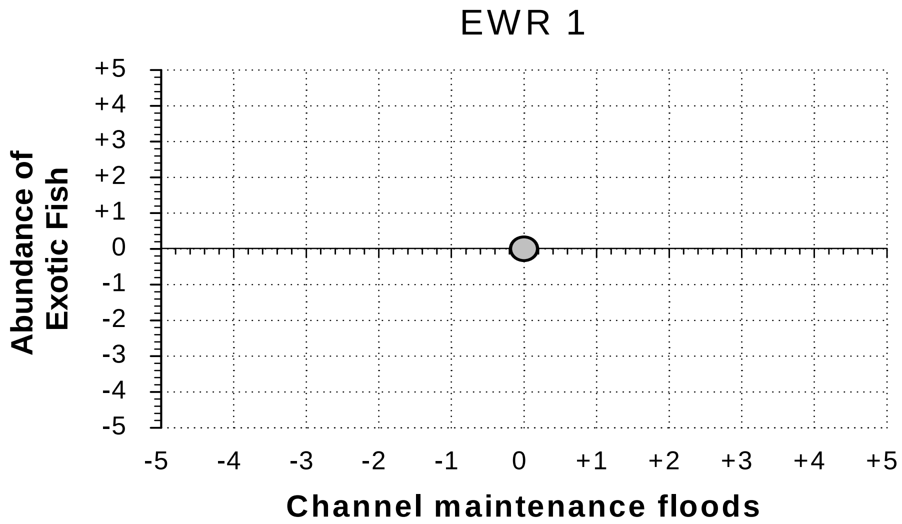
EWR 3 & 4

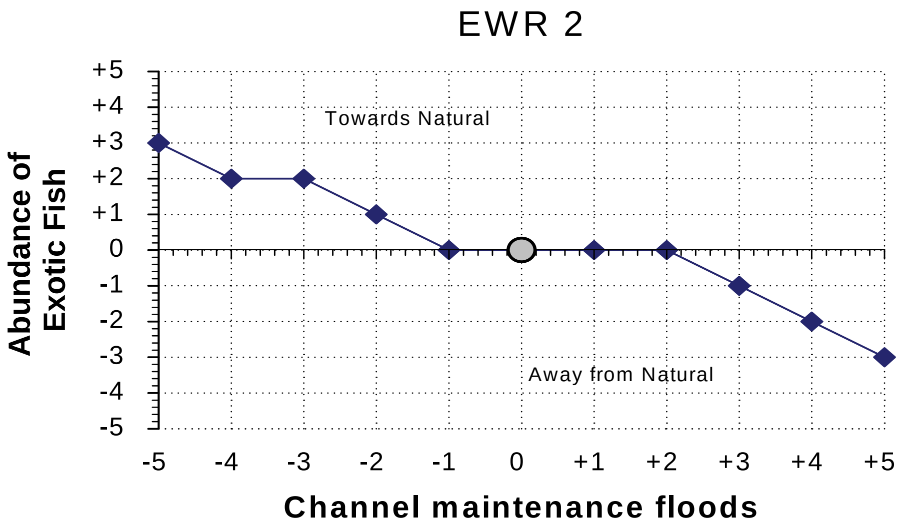


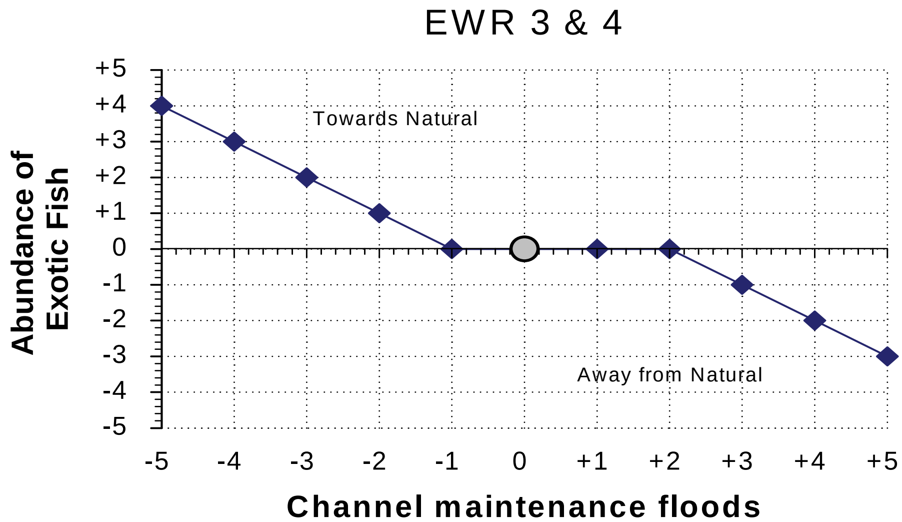

EWR 1
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods


EWR 2
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods

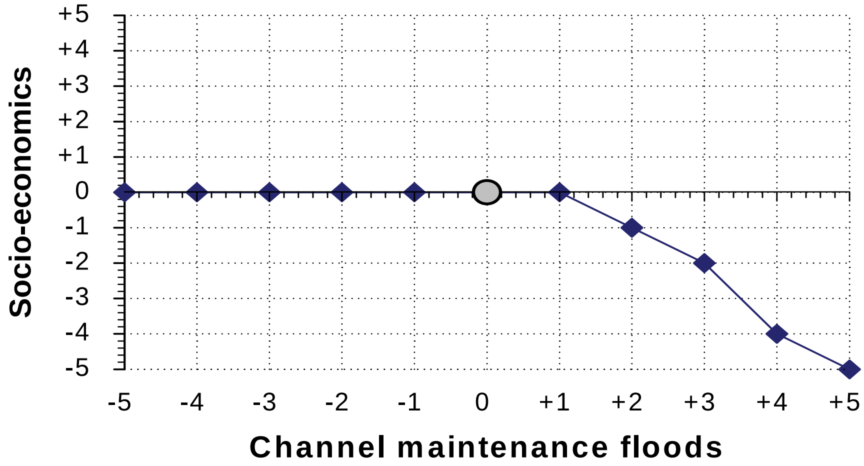

EWR 3 & 4
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel maintenance floods


EWR 1
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

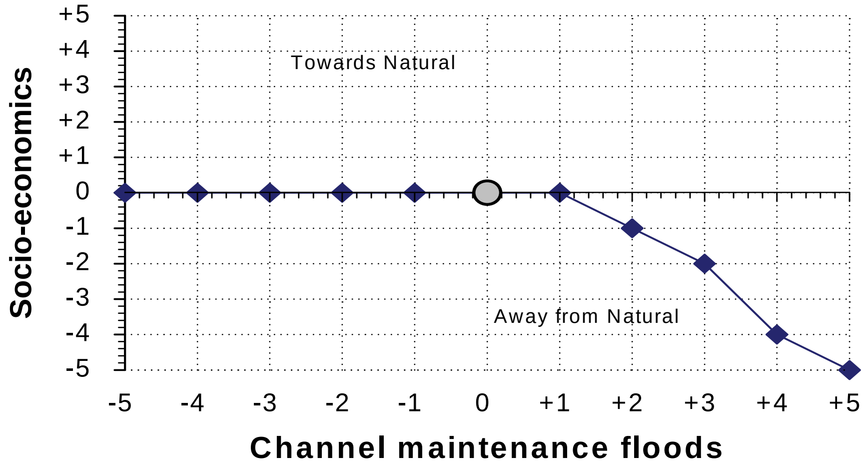

EWR 2
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods


EWR 3 & 4
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

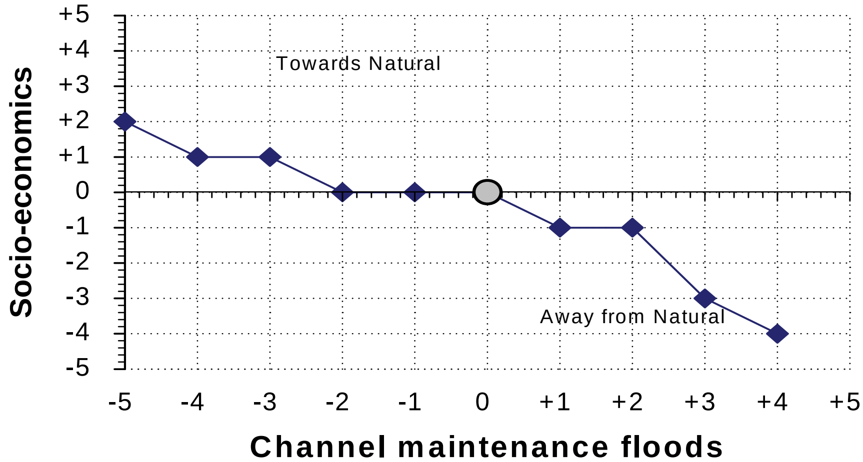
EWR 1

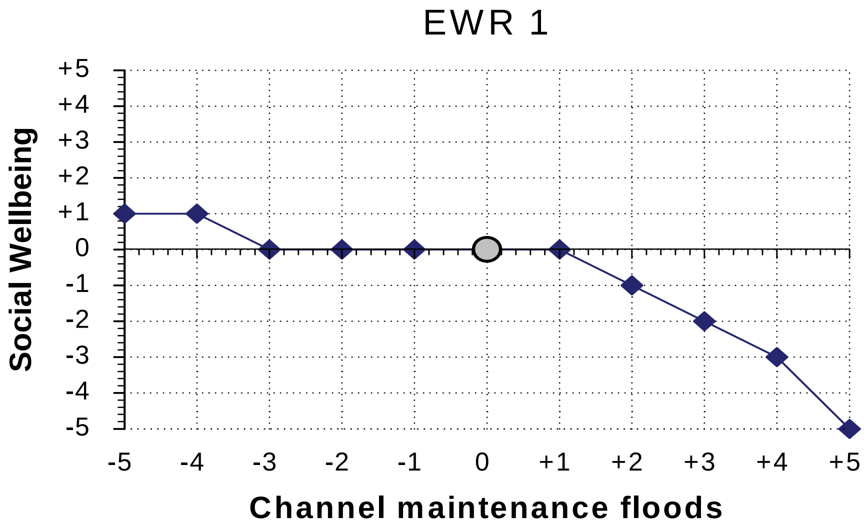


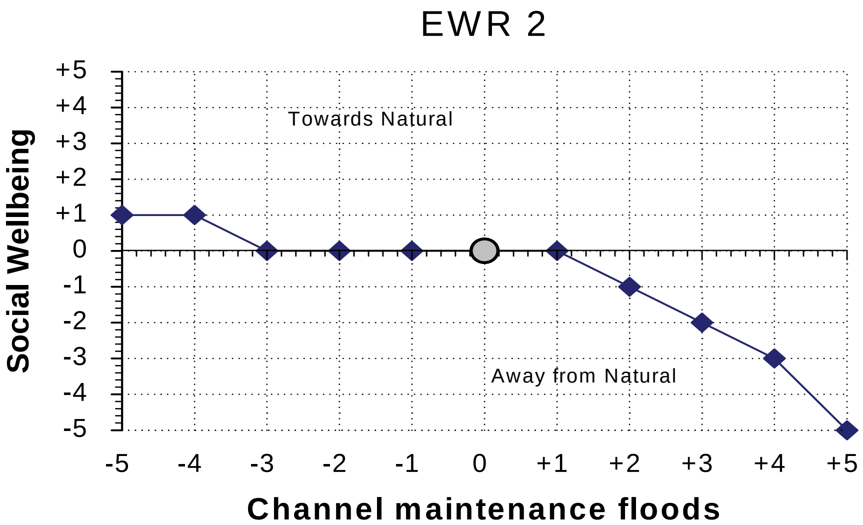
EWR 2

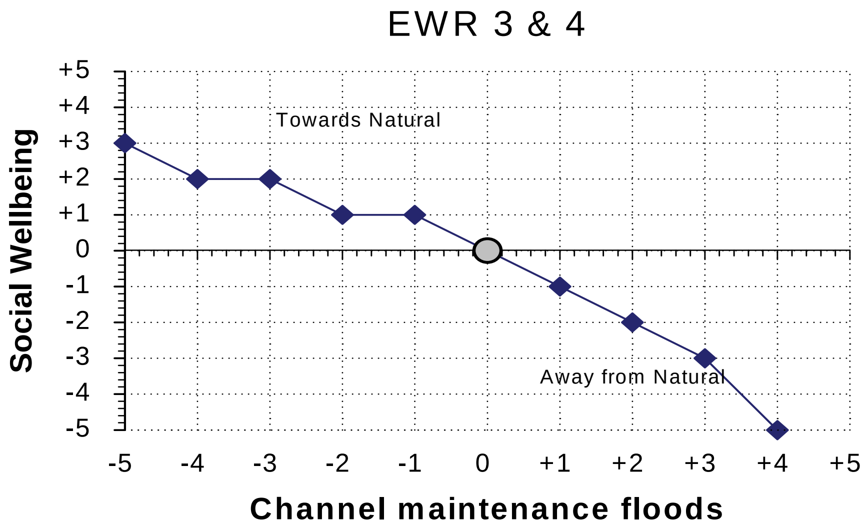


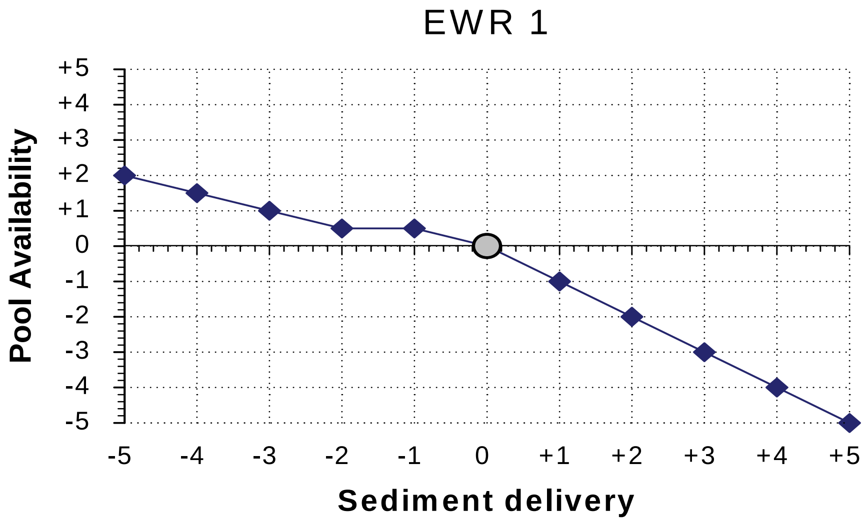
EWR 3 & 4

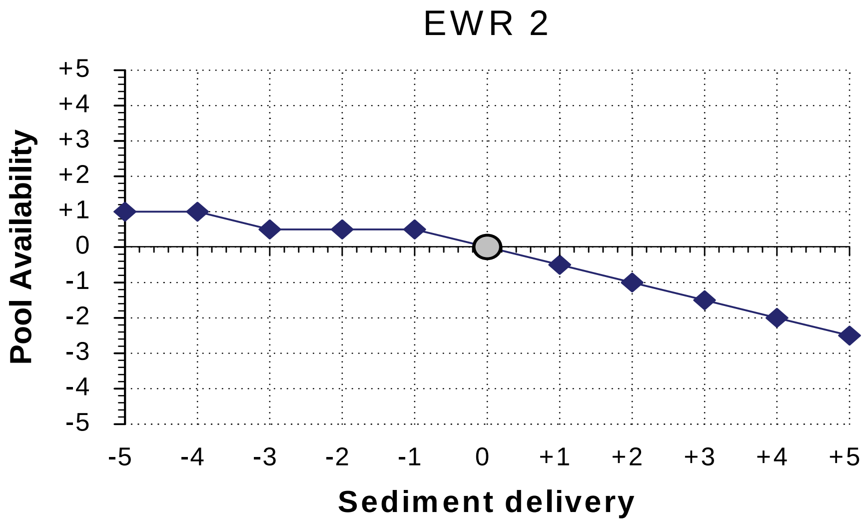


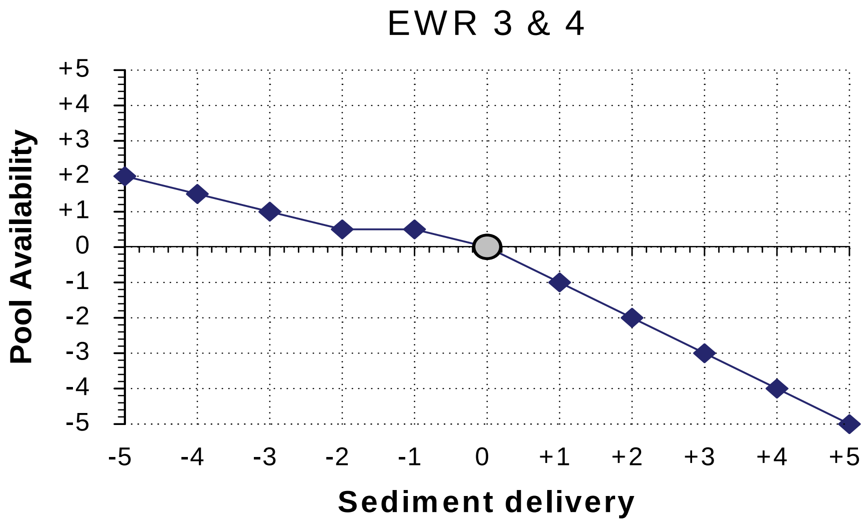

EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

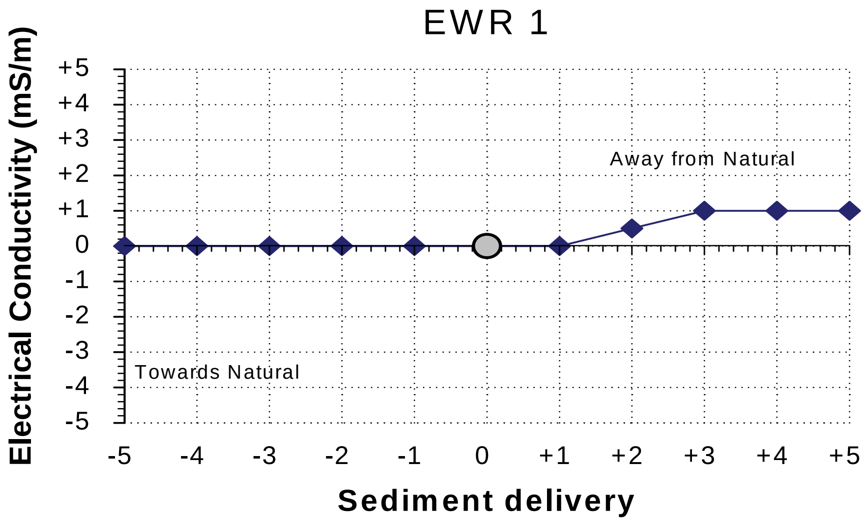

EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

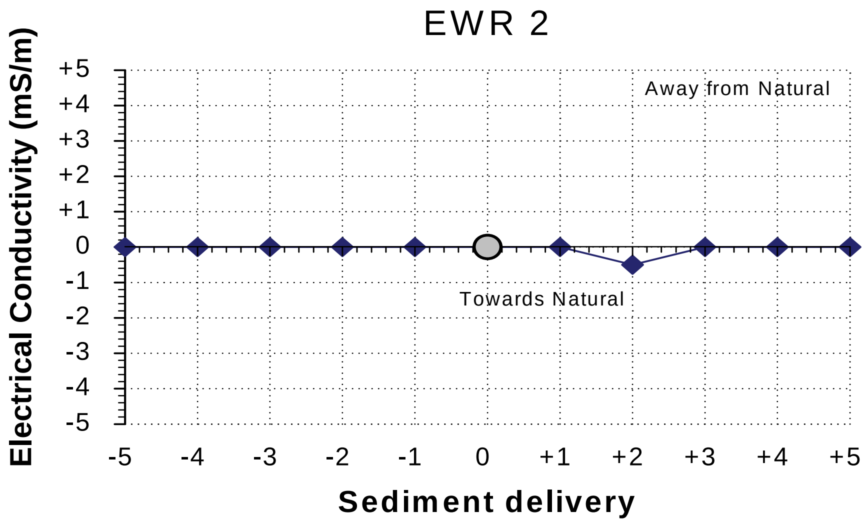

EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel maintenance floods

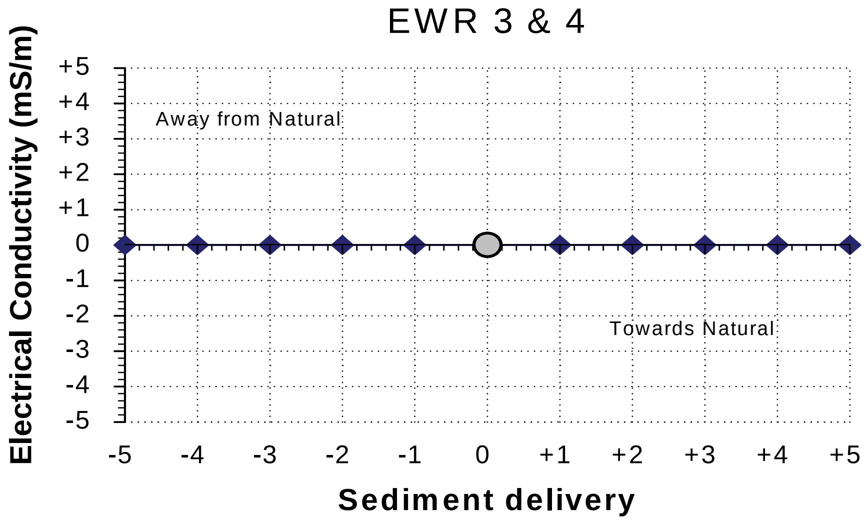

EWR 1
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

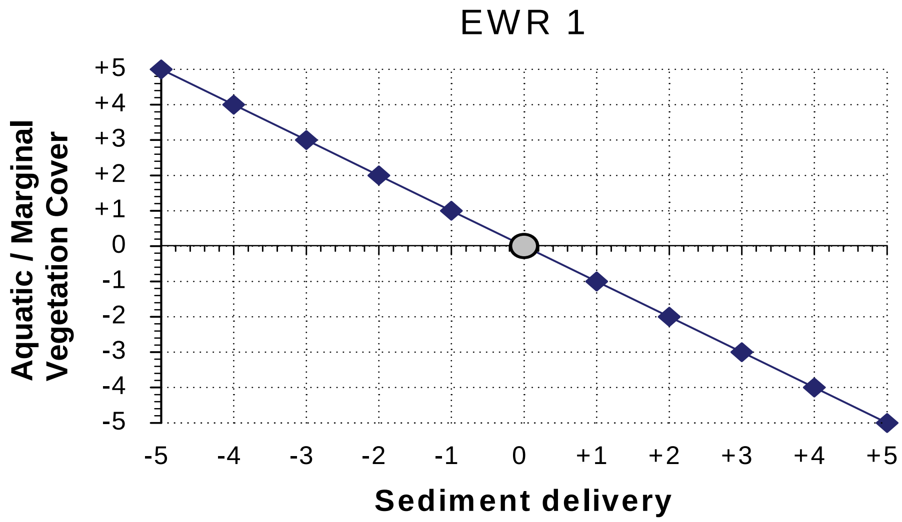

EWR 2
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

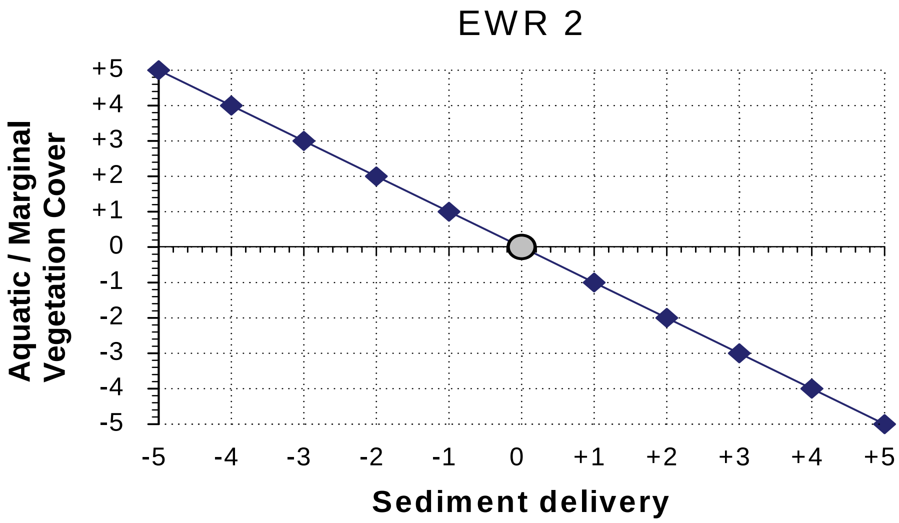

EWR 3 & 4
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

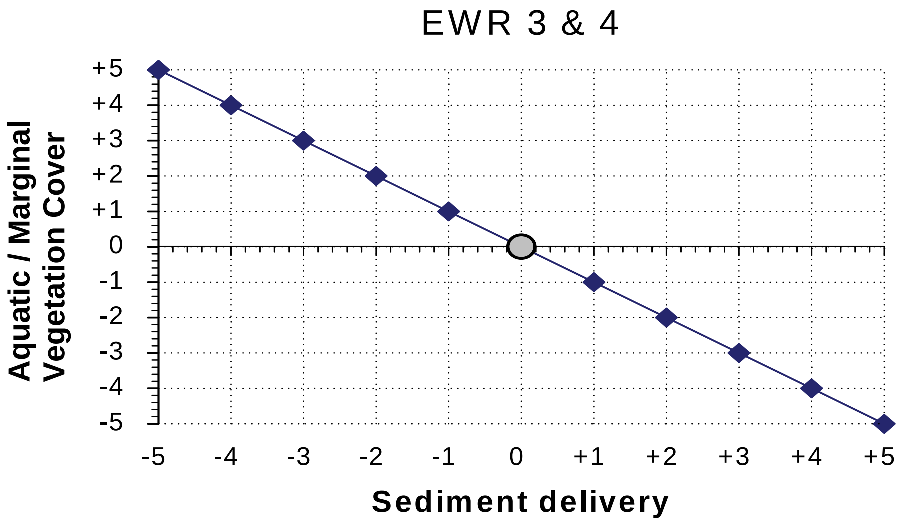

EWR 1
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Sediment delivery

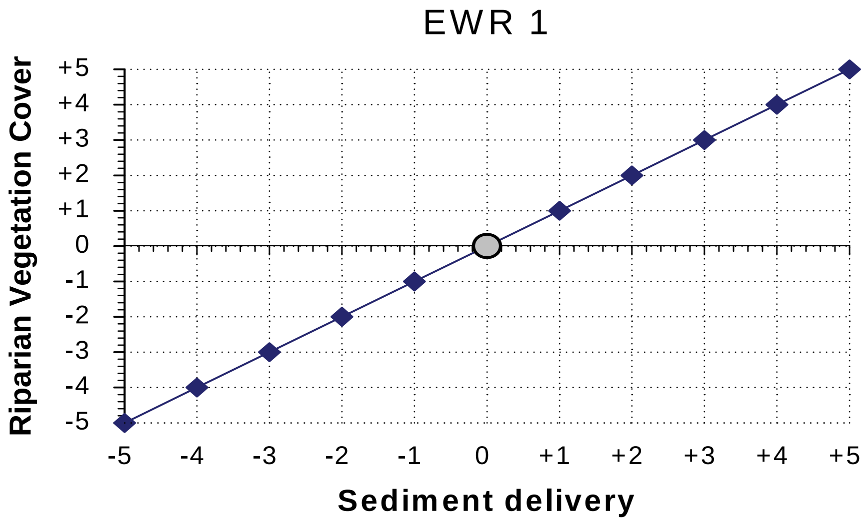

EWR 2
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Sediment delivery

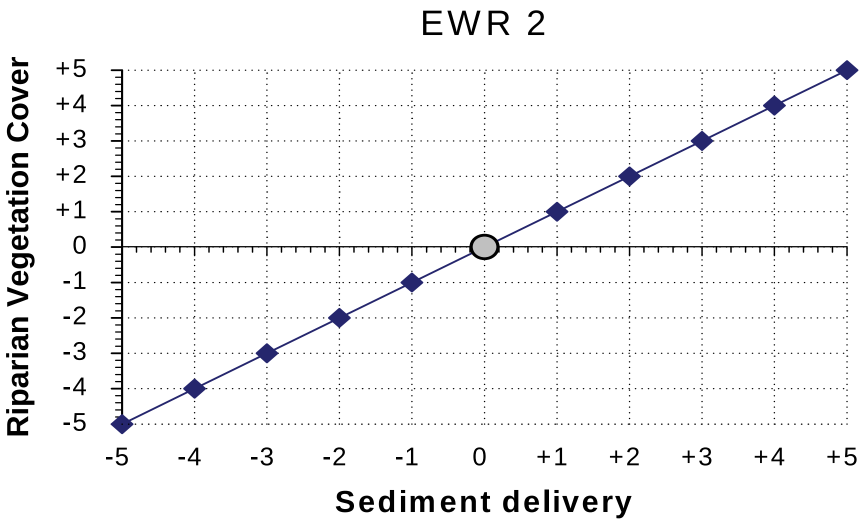

EWR 3 & 4
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Sediment delivery


EWR 1
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

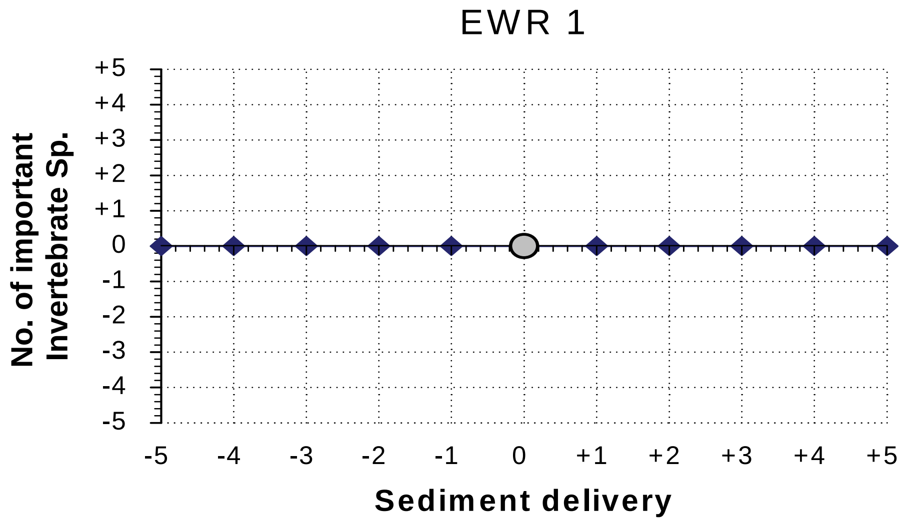

EWR 2
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

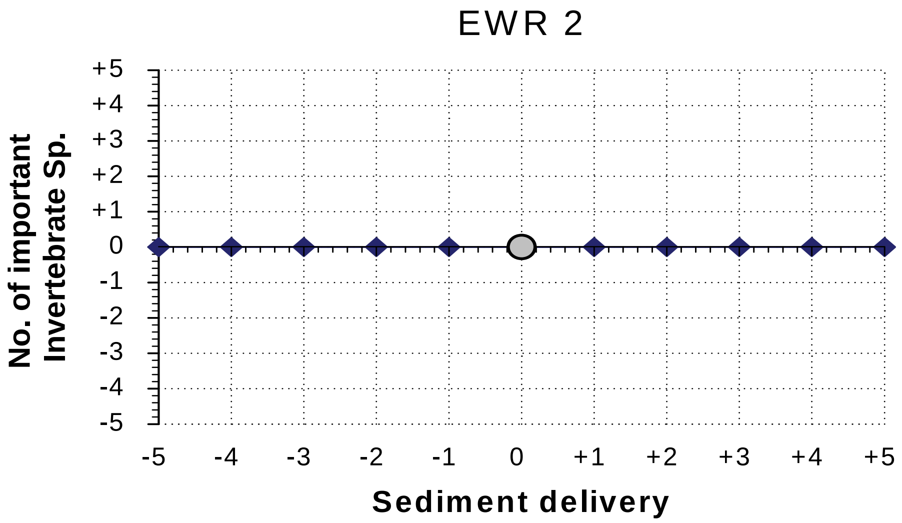

EWR 3 & 4
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

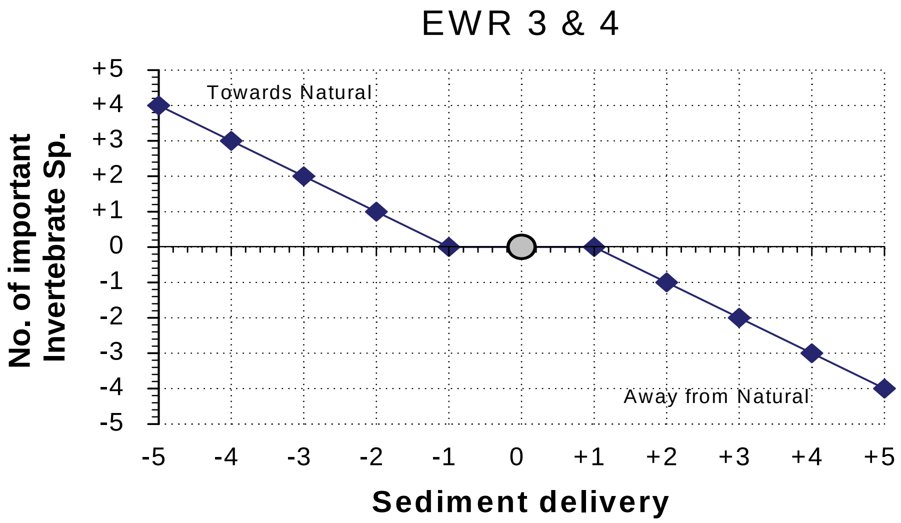

EWR 1
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

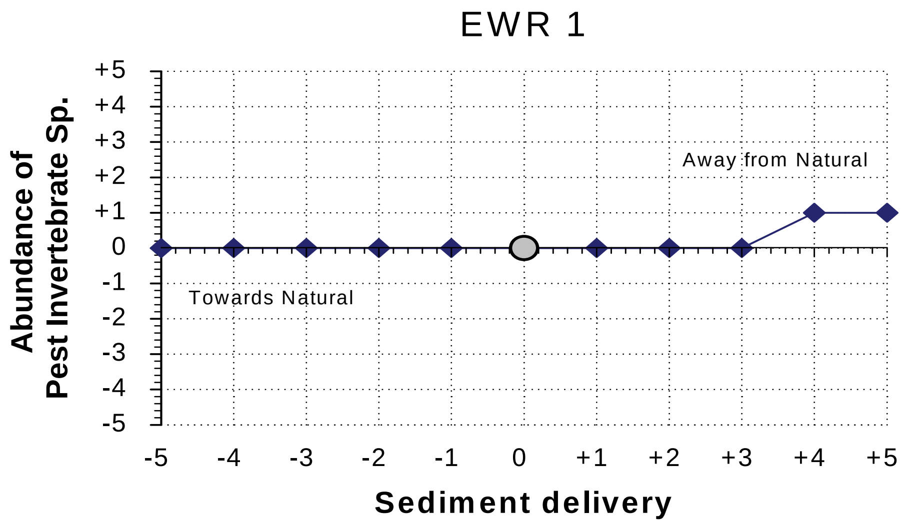

EWR 2
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

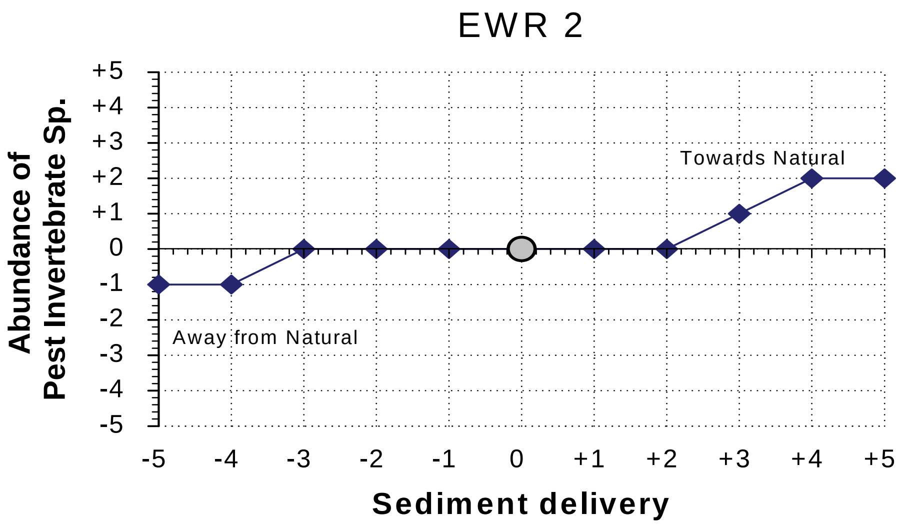

EWR 3 & 4
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

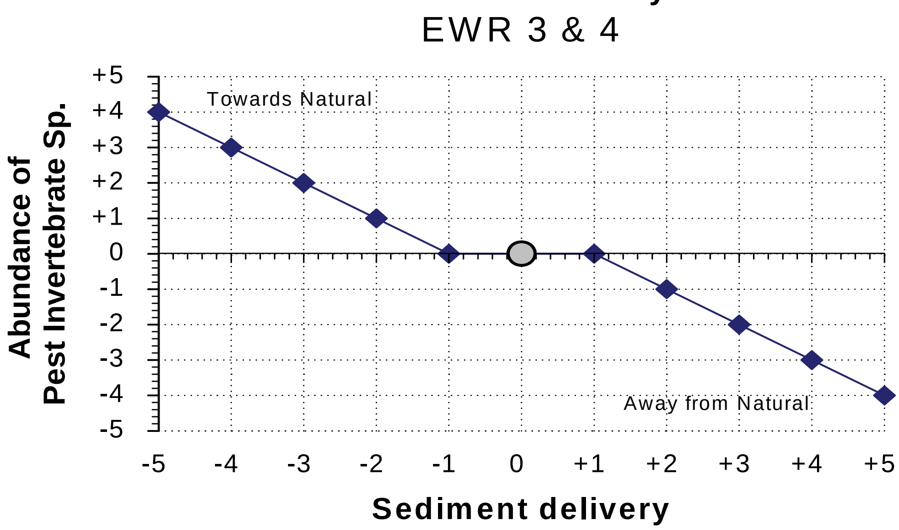

EWR 1
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

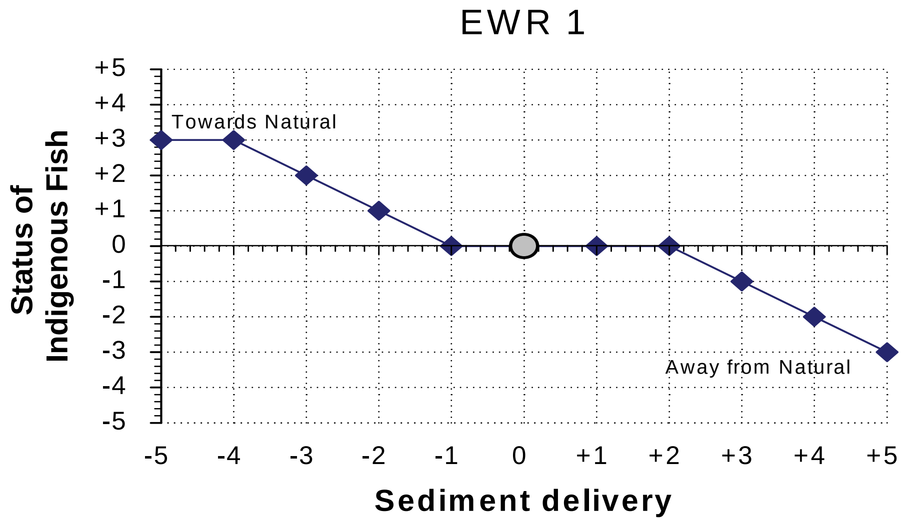

EWR 2
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

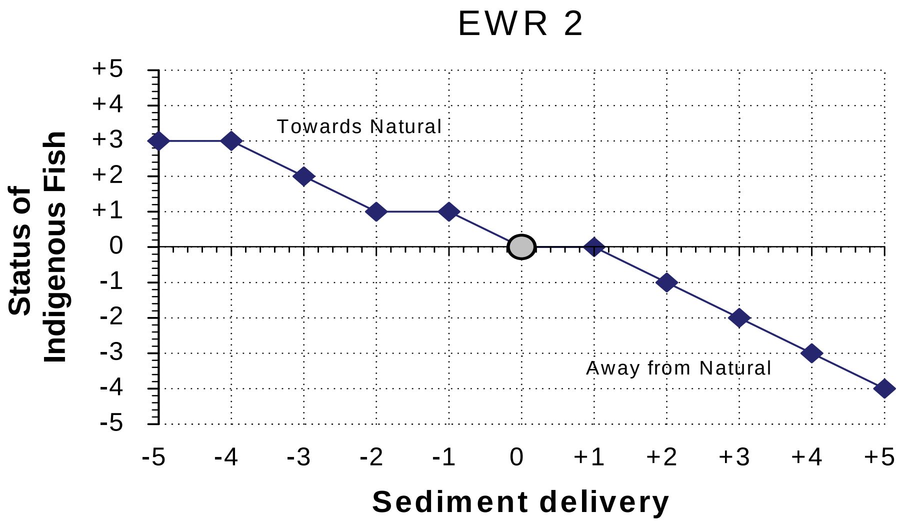

EWR 3 & 4
No. of important Invertebrate Sp.
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

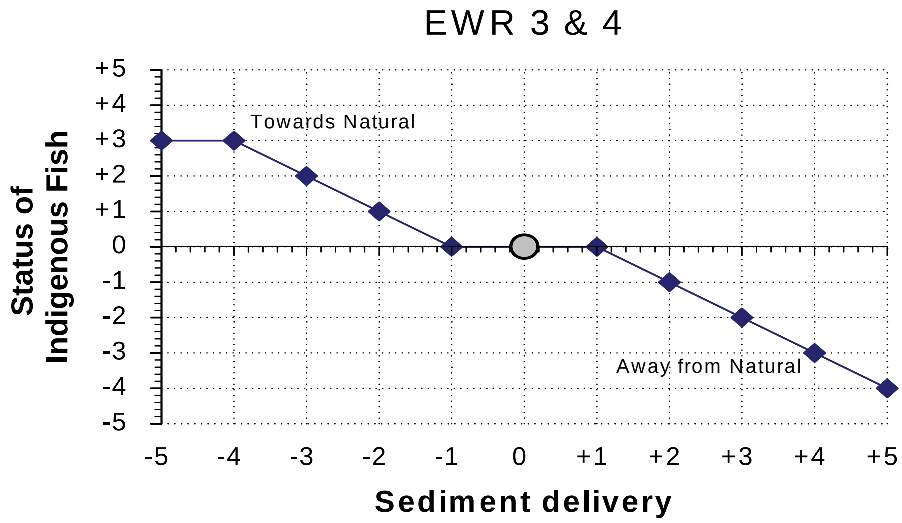

EWR 1
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

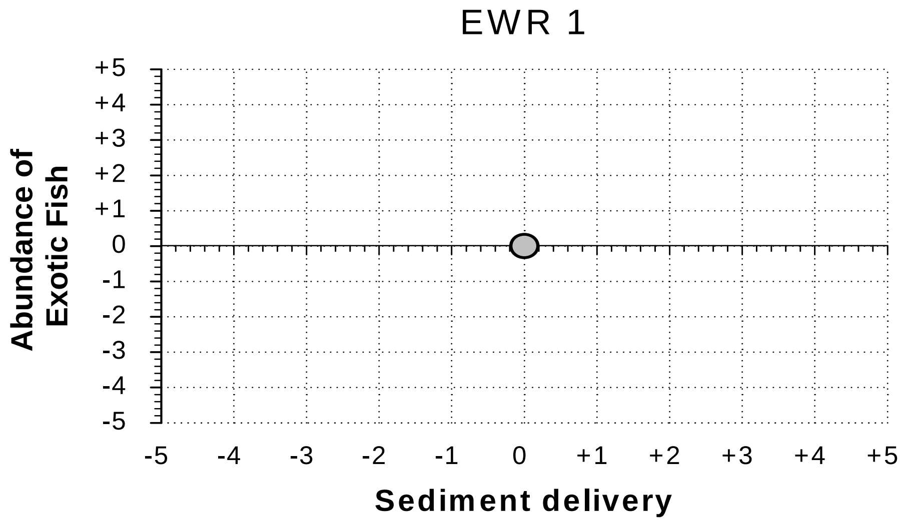

EWR 2
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

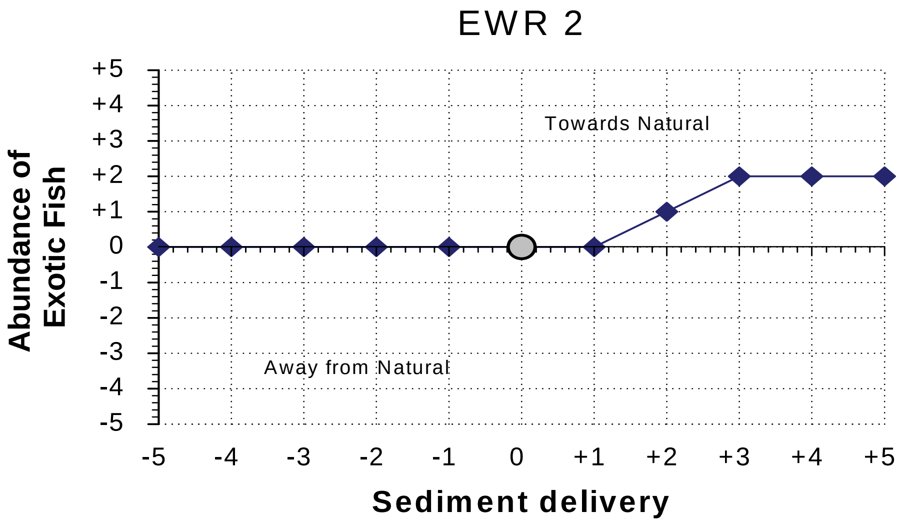

EWR 3 & 4
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

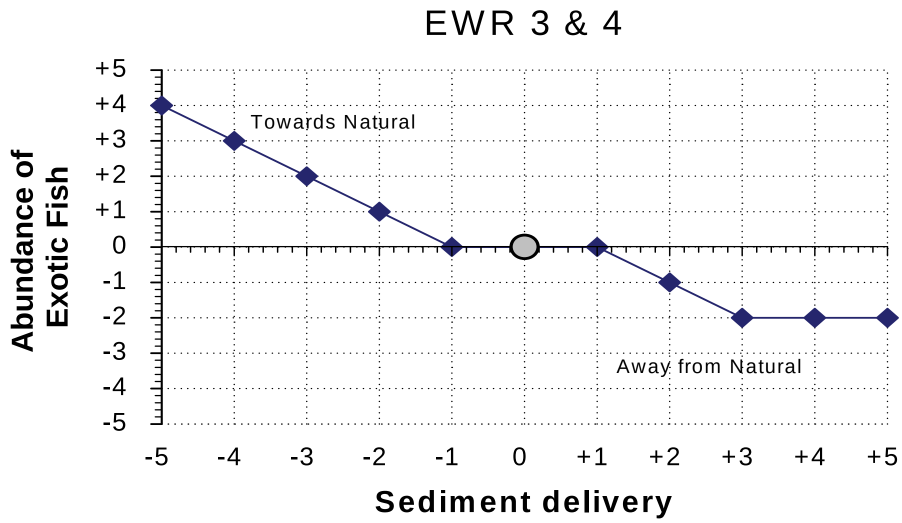

EWR 1
Status of Indigenous Fish
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

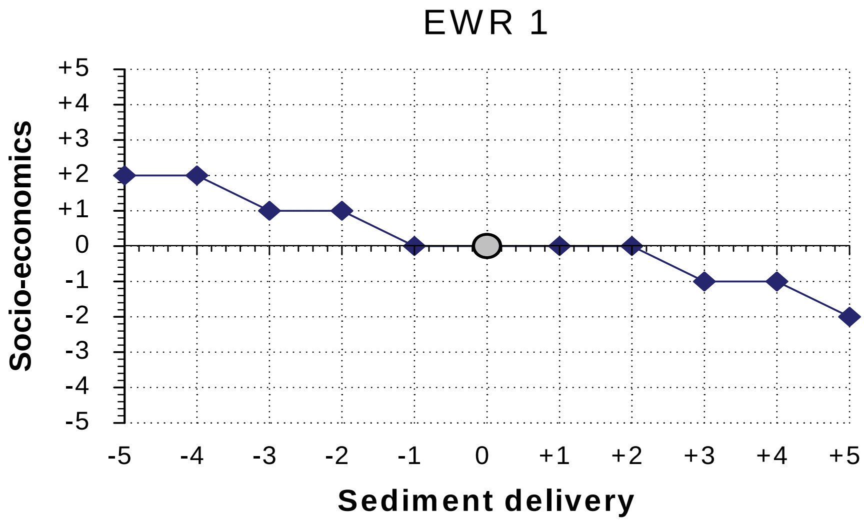

EWR 2
Status of Indigenous Fish
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

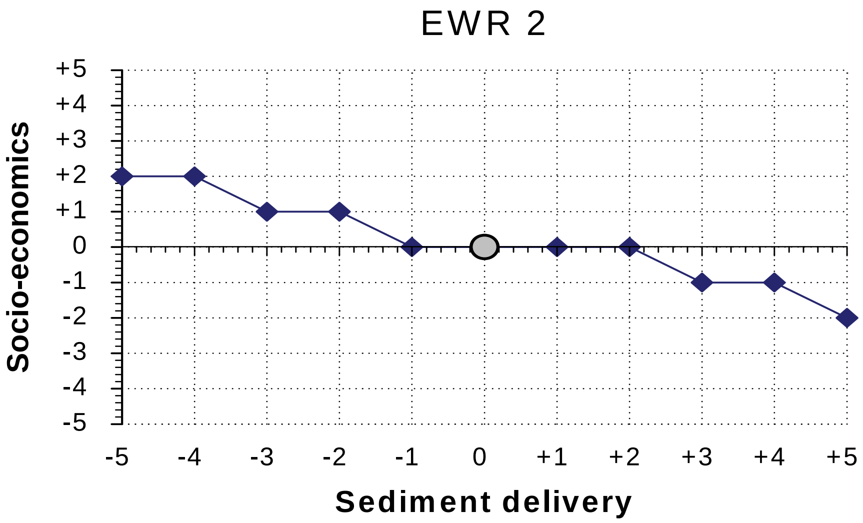

EWR 3 & 4
Status of Indigenous Fish
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Sediment delivery

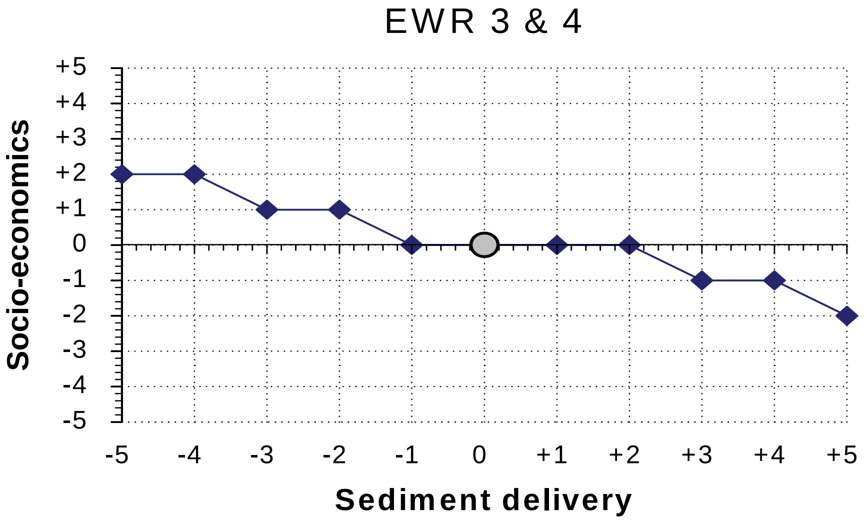

EWR 1
Abundance of Exotic Fish
Sediment delivery
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5


EWR 2
Abundance of Exotic Fish
Sediment delivery
Towards Natural
Away from Natural

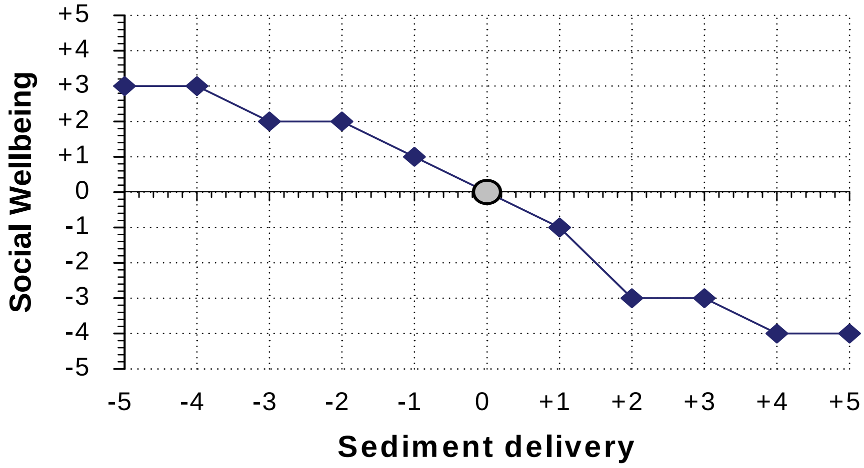

EWR 3 & 4
Abundance of Exotic Fish
Sediment delivery
Towards Natural
Away from Natural


EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Sediment delivery

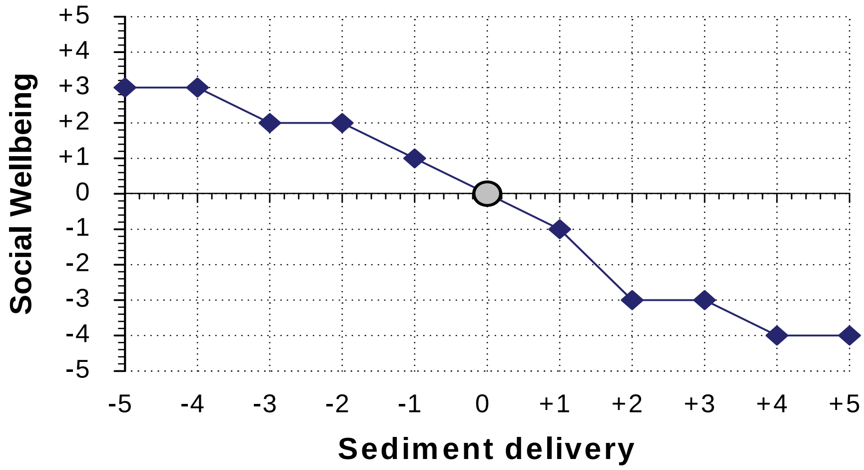

EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Sediment delivery


EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Sediment delivery

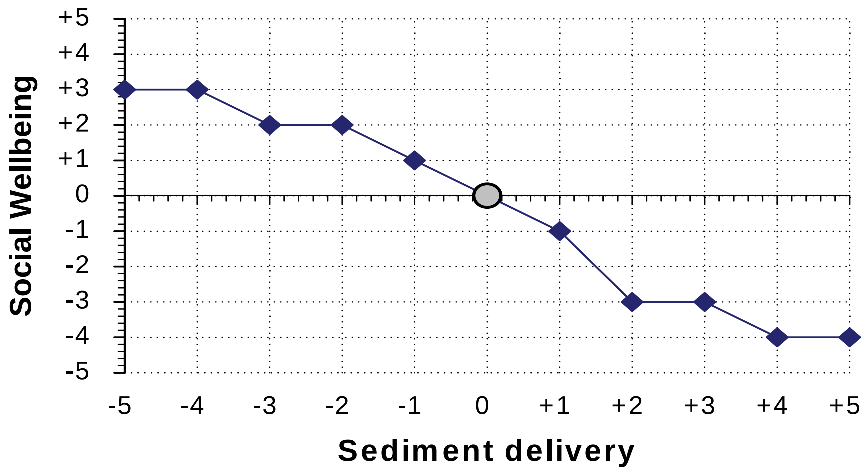
EWR 1

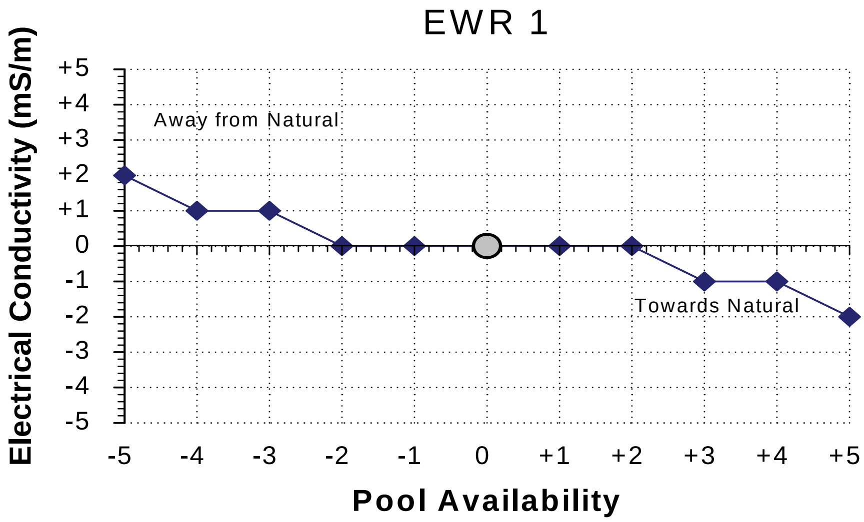


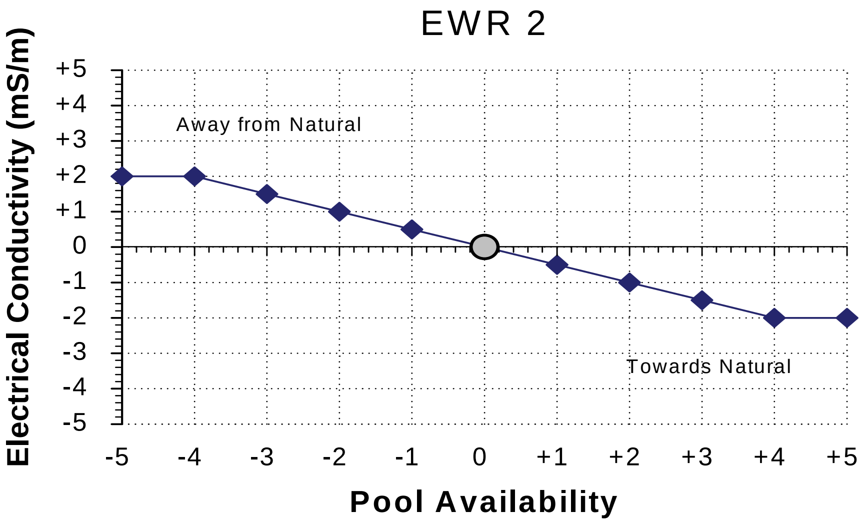
EWR 2

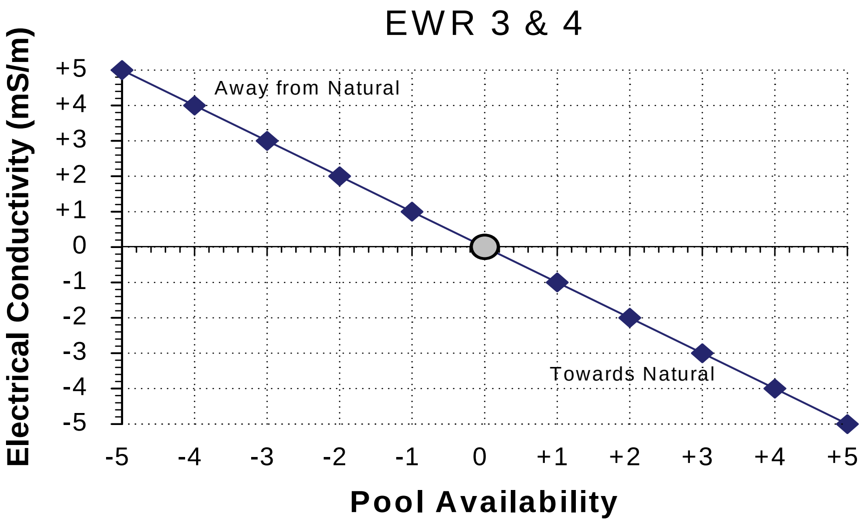


EWR 3 & 4

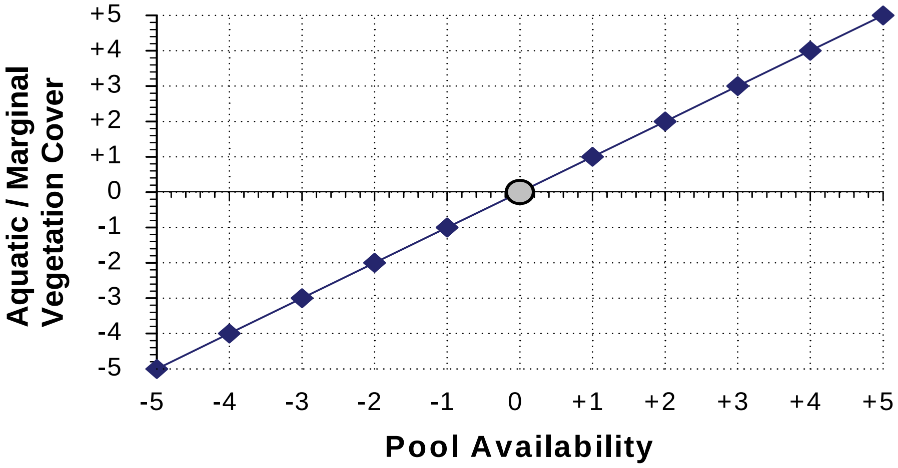



EWR 1
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

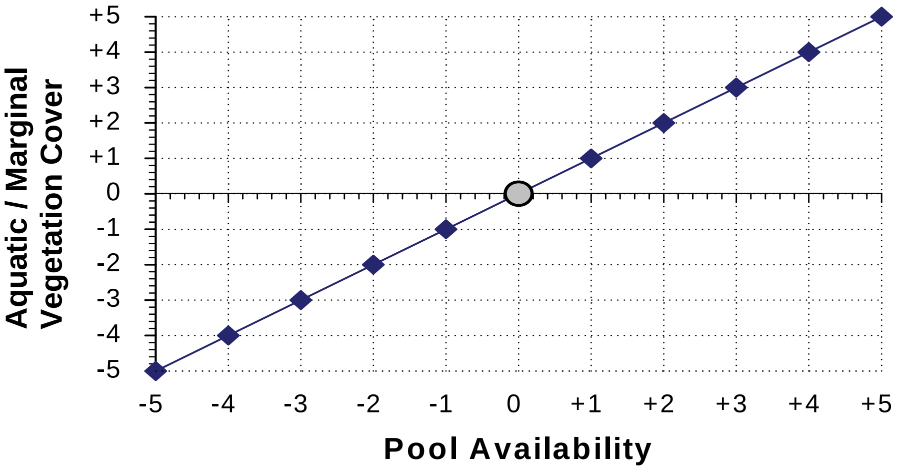

EWR 2
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability


EWR 3 & 4
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

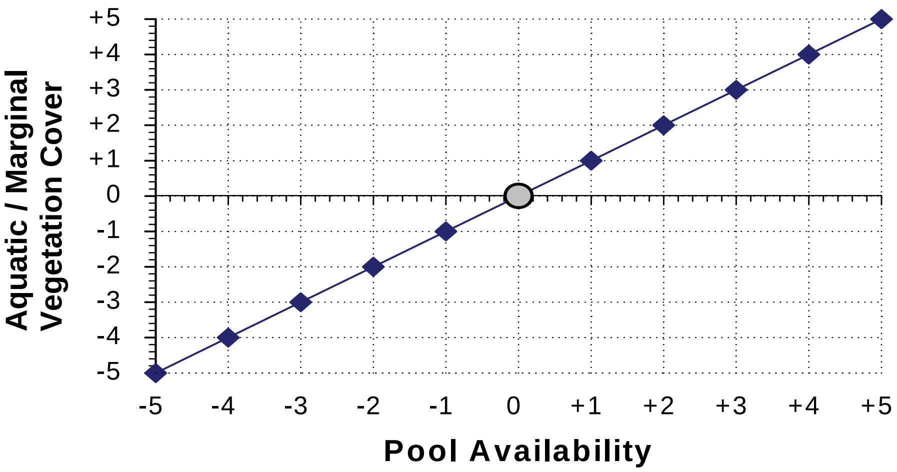
EWR 1



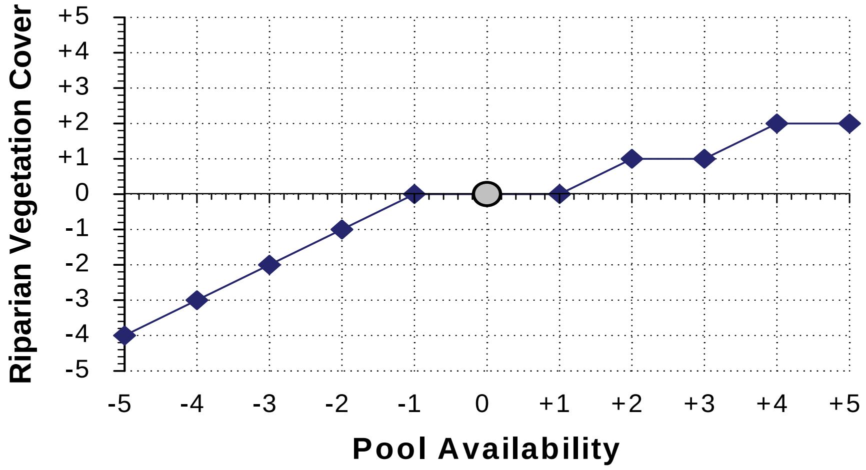
EWR 2



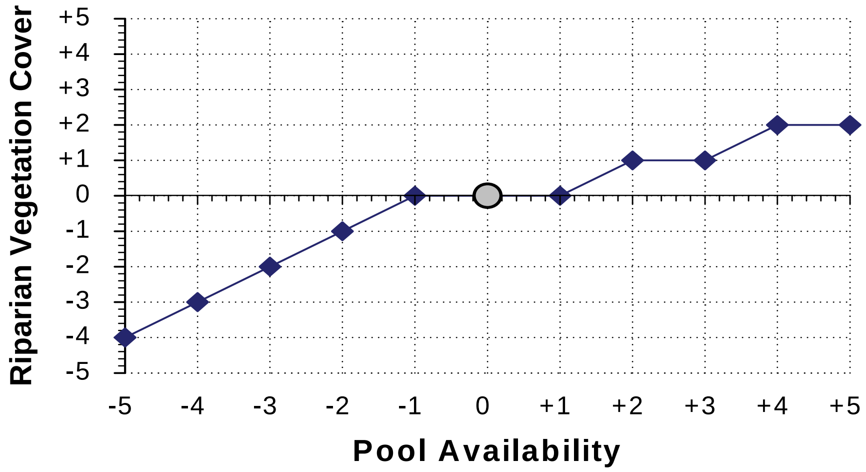
EWR 3 & 4



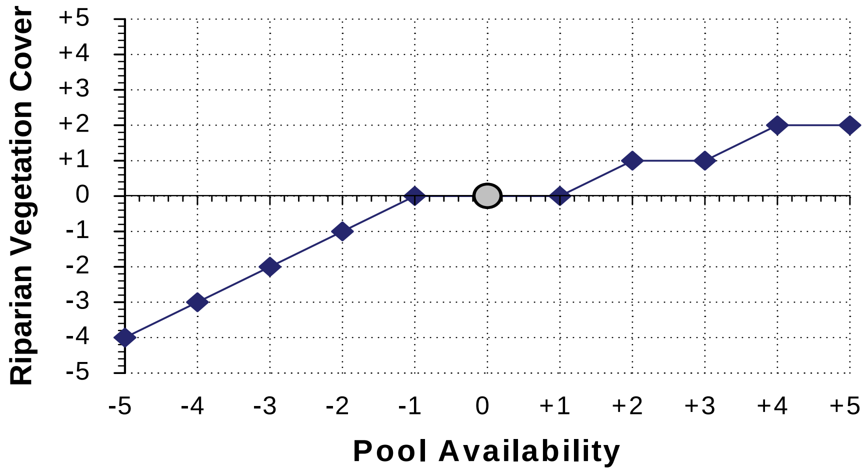
EWR 1

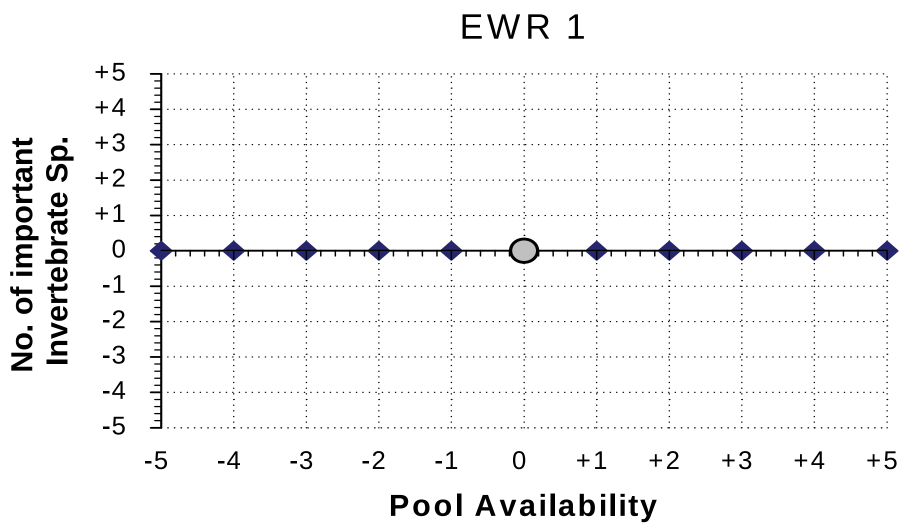


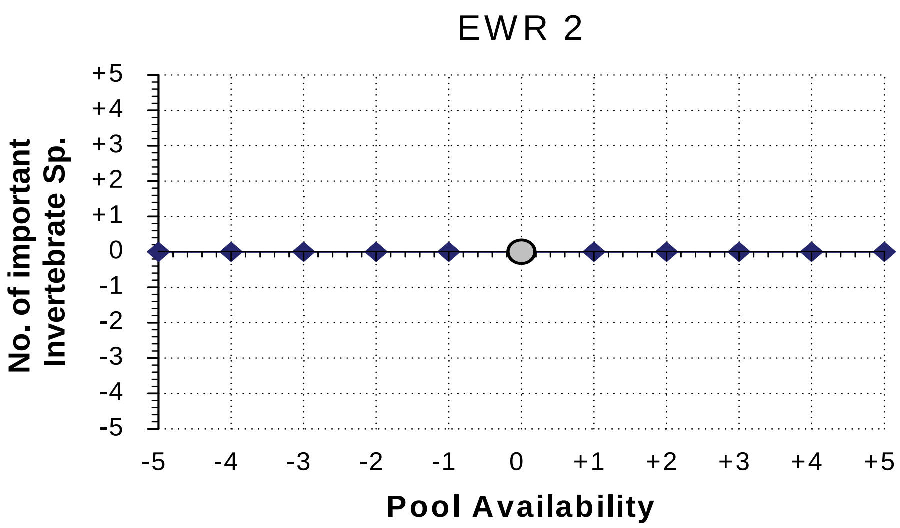
EWR 2

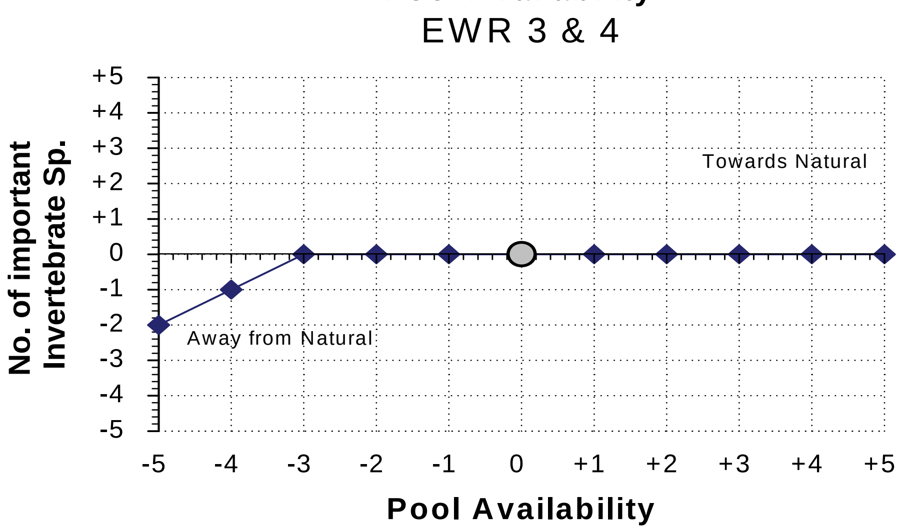


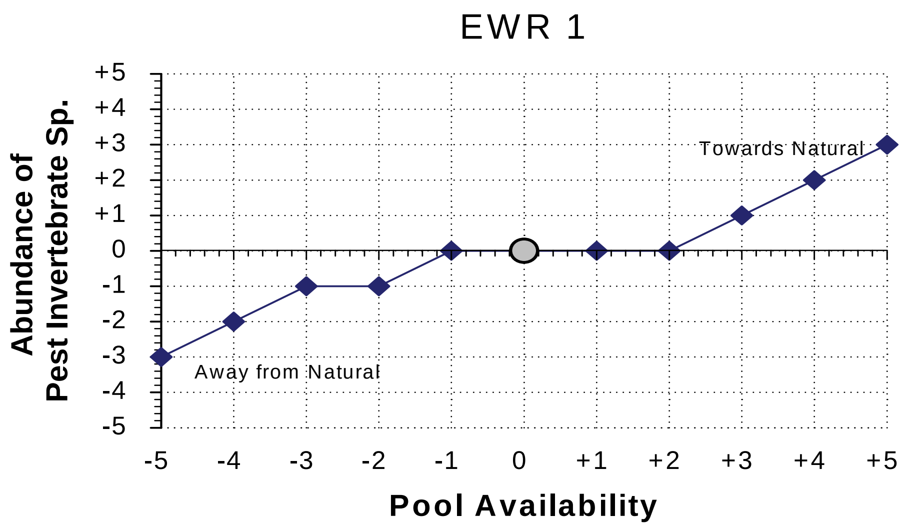
EWR 3 & 4

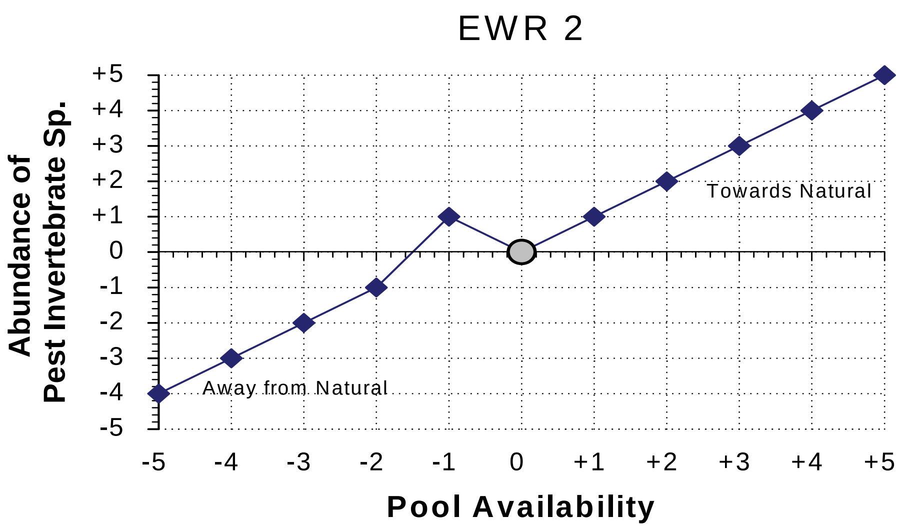


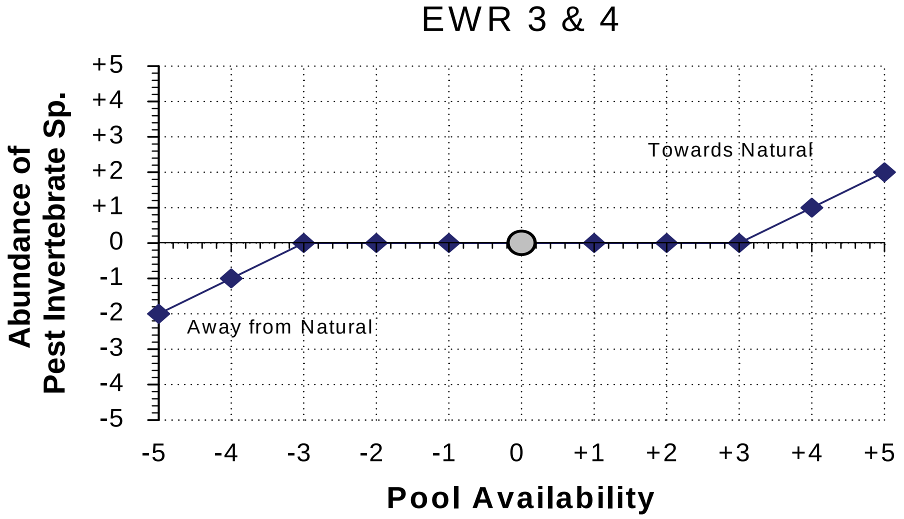

EWR 1
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability

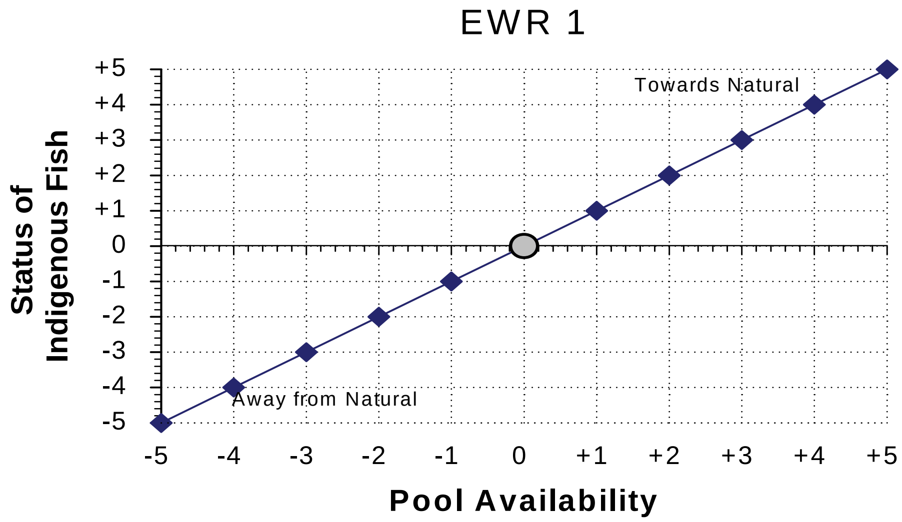

EWR 2
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability

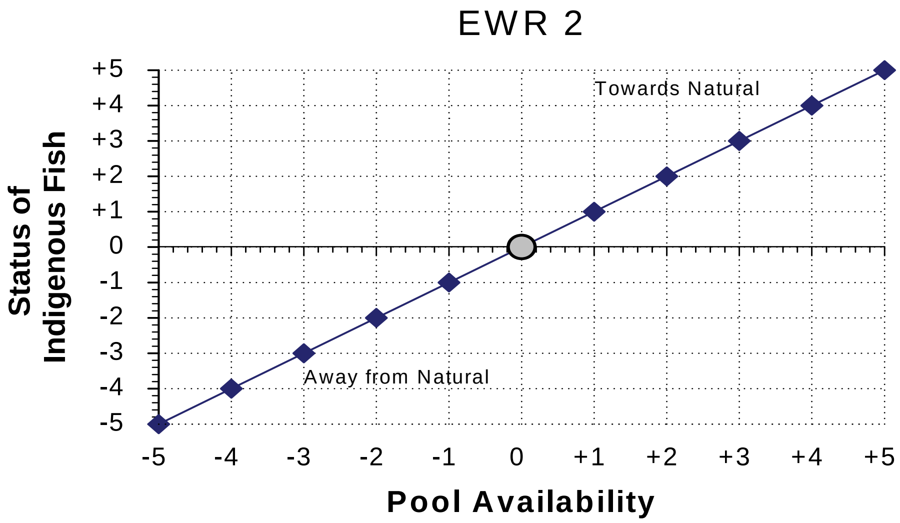

EWR 3 & 4
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability

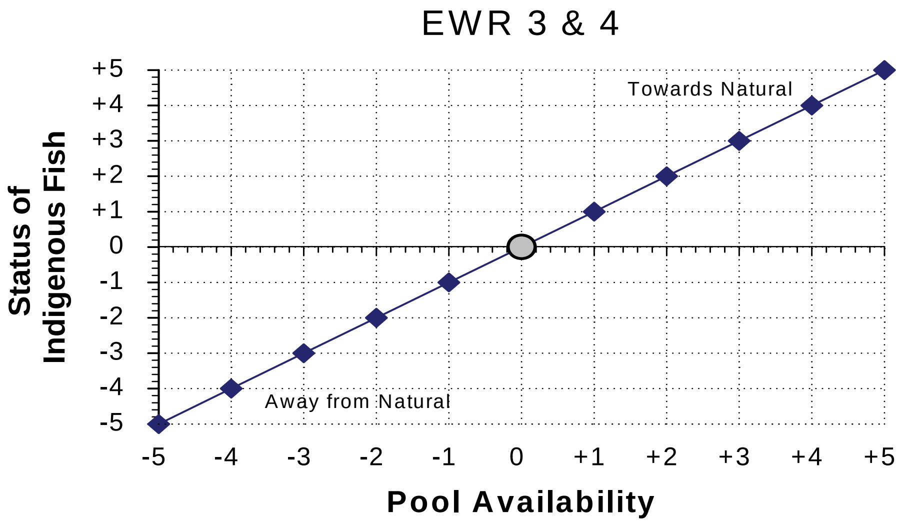

EWR 1
Abundance of
Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

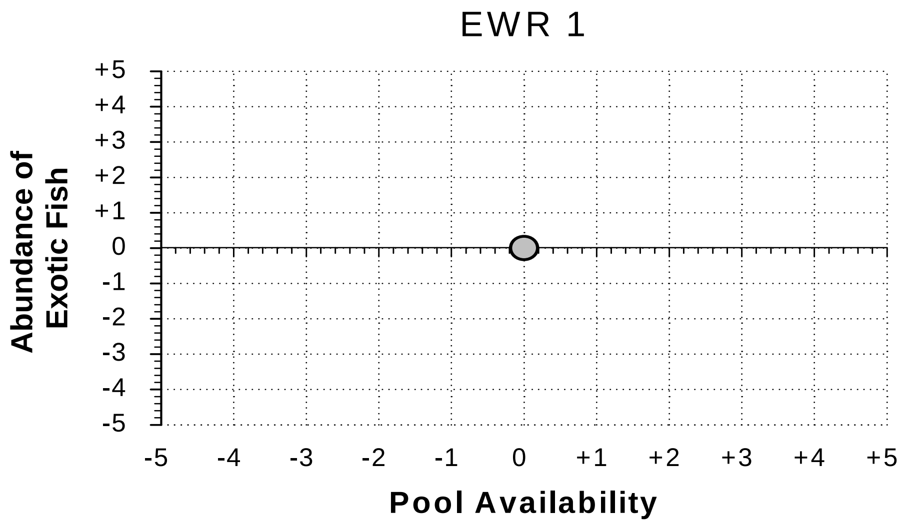

EWR 2
Abundance of
Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

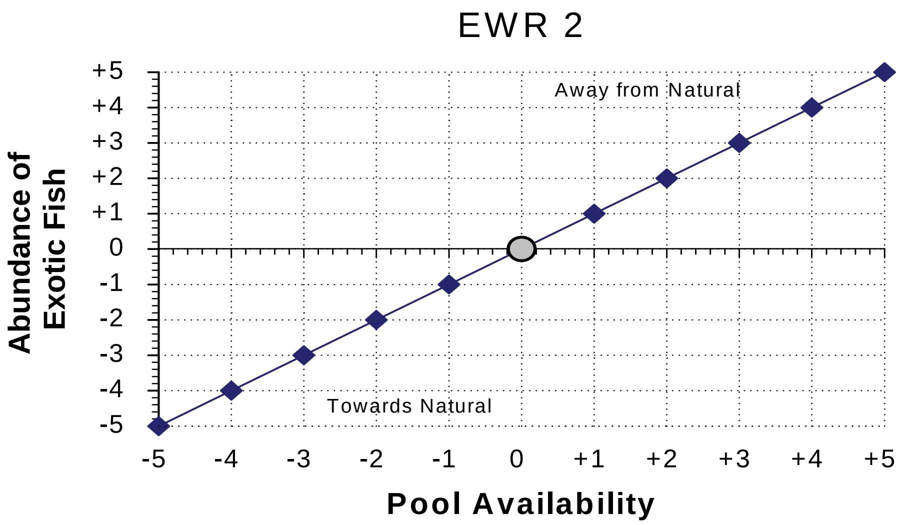

EWR 3 & 4
Abundance of
Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

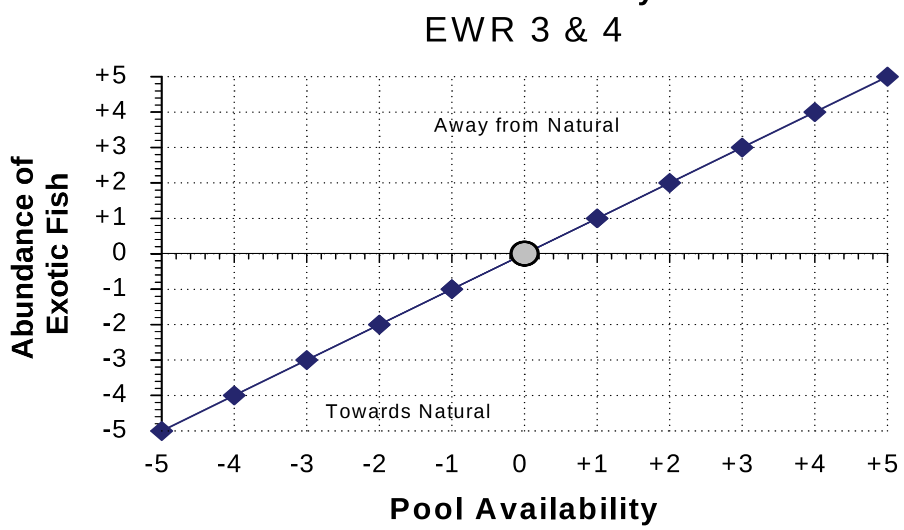

EWR 1
Status of Indigenous Fish
Towards Natural
Away from Natural
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5


EWR 2
Status of Indigenous Fish
Towards Natural
Away from Natural
Pool Availability

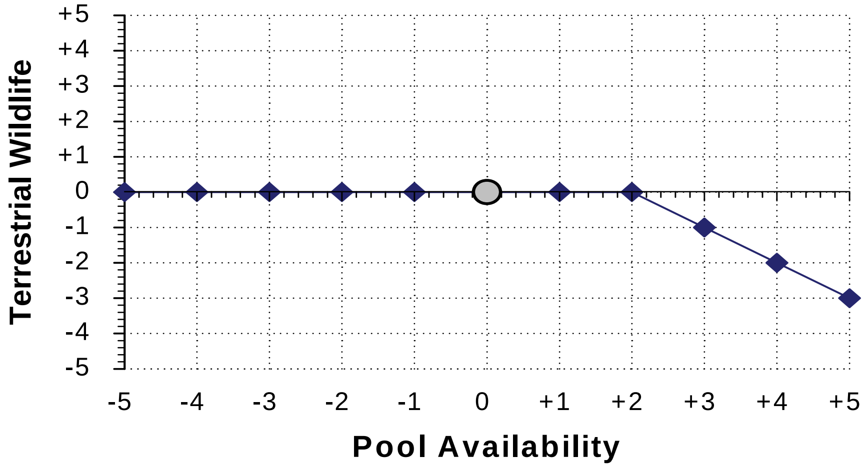

EWR 3 & 4
Status of Indigenous Fish
Towards Natural
Away from Natural
Pool Availability


EWR 1
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability

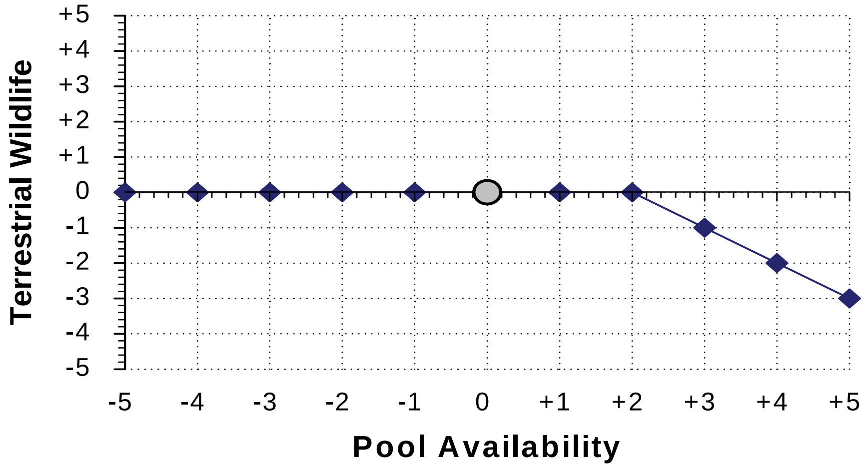

EWR 2
Abundance of Exotic Fish
Away from Natural
Towards Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability


EWR 3 & 4
Abundance of Exotic Fish
Away from Natural
Towards Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability

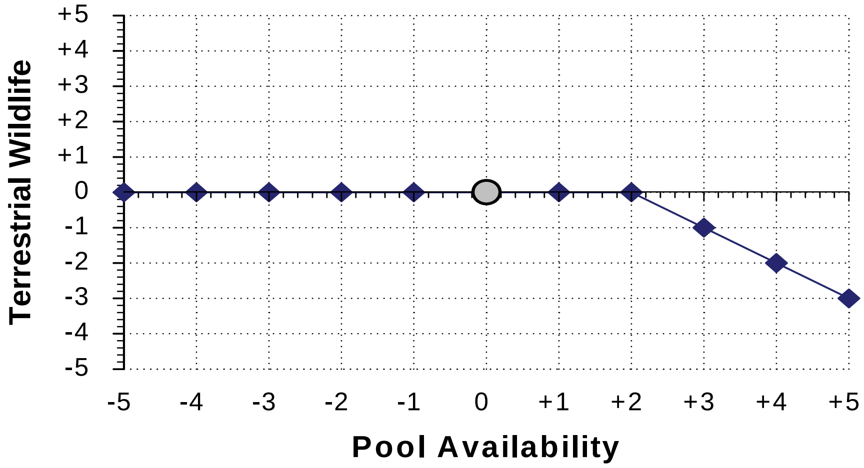
EWR 1

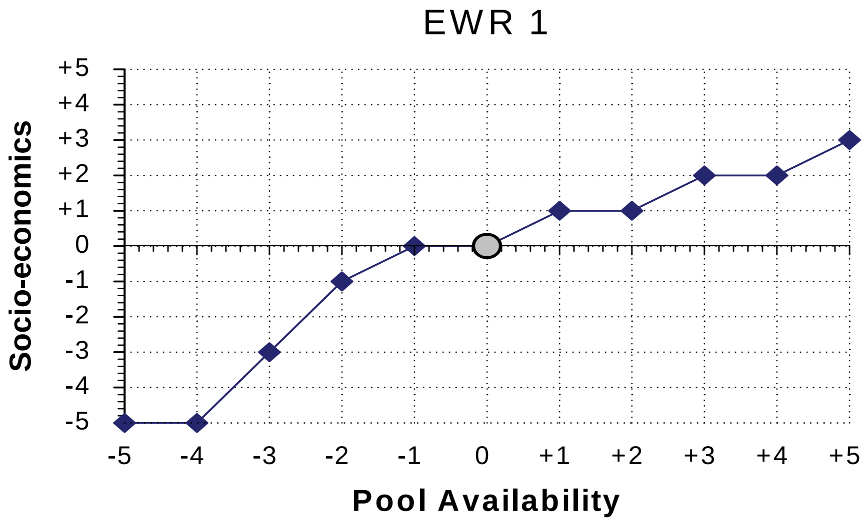


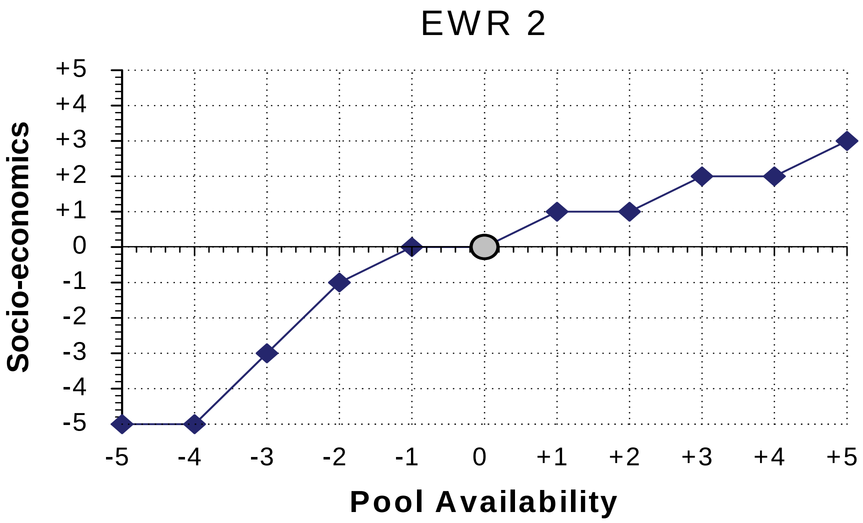
EWR 2

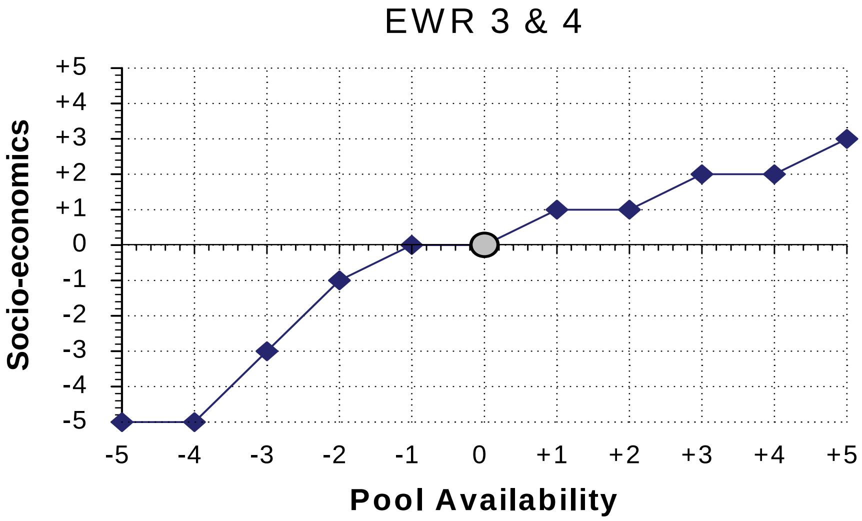


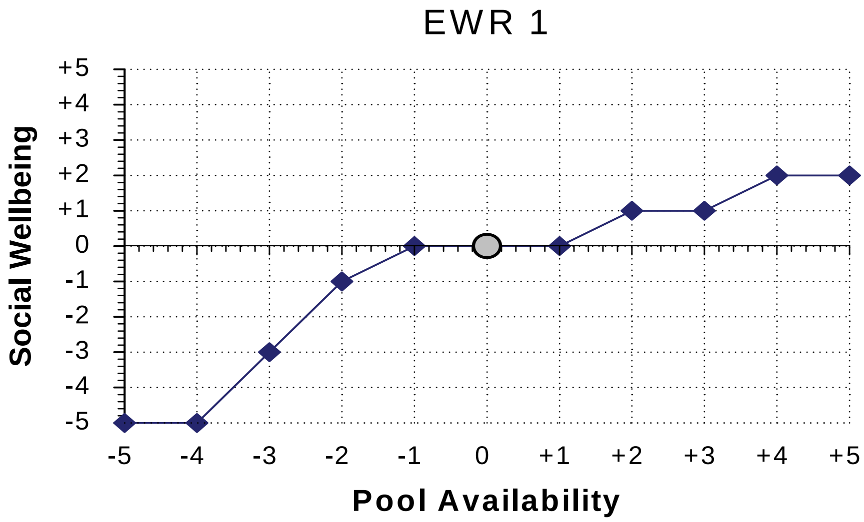
EWR 3 & 4

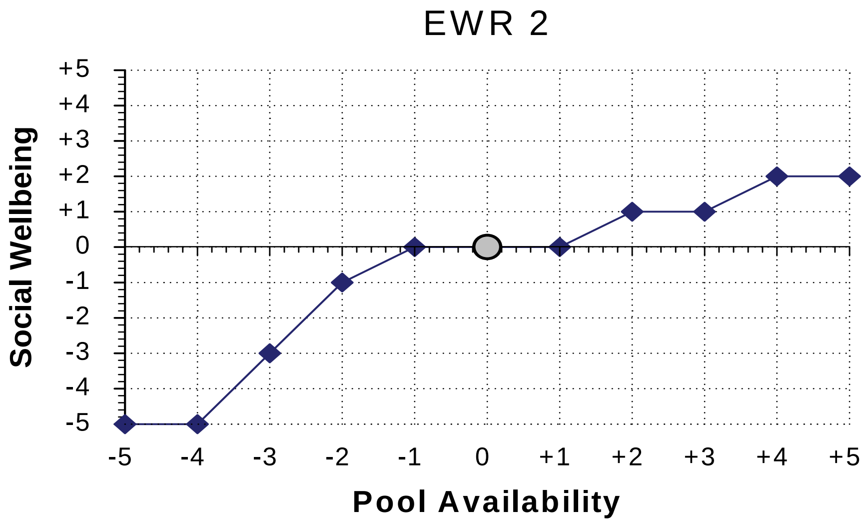


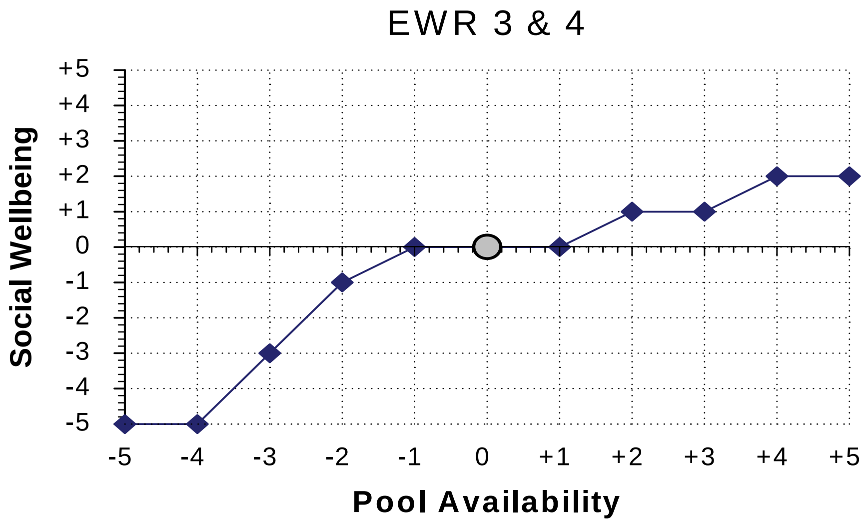

EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

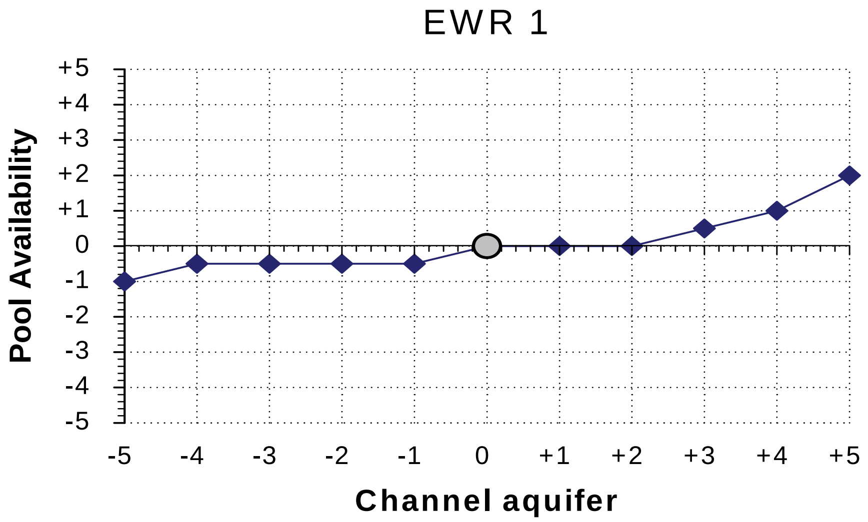

EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

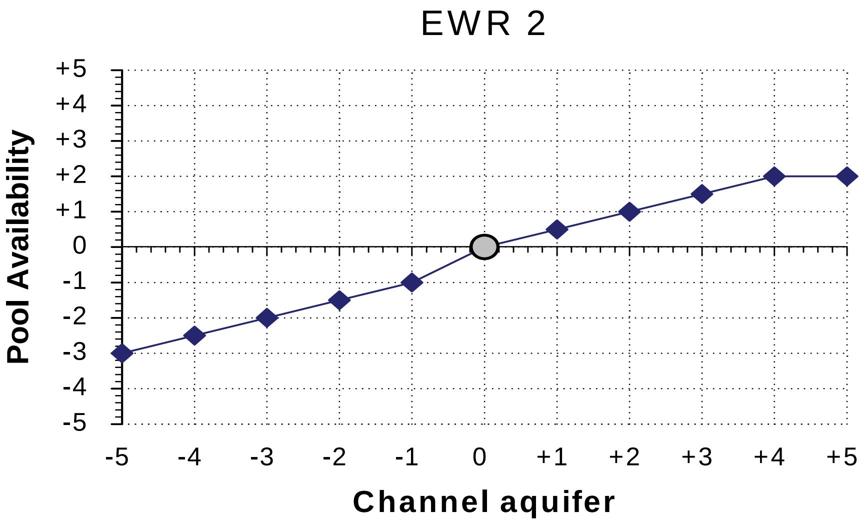

EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Pool Availability

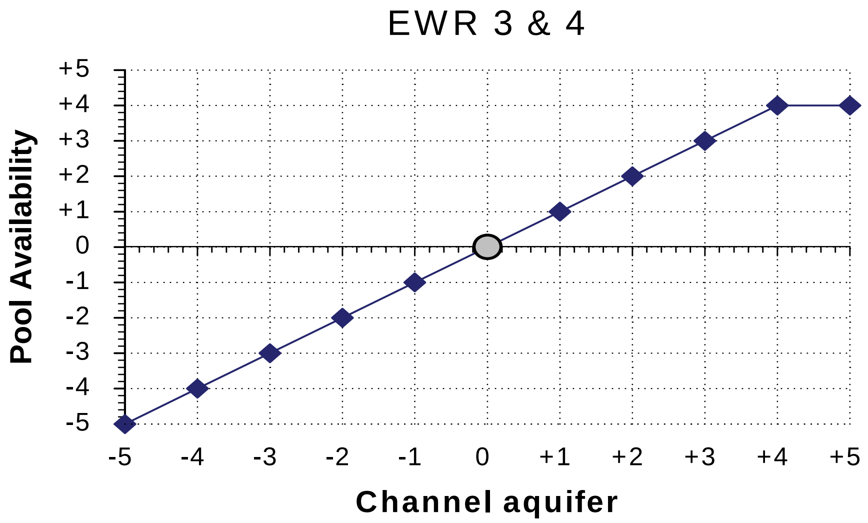

EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability

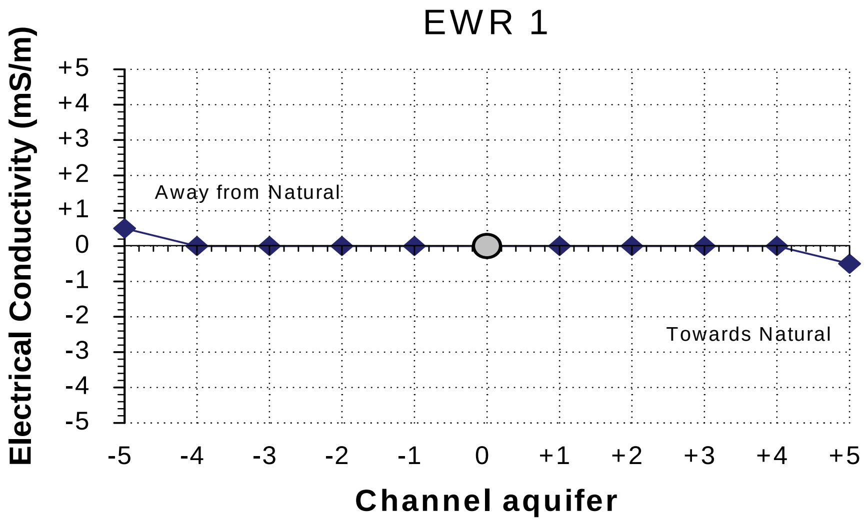

EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability


EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Pool Availability

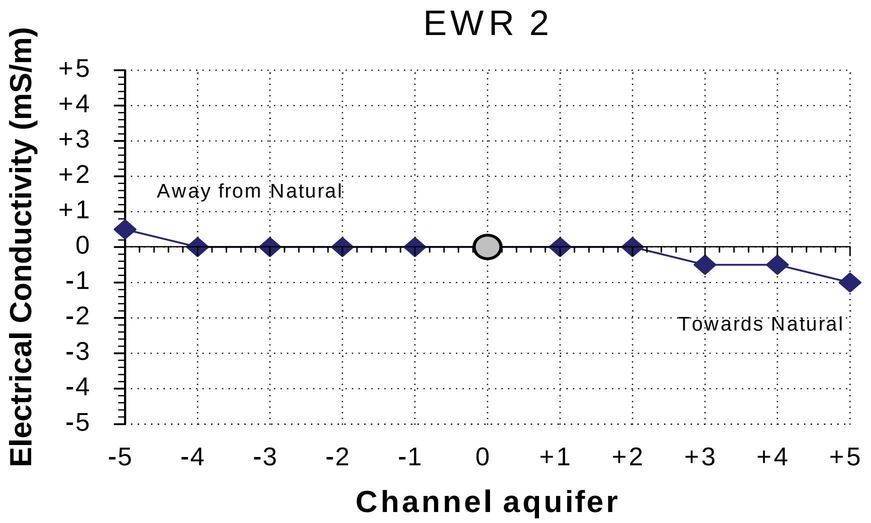

EWR 1
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer


EWR 2
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

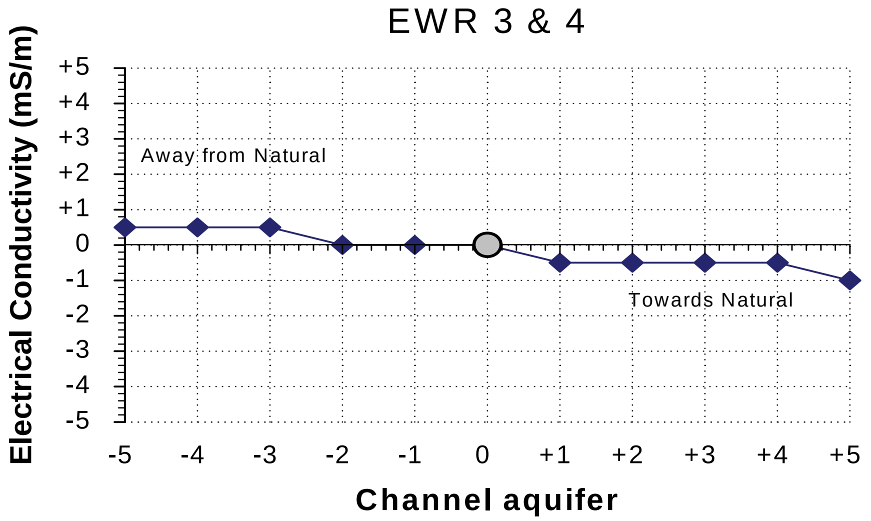

EWR 3 & 4
Pool Availability
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer



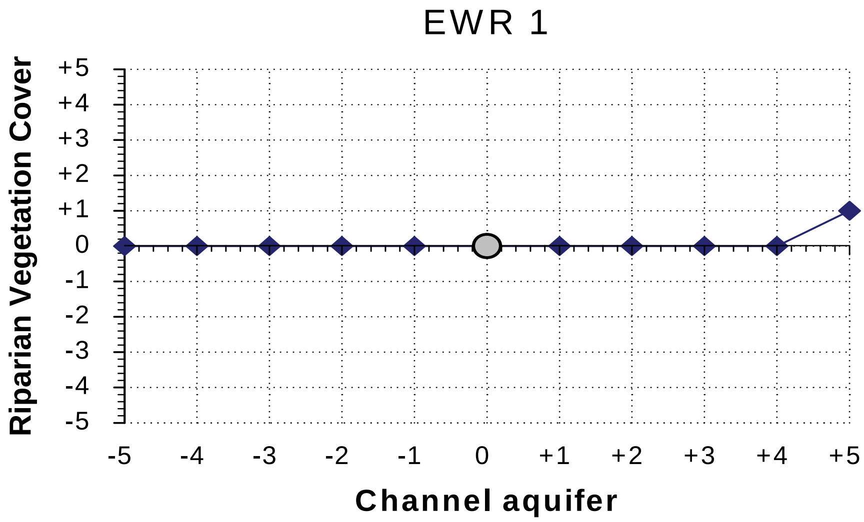
EWR 1
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel aquifer

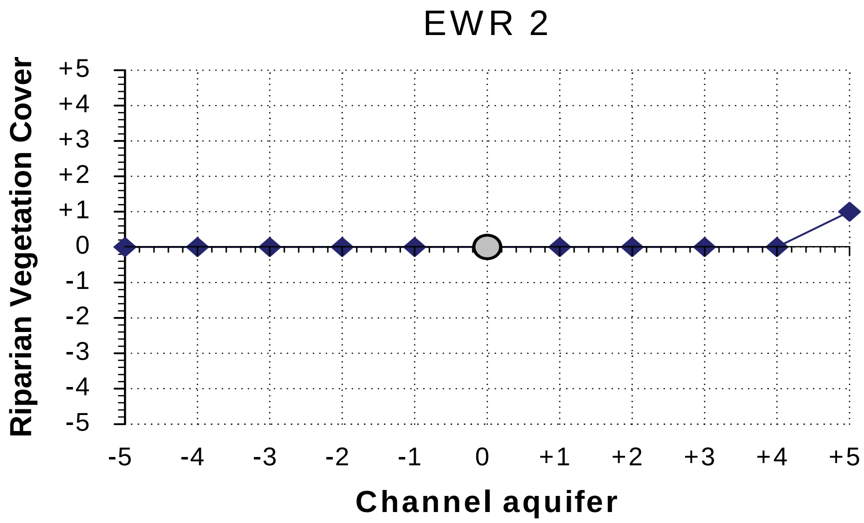


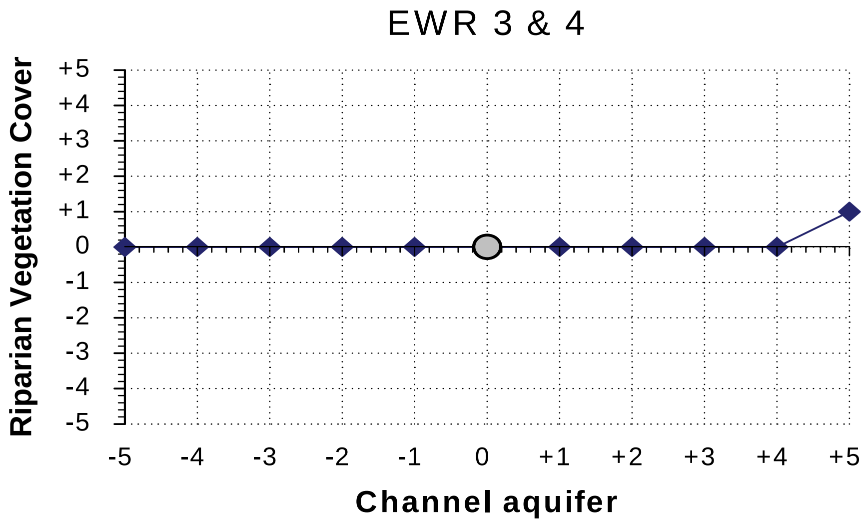
EWR 2
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel aquifer

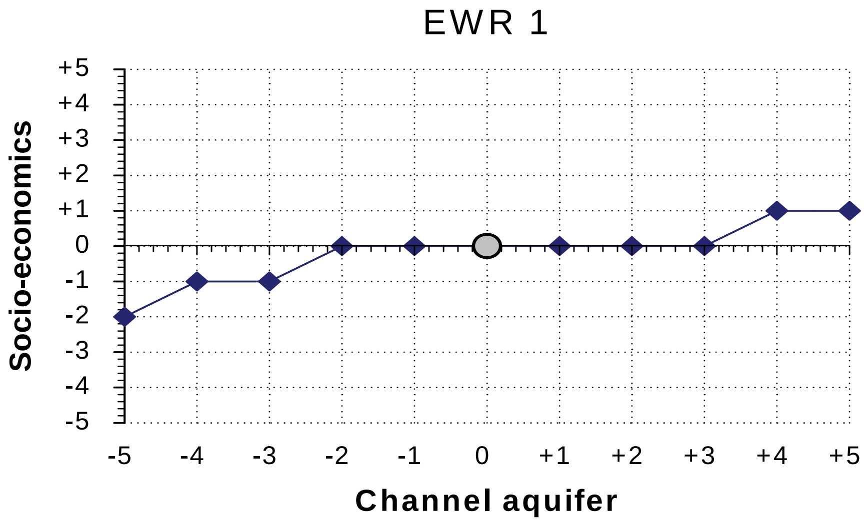


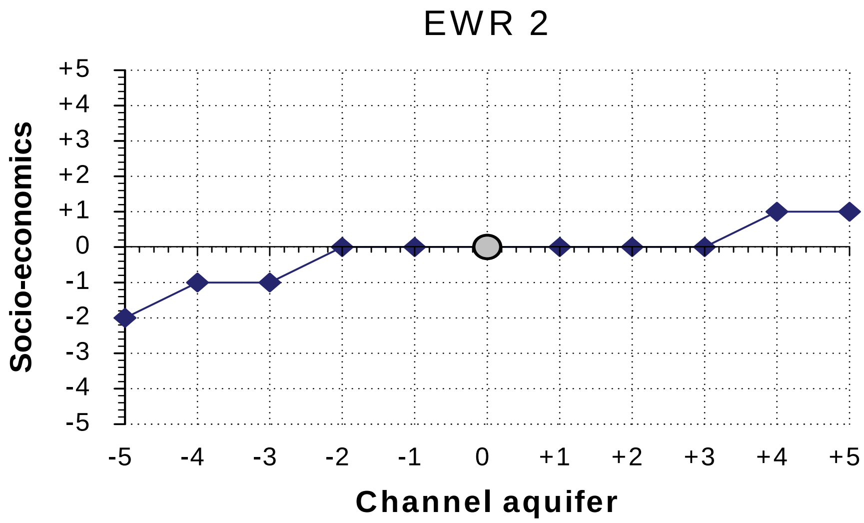
EWR 3 & 4
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Channel aquifer

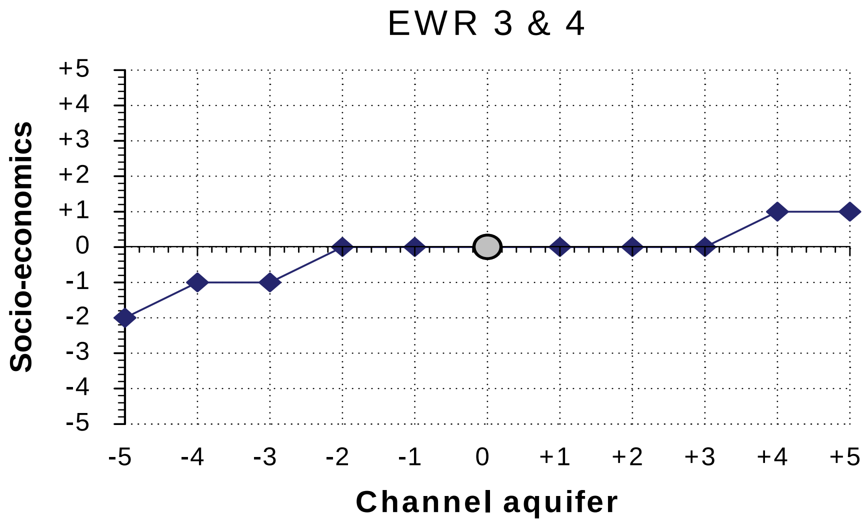

EWR 1
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

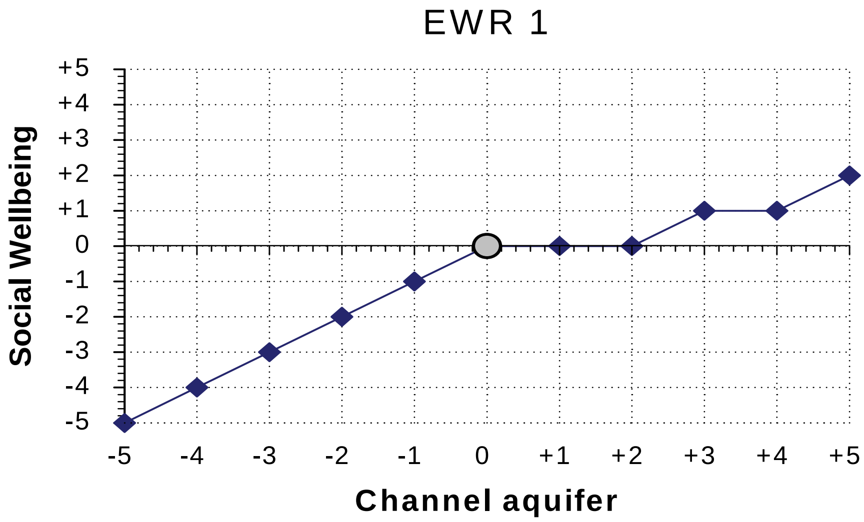

EWR 2
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

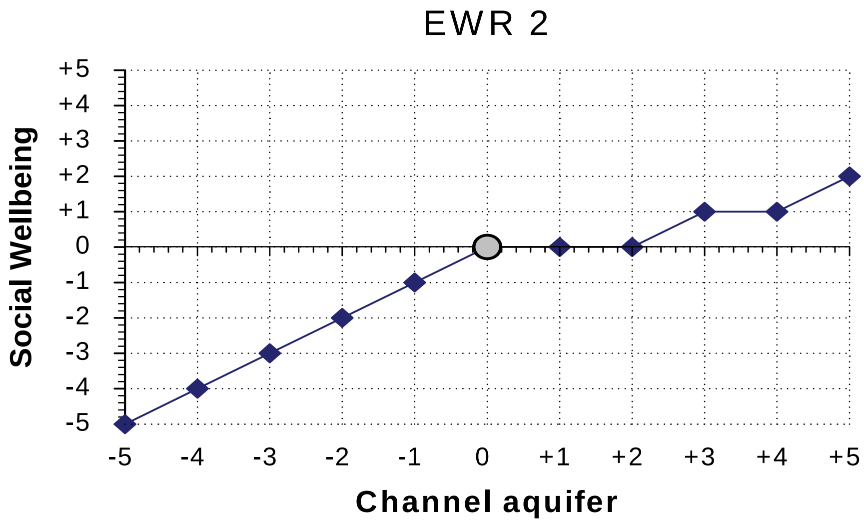

EWR 3 & 4
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

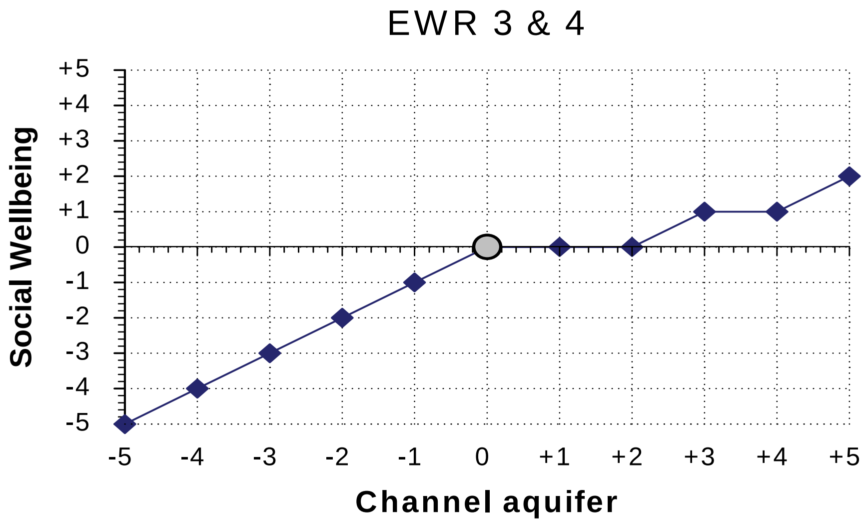

EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

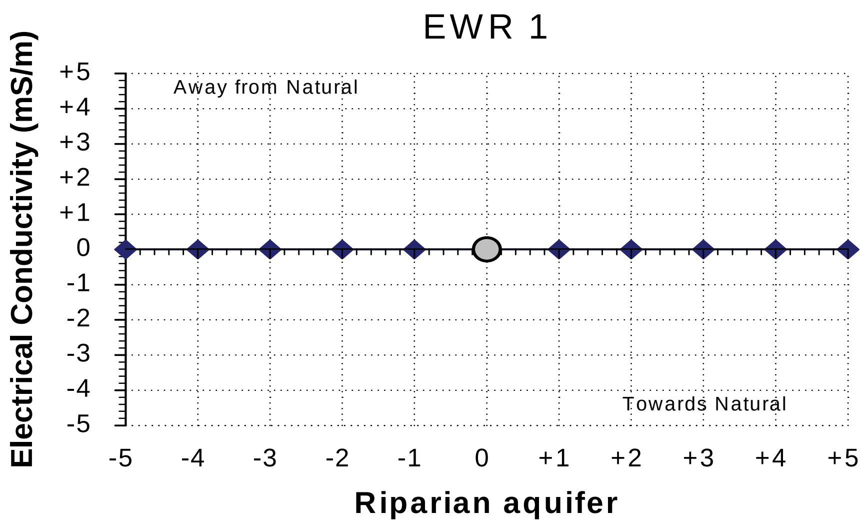

EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

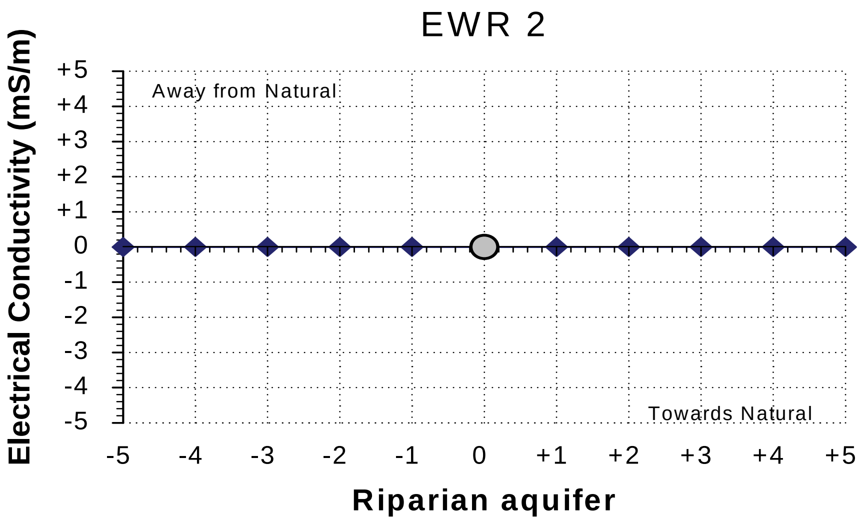

EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

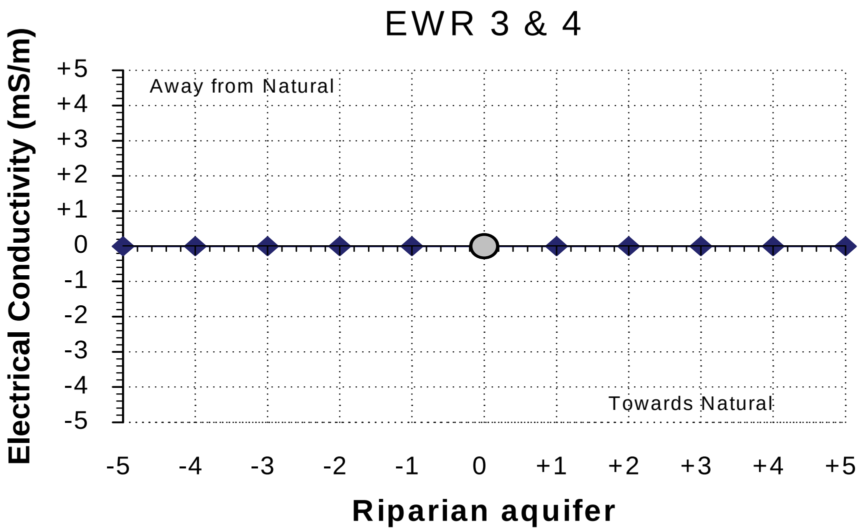

EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

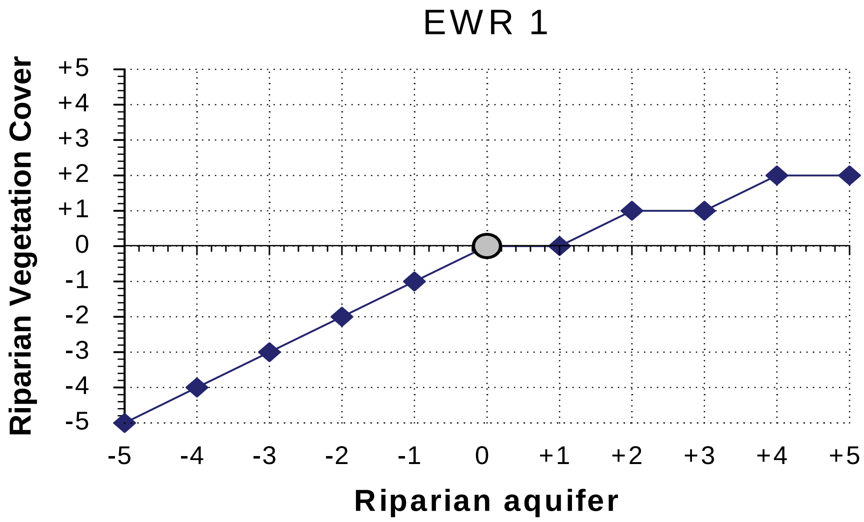

EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

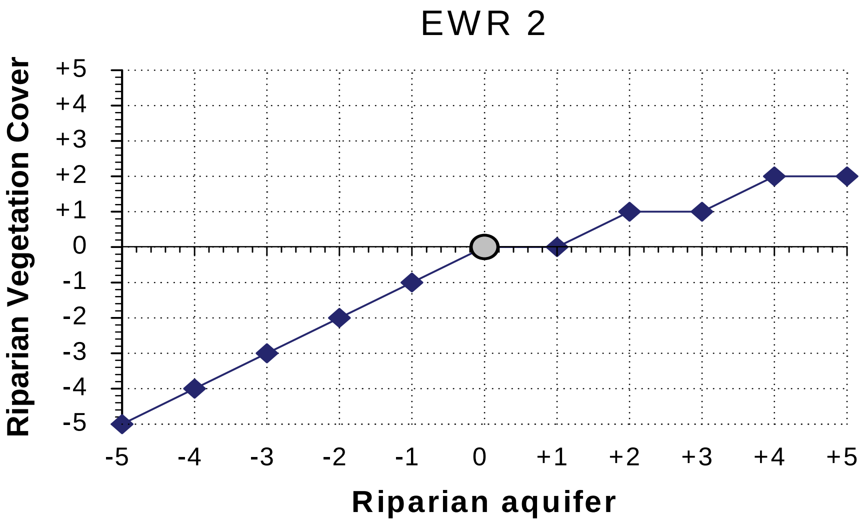

EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Channel aquifer

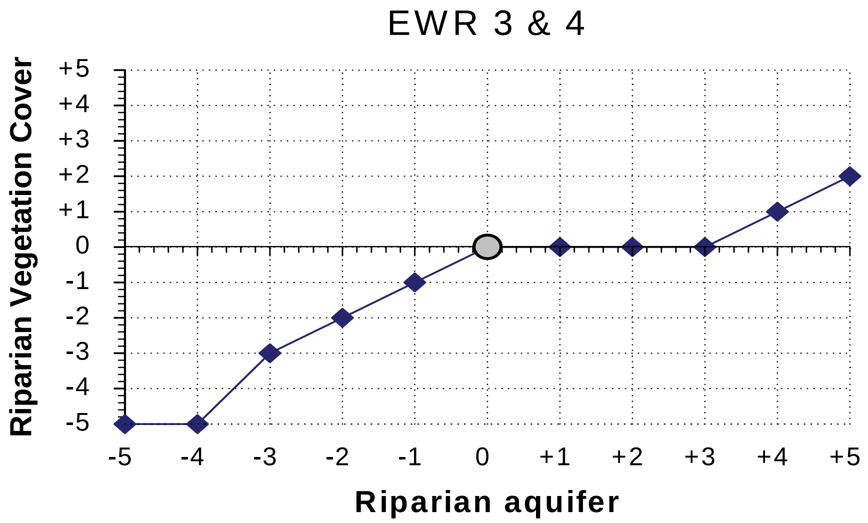

EWR 1
Away from Natural
Towards Natural
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

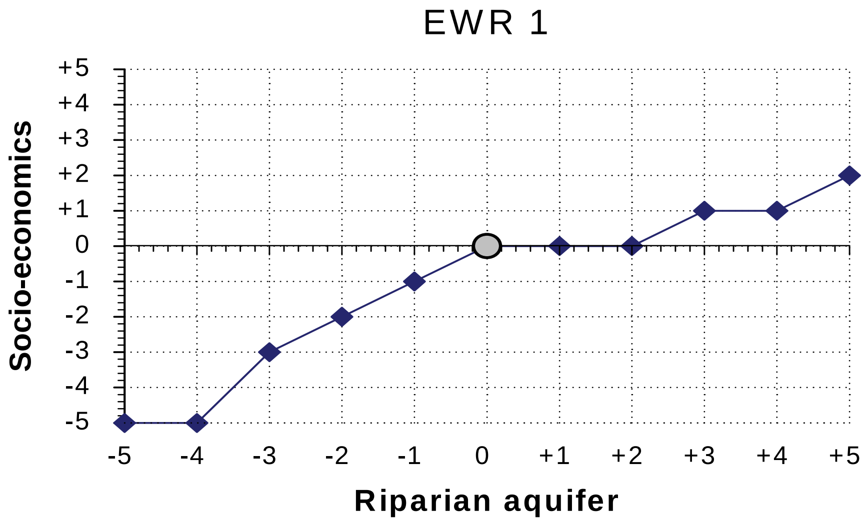

EWR 2
Away from Natural
Towards Natural
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

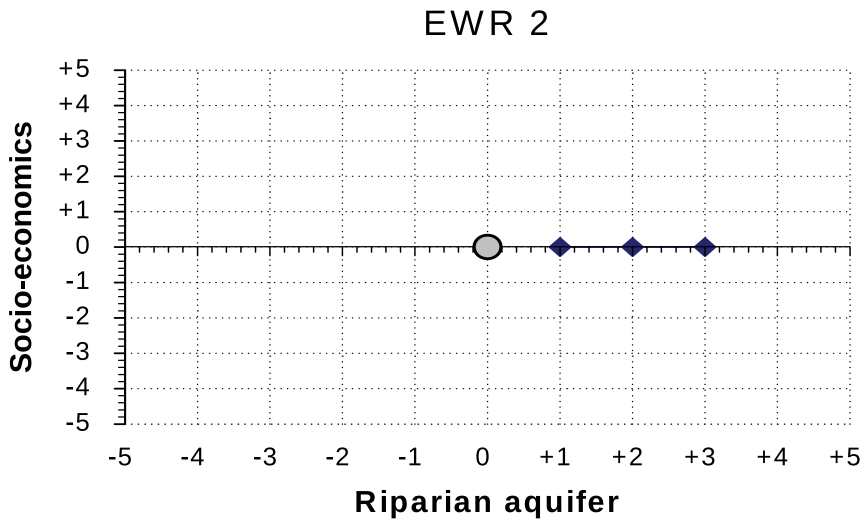

EWR 3 & 4
Away from Natural
Towards Natural
Electrical Conductivity (mS/m)
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

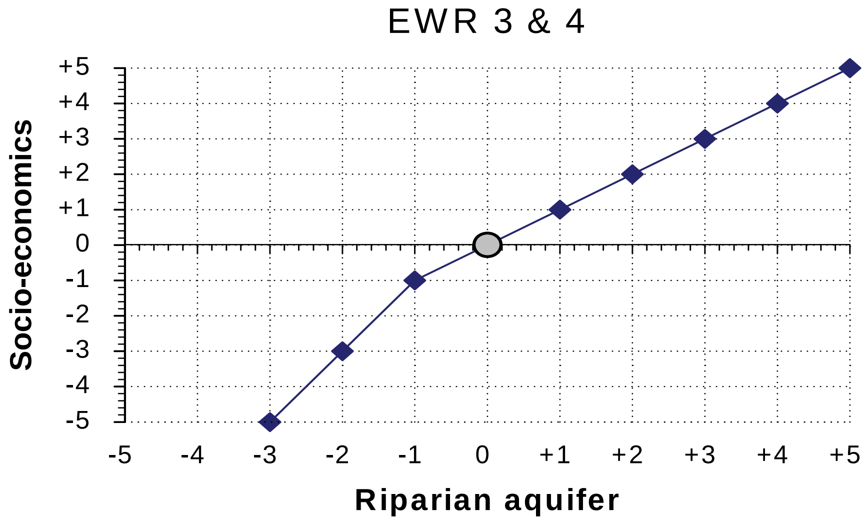

EWR 1
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

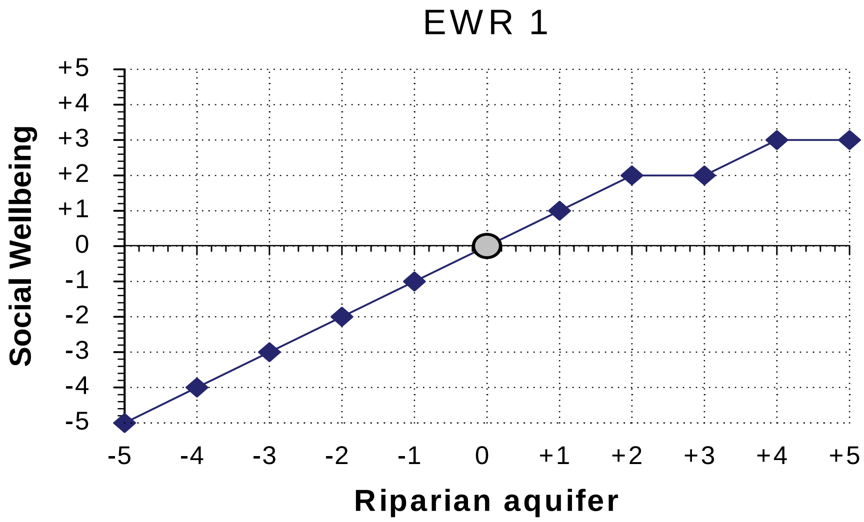

EWR 2
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

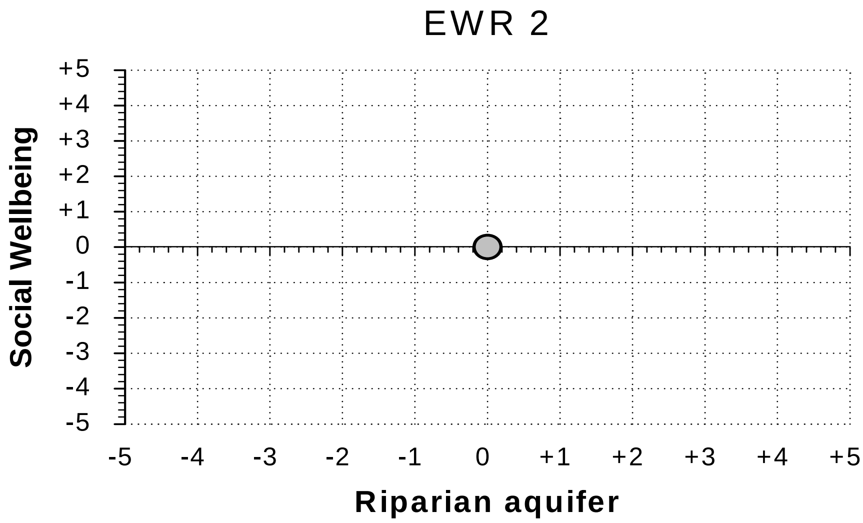

EWR 3 & 4
Riparian Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

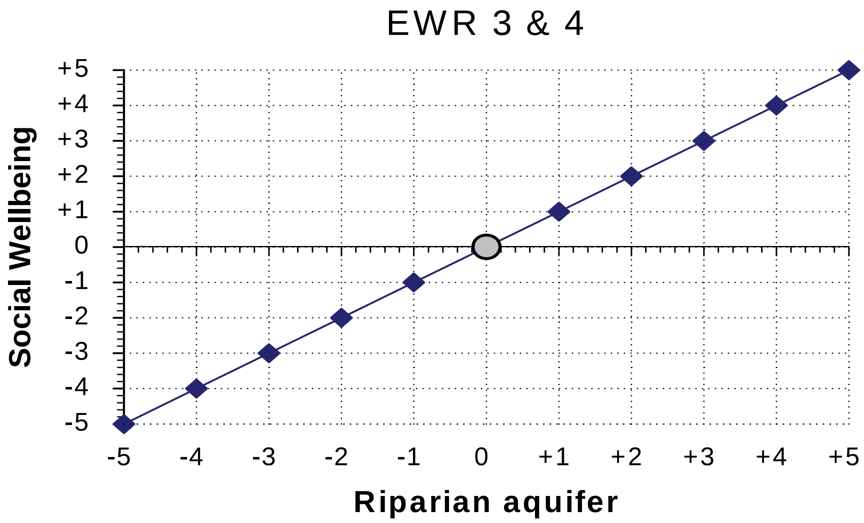

EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

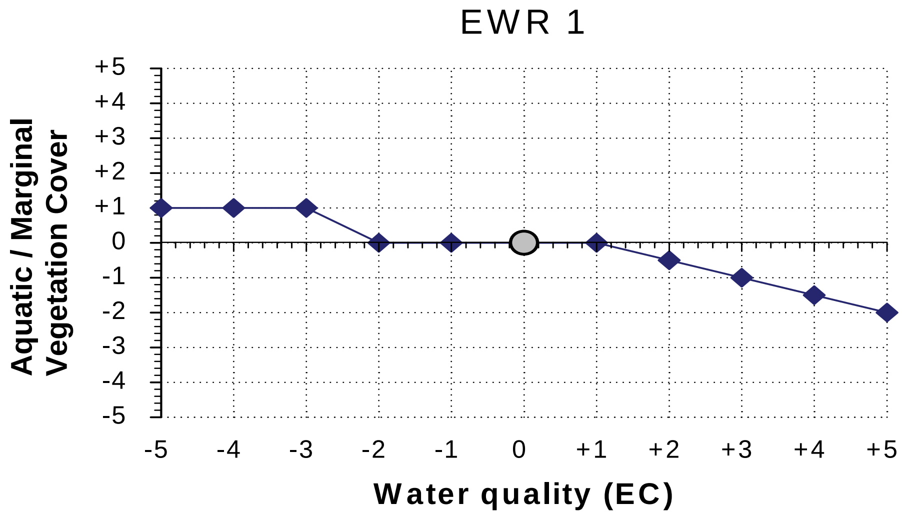

EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

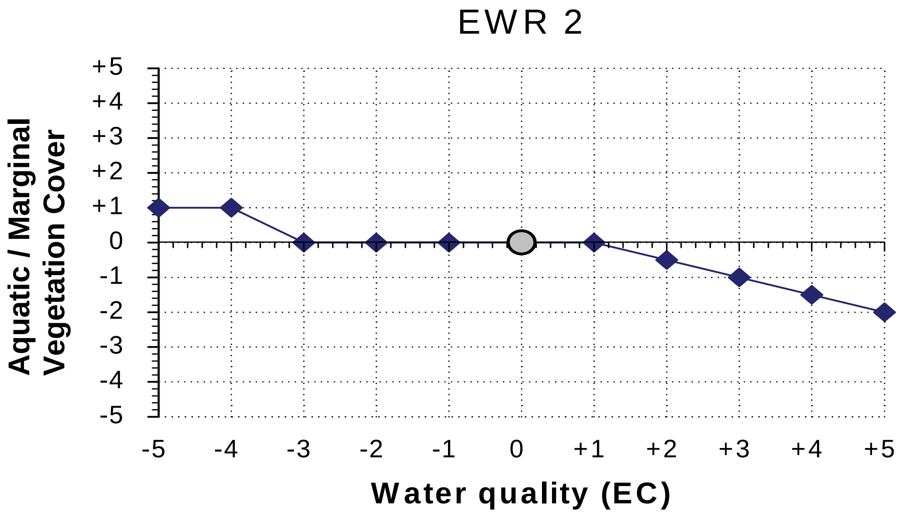

EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

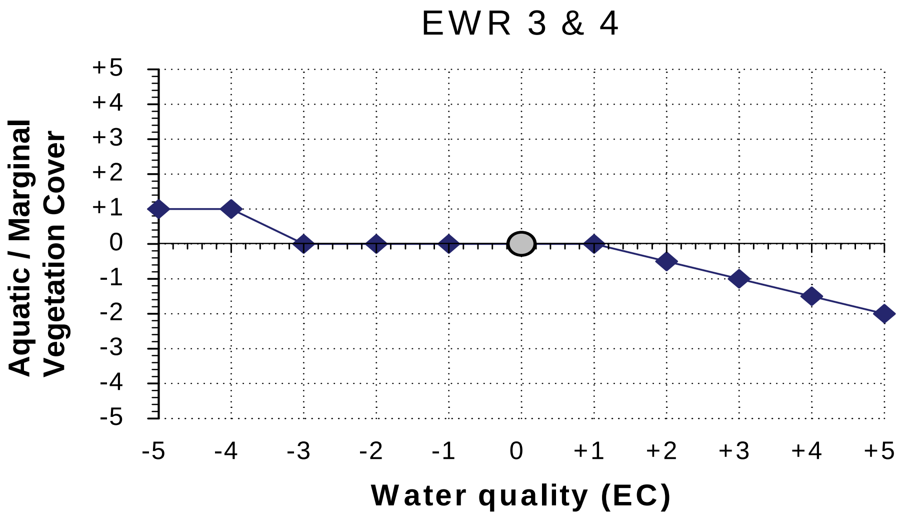

EWR 1
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Social Wellbeing
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

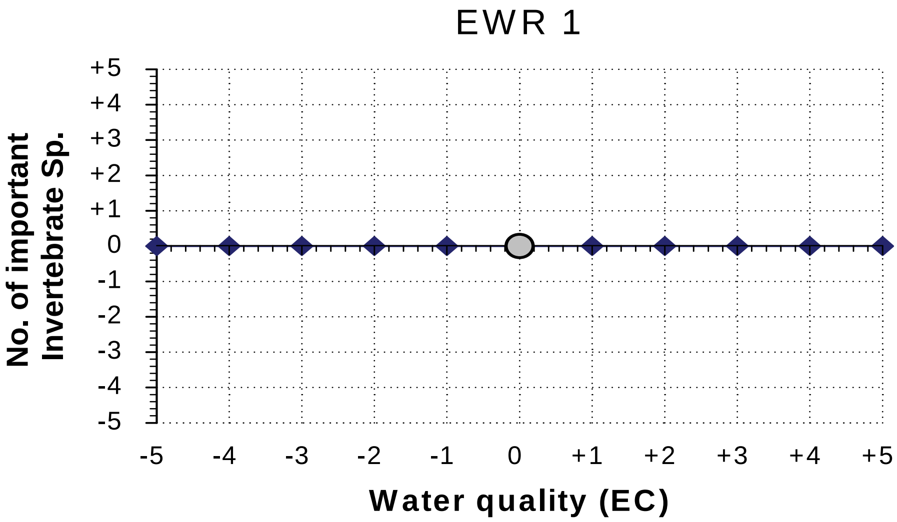

EWR 2
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Social Wellbeing
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

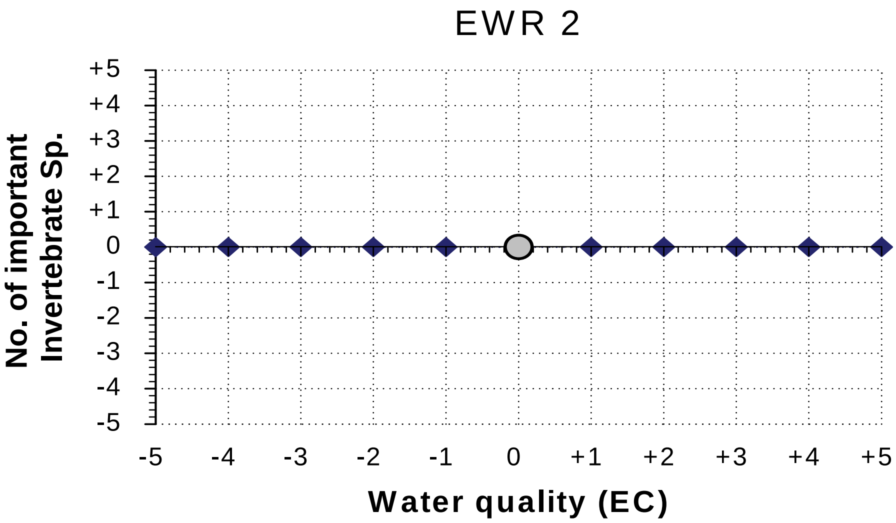

EWR 3 & 4
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Social Wellbeing
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian aquifer

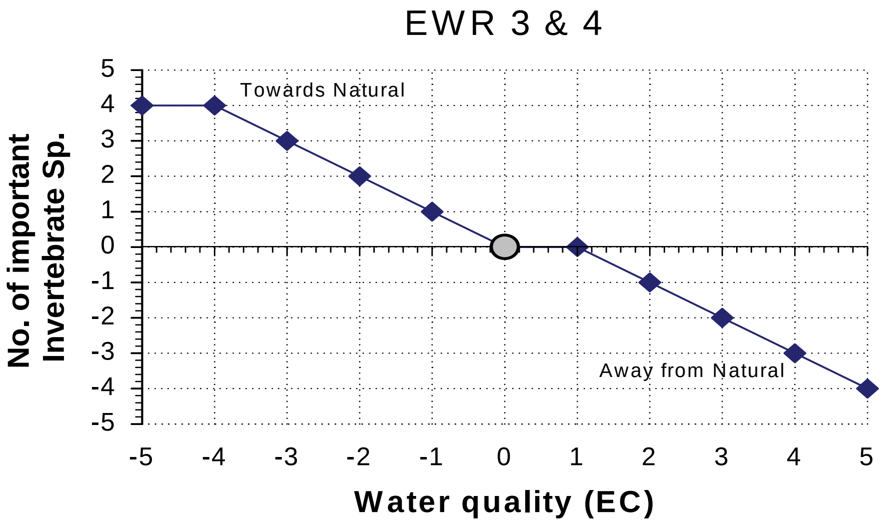

EWR 1
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

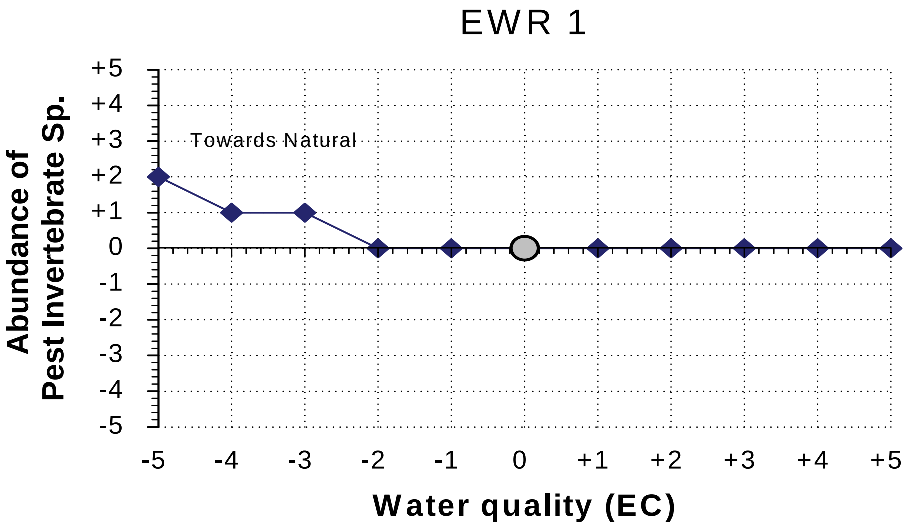

EWR 2
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

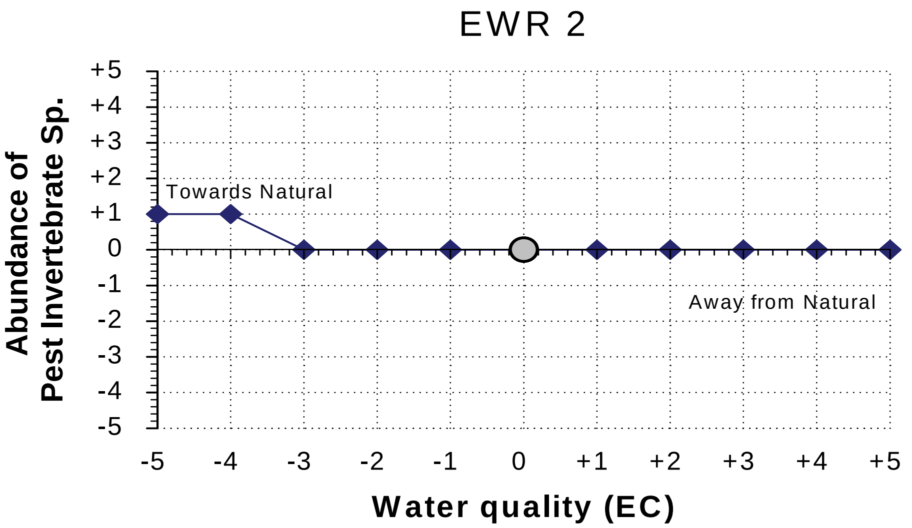

EWR 3 & 4
Aquatic / Marginal Vegetation Cover
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

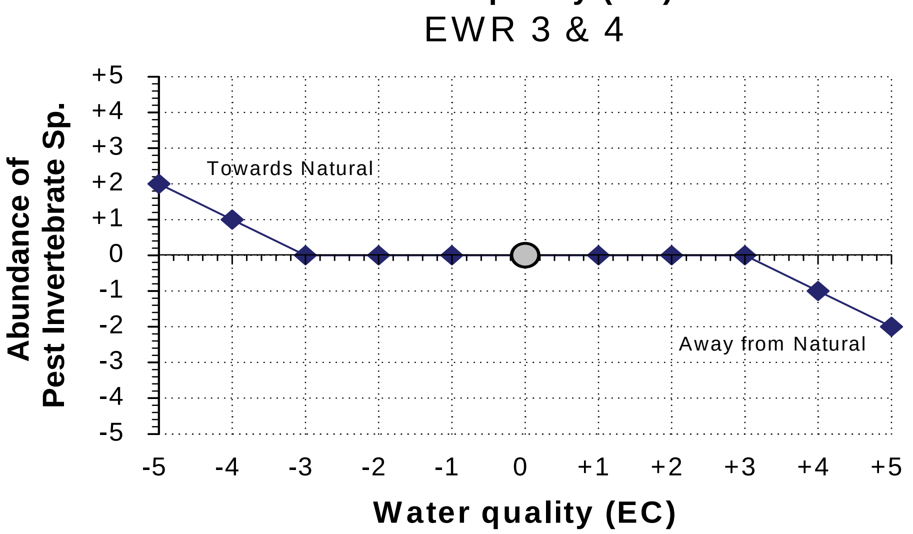

EWR 1
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

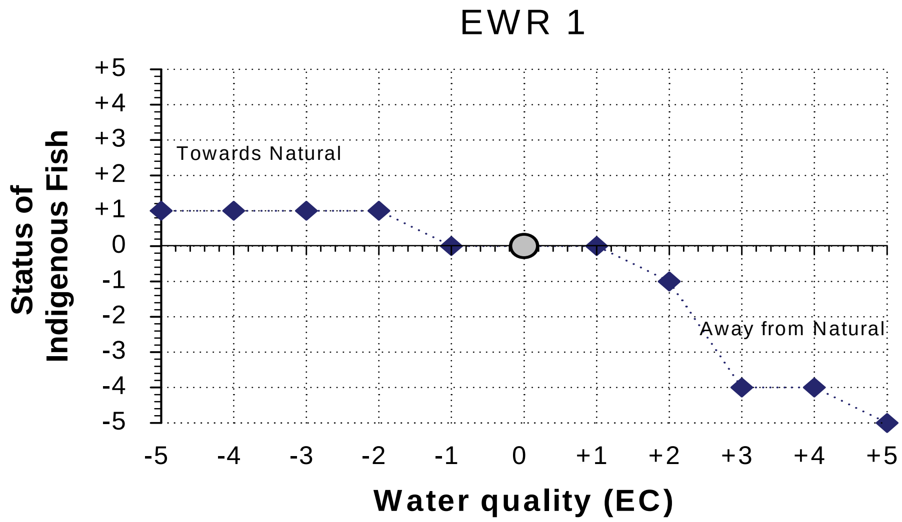

EWR 2
No. of important Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

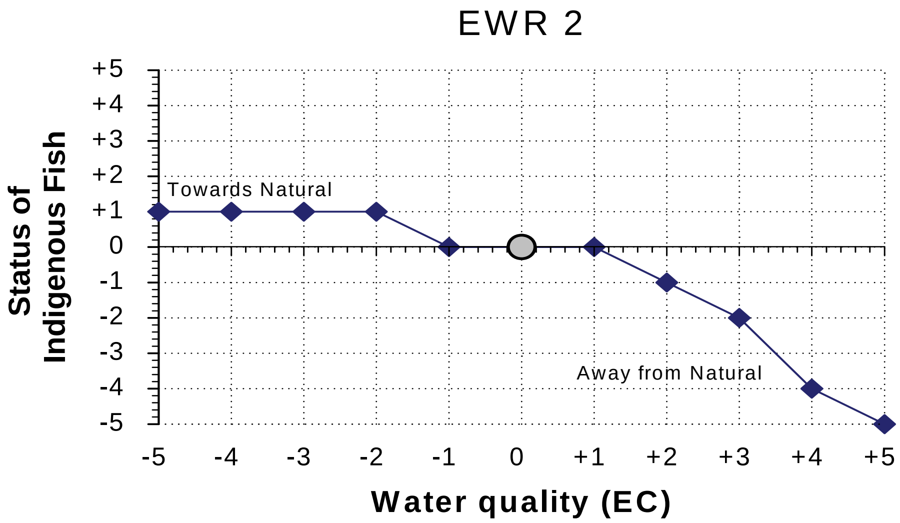

EWR 3 & 4
No. of important Invertebrate Sp.
5
4
3
2
1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 1 2 3 4 5
Water quality (EC)

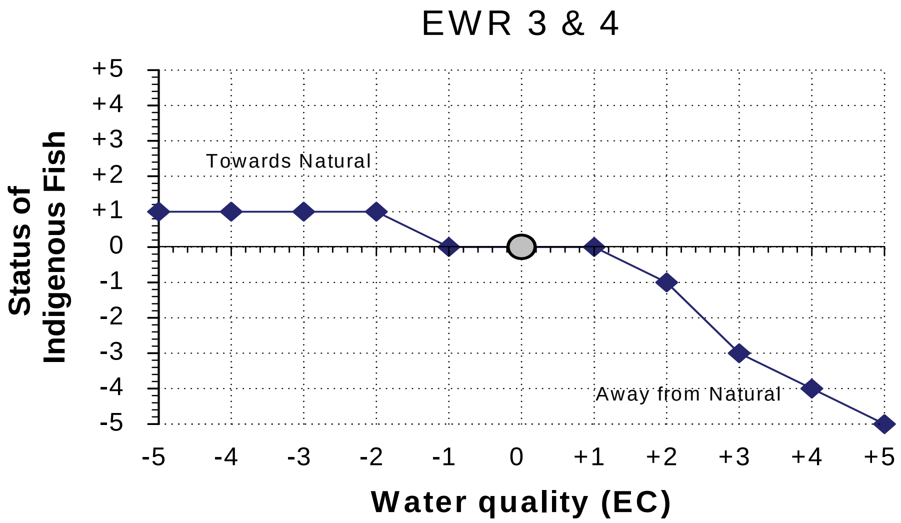

EWR 1
Abundance of
Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Water quality (EC)

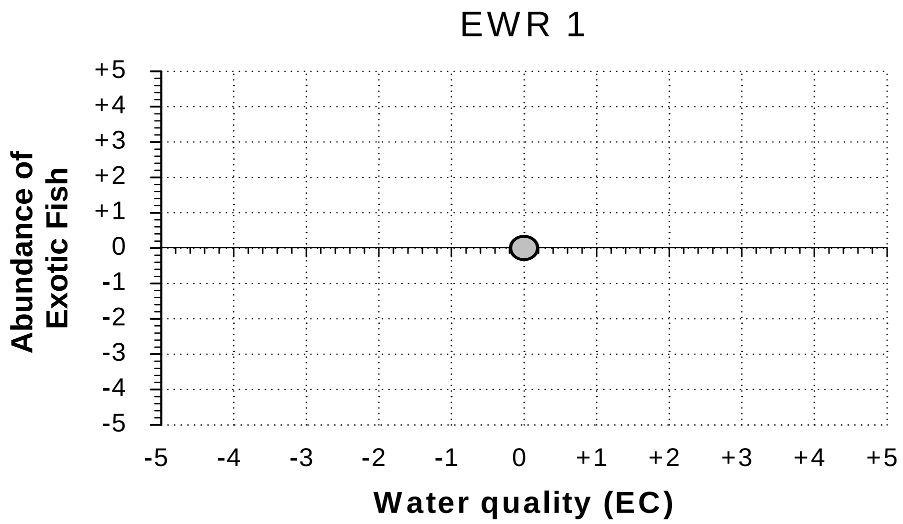

EWR 2
Abundance of
Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Water quality (EC)

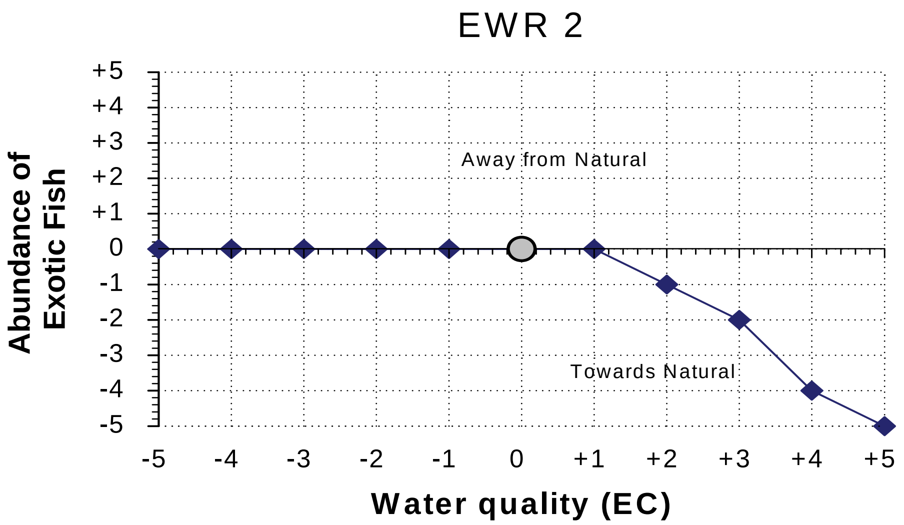

EWR 3 & 4
Abundance of
Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Water quality (EC)

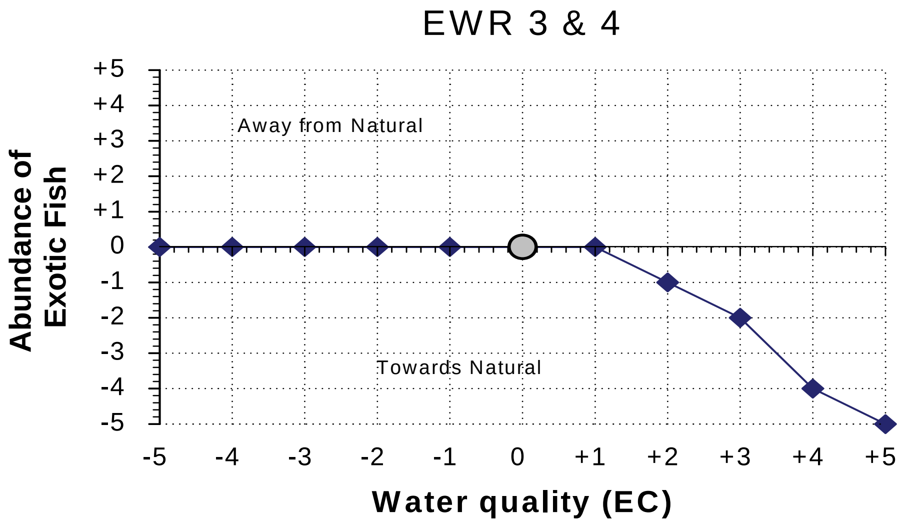

EWR 1
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Water quality (EC)

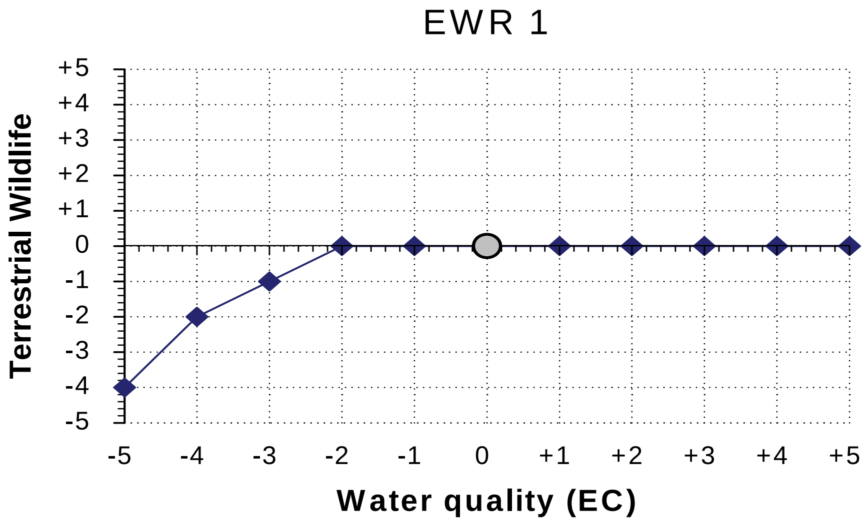

EWR 2
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Water quality (EC)

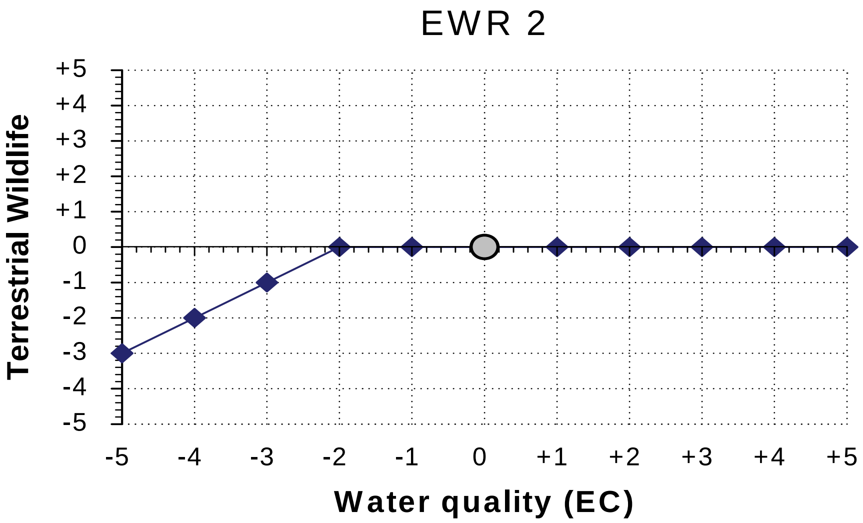

EWR 3 & 4
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Water quality (EC)

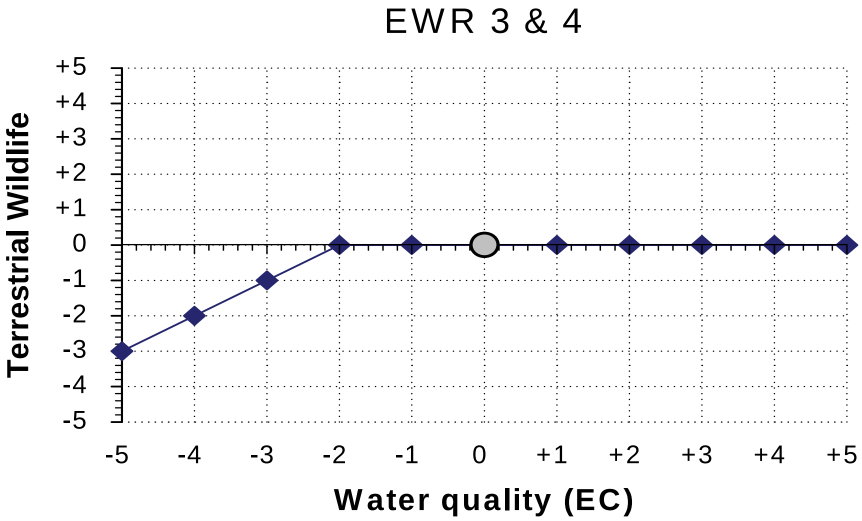

EWR 1
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

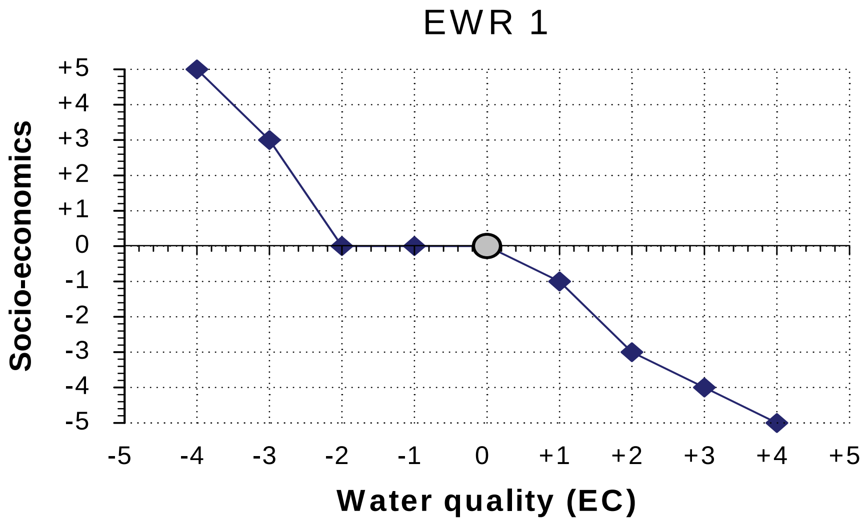

EWR 2
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

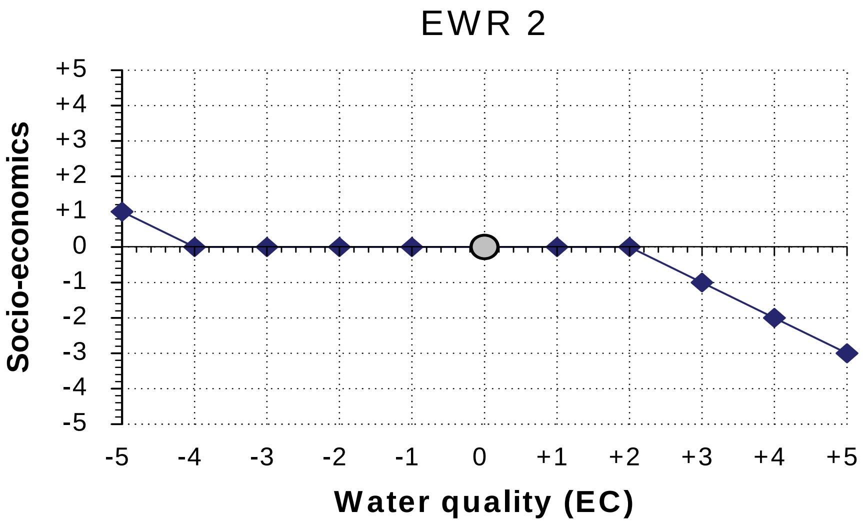

EWR 3 & 4
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

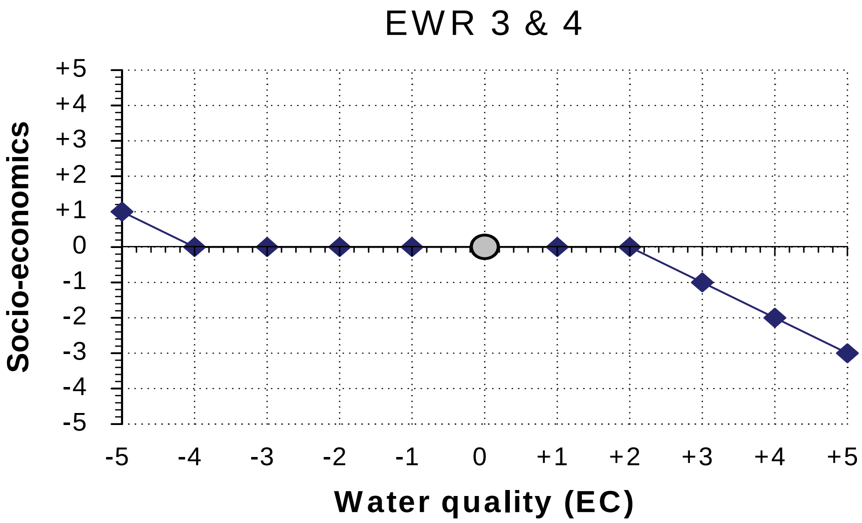

EWR 1
Terrestrial Wildlife
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

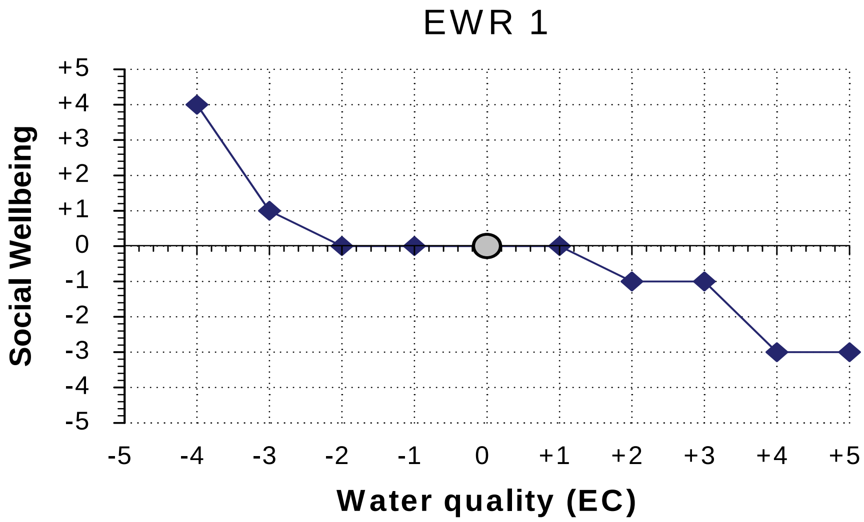

EWR 2
Terrestrial Wildlife
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

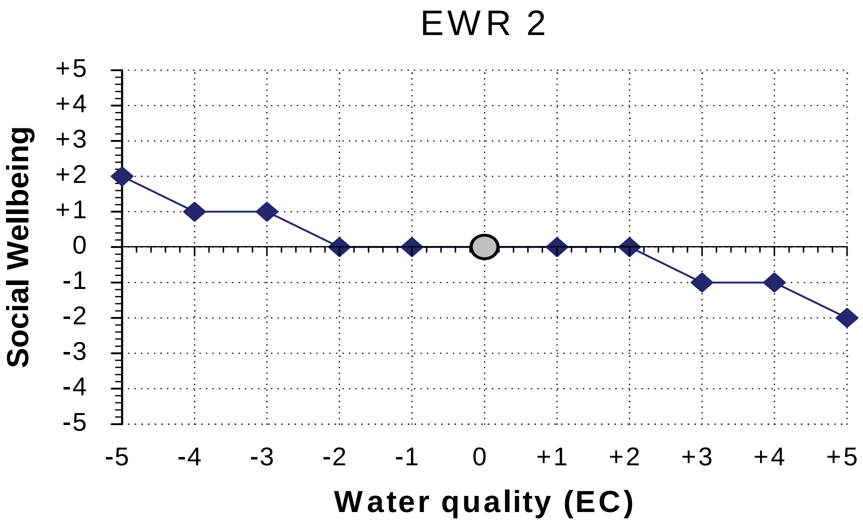

EWR 3 & 4
Terrestrial Wildlife
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

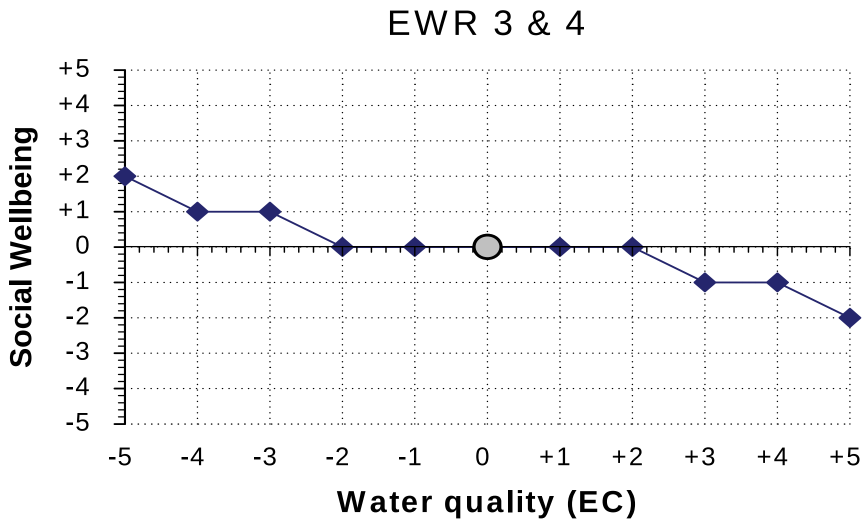

EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)


EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

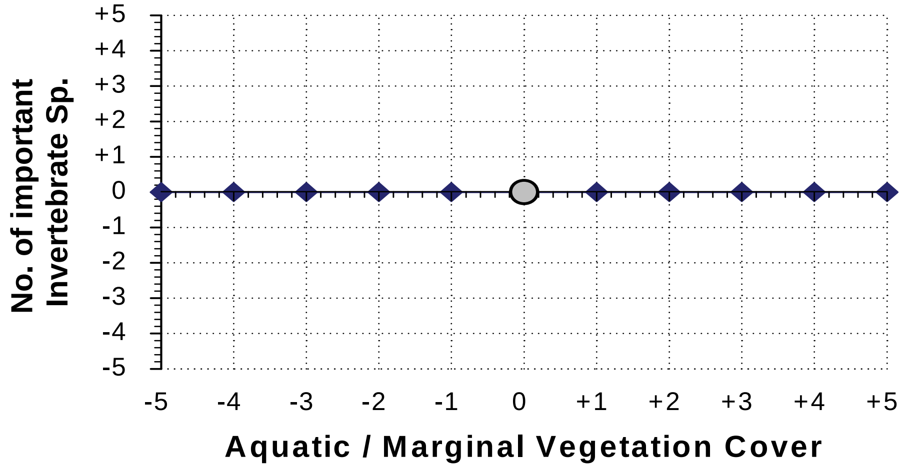

EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)


EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

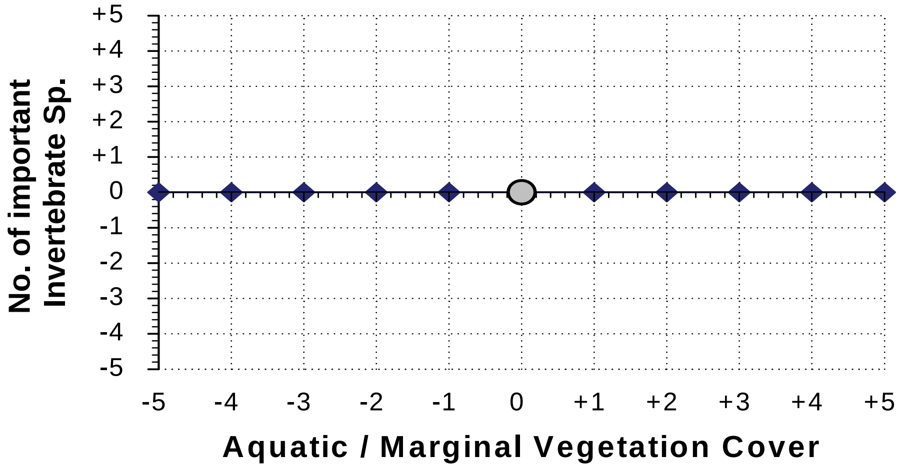

EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)


EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Water quality (EC)

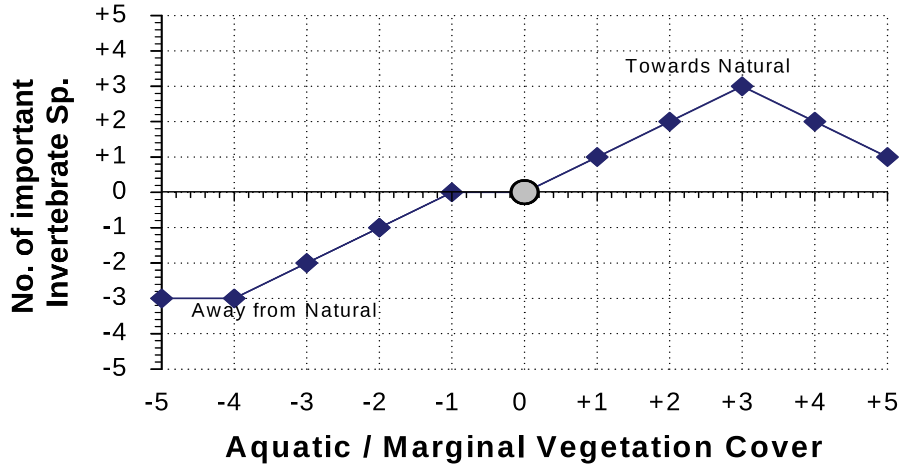
EWR 1

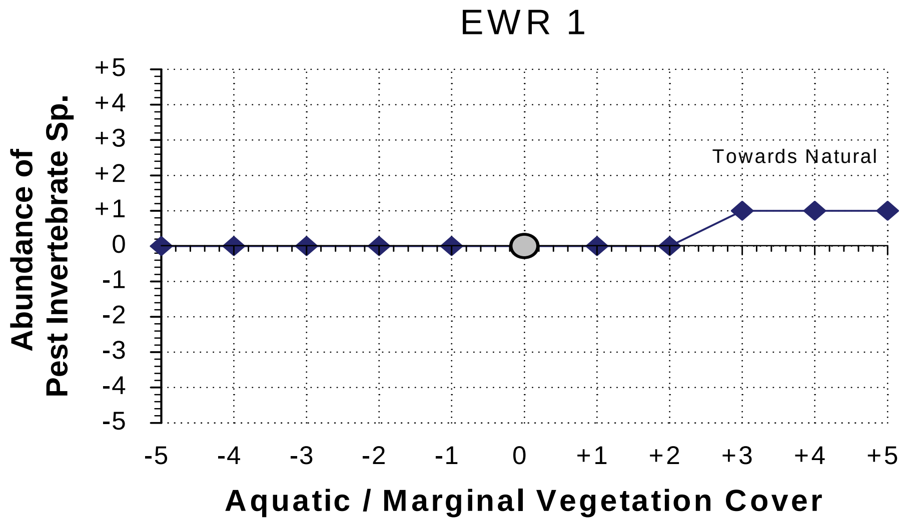


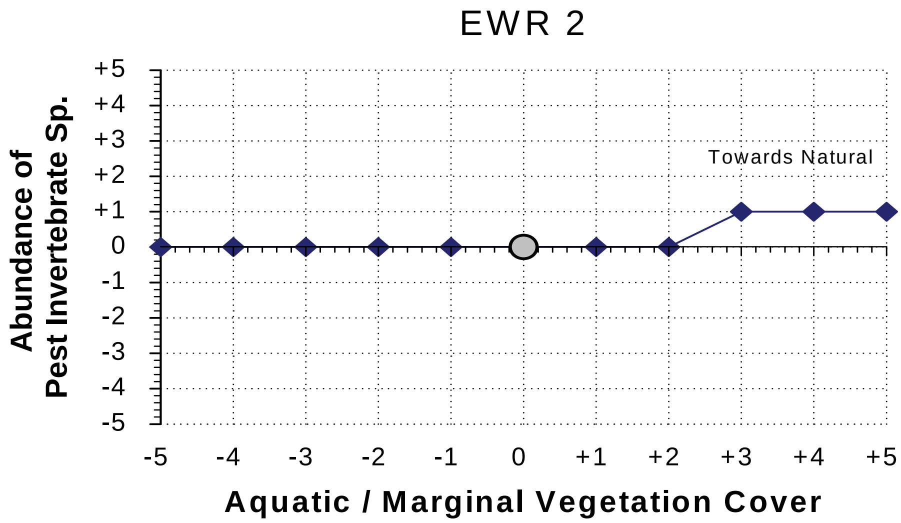
EWR 2

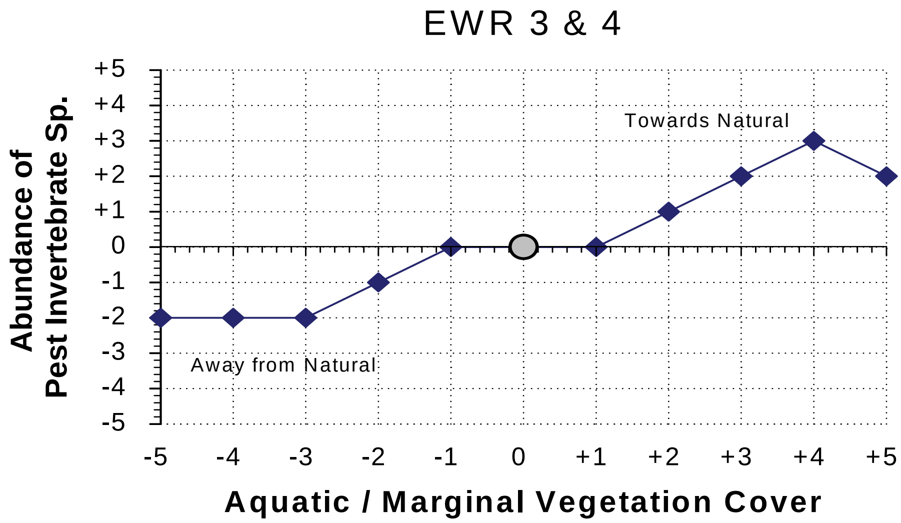


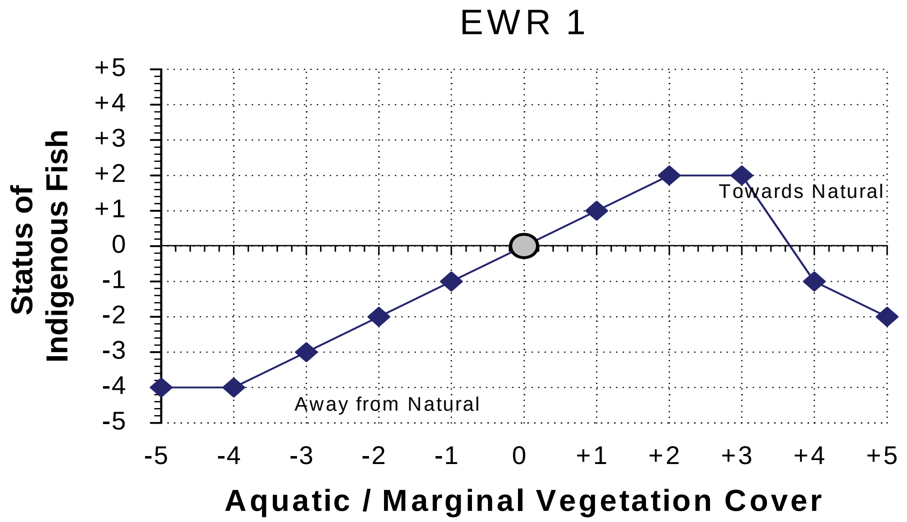
EWR 3 & 4

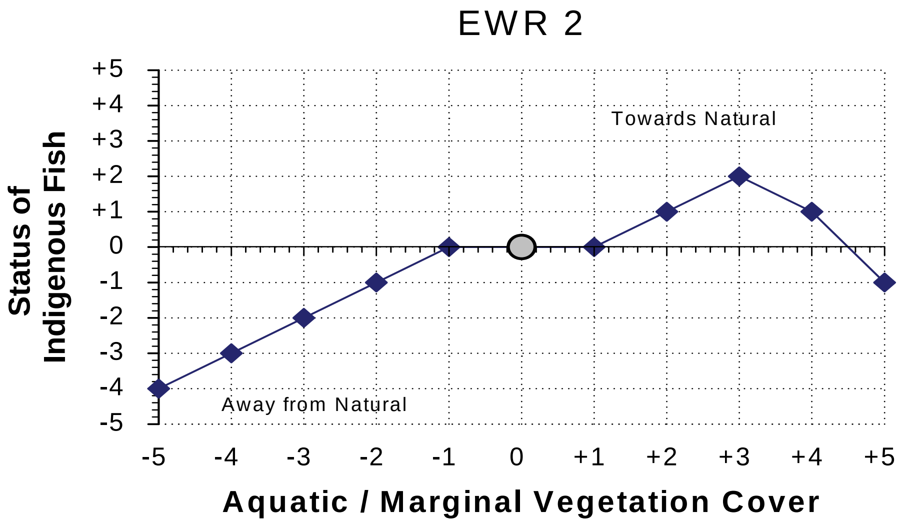


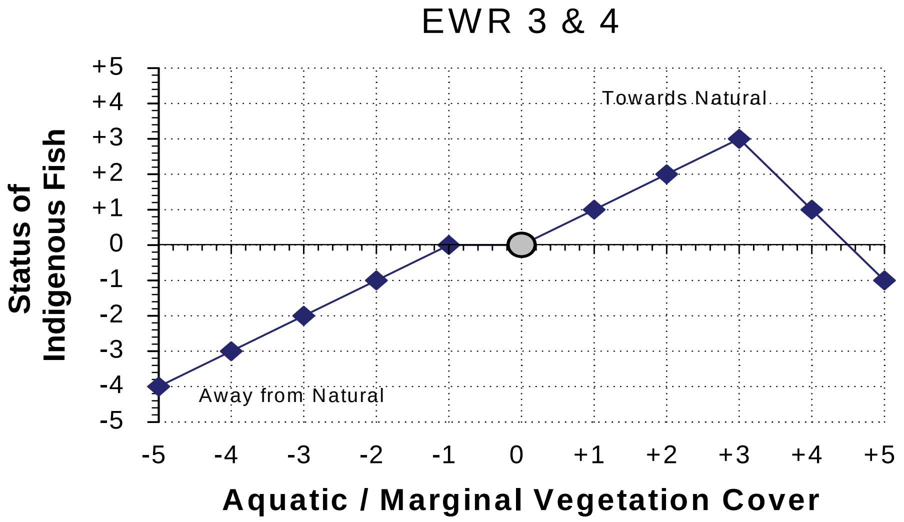

EWR 1
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover


EWR 2
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover

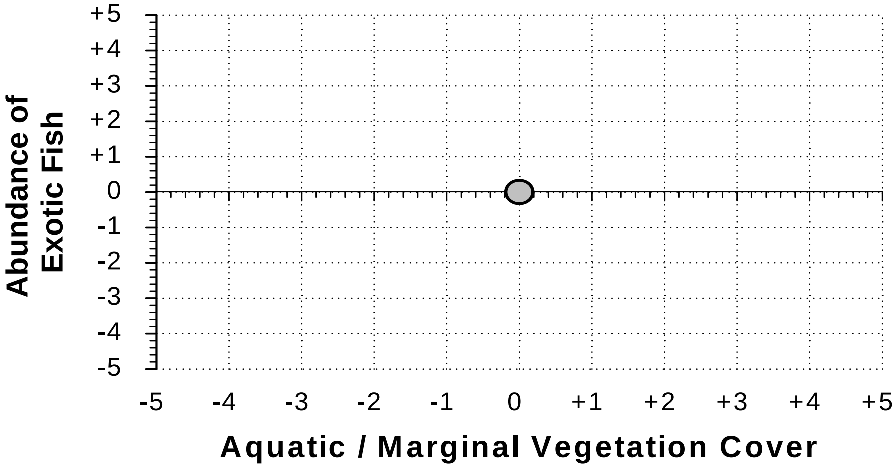

EWR 3 & 4
Abundance of Pest Invertebrate Sp.
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover


EWR 1
Status of Indigenous Fish
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover

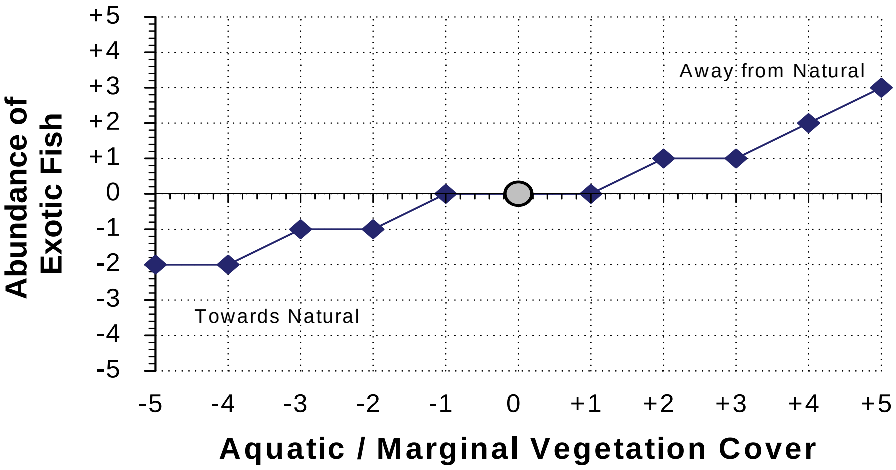

EWR 2
Status of Indigenous Fish
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover


EWR 3 & 4
Status of Indigenous Fish
Towards Natural
Away from Natural
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover

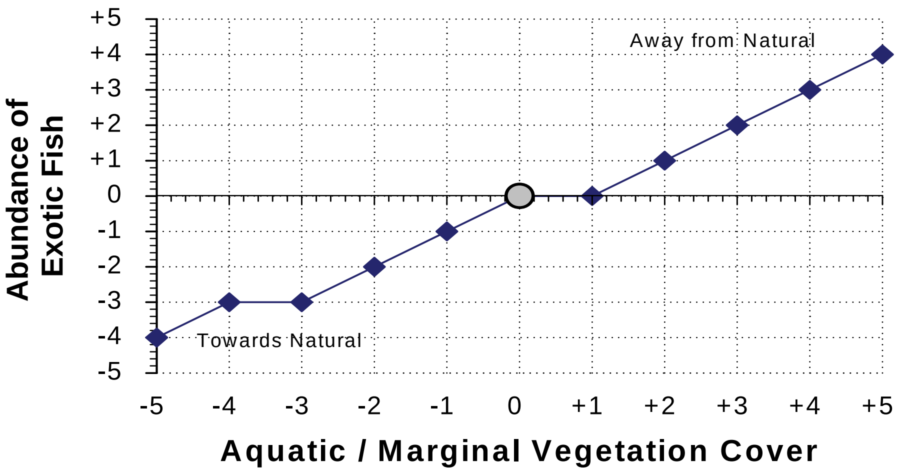
EWR 1



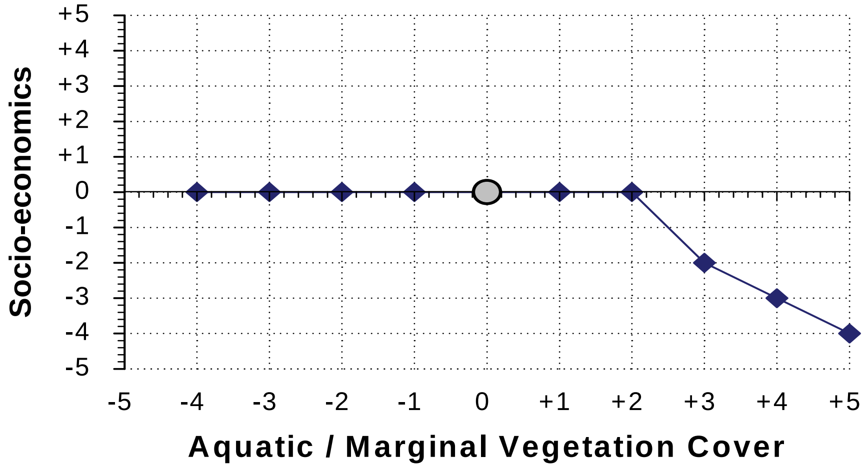
EWR 2



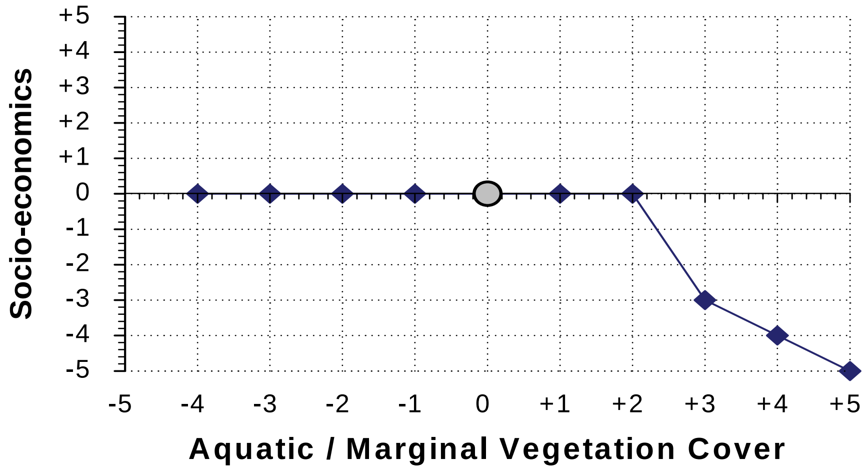
EWR 3 & 4



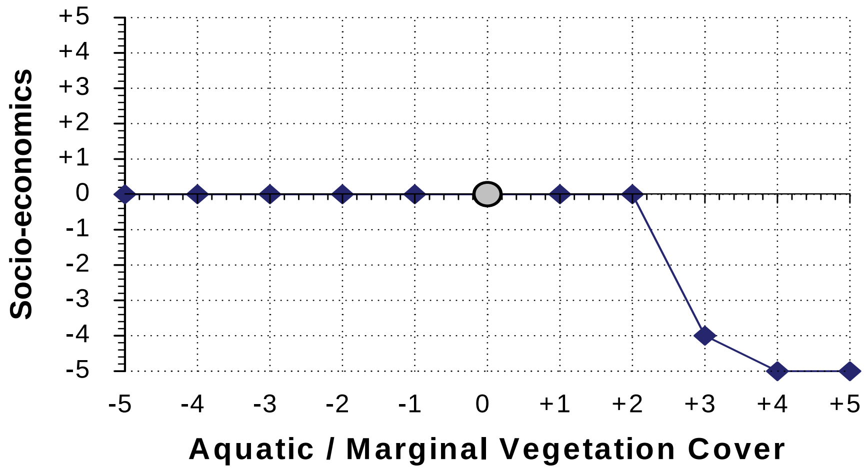
EWR 1

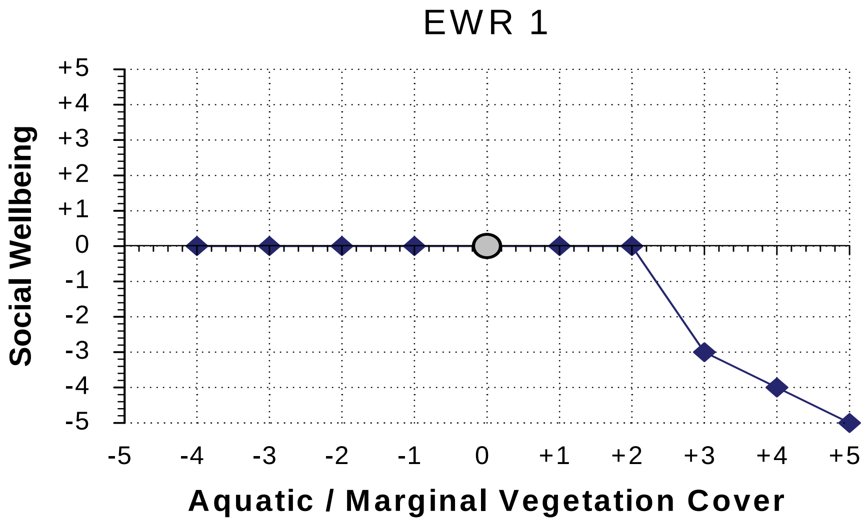


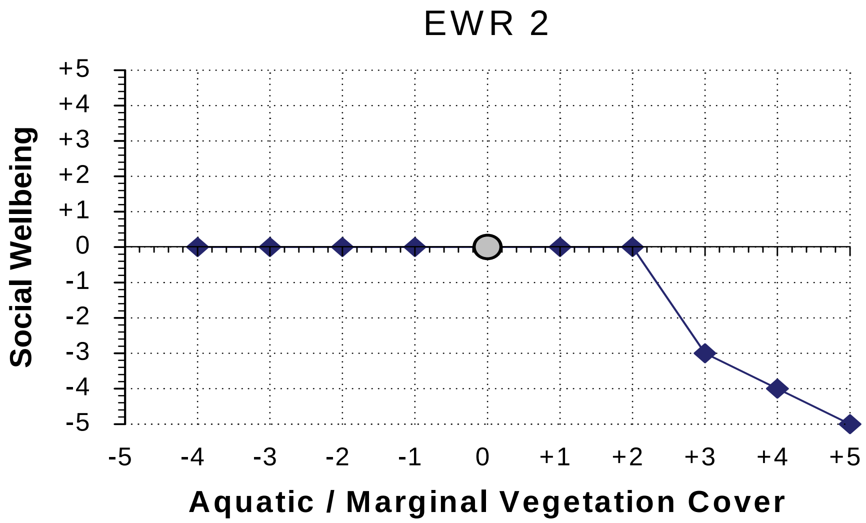
EWR 2

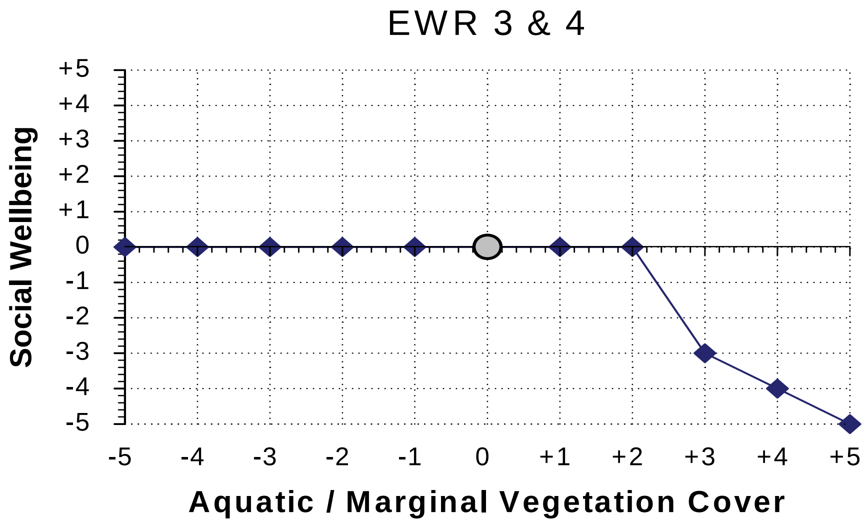


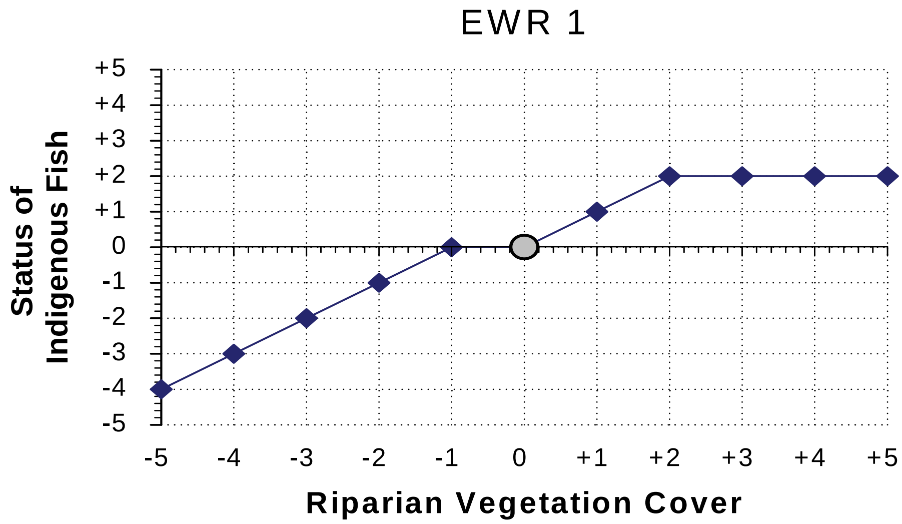
EWR 3 & 4

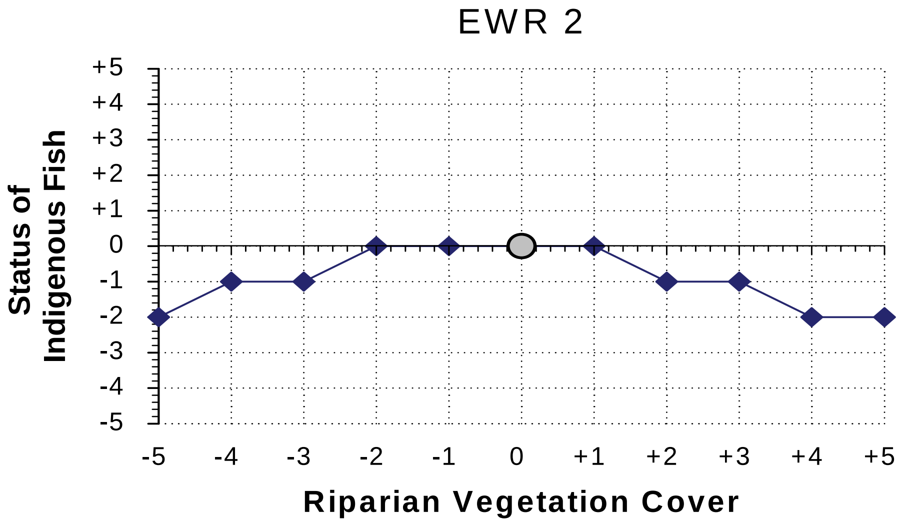


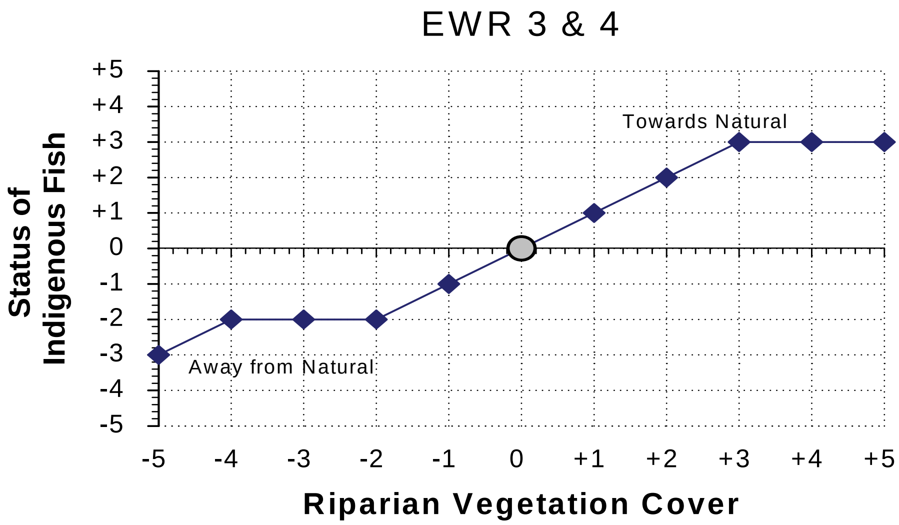

EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover

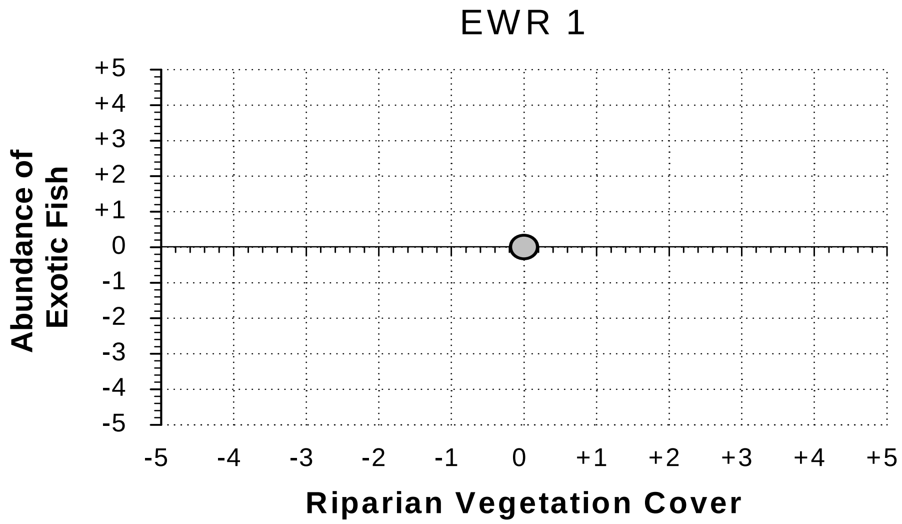

EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover

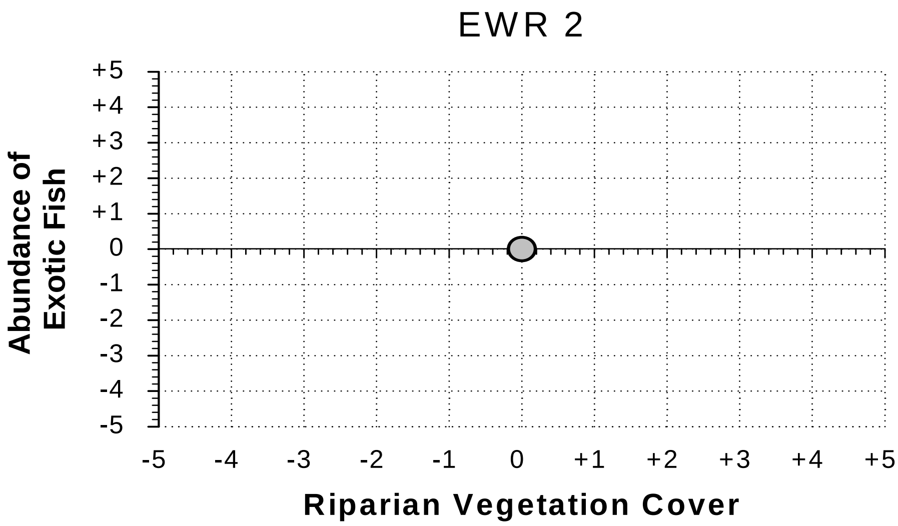

EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Aquatic / Marginal Vegetation Cover

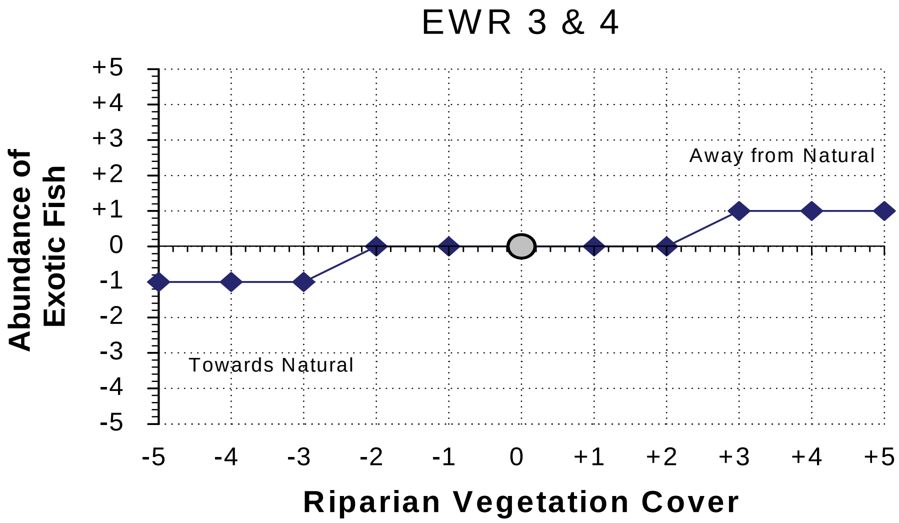

EWR 1
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Status of Indigenous Fish
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Riparian Vegetation Cover


EWR 2
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Status of Indigenous Fish
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Riparian Vegetation Cover

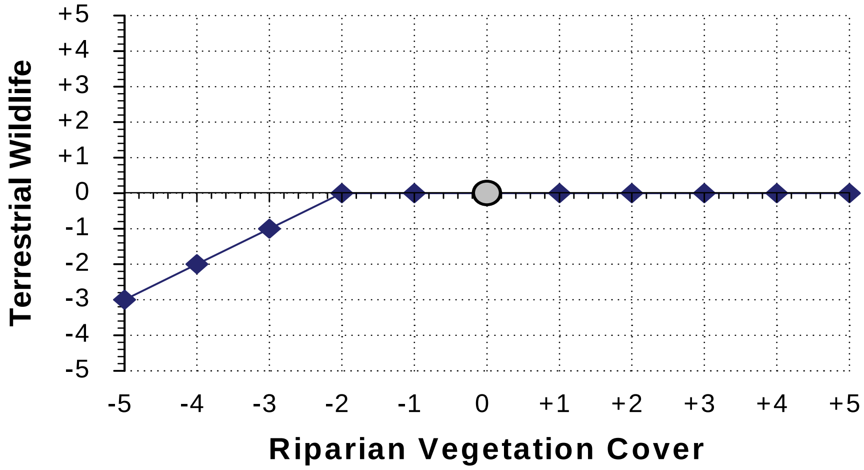

EWR 3 & 4
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Status of Indigenous Fish
Towards Natural
Away from Natural
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Riparian Vegetation Cover


EWR 1
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover


EWR 2
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover


EWR 3 & 4
Abundance of Exotic Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Away from Natural
Towards Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover

EWR 1



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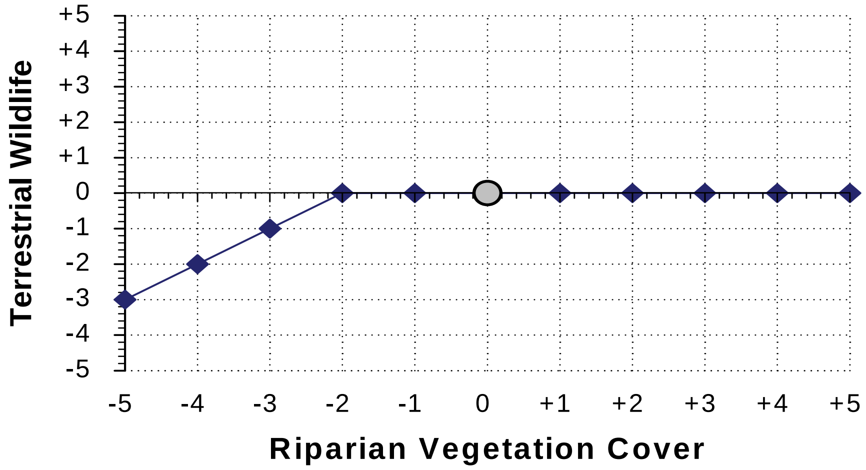
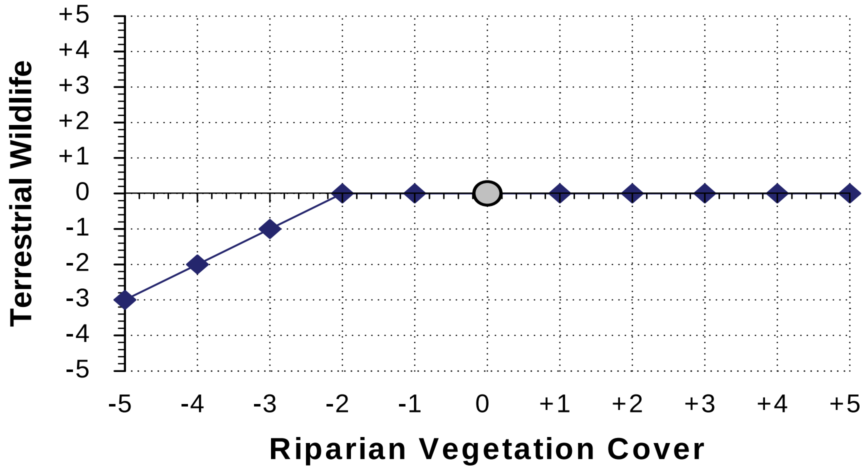
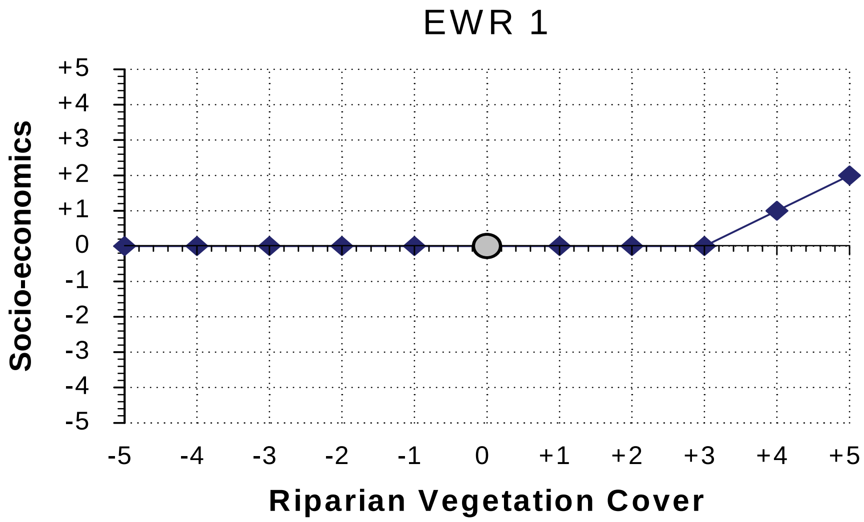
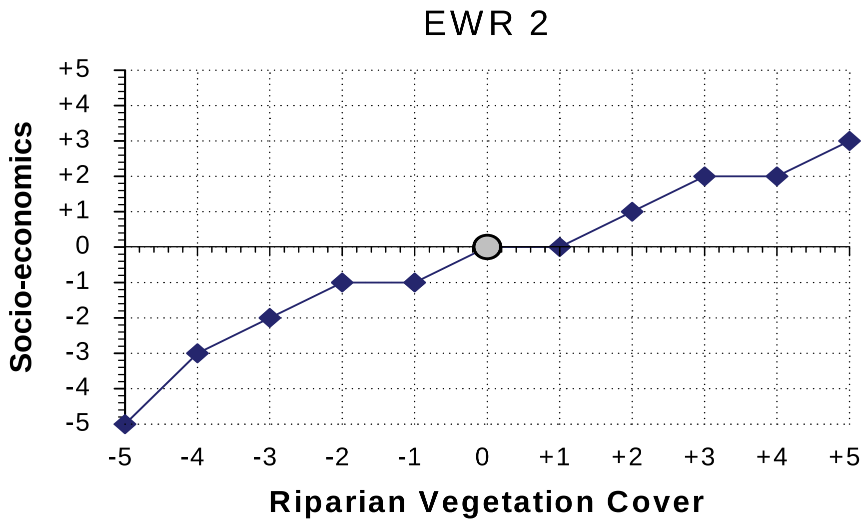
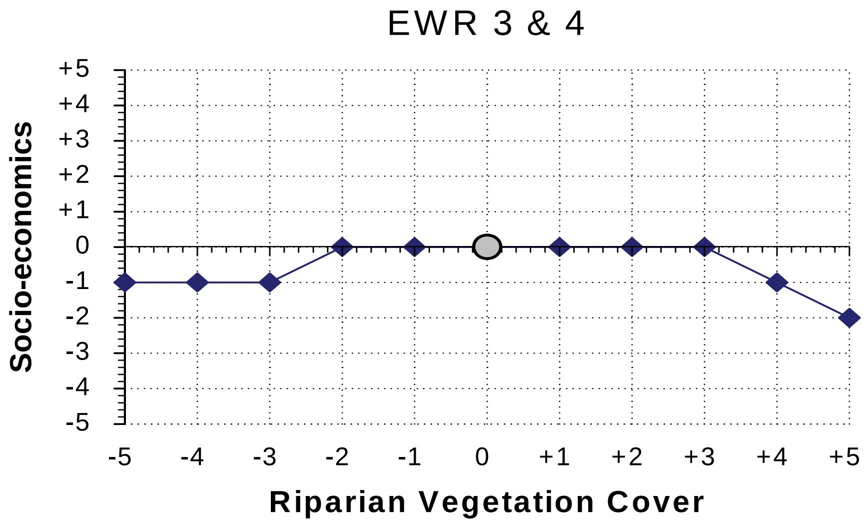


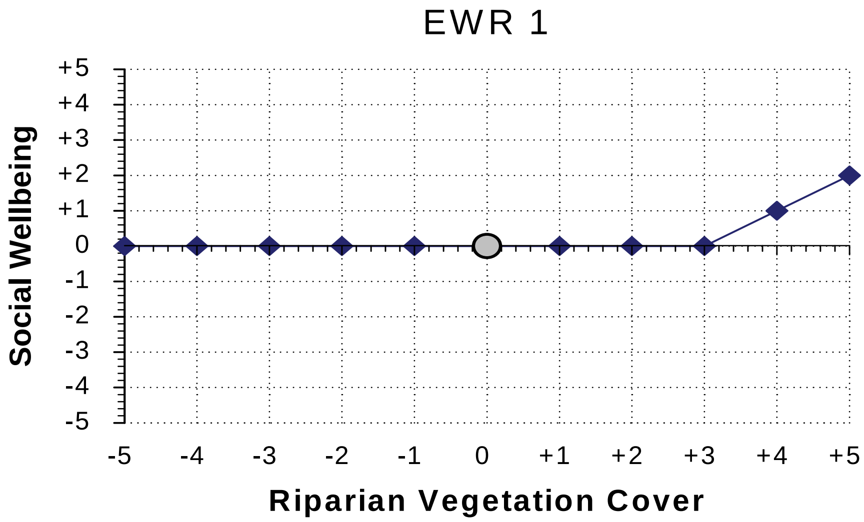
EWR 3 & 4

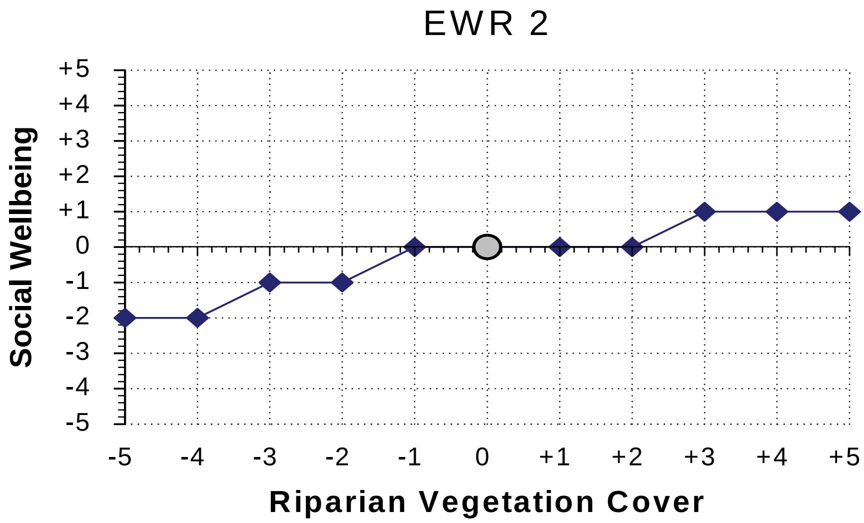


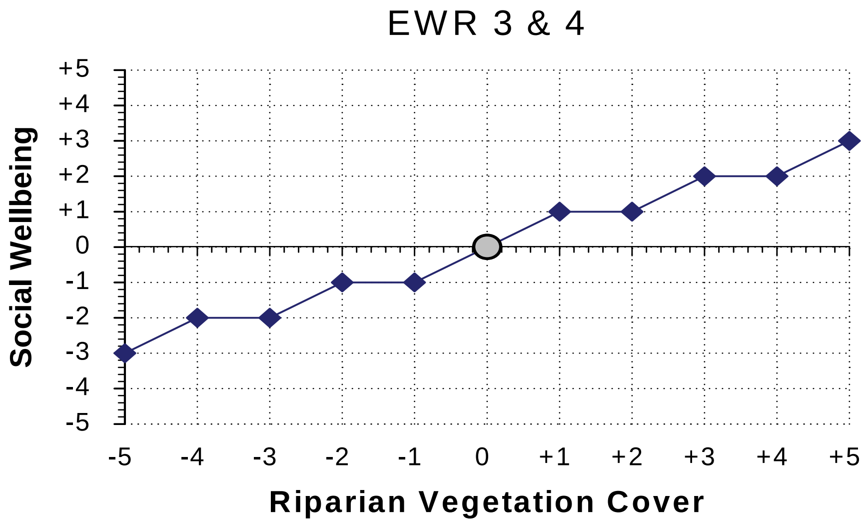

EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover

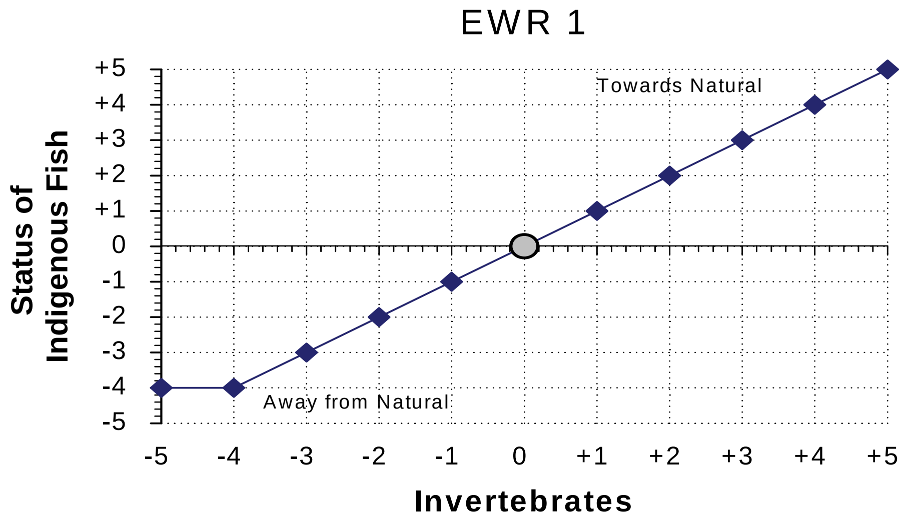

EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover

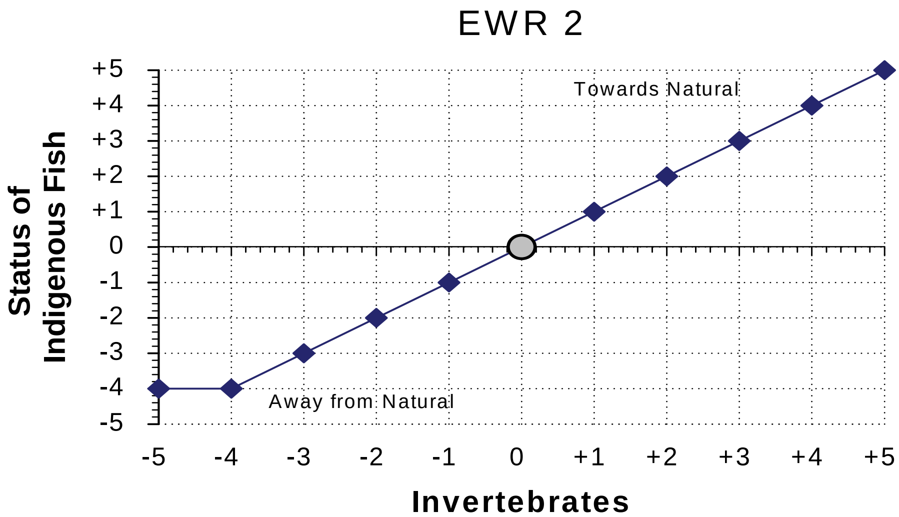

EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover

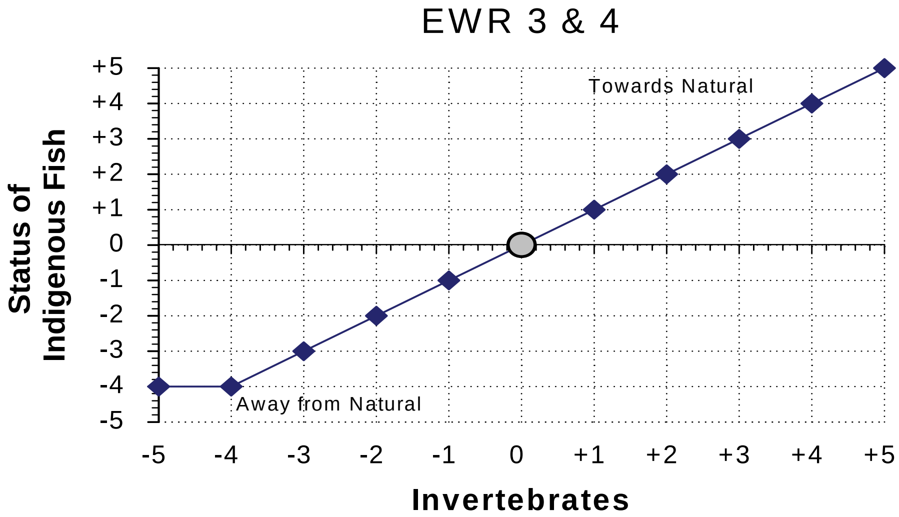

EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover


EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover

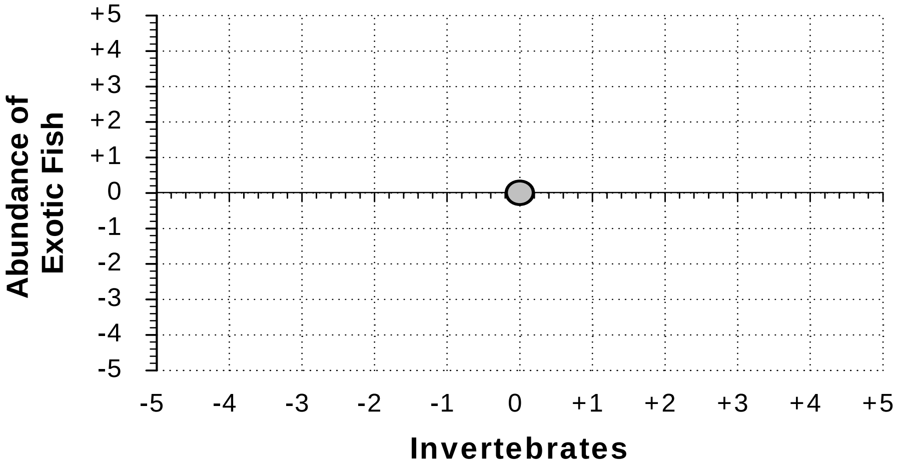

EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Riparian Vegetation Cover


EWR 1
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Invertebrates


EWR 2
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Invertebrates


EWR 3 & 4
Status of Indigenous Fish
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
Towards Natural
Away from Natural
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Invertebrates

EWR 1



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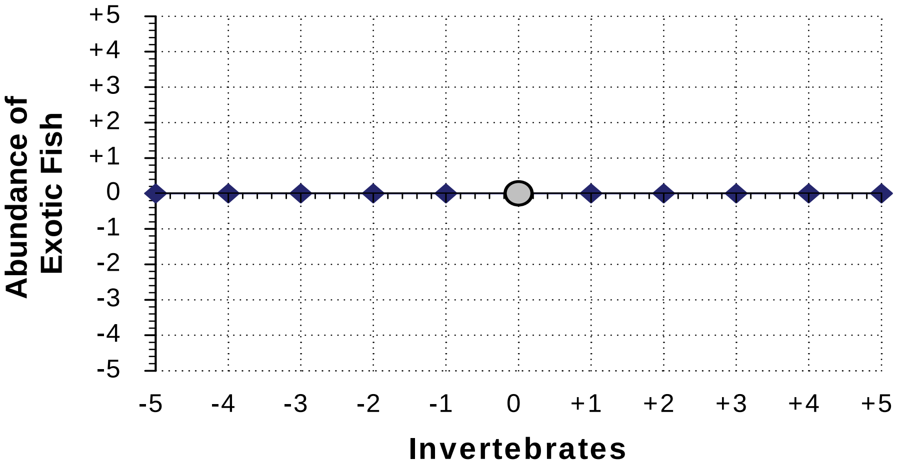
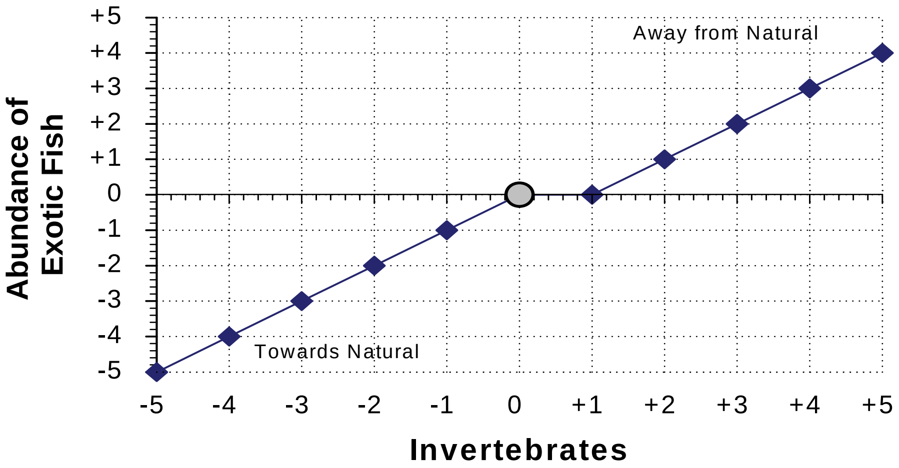
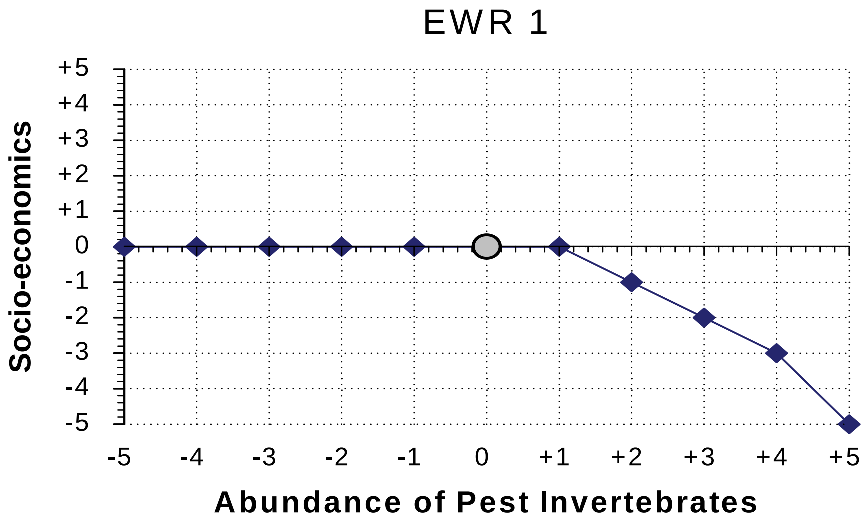
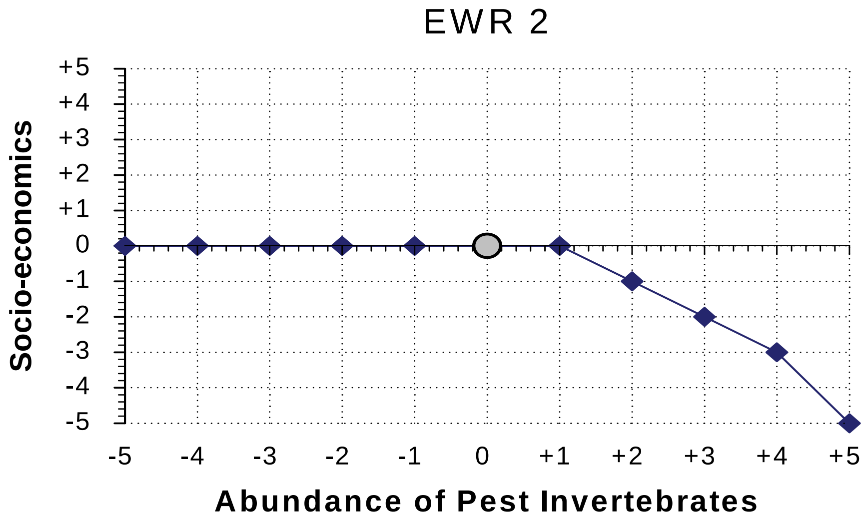
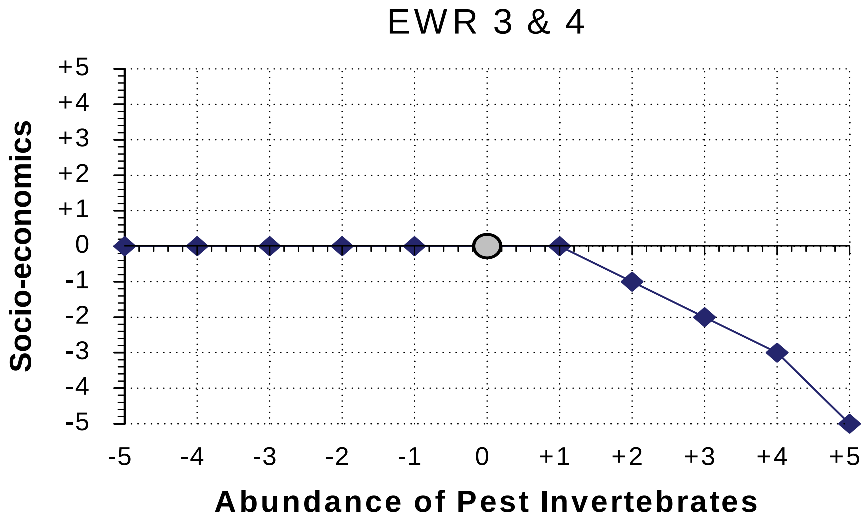


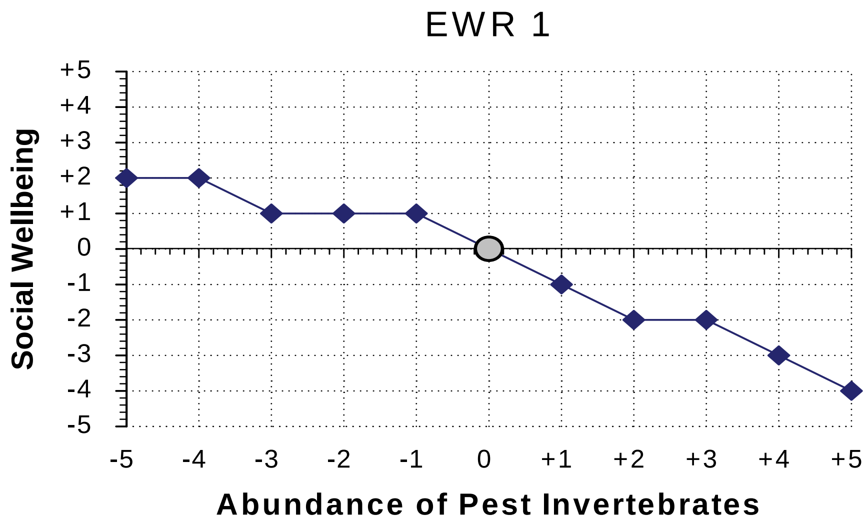
EWR 3 & 4

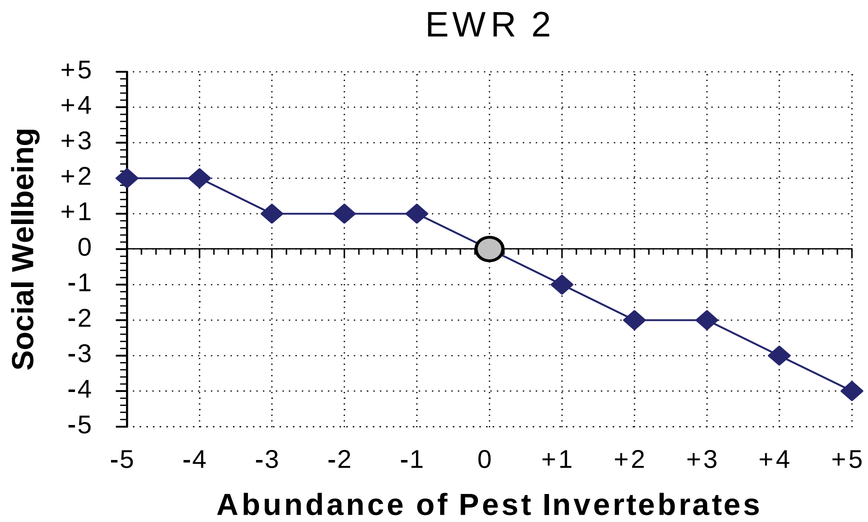


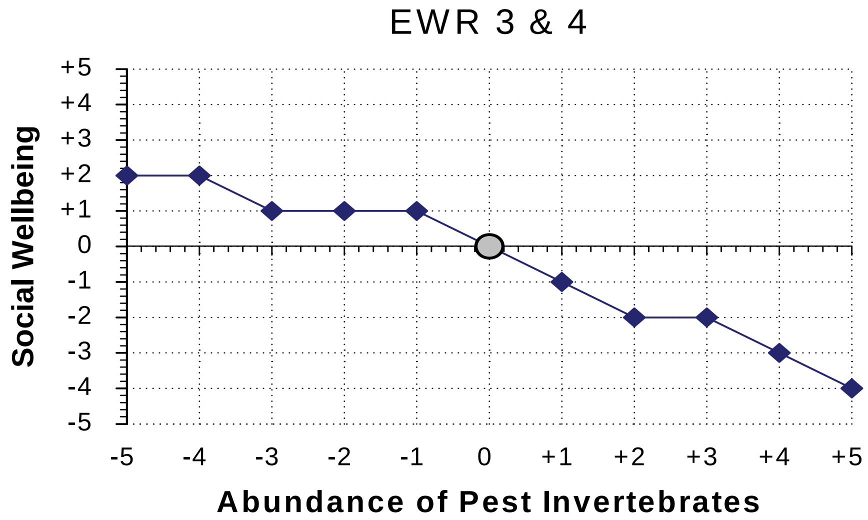

EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance of Pest Invertebrates


EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance of Pest Invertebrates

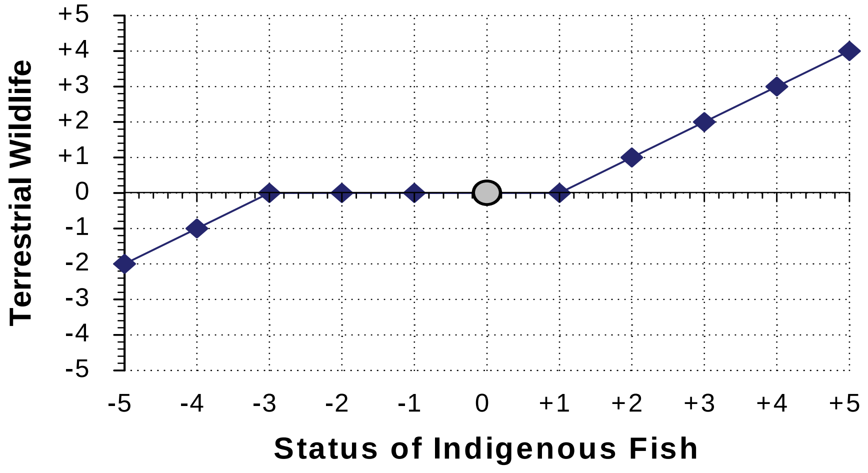

EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance of Pest Invertebrates


EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance of Pest Invertebrates

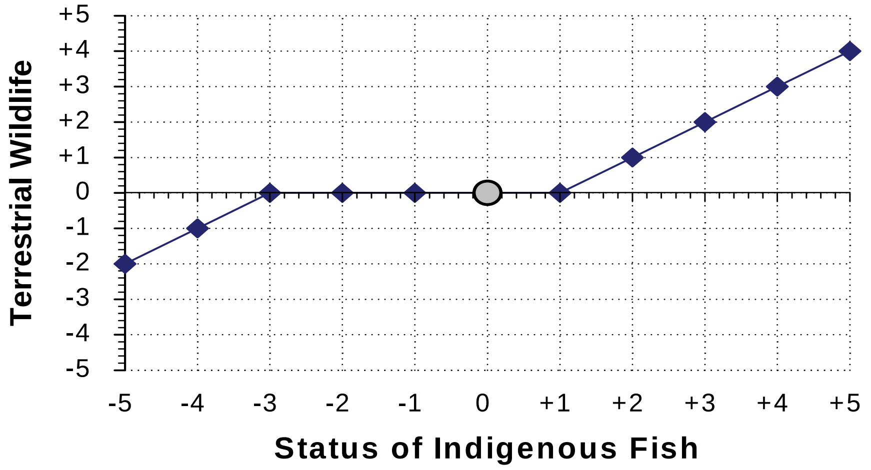

EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance of Pest Invertebrates


EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance of Pest Invertebrates

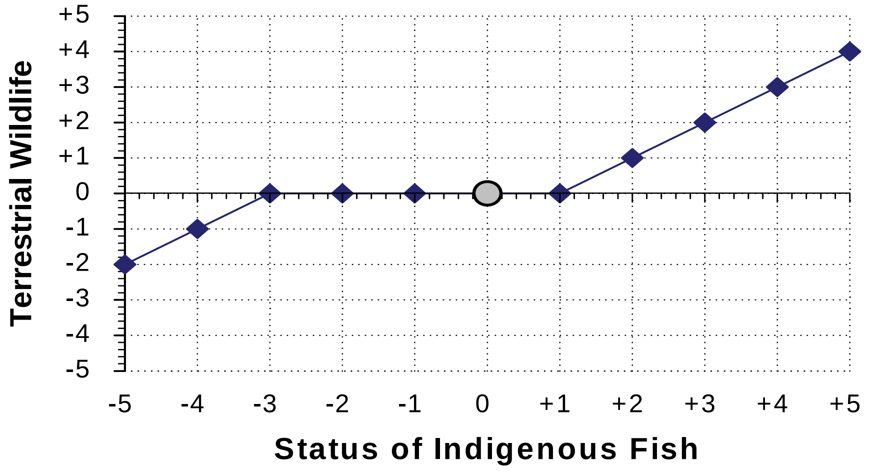
EWR 1

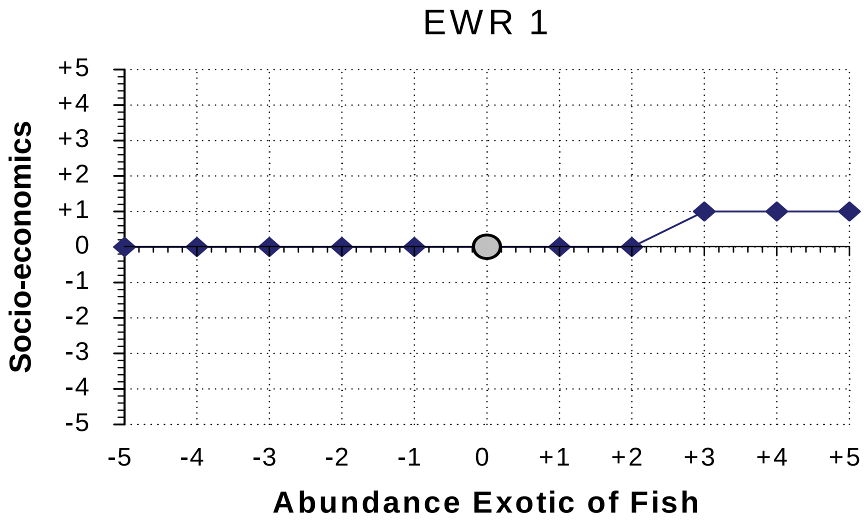


EWR 2



EWR 3 & 4




EWR 1
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
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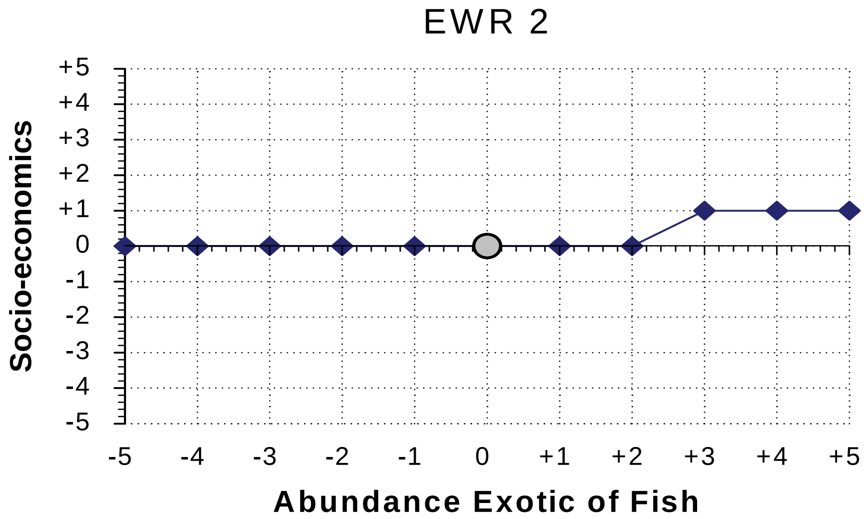
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Abundance Exotic of Fish


EWR 2
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
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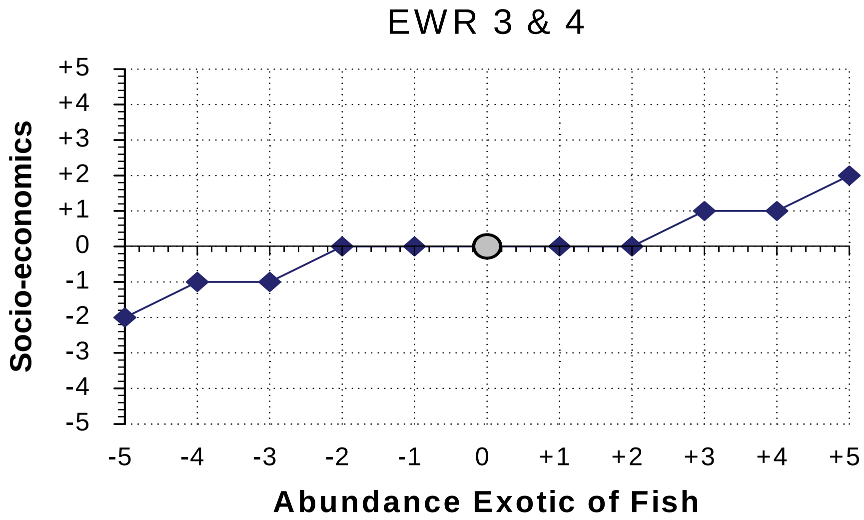
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Abundance Exotic of Fish


EWR 3 & 4
Socio-economics
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
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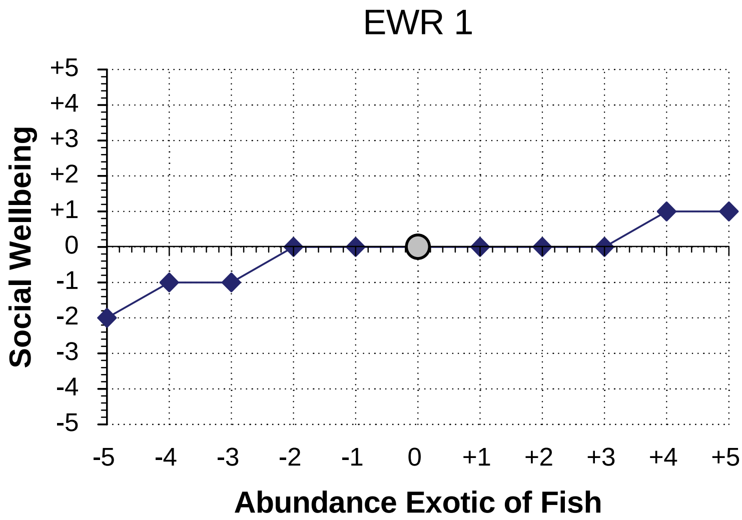
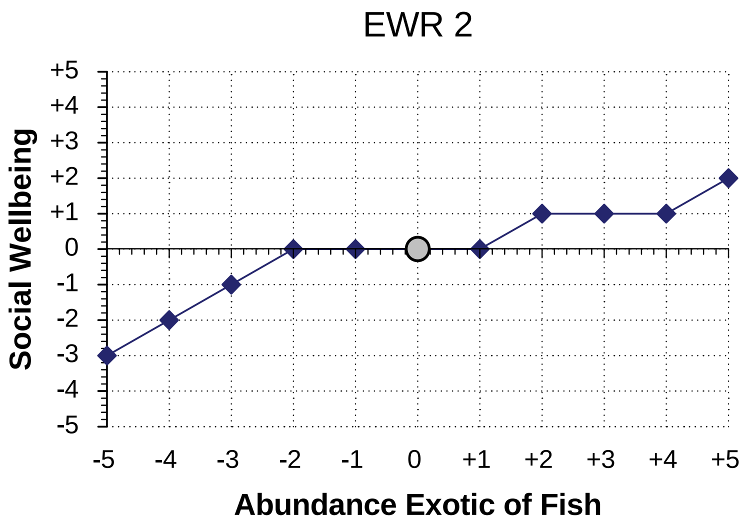
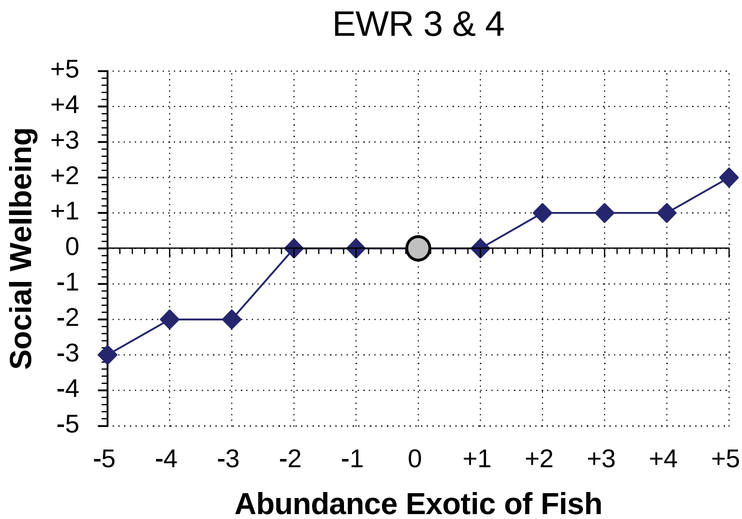
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Abundance Exotic of Fish


EWR 1
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance Exotic of Fish


EWR 2
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance Exotic of Fish


EWR 3 & 4
Social Wellbeing
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-5 -4 -3 -2 -1 0 +1 +2 +3 +4 +5
Abundance Exotic of Fish

Appendix G: Motivations by specialist for the indicators selected and weightings of drivers for EWR1, EWR2 and EWR3 & 4.

EWR1

Site: EWR1						
Indicators (Responders)	**Drivers selected**	**Motivation**	**Weight-ing**	**Motivation**	**Drivers dropped**	**Motivation**
Connectivity			1			
Flood regime			1			
Sediment delivery			1			
Channel aquifer	Connectivity		1			
Riparian aquifer	Connectivity		1	Drivers equally important	None	
	Flood regime		1			
Pools	Connectivity		1	Drivers equally important	None	
	Flood regime		1			
	Sediment delivery		1			
	Channel aquifer		1			
Water quality (EC)	Flood regime	Represents connectivity and sediment delivery, as well as, pool maintenance (sediment input and scouring and water quality). The flood regime has a major impact on water quality (flushing).	1	Drivers equally important	Connectivity	Very little natural connectivity except during larger floods.
					Sediment delivery	Driver covered by floods
	Channel aquifer	Sustains the pools and water quality and aquatic/marginal vegetation.	1		Riparian aquifer	Negligible input into the channel aquifer and pools
					Pools	Channel aquifer and floods covers the pools
Riparian vegetation cover	Flood regime	Floods usually damage the riparian vegetation and cause a setback in the succession of the plant community	1	Drivers equally important	Connectivity	
	Riparian aquifer	It sustains the riparian plant community	1		Sediment delivery	

	Pools	Sustains the aquatic habitat for aquatic plants	1		Channel aquifer	
Aquatic/ marginal vegetation cover	Flood regime	Floods recharge pools but usually remove unanchored aquatics from the pools. This resets the system and create vacant niches for aquatic species to colonise again	1	Drivers equally important	Connectivity Sediment delivery	
	Pools	Sustains the aquatic plant habitat	1		Channel aquifer	
	Water quality (EC)	Most aquatic plants especially exotics flourish in conditions when the quality is poor (eutrophication)	1		Riparian aquifer	
No. of important invertebrate species	NOT CONSIDERED	No important (in terms of unique, threatened, sensitive to flow, habitat or water quality) species were present at the site				
Abundance pest invertebrates	Flood regime	Influences habitat (scouring out silt, rearranging substrate) and brings in nutrients. Also determines time water is available for invertebrates to complete life-cycle.	1	Drivers equally important	Connectivity	Availability of pools includes connectivity as secondary driver. Increase in connectivity would increase pool availability, as well as pool area and disturbance.
	Pools	Determines persistence of habitat available and serves as refugia.	1		Sediment delivery	Sediment delivery is included in floods as well as pools as a secondary driver. Sediment delivery would not have much influence at site as no riffles or rapids are present.
	Aquatic/ marg. veg cover	Serves as attachment sites, escape from predators and increases food availability.	1		Water quality	Macro-invertebrates present at site are not particularly water quality sensitive and would

						probably survive if water quality deteriorated.
Status of indigenous fish	Connectivity	Connectivity of surface water important for fish movement, re-stocking and population health.	1	This river section which has a naturally low frequency of connectivity of surface water. Pool habitat is very important for the persistence of fish in this section, and was given a weighting of 2	Sediment delivery	EWR1 is situated in a very flat part of the catchment. Sediment delivery was not perceived as an important issue in this part of the catchment.
	Flood regime	Reproductive cycles adapted to natural flood regime. Maintenance of pool habitat and water quality.	1		No. of important invert. species	The invertebrate food species are all generalist sp. which should be present if pool habitat is present.
	Pools	Pool habitat essential for fish persistence	2			
	Water quality (EC)	Conductivity naturally high in this river section. Further increase could be detrimental to *B. anoplus* population	1			
	Aquatic/ marg. veg cover	*B. anoplus* has a high preference for plant cover.	1			
Abundance exotic fish	NOT CONSIDERED	No exotic fish species present in river section				
Terrestrial Wildlife	Pools		1	Drivers equally important	None	
	Water quality (EC)		1			
	Riparian vegetation cover		1			
	Status of indigenous fish		1			
Contribution to parent river	Flood regime		1		Connectivity	
					Sediment delivery	
					Water quality	
					Important inverts	
					Indigenous fish	
					Exotic fish	
Socio-economics	Flood regime		1	Drivers equally	Connectivity	

				important	Sediment delivery	
	Riparian aquifer		1		Channel aquifer	
					Pools	
	Pest inv		1		Water quality	
					Riparian vegetation	
					Aquatic vegetation	
					Indigenous fish	
Social wellbeing	Flood regime		1	Drivers equally important	Connectivity	
					Sediment delivery	
	Riparian aquifer		1		Channel aquifer	
					Pools	
	Pest inv		1		Water quality	
					Riparian vegetation	
					Aquatic vegetation	
					Status of indigenous fish	

EWR2

Site: EWR2						
Indicators (Responders)	**Drivers selected**	**Motivation**	**Weight-ing**	**Motivation**	**Drivers dropped**	**Motivation**
Connectivity			1			
Flood regime			1			
Sediment delivery			1			
Channel aquifer	Connectivity		1			
Riparian aquifer	Connectivity		1	Drivers equally important	*None*	
	Flood regime		1			
Pools	Connectivity		1	Drivers equally important	*None*	
	Flood regime		1			
	Sediment delivery		1			
	Channel aquifer		1			
Water quality (EC)	Connectivity	Connectivity is severely impacted by manmade structures (weirs and farm dams) and is much less frequent than under natural conditions	1	Drivers equally important	Sediment delivery	Driver covered by floods
	Flood regime	Plays an important role in maintaining/resetting the water quality of the pools.			Riparian aquifer	Negligible input into the channel aquifer and pools.
	Channel aquifer	Maintains the pools and water quality and aquatic/marginal vegetation.	1		Pools	Channel aquifer, connectivity and floods cover the pools
Riparian vegetation cover	Flood regime	Floods usually damage the riparian vegetation and cause a setback in the succession of the plant community	1	Drivers equally important		
	Channel aquifer	Sustains the aquatic habitat for aquatic plants	1			
	Riparian aquifer	It sustains the riparian	1			

		plant community				
Aquatic/ marginal vegetation cover	Flood regime	Floods recharge pools but usually remove unanchored aquatics from the pools. This resets the system and create vacant niches for aquatic species to colonise again	1	Drivers equally important		
	Channel aquifer	It maintains pools for extended periods	1			
	Pools	Sustains the aquatic plant habitat and therefore also the aquatic /marginal vegetation				
	Water quality (EC)	Most aquatic plants especially exotics flourish in conditions when the quality is poor (eutrophication)	1			
No. of important invertebrate species	NOT CONSIDERED	No important (in terms of unique, threatened, sensitive to flow, habitat or water quality) species were present at the site				
Abundance pest invertebrates	Flood regime	Influences food, and habitat availability. (see comments at site EWR1)	1	Aquatic/marginal vegetation is important at this site as it dries and becomes shallow, predation increases and vegetation serves as cover for invertebrates as well as habitat.	Connectivity	Availability of pools includes connectivity as secondary driver. Increase in connectivity would increase pool availability, as well as pool area and disturbance.
	Pools	Mostly *Culex* spp. present at site which prefer pool habitat and would therefore decrease or increase with change in pool size.	1		Sediment delivery	Sediment delivery is included in floods as well as pools as a secondary driver. Sediment delivery would not have much influence at site as no riffles or rapids are present.
	Water quality	*Culex* possibly *pipiens* present at site. Not particularly sensitive to increases in conductivity				

		but could increase slightly in abundance if conductivity were reduced.				
	Aquatic/marginal vegetation	Vegetation serves as food, attachment source and helps with escape from predators.	2			
Status of indigenous fish	Connectivity	Connectivity of surface water important for fish movement, re-stocking and population health.	2	Although connectivity is naturally low it remains very important for fish movement, restocking after dry periods (study pool dried out twice during study) and maintaining healthy fish comm. Natural connectivity severely reduced by weirs and small dams.	Sediment delivery	Flat topography in this part of the catchment. Sediment delivery included in flood regime and connectivity.
	Flood regime	Reproductive cycles adapted to natural flood regime. Maintain fish habitat: flushing out of pools, resetting water quality, pool scouring, etc.	1		Water quality	Fish occurring in this river section moderately tolerant to water quality changes. Flood regime and connectivity expected to cover water quality.
	Pools	Pool habitat essential for fish persistence.	1		Riparian vegetation	Trees not part of natural riparian veg. community. Shade & habitat requirements of fish mostly provided by marginal veg.
	Aquatic/marginal vegetation	Aquatic and marginal vegetation provide food and cover.	1		Important invertebrates	The invertebrate food species are all generalist sp. which should be present if pool habitat is present.
Abundance exotic fish	Connectivity	Connectivity enables exotic sp. to spread	1	*C. carpio* strongly associated with slow-flowing/standing water and soft substrates prevalent in pools.	Sediment delivery	Sediment delivery included in flood regime and connectivity.
	Flood regime	*C. carpio* populations possibly benefitted by reduced floods.	1		Water quality	*C. carpio* tolerant to water quality changes.
	Pools	*C. carpio* favours pool (and dam) habitat.	2		Riparian vegetation	Trees not part of natural riparian veg. community. Shade & habitat requirements of fish mostly provided by marginal veg.
	Aquatic/marginal vegetation	Potential food source, provides cover and substrate for eggs.	1		Important invertebrates	Invertebrate food species are all generalist sp. which should be present if pool habitat is present.
Terrestrial Wildlife	Pools		1	Drivers equally important		
	Water quality (EC)		1			

	Riparian vegetation cover		1			
	Status of indigenous fish		1			
Contribution to parent river	Flood regime		1	Drivers equally important		
	Exotic fish abundance		1			
Socio-economics	Flood regime		1	Drivers equally important		
	Riparian aquifer		1			
	Pools		1			
	Riparian vegetation		1			
	Aquatic/marginal vegetation		1			
	Pest invertebrates		1			
	Fish		1			
Social wellbeing	Flood regime		1	Drivers equally important		
	Riparian aquifer		1			
	Pools		1		*Aquatic vegetation Status of indigenous fish*	
	Riparian vegetation		1			
	Aquatic vegetation		1			
	Pest invertebrates		1			
	Fish		1			

EWR3 & 4

Site: EWR3&4						
Indicators (Responders)	**Drivers selected**	**Motivation**	**Weight-ing**	**Motivation**	**Drivers dropped**	**Motivation**
Connectivity			1			
Flood regime			1			
Sediment delivery			1			
Channel aquifer	Connectivity		1			
Riparian aquifer	Connectivity		1	Drivers equally important	None	
	Flood regime		1			
Pools	Connectivity		1	Drivers equally important	None	
	Flood regime		1			
	Sediment delivery		1			
	Channel aquifer		1			
Water quality (EC)	Flood regime	Maintains the pools and water quality. Resets the system.	1	Drivers equally important	Connectivity	Driver represented by connectivity
					Sediment delivery	Driver covered by floods
	Connectivity	Connectivity is more regular than at EWR1 and 2 and maintains the pools and the channel aquifer.	1		Riparian aquifer	Negligible input into the channel aquifer and pools
					Pools	Channel aquifer and floods covers the pools
Riparian vegetation cover	Flood regime	Floods usually damage the riparian vegetation and cause a setback in the succession of the plant community	1		Connectivity	
	Riparian aquifer	It sustains the riparian plant community	2		Channel aquifer	
Aquatic/ marginal vegetation cover	Flood regime	Maintains the pools and water quality. Resets the system	1		Connectivity Sediment delivery	
	Pools	Sustains the aquatic plant habitat and therefore also the aquatic /marginal	2		Channel aquifer	

		vegetation				
	Water quality (EC)	Most aquatic plants especially exotics flourish in conditions when the quality is poor (eutrophication)	1		Riparian aquifer	
No. of important invertebrate species	Connectivity	Upstream and downstream areas, pools and riffles/rapids need to be connected to maintain genetic diversity	3	Loss in connectivity would lead to critical loss of important species which prefer riffles and rapids.	Sediment delivery	Sediment delivery is included as secondary driver in floods and connectivity
	Flood regime	Flow between pools, riffles and rapids needed to replenish nutrients, wash out sediment and rearrange substrate (critical habitat for invertebrates).	2	Floods are needed to rearrange and clean Stones in current (SIC) habitat at sites which is a critical habitat type for important species at sites.	Water quality	Mostly flow and habitat sensitive invertebrates present and none which are particularly water quality sensitive. Water quality is included as secondary diver in floods and connectivity.
	Pools	Serve as refugia during low to no flow periods	1			
	Aquatic/marginal vegetation	Important as attachment sites, food, cover and refugia (during high flow	1			
Abundance pest invertebrates	Connectivity	Flow sensitive pest species (*Simulium* spp.) present at sites. Connectivity needed to ensure variability of flow pattern. (Some *Simulium* spp. prefer constant flow downstream of dams and weirs and increase under these conditions)	3	Loss in connectivity would lead to critical increase in pest species which prefer constant flow downstream of weirs and dams.	Sediment delivery	Sediment delivery is included as secondary driver in floods and connectivity
	Flood regime	Floods needed for habitat renewal and disturbance (stagnant pools lead to increase in *Anopheles* and *Culex* spp. abundance)	2	Loss in floods would lead to increase in pest species which prefer stagnant pool habitat.		
	Pools	Pool availability directly	1		Water quality	Mostly flow and habitat sensitive

		associated with increase or decrease in *Anopheles* and *Culex* spp.				pest invertebrates present and none which are particularly water quality sensitive. Water quality is included as secondary diver in floods and connectivity.
	Aquatic/marginal vegetation	Vegetation needed for attachment sites, cover and food.	1			
Status of indigenous fish	Connectivity	Connectivity of surface water important for fish movement, re-stocking and population health.	2	Being situated in the lower part of the catchment, connectivity is very important for fish movement between pools, as well as, between the Orange and Seekoei com-munities. Allowing restocking from parent river after dry periods (study pools dried out twice during study). Lower part of the river important for fish spawning.	Sediment delivery	Sediment delivery covered by flood regime and connectivity. Flood regime to maintain pools, rapids/riffles and gravel beds.
	Flood regime	Reproductive cycles adapted to natural flood regime. Flood regime also maintains pools, rapids/riffles and gravel beds.	1		Water quality	All fish sp. moderately tolerant to water quality changes. Flood regime and connectivity expected to cover water quality.
	Pools	Pool habitat especially important for larger sp. Also, essential for fish persistence during dry periods.	2	Pool persistence important for fish persistence during dry periods.	Riparian vegetation	Although riparian vegetation is a potential source of food material, cover and shade at the site, the aquatic/marginal veg. was perceived to be more important and was rather included. The riparian veg. should be covered by the flood regime (and riparian aquifer).
	Aquatic/marginal vegetation	Aquatic and marginal vegetation important source of food and cover.	1		Important invertebrates	Invertebrate food species mostly generalist sp. which should be present if pool habitat is present.
Abundance exotic fish	Connectivity	Connectivity enable exotic sp. to spread	2	Connectivity would allow exotic sp. to spread, especially *M. salmoides* which was	Sediment delivery	Sediment delivery covered by flood regime and connectivity. Flood regime to maintain pools, rapids/riffles and gravel beds

	Flood regime	Floods restoring Both exotic sp. prefers	1	recently introduced.	Water quality	Exotic sp. tolerant to water quality changes
	Pools	*C. carpio* & *M. salmoides* favours the standing/slow-flowing conditions prevalent in pools.	2	Exotic sp. strongly prefers pool habitat.	Riparian vegetation	Although riparian vegetation is a potential source of food material, cover and shade at the site, the aquatic/marginal veg. was perceived to be more important and was rather included. The riparian veg. should be covered by the flood regime (and riparian aquifer).
	Aquatic/marginal vegetation	Important source of food & cover to exotic sp.	1		Important invertebrates	Invertebrate food species are all generalist sp. which should be present if pool habitat is present.
Terrestrial Wildlife	Pools		2		None	
	Water quality (EC)		1			
	Riparian vegetation cover		1			
	Status of indigenous fish		1			
Contribution to parent river	Flood regime		1	Drivers equally important	Connectivity	
	Sediment delivery		1		Sediment delivery	
	Pest invertebrates		1		Water quality Important inverts	
	Indigenous fish	The bottom part of the Seekoei is an important spawning ground for fish.	1		Exotic fish	Exotic sp. present in main channel.
Socio-economics	Flood regime		2		Connectivity Sediment delivery	
	Riparian aquifer		2		Channel aquifer Pools	
	Pools		1		Water quality Riparian vegetation Aquatic vegetation Indigenous fish	
	Pest invertebrates		1			
	Fish		1			
	Pest invertebrates		1			
	Fish		1			

Social wellbeing	Flood regime		2			
	Riparian aquifer		2			
	Pools		1			
	Riparian veg.		1			
	Pest invertebrates		1			
	Fish		1			

Appendix H: Final predictions for EWR sites for Scenarios 2, 3 & 4.

SCENARIO 2: Removal of man-made structures from the river channel – EWR1.

Scenario 2 EWR1 Responders	Driver	Response curve value	Toward/ away	Weight-ing	Weighted alloca-tion	Weighted sum
Connectivity		3	T	1		**3**
Flood regime		2	T	1		**2**
Sediment delivery		0	--	1		**0**
Channel aquifer	Connectivity	0.5	T	1	1	**0.5**
Riparian aquifer	Connectivity	0	--	1	0.500	**0.0**
	Flood regime	0	--	1	0.500	
Pools	Connectivity	1.5	T	1	0.250	**0.625**
	Flood regime	1	T	1	0.250	
	Sediment delivery	0	--	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Flood regime	-2	T	1	0.500	**-1.0**
	Channel aquifer	0	--	1	0.500	
Riparian vegetation cover	Flood regime	-2	T?	1	0.333	**-0.667**
	Riparian aquifer	0	--	1	0.333	
	Pools	0	--	1	0.333	
Aquatic/ marginal vegetation cover	Flood regime	-2	T	1	0.333	**-0.458**
	Pools	0.625	T	1	0.333	
	Water quality (EC)	0	--	1	0.333	
No. of important invertebrate species						
Abundance pest invertebrates	Flood regime	-1	T	1	0.333	**-0.333**
	Pools	0	--	1	0.333	
	Aquatic/ marg. veg cover	0	--	1	0.333	
Status of indigenous fish	Connectivity	1	T	1	0.167	**0.549**
	Flood regime	1.5	T	1	0.167	
	Pools	0.625	T	2	0.333	
	Water quality (EC)	0	--	1	0.167	
	Aquatic/ marg. veg cover	-0.458	A	1	0.167	
Abundance exotic fish						
Terrestrial Wildlife	Pools	0	--	1	0.250	**0.000**
	Water quality (EC)	0	--	1	0.250	
	Riparian vegetation cover	0	--	1	0.250	

	Status of indigenous fish	0	--	1	0.250	
Contribution to parent river	Flood regime	0	--	1	1.000	**0.000**
Socio-economics	Flood regime	-1	A	1	0.333	**-0.333**
	Riparian aquifer	0	--	1	0.333	
	Pest inv	0	--	1	0.333	
Social wellbeing	Flood regime	-1	A	1	0.333	**-0.444**
	Riparian aquifer	0	--	1	0.333	
	Pest inv	-0.333	T	1	0.333	

SCENARIO 2: Removal of man-made structures from the river channel – EWR2

Scenario: 2 EWR2 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		3	T	1		**3**
Flood regime		3	T	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	
	Channel aquifer	0	--	1	0.333	
Riparian vegetation cover	Flood regime	-3	T	1	0.333	**-1.000**
	Channel aquifer	0	--	1	0.333	
	Riparian aquifer	0	--	1	0.333	
Aquatic/ marginal vegetation cover	Flood regime	-3	T	1	0.250	**-0.438**
	Channel aquifer	0	--	1	0.250	
	Pools	1.25	T	1	0.250	
	Water quality (EC)	0	--	1	0.250	
No. of important invertebrate species						
Abundance pest invertebrates	Flood regime	2	T	1	0.200	**0.650**
	Pools	1.25	T	1	0.200	
	Water quality (EC)	0	--	1	0.200	
	Aquatic/ marg. veg cover	0	--	2	0.400	
Status of indigenous fish	Connectivity	2	T	2	0.400	**1.650**
	Flood regime	3	T	1	0.200	
	Pools	1.25	T	1	0.200	
	Aquatic/ marg. veg cover	0	--	1	0.200	
Abundance exotic fish	Connectivity	0	--	1	0.200	**0.300**
	Flood regime	-1	T	1	0.200	
	Pools	1.25	A	2	0.400	
	Aquatic/ marg. veg cover	0	--	1	0.200	
Terrestrial Wildlife	Pools	0	--	1	0.250	**0.125**
	Water quality (EC)	0	--	1	0.250	

	Riparian vegetation cover	0	--	1	0.250	
	Status of indigenous fish	0.5	T	1	0.250	
Contribution to parent river	Flood regime	0	--	1	0.500	**0.000**
	Abundance exotic fish	0	--	1	0.500	
Socio-economics	Flood regime	-2	A	1	0.143	**-0.286**
	Riparian aquifer	0	--	1	0.143	
	Pools	1	T	1	0.143	
	Riparian Vegetation Cover	-1	A	1	0.143	
	Aquatic / Marginal Vet	0	--	1	0.143	
	Pest inv	0	--	1	0.143	
	Fish	0	--	1	0.143	
Social wellbeing	Flood regime	-2	A	1	0.143	**-0.336**
	Riparian aquifer	0	--	1	0.143	
	Pools	0.25	T	1	0.143	
	Riparian Vegetation Cover	0	--	1	0.143	
	Aquatic / Marginal Vet	0	--	1	0.143	
	Pest inv	-0.6	A	1	0.143	
	Fish	0	--	1	0.143	

SCENARIO 2: Removal of man-made structures from the river channel – EWR3&4

Scenario: 2 EWR3 & 4 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		1	T	1		1
Flood regime		3	T	1		3
Sediment delivery		0		1		0
Channel aquifer	Connectivity	0	--	1	1	0
Riparian aquifer	Connectivity	0.5	T	1	0.500	0.250
	Flood regime	0.5	T	1	0.500	
Pools	Connectivity	2	T	1	0.250	1.750
	Flood regime	5	T	1	0.250	
	Sediment delivery	0	--	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Connectivity	-1	T	1	0.500	-2.000
	Flood regime	-3	T	1	0.500	
Riparian vegetation cover	Flood regime	-3	A	1	0.333	-1.000
	Riparian aquifer	0	--	2	0.667	
Aquatic/ marginal vegetation cover	Flood regime	-3	A	1	0.250	0.125
	Pools	1.75	T	2	0.500	
	Water quality (EC)	0	--	1	0.250	
No. of important invertebrate species	Connectivity	1	T	3	0.429	1.304
	Flood regime	3	T	2	0.286	
	Pools	0	--	1	0.143	
	Aquatic/ marg. veg cover	0.125	T	1	0.143	
Abundance pest invertebrates	Connectivity	0	--	3	0.429	0.571
	Flood regime	2	T	2	0.286	
	Pools	0	--	1	0.143	
	Aquatic/ marg. veg cover	0	--	1	0.143	
Status of indigenous fish	Connectivity	1	T	2	0.333	1.438
	Flood regime	3	T	1	0.167	
	Pools	1.75	T	2	0.333	
	Aquatic/ marg. veg cover	0.125	T	1	0.167	
Abundance exotic fish	Connectivity	0	--	2	0.333	0.417
	Flood regime	-1	T	1	0.167	
	Pools	1.75	A	2	0.333	
	Aquatic/ marg. veg cover	0	--	1	0.167	
Terrestrial Wildlife	Pools	0	--	2	0.400	0.088
	Water quality (EC)	0	--	1	0.200	
	Riparian vegetation cover	0	--	1	0.200	

	Status of indigenous fish	0.44	T	1	0.200	
Contribution to parent river	Flood regime	3	T	1	0.250	0.938
	Sediment delivery	0	--	1	0.250	
	Pest inv	0.25	A	1	0.250	
	Status of indigenous fish	0.5	T	1	0.250	
Socio-economics	Flood regime	-3	A	2	0.286	-0.643
	Riparian aquifer	0.25	T	2	0.286	
	Pools	1	T	1	0.143	
	Pest inv	0	--	1	0.143	
	Fish	0	--	1	0.143	
Social wellbeing	Flood regime	-3	A	2	0.250	-0.781
	Riparian aquifer	0.25	T	2	0.250	
	Pools	0.75	T	1	0.125	
	Riparian Vegetation Cover	-1	A	1	0.125	
	Pest inv	-0.5	T	1	0.125	
	Fish	0	--	1	0.125	

SCENARIO 3: Densification of farms – 20% loss of vegetation cover from present day condition – EWR1.

Scenario: 3 Site EWR1 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		1	A	1		1
Flood regime		1	A	1		1
Sediment delivery		3	A	1		3
Channel aquifer	Connectivity	0.5	T	1	1	0.5
Riparian aquifer	Connectivity	0	--	1	0.500	0.000
	Flood regime	0	--	1	0.500	
Pools	Connectivity	0.5	T	1	0.250	-0.500
	Flood regime	0.5	T	1	0.250	
	Sediment delivery	-3	A	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Flood regime	-0.5	T	1	0.500	-0.250
	Channel aquifer	0	--	1	0.500	
Riparian vegetation cover	Flood regime	-1	A	1	0.333	-0.333
	Riparian aquifer	0	--	1	0.333	
	Pools	0	--	1	0.333	
Aquatic/ marginal vegetation cover	Flood regime	-1	A	1	0.333	-0.500
	Pools	-0.5	A	1	0.333	
	Water quality (EC)	0	--	1	0.333	
No. of important invertebrate species						
Abundance pest invertebrates	Flood regime	0	--	1	0.333	0.000
	Pools	0	--	1	0.333	
	Aquatic/ marg. veg cover	0	--	1	0.333	
Status of indigenous fish	Connectivity	0	--	1	0.167	-0.250
	Flood regime	0	--	1	0.167	
	Pools	-0.5	A	2	0.333	
	Water quality (EC)	0	--	1	0.167	
	Aquatic/ marg. veg cover	-0.5	A	1	0.167	
Abundance exotic fish						
Terrestrial Wildlife	Pools	0	--	1	0.250	0.000
	Water quality (EC)	0	--	1	0.250	
	Riparian vegetation cover	0	--	1	0.250	
	Status of indigenous fish	0	--	1	0.250	
Contribution to parent river	Flood regime	0	--	1	1.000	0.000
Socio-economics	Flood regime	0	--	1	0.333	0.000
	Riparian aquifer	0	--	1	0.333	
	Pest inv	0	--	1	0.333	
Social wellbeing	Flood regime	0	--	1	0.333	0.000
	Riparian aquifer	0	--	1	0.333	

	Pest inv	0	--	1	0.333	

SCENARIO 3: Densification of farms – 20% loss of vegetation cover from present day condition – EWR2

Scenario: 3 Site EWR2 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		1	A	1		1
Flood regime		2	A	1		2
Sediment delivery		2	A	1		2
Channel aquifer	Connectivity	0	--	1	1	0
Riparian aquifer	Connectivity	0	--	1	0.500	0.000
	Flood regime	0	--	1	0.500	
Pools	Connectivity	1	T	1	0.250	0.500
	Flood regime	2	T	1	0.250	
	Sediment delivery	-1	A	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Connectivity	-0.5	T	1	0.333	-0.833
	Flood regime	-2	T	1	0.333	
	Channel aquifer	0	--	1	0.333	
Riparian vegetation cover	Flood regime	-2	A	1	0.333	-0.667
	Channel aquifer	0	--	1	0.333	
	Riparian aquifer	0	--	1	0.333	
Aquatic/ marginal vegetation cover	Flood regime	-2	A	1	0.250	-0.375
	Channel aquifer	0	--	1	0.250	
	Pools	0.5	T	1	0.250	
	Water quality (EC)	0	--	1	0.250	
No. of important invertebrate species						
Abundance pest invertebrates	Flood regime	1	T	1	0.200	0.300
	Pools	0.5	T	1	0.200	
	Water quality (EC)	0	--	1	0.200	
	Aquatic/ marg. veg cover	0	--	2	0.400	
Status of indigenous fish	Connectivity	0	--	2	0.400	0.500
	Flood regime	2	T	1	0.200	
	Pools	0.5	T	1	0.200	
	Aquatic/ marg. veg cover	0	--	1	0.200	
Abundance exotic fish	Connectivity	0	--	1	0.200	0.200
	Flood regime	0	--	1	0.200	
	Pools	0.5	A	2	0.400	
	Aquatic/ marg. veg cover	0	--	1	0.200	
Terrestrial Wildlife	Pools	0	--	1	0.250	0.000
	Water quality (EC)	0	--	1	0.250	
	Riparian vegetation cover	0	--	1	0.250	
	Status of indigenous fish	0	--	1	0.250	
Contribution to parent river	Flood regime	0	--	1	0.500	0.000
	Abundance exotic fish	0	--	1	0.500	

Socio-economics	Flood regime	-1		1	0.143	-0.157
	Riparian aquifer	0	--	1	0.143	
	Pools	0.5		1	0.143	
	Riparian Vegetation Cover	-0.6		1	0.143	
	Aquatic / Marginal Vet	0	--	1	0.143	
	Pest inv	0	--	1	0.143	
	Fish	0	--	1	0.143	
Social wellbeing	Flood regime	-1	T?A?	1	0.143	-0.186
	Riparian aquifer	0	--	1	0.143	
	Pools	0	--	1	0.143	
	Riparian Vegetation Cover	0	--	1	0.143	
	Aquatic / Marginal Vet	0	--	1	0.143	
	Pest inv	-0.3		1	0.143	
	Fish	0	--	1	0.143	

SCENARIO 3: Densification of farms – 20% loss of vegetation cover from present day condition – EWR3 & 4.

Scenario: 3 Site EWR3 & 4 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		1	A	1		1
Flood regime		1	A	1		1
Sediment delivery		4	A	1		4
Channel aquifer	Connectivity	0	--	1	1	0
Riparian aquifer	Connectivity	0.5	T	1	0.500	0.250
	Flood regime	0.5	T	1	0.500	
Pools	Connectivity	2	T	1	0.250	0.000
	Flood regime	2	T	1	0.250	
	Sediment delivery	-4	A	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Connectivity	-1	T	1	0.500	-1.000
	Flood regime	-1	T	1	0.500	
Riparian vegetation cover	Flood regime	-1	A	1	0.333	-0.333
	Riparian aquifer	0	--	2	0.667	
Aquatic/ marginal vegetation cover	Flood regime	-1	A	1	0.250	-0.250
	Pools	0	--	2	0.500	
	Water quality (EC)	0	--	1	0.250	
No. of important invertebrate species	Connectivity	1	T	3	0.429	0.714
	Flood regime	1	T	2	0.286	
	Pools	0	--	1	0.143	
	Aquatic/ marg. veg cover	0	--	1	0.143	
Abundance pest invertebrates	Connectivity	0	--	3	0.429	0.000
	Flood regime	0	--	2	0.286	
	Pools	0	--	1	0.143	
	Aquatic/ marg. veg cover	0	--	1	0.143	
Status of indigenous fish	Connectivity	1	T	2	0.333	0.500
	Flood regime	1	T	1	0.167	
	Pools	0	--	2	0.333	
	Aquatic/ marg. veg cover	0	--	1	0.167	
Abundance exotic fish	Connectivity	0	--	2	0.333	-0.042
	Flood regime	0	--	1	0.167	
	Pools	0	--	2	0.333	
	Aquatic/ marg. veg cover	-0.25	T	1	0.167	
Terrestrial Wildlife	Pools	0	--	2	0.400	0.000
	Water quality (EC)	0	--	1	0.200	
	Riparian vegetation cover	0	--	1	0.200	
	Status of indigenous fish	0	--	1	0.200	
Contribution to parent river	Flood regime	2	A	1	0.250	1.565
	Sediment delivery	4	A	1	0.250	
	Pest inv	0.07	A	1	0.250	

	Status of indigenous fish	0.19	A	1	0.250	
Socio-economics	Flood regime	-1		2	0.286	-0.214
	Riparian aquifer	0.25		2	0.286	
	Pools	0		1	0.143	
	Pest inv	0		1	0.143	
	Fish	0	--	1	0.143	
Social wellbeing	Flood regime	-1		2	0.250	-0.229
	Riparian aquifer	0.25		2	0.250	
	Pools	0	--	1	0.125	
	Riparian Vegetation Cover	-0.33		1	0.125	
	Pest inv	0		1	0.125	
	Fish	0	--	1	0.125	

SCENARIO 4: Ecotourism activities resulting in a 15% improvement in catchment cover from present day conditions, as well as abstraction from springs in the riparian zone – EWR1.

Scenario: 4 **Site EWR1** **Responder**	**Driver**	**Response curve value**	**Toward/ away**	**Weighting**	**Weighted allocation**	**Weighted sum**
Connectivity		-1	A	1		-1
Flood regime		-1	A	1		-1
Sediment delivery		-1	T	1		-1
Channel aquifer	Connectivity	-0.5	A	1	1	-0.5
Riparian aquifer	Connectivity	0	--	1	0.500	0.000
	Flood regime	0	--	1	0.500	
Pools	Connectivity	-0.5	A	1	0.250	-0.188
	Flood regime	-0.5	A	1	0.250	
	Sediment delivery	0.5	T	1	0.250	
	Channel aquifer	-0.25	A	1	0.250	
Water quality (EC)	Flood regime	0	--	1	0.500	0.000
	Channel aquifer	0	--	1	0.500	
Riparian vegetation cover	Flood regime	1	A	1	0.333	0.333
	Riparian aquifer	0	--	1	0.333	
	Pools	0	--	1	0.333	
Aquatic/ marginal vegetation cover	Flood regime	1	A	1	0.333	0.271
	Pools	-0.188	A	1	0.333	
	Water quality (EC)	0	--	1	0.333	
No. of important invertebrate species					#DIV/0!	#DIV/0!
Abundance pest invertebrates	Flood regime	0	--	1	0.333	0.000
	Pools	0	--	1	0.333	
	Aquatic/ marg. veg cover	0	--	1	0.333	
Status of indigenous fish	Connectivity	0	--	1	0.167	-0.233
	Flood regime	-1	A	1	0.167	
	Pools	-0.2	A	2	0.333	
	Water quality (EC)	0	--	1	0.167	
	Aquatic/ marg. veg cover	0	--	1	0.167	
Abundance exotic fish					#DIV/0!	#DIV/0!
Terrestrial Wildlife	Pools	0	--	1	0.250	0.000
	Water quality (EC)	0	--	1	0.250	
	Riparian vegetation cover	0	--	1	0.250	
	Status of indigenous fish	0	--	1	0.250	
Contribution to parent river	Flood regime	0	--	1	1.000	0.000
Socio-economics	Flood regime	0	--	1	0.333	0.000
	Riparian aquifer	0	--	1	0.333	
	Pest inv	0	--	1	0.333	
Social wellbeing	Flood regime	0		1	0.333	0.110

	Riparian aquifer	0.33	--	1	0.333	
	Pest inv	0	--	1	0.333	

SCENARIO 4: Ecotourism activities resulting in a 15% improvement in catchment cover from present day conditions, as well as abstraction from springs in the riparian zone – EWR2.

Scenario 4 EWR 2 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		-1	A	1		-1
Flood regime		-1	A	1		-1
Sediment delivery		-2	T	1		-2
Channel aquifer	Connectivity	0	--	1	1	0
Riparian aquifer	Connectivity	0	--	1	0.500	0.000
	Flood regime	0	--	1	0.500	
Pools	Connectivity	-1	A	1	0.250	-0.375
	Flood regime	-1	A	1	0.250	
	Sediment delivery	0.5	T	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Connectivity	0.5	A	1	0.333	0.500
	Flood regime	1	A	1	0.333	
	Channel aquifer	0	--	1	0.333	
Riparian vegetation cover	Flood regime	1	A	1	0.333	0.333
	Channel aquifer	0	--	1	0.333	
	Riparian aquifer	0	--	1	0.333	
Aquatic/ marginal vegetation cover	Flood regime	1	A	1	0.250	0.156
	Channel aquifer	0	--	1	0.250	
	Pools	-0.375	A	1	0.250	
	Water quality (EC)	0	--	1	0.250	
No. of important invertebrate species					#DIV/0!	#DIV/0!
Abundance pest invertebrates	Flood regime	1	A	1	0.200	0.250
	Pools	0.25	A	1	0.200	
	Water quality (EC)	0	--	1	0.200	
	Aquatic/ marg. veg cover	0	--	2	0.400	
Status of indigenous fish	Connectivity	0		2	0.400	-0.480
	Flood regime	-2	A	1	0.200	
	Pools	-0.4	A	1	0.200	
	Aquatic/ marg. veg cover	0	--	1	0.200	
Abundance exotic fish	Connectivity	0	--	1	0.200	-0.160
	Flood regime	0	--	1	0.200	
	Pools	-0.4	T	2	0.400	
	Aquatic/ marg. veg cover	0	--	1	0.200	
Terrestrial Wildlife	Pools	0	--	1	0.250	0.000
	Water quality (EC)	0	--	1	0.250	
	Riparian vegetation cover	0	--	1	0.250	
	Status of indigenous fish	0	--	1	0.250	
Contribution to	Flood regime	0	--	1	0.500	0.000

parent river	Abundance exotic fish	0	--	1	0.500	
Socio-economics	Flood regime	0	--	1	0.143	0.000
	Riparian aquifer	0	--	1	0.143	
	Pools	0	--	1	0.143	
	Riparian Vegetation Cover	0	--	1	0.143	
	Aquatic / Marginal Vet	0	--	1	0.143	
	Pest inv	0	--	1	0.143	
	Fish	0	--	1	0.143	
Social wellbeing	Flood regime	0	--	1	0.143	-0.036
	Riparian aquifer	0	--	1	0.143	
	Pools	0	--	1	0.143	
	Riparian Vegetation Cover	0	--	1	0.143	
	Aquatic / Marginal Vet	0	--	1	0.143	
	Pest inv	-0.25		1	0.143	
	Fish	0	--	1	0.143	

SCENARIO 4: Ecotourism activities resulting in a 15% improvement in catchment cover from present day conditions, as well as abstraction from springs in the riparian zone – EWR3 & 4.

Scenario: 4 EWR3 & 4 Responder	Driver	Response curve value	Toward/ away	Weighting	Weighted allocation	Weighted sum
Connectivity		-1	A	1		-1
Flood regime		-1	A	1		-1
Sediment delivery		-1	T	1		-1
Channel aquifer	Connectivity	0	--	1	1	0
Riparian aquifer	Connectivity	-0.5	A	1	0.500	-0.250
	Flood regime	-0.5	A	1	0.500	
Pools	Connectivity	-0.5	A	1	0.250	-0.125
	Flood regime	-0.5	A	1	0.250	
	Sediment delivery	0.5	T	1	0.250	
	Channel aquifer	0	--	1	0.250	
Water quality (EC)	Connectivity	1	A	1	0.500	1.000
	Flood regime	1	A	1	0.500	
Riparian vegetation cover	Flood regime	1	A	1	0.333	0.167
	Riparian aquifer	-0.25	A	2	0.667	
Aquatic/ marginal vegetation cover	Flood regime	1	A	1	0.250	0.188
	Pools	-0.125	A	2	0.500	
	Water quality (EC)	0	--	1	0.250	
No. of important invertebrate species	Connectivity	-1	A	3	0.429	-0.689
	Flood regime	-1	A	2	0.286	
	Pools	0	--	1	0.143	
	Aquatic/ marg. veg cover	0.18	T	1	0.143	
Abundance pest invertebrates	Connectivity	1	A	3	0.429	0.714
	Flood regime	1	A	2	0.286	
	Pools	0	--	1	0.143	
	Aquatic/ marg. veg cover	0	--	1	0.143	
Status of indigenous fish	Connectivity	-1	A	2	0.333	-0.512
	Flood regime	-1	A	1	0.167	
	Pools	-0.125	A	2	0.333	
	Aquatic/ marg. veg cover	0.18	T	1	0.167	
Abundance exotic fish	Connectivity	0	--	2	0.333	-0.042
	Flood regime	0	--	1	0.167	
	Pools	-0.125	T	2	0.333	
	Aquatic/ marg. veg cover	0	--	1	0.167	
Terrestrial Wildlife	Pools	0	--	2	0.400	0.000
	Water quality (EC)	0	--	1	0.200	
	Riparian vegetation cover	0	--	1	0.200	
	Status of indigenous fish	0	--	1	0.200	
Contribution to parent river	Flood regime	-1	A	1	0.250	-0.300
	Sediment delivery	-0.25	T	1	0.250	
	Pest inv	0.175	A	1	0.250	

	Status of indigenous fish	-0.125	A	1	0.250	
Socio-economics	Flood regime	0		2	0.286	-0.071
	Riparian aquifer	-0.25		2	0.286	
	Pools	0	--	1	0.143	
	Pest inv	0	--	1	0.143	
	Fish	0	--	1	0.143	
Social wellbeing	Flood regime	1		2	0.250	0.121
	Riparian aquifer	-0.25		2	0.250	
	Pools	0	--	1	0.125	
	Riparian Vegetation Cover	0.167		1	0.125	
	Pest inv	-0.7		1	0.125	
	Fish	0	--	1	0.125	