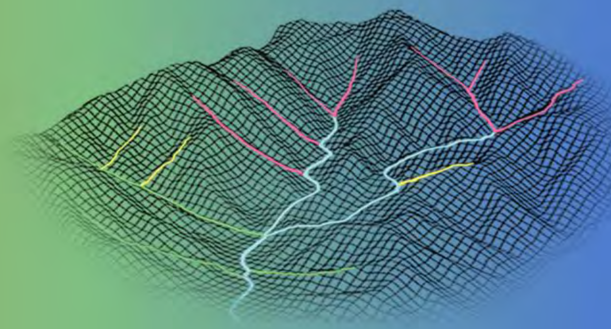

New Zealand River Environment Classification User Guide

Ministry for the Environment
Manatū Mō Te Taiao
NIWA
Taihoro Nukurangi

New Zealand River Environment Classification User Guide

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The River Environment Classification system (REC) was produced for the Ministry for the Environment by the National Institute of Water and Atmospheric Research (NIWA).

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Note to Readers

In September 2010, the River Environment Classification databases were re-released to the public. New licensing conditions were applied to the data and distributed online. This document has been updated to remove all references that are now out of date.
No updates of the REC tools have been carried out. However, the functions described in this document may still be useful for users as these can be replicated in modern applications.

Foreword

The River Environment Classification system is a powerful resource management tool. It organises and maps information about the physical characteristics of New Zealand's rivers, including catchment climate, topography, geology and land cover. Information is mapped by individual river segment for New Zealand's entire river network – over 425 million kilometres of river. The maps and information can be used for a range of water management purposes. These include environmental assessments, policy development and environmental monitoring and reporting.

The River Environment Classification along with the previous Land Environment Classification system brings us closer to a suite of ecosystem-based classifications for environmental management. Such classifications provide a context for interpreting environmental information – one where ecosystems feature in planning and decision-making. Now we have a nationally consistent river environment classification that can be applied at different scales and levels of detail from local to national. This makes it suitable for use by any resource management agency.

The River Environment Classification represents a significant achievement for the Ministry for the Environment and the National Institute of Water and Atmospheric Research (NIWA). It is also a significant achievement for those councils and individuals who test drove it and contributed to its development. Now water resource managers can use the River Environment Classification and explore what it has to offer.

Hon Marian L Hobbs
Minister for the Environment

Acknowledgements

Development of the New Zealand River Environment Classification (REC) has been funded by The Ministry for the Environment (MfE) and various regional councils. Development of REC began in 1997 and the evolution of REC represents the collective involvement and support of many people. The National Institute of Water and Atmospheric Research (NIWA) are grateful for the financial support of the Ministry for the Environment (Kirsty Johnston, Megan Linwood, Eric Pyle, and Ruth Berry) and the Environmental Hydrology and Hydraulics Program (Contract C01813) of the Foundation for Research Science and Technology (New Zealand).

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A number of regional councils helped develop REC by trialling it as an assessment and planning tool. In particular, we thank the support and contributions from Pam Guest, Raymond Ford, Ken Taylor, and Adrian Meredith of Environment Canterbury; Scott Crawford, Deidre Francis, and Keith Hamill of Environment Southland; Trevor James of the West Coast Regional Council, Andrew Fenemor formerly of Tasman District Council, and Murray McLea of the Wellington Regional Council.

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Executive Summary

River Environment Classification[1] **(**REC) is a system that classifies New Zealand's rivers at a range of spatial scales. The Ministry for the Environment (MfE) and various regional councils have supported the development of the REC.

- The REC is a spatial framework for regional (or larger) scale environmental monitoring and reporting, environmental assessment and management. Spatial frameworks are tools that assist with: organising empirical data, extrapolating data and information to locations with no data, stratifying variation in rivers so that monitoring sites can be selected and management activities can be prioritised, summarising the characteristics of types of rivers so that management expectations and controls can be set that are justifiable, specific and achievable.

- The REC groups and classifies rivers, or parts of rivers, at six hierarchical levels. The location of each REC *class* is mapped so that the class of any section of river in New Zealand can be identified. REC classes discriminate variation in physical and biological characteristics at a range of spatial scales. Characteristics that are important for management such as hydrology, hydraulics, water quality and biological communities are similar within classes and significantly different between classes.

- Each of the REC's six hierarchical classification *levels* is defined by one of six *controlling factors* (referred to as factors). These factors are Climate, Source-of-Flow, Geology, Land-Cover, Network-Position and Valley-Landform. There is an increasing number of potential classes moving down the REC hierarchy.

- The REC represents rivers as networks of sections including their upstream catchments. Sections have an average length of 700 metres. The class of each section is based on an evaluation of six factors. The first four factors are the climate, topography, geology and land cover of the upstream catchment of individual sections of the river network. The last two factors are the Network-Position and the landform of the valley of each section of the network.

- Each factor is subdivided into *categories* that discriminate variation in characteristics. Choice of categories has been guided by scientific knowledge of the causes of patterns in characteristics of rivers at different spatial scales. The higher levels of the REC discriminate large-scale patterns in general characteristics. The lower the level of the classification used, the smaller the scale of the patterns that are defined by REC. Thus, the lower the classification level used, the smaller the scale of the patterns and the more specific the characteristics that can be discriminated.

[1] The glossary contains definitions for specific terms. The first mention of these terms in both the executive summary and body of the manual has been made in italic text.

- Each level of the REC hierarchy is based on differences in a set of *processes* (for example hydrological processes) that are assumed to be the cause of patterns in physical and biological characteristics at a typical spatial scale. These processes directly affect the physical and biological characteristics of rivers and, therefore, discriminate variation in environmental values and economic resources of rivers, as well as the effects of resource use. Recognition of the spatial scale at which processes vary is important for determining the scale at which management activities (such as monitoring) are carried out.

- The REC can be used to assess the spatial distribution of river resources and values across an area such as a jurisdictional region based on an understanding of the way factors control the physical and biological characteristics of rivers.

- Classes can be treated as *management units*, each of which can be linked to a monitoring strategy, used as a framework for reporting environmental data, or as units that have specific management provisions such as in regional plans.

- The REC is provided as a *GIS (Geographic Information System)* layer. This layer can be displayed as a series of maps showing classes at each level of the REC hierarchy. Maps can be displayed to suit particular management requirements.

- This user guide comprises of three parts. Part I describes the conceptual framework for the REC and discusses its use as a spatial framework. Part II describes the use of REC in a GIS system. Part III describes three case studies that use the REC as a spatial framework for broad scale environmental assessment.

PART I Concepts and use

1 Introduction

SUMMARY
This section explains ecosystem management, how it relates to the Resource Management Act, and how within this framework REC can be utilised to manage New Zealand's rivers.

1.1 The use of spatial frameworks for resource management

Increasingly, humans are recognising the need to sustain the life-supporting capacity of the earth's ecosystems. As a consequence, the focus of resource management has shifted from single objectives, such as maximising production or protecting iconic species, to the management of whole ecosystems. The shift towards 'ecosystem management[2]' has become increasingly accepted worldwide[3] and is based on the idea that using ecosystems as a context for sustainable management helps to focus on the capacity of the biophysical resources for use, while sustaining them in the long term. However, ecosystems are not uniform and show differences in space, causing variation in their characteristics and capacity for resource use. Management must vary over space, depending on the value communities place on a resource and the capacity of particular ecosystems for resource use. Therefore, management is concerned with the spatial organisation, or patterns, of ecosystems and their characteristics.

One tool that is required to define patterns at landscape scales is a *spatial framework.* Spatial frameworks delineate areas within which ecological characteristics are similar and distinctive from adjoining areas. Spatial frameworks are tools that support ecosystem-based resource and conservation management by mapping spatial units according to multiple environmental and/or ecological characteristics. A spatial framework maps the pattern of ecosystems by subdividing an area (e.g. a region) into groups or *classes* on the basis of similarities and differences in ecologically relevant characteristics.

Spatial frameworks have multiple applications in ecosystem-based resource and conservation management. They help to organise and stratify environmental data and information, and aid data interpretation and reporting. Spatial frameworks can be used as a basis for defining areas that are managed to achieve a particular outcome. These areas or *management units* can be linked to justifiable objectives, policies and methods in plans. Spatial frameworks are also used to quantify the extent and form of particular environment types (e.g. as a part of establishing or evaluating conservation reserve networks). The Ministry for the Environment (MfE) have pursued the

[2] Christensen, et al. (1996)

[3] Park (2000)

development of spatial frameworks for terrestrial, river, wetland and marine ecosystems[4] to provide a framework for environmental monitoring and reporting and for carrying out functions under the RMA.

1.2 River Environment Classification

The Ministry for the Environment (MfE), regional councils, and many other individuals and organisations have supported the development of the *New Zealand River Environment Classification (REC)* since 1997. The REC groups rivers and parts of river networks that share similar ecological characteristics, including physical and biological. Rivers that share the same class can be treated as similar to one another and different to rivers in other classes. The REC classification system groups rivers according to several environmental factors that strongly influence or cause the rivers' physical and ecological characteristics (climate, topography, geology and land cover). This means rivers that are geographically separate, but which are similar with respect to these factors, will be part of the same class and therefore the same management unit.

The REC classification comprises a hierarchy of six *levels*. The hierarchical organisation of classes defines groups of rivers in a logical progression from a small number of high-level groups to a large number of low-level groups (Figure 1.1). High-level classes group together rivers that share similarities in general characteristics (e.g. the seasonality of the flow regime, frequency of floods and low flows). Successive lower level classes group together rivers that share similarities in more specific characteristics (e.g. water chemistry and biological communities). Colour has been used in Figure 1.1 to represent the characteristics of each class. The highest-level group comprises an equal mix of red and blue. The lower level classes have a greater proportion of one colour. In addition, when mapped, high levels of the classification delineate large-scale patterns and successive levels of classification delineate increasingly smaller scale patterns. The REC, therefore, defines a hierarchy in spatial scales.

[4] MFE (1998a; 1998b)

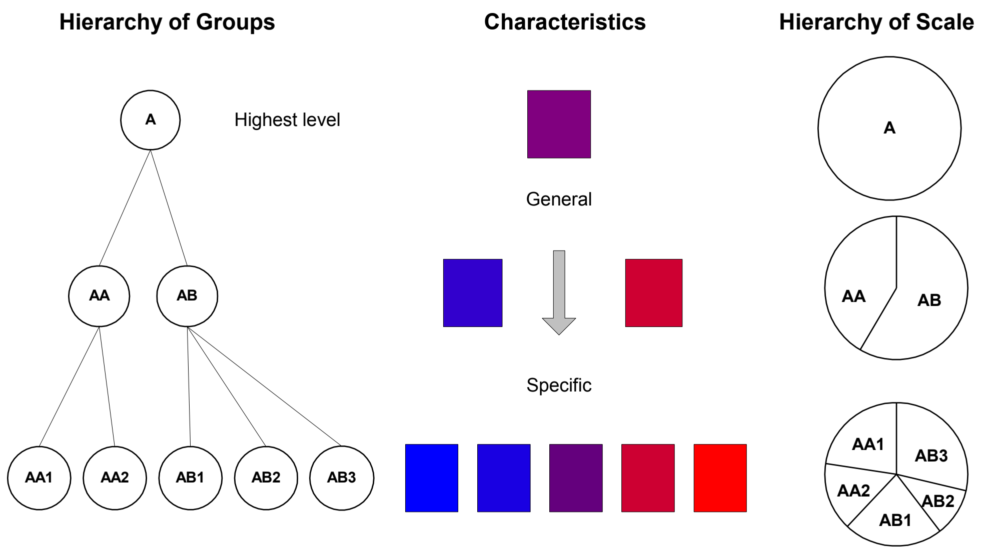


Figure 1.1 **Schematic diagram showing hierarchy of classes, characteristics and spatial scales.**

1.3 The purpose of REC

The purpose of all classifications is to group objects into classes that can then be treated as though they share similar characteristics. The REC groups rivers into classes at a variety of levels of detail and scales (Figure 1.1). Rivers with the same class are expected to have similar physical environments and ecosystems, similar environmental and economic values and similar responses to human disturbance despite the possibility that they are geographically separated. The similarity among rivers within a class means that REC classes can be used to stratify monitoring sites within a region and as a basis for reporting environmental data. The characteristics of each class can be used to make management decisions in a rational and meaningful way for the class as a whole. This allows more efficient use of limited information because data from sites can be used to characterise the conditions of locations for which data does not exist.

Lower levels of the REC provide a larger number of groups within which characteristics become increasingly similar. This allows resource managers to choose a level of differentiation of rivers that is appropriate to the characteristics of interest.

The REC is provided as a map that is accessible by *Geographic Information Systems (GIS)*. Some of the applications that the REC, together with a GIS, assists with include:

- compilation of inventories of river resources
- design of monitoring programmes
- grouping data from similar rivers (i.e. the same REC class) to characterise the class as a whole and/or variability within classes

- extrapolation of data or specific site information to other sites of the same REC class
- expansion of models to larger areas on the basis of REC class
- development of objectives and standards for specific types of rivers (i.e. REC classes) as part of policy development
- evaluation of uniqueness and significance of specific areas
- reporting water quality and quantity data, e.g. for state of the environment reporting.

The combination of these applications of the REC provides a basis for resource managers to develop strategic policy using rational and justifiable information in the absence of specific detailed information for each river. The REC also enables policy and management criteria (e.g. water quality standards) to be varied spatially in accordance with the characteristics of different types of rivers, possibly to a greater level of detail than in the past.

2 Understanding spatial frameworks

SUMMARY
This section discusses environmental classification and spatial frameworks in general and their use for environmental management.

Spatial frameworks delineate areas within which physical and/or ecological characteristics are similar and distinct from adjoining areas. The basis of a spatial framework is a classification of spatial units such as sections of river. The different types of classification that underlie spatial frameworks explain differences in their features, and their strengths and weaknesses. It is important that a user has background knowledge of the principles used for classification. This allows the user to evaluate whether the classification is appropriate for a specific application.

Classification may be based on geographic locality (e.g. New Zealand Ecological Districts and Regions), biological characteristics (e.g. vegetation such as the New Zealand Land Cover Database) or environmental (physical) characteristics (e.g. Land Environments of New Zealand (LENZ) and the REC). Classifications based on environmental characteristics group spatial units according to their similarity with respect to the environmental drivers of ecosystem pattern. Environmental classifications such as REC produce spatial frameworks that are *geographically independent* – that is the classes identify similar ecosystem types that may show wide geographic dispersion[5]. When mapped, geographically independent classifications produce a mosaic of patches that may recur across the landscape.

Environmental classification systems, such as the REC, subdivide continuously varying environmental gradients into independent categories. However, these groups and patterns do not usually exist as distinct separate entities in nature – they are more often a continuum with no discrete boundary or edge. This simplification of reality is important to bear in mind when considering a spatial framework. The mapped pattern of classes is a simplification of ecological patterns of high complexity (patterns being the variation in biophysical characteristics across the landscape).

Environmental classifications, such as the REC, assume the environment is the context in which ecosystems develop and that environmental patterns will match biological patterns. Taken at face value this is limiting because over time long-term biogeography and short-term disturbances as well as biological processes such as predation, migration and dispersal can be important influences on biological patterns. Although the patterns that are based on environmental conditions do not represent the full complexity of the real world, the simplification of reality is often useful for

[5] Detenbeck (2000)

analysing, reporting and decision-making provided the implications of the simplification are understood and provided for.

3 How REC functions – the top-down hierarchy

SUMMARY
This section outlines the REC's hierarchy of six controlling factors.

The REC hierarchy consists of six *controlling factors* (hereafter referred to as *factors*), which define the six hierarchical *levels* of the classification (see Table 1.1 and Figure 1.2). The first four levels group parts of rivers according to similarities in the Climate, Topography, Geology and Land-Cover of their catchments. The fifth and sixth levels group parts of rivers according to similarities in attributes of the local section of the river network: Network-Position and Valley-Landform. Each level of the REC is referred to by the factor that defines that level (e.g. the Source-of-Flow level and the Land-Cover level).

Each factor is subdivided into *categories*. The categories define the groups or classes at each level of the classification. For example, at the Climate level there are six categories subdividing rivers into classes of Cool-Extremely-Wet, Cool-Wet, Cool-Dry, Warm-Extremely-Wet, Warm-Wet, and Warm-Dry. At the second level, eight Source-of-Flow[6] categories are based on differences in topography; Glacial-Mountain, Mountain, Hill, Low-Elevation, Lake, Spring, Wetland and Regulated. Geology includes the categories: Hard-Sedimentary, Soft-Sedimentary and Volcanic. Land-Cover includes categories that reflect both the type of vegetation and the land use within the catchment such as Pastoral, Indigenous-Forest and Tussock. The class at any level is simply the sequence of categories at that and all previous levels, e.g. Warm-Dry Low-Elevation Volcanic rivers. The conventions for class identification are discussed in detail in Section 7.

[6] Source-of-Flow in the classification is the name for the classification level that combines climate and topography of the catchment.

Table 1.1 Factors defining the REC classification levels.

Factor	Description of factor
Climate	Catchment climate
Topography	Catchment topography
Geology	Catchment geology
Land-Cover	Catchment land cover
Network-Position	Position of the section of river within the catchment network (i.e. stream order)
Valley-Landform	Landform of the valley the river section is located within

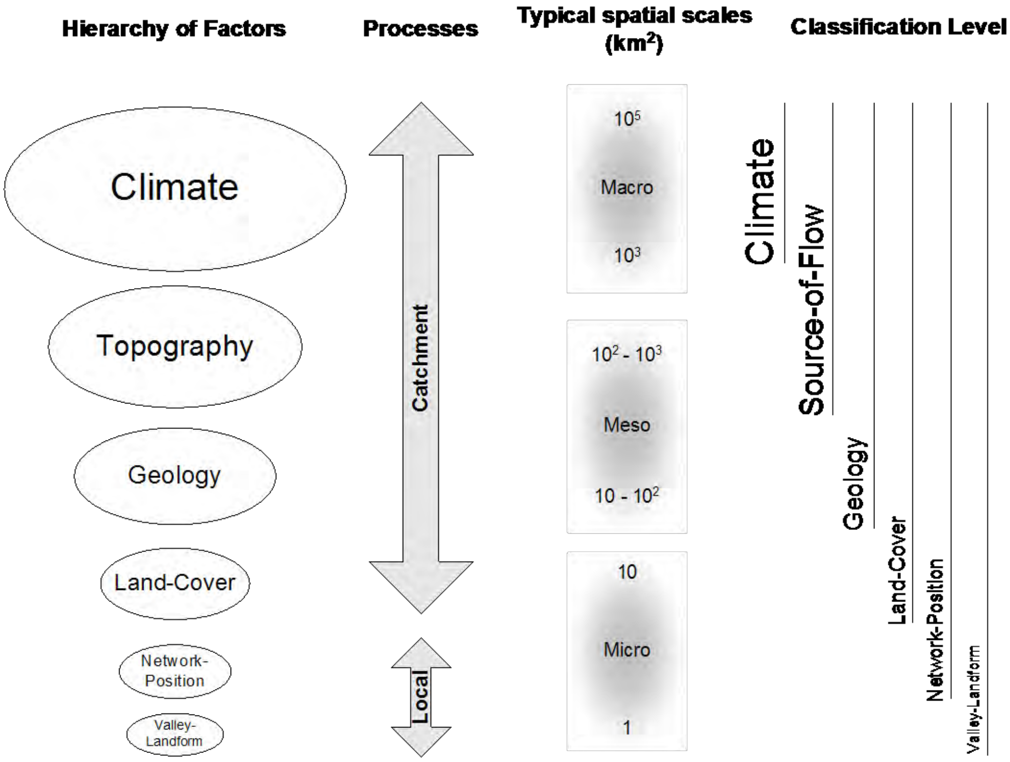


Figure 1.2 The six factors that define the six hierachical levels and control physical patterns at different spatial scales in rivers (adapated from Snelder and Biggs 2002).

The choice of each factor in the REC hierarchy has been made based on scientific understanding of the way the factors cause patterns in physical and associated biological characteristics among rivers and parts of rivers. The map of REC classes delineates hierarchical patterns that reflect the scales at which differences in particular physical characteristics can be discriminated. These patterns include seasonal flows, sediment loads, water chemistry, *morphology* (being the shape of the channel) and channel *substrate*. The REC assumes that ecological patterns are largely determined by these physical conditions. Thus the REC hierarchy of factors controls both physical and biological patterns. The mechanisms of control are discussed in more detail in Section 6.

The classification is mapped and stored as a GIS layer. GIS can be used to view the classification at any of the six levels. When mapped, the higher levels of the classification show large-scale patterns where rivers can share the same class over large spatial areas. Lower levels of the classification, when mapped, show smaller scale patterns associated with the more specific characteristics that vary at smaller scales.

The first level of the hierarchy - Climate - delineates large-scale patterns. These patterns discriminate differences in what can be considered as the general characteristics of rivers: flow and temperature (the *hydrological* and *temperature regimes)*. The Source-of-Flow level of the classification delineates smaller scale patterns that correspond to more specific similarities in hydrological and temperature regimes as well as discriminating differences in the supply and transport of sediment and, therefore, patterns in *sediment regimes*. Rivers that have the same class at the Source-of-Flow level of the classification are further subdivided into groups based on Geology and then the Land-Cover of their catchments. These lower REC levels define finer scale patterns that correspond with more specific similarities in hydrological and sediment regimes as well as water chemistry.

The theoretical basis for the REC hierarchy assumes that the factors act in a hierarchical manner such that the characteristics at lower levels of the classification are in part determined by the factors at higher levels. For example the Valley-Landform of a section of river channel may determine whether the hydraulic conditions provide for a particular fish habitat. This factor varies over short sections of the river network. However, the overarching factor, Climate, determines water temperature and broadly identifies large-scale areas that are generally suitable for the species. Geology determines whether water chemistry and channel bed material (substrate) are suitable for spawning. Accordingly the mapped patterns are a spatial hierarchy with patterns at higher levels of the classification becoming fragmented by lower levels of the classification (see Figure 1.3).

4 Controlling factors and river networks

SUMMARY

This section describes the REC river networks, comprising individual network 'sections' that are associated with their own upstream catchment. The first four REC factors describe the climate, topography, geology and land cover of each section's upstream catchment. The fifth and sixth factors describe the local attributes of the section itself.

The REC assumes that the patterns of physical and biological characteristics in river environments are responses to river flow and hydraulic *(fluvial)* processes. Fluvial processes are driven by the downstream *flux* of water and constituents sourced from the surrounding catchment. Because water and its constituents are produced by the catchment, the first four factors are attributes of the catchment. These factors broadly determine patterns in characteristics in the downstream direction. For instance, the flow from snow-capped mountains during summer melt results in cold, clean, high flows even where a river is crossing a Low elevation area such as the Canterbury Plains. In other words, rivers express the controlling effect of factors operating within their catchments, and these effects may be seen in characteristics that are remote from the actual factors themselves.

This is the reason that the REC classification is based on a *network* and classes appear as a *linear mosaic* (see Figure 1.3). Mosaic refers to the assortment of classes across the landscape. Each piece of the river network is a section of line in the mosaic. Each section of the network is classified according to the factor operating in its unique upstream catchment. The REC differs considerably from other forms of landscape or ecosystem classification where classes usually appear as a mosaic of patches across a landscape.

A river network can traverse considerable variation in landscape. Figure 1.4 shows a three dimensional depiction of the topography of the Ashley River in Canterbury. Each section of the network has been classified by the dominant catchment topography. The headwaters of this river originate high in the mountains. The headwater sections of the network are classified Mountain and are coloured blue. Further downstream the catchment is dominated by lower elevation Hill topography (coloured red). At the lower end of the network the tributaries are dominated by Low elevation catchments (coloured green). The REC classes, therefore, change from Mountain to Hill to Low-Elevation moving down the network. This is consistent with the idea that the physical and biological characteristics of rivers are the result of the network and at any given location may be dominated by attributes that are determined upstream of the point being considered.

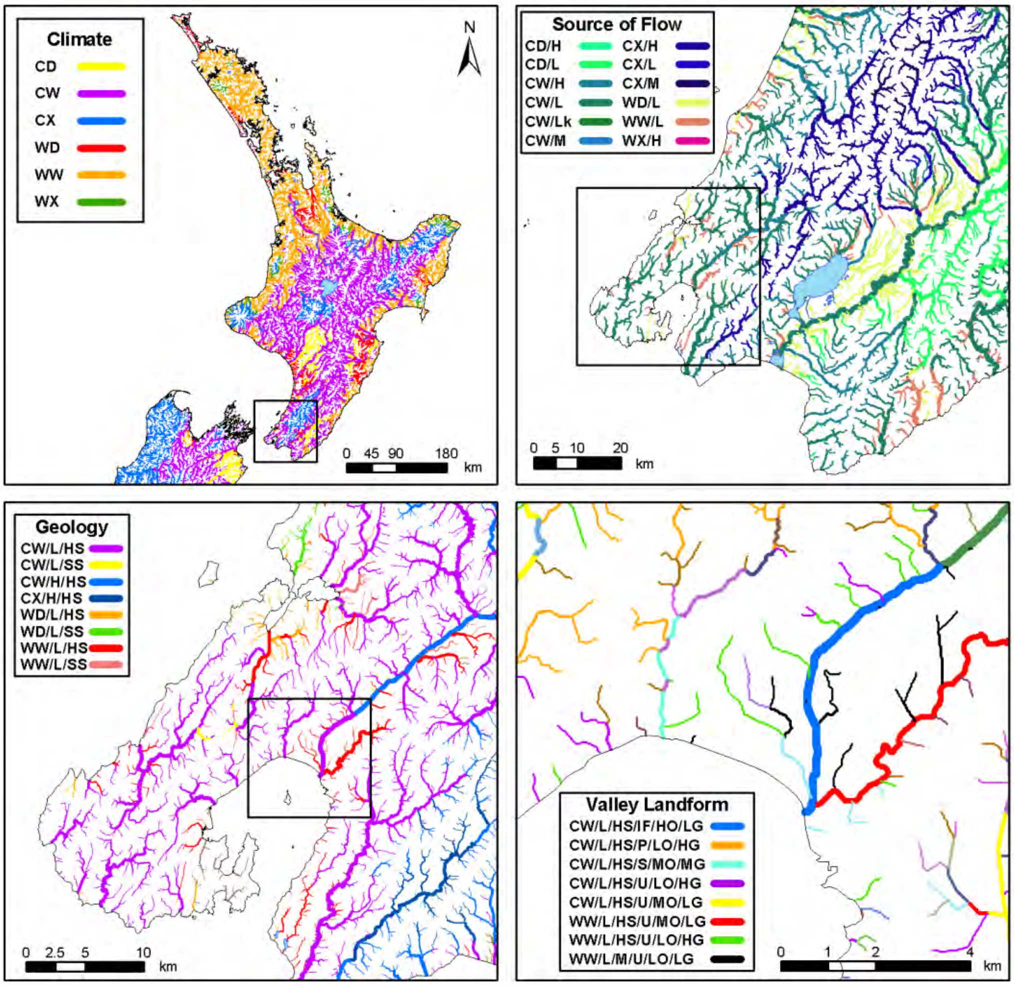


Figure 1.3 **Map of the REC at successive classification levels, where each level incorporates smaller scale factors (See Table 1.9 for the key to the map legends).**

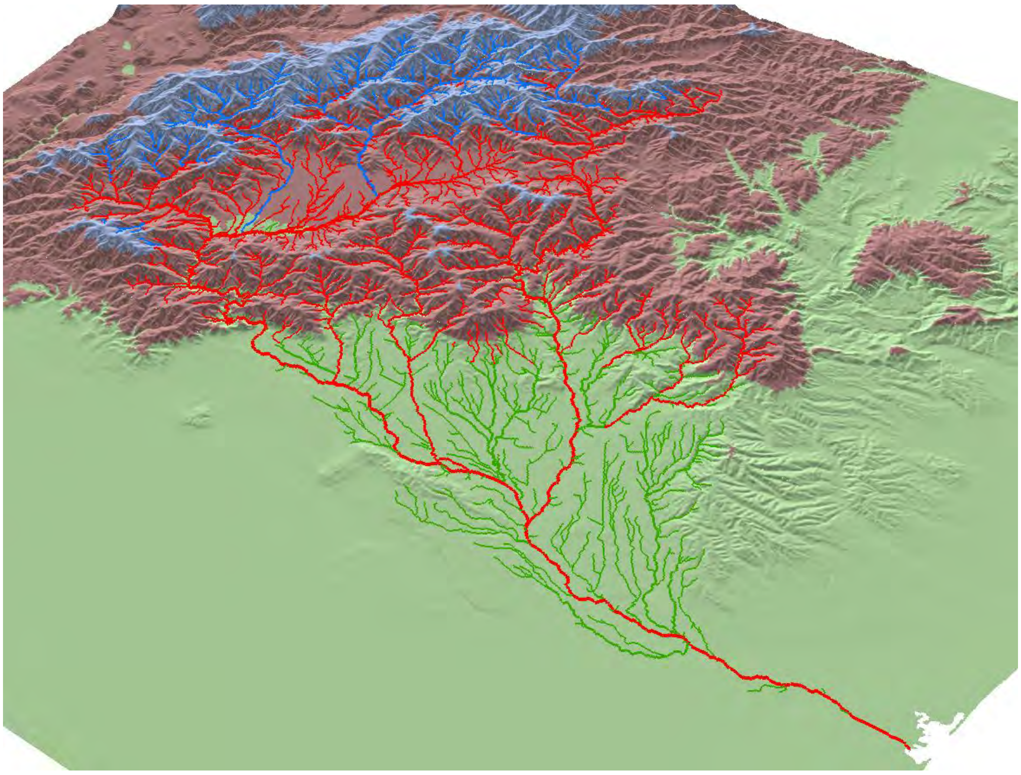


Figure 1.4 Three-dimensional representation of the topography of a single catchment (Ashley River, Canterbury).

5 The REC hierarchy of factors and physical processes

SUMMARY

This section explains why the factors were chosen in the REC hierarchy and how each level of hierarchy describes a set of processes. These processes determine the patterns of physical characteristics that the REC delineates.

The characteristics of rivers are the outcome of a variety of physical processes. The scientific understanding of these various processes underlies the choice of the REC factors. A key to using the REC is to understand the relationship between the factors and physical processes and the characteristic spatial scales at which various processes determine patterns in river ecosystems.

Most of the physical and chemical characteristics of rivers are the outcome of a number of interacting processes. These processes are largely determined or 'controlled' by the REC's factors (Table 1.2). Because these factors vary at typical spatial scales, the processes and patterns in the characteristics they produce also vary at typical spatial scales. The first four factors in the REC hierarchy characterise 'catchment processes' (Figure 1.2). Catchment processes refer to the processes that supply and route water, sediment and other constituents of flow through and off a landscape. The fifth and sixth factors characterise 'local processes' (Figure 1.2), which are understood as the outcome of catchment processes (e.g. *hydrology* and sediment supply) interacting with topographic factors operating at the scale of the local channel network. For example, the *hydraulic* conditions in rivers (depths and velocities) are controlled by flow from the catchment interacting with the local channel conditions such as slope or width. Consequently, as well as defining a spatial hierarchy, the hierarchical organisation of factors reflects a process hierarchy.

The following examples illustrate the concept of process hierarchies. Rainfall, evaporation and catchment storage and release of water are processes that broadly determine the flow regimes of rivers. Climate is the dominant control on these processes because it determines the total quantity of water a catchment receives. Patterns of Climate are generally homogenous (that is, similar) over large spatial areas. Climate, therefore, is used to subdivide rivers into large groups that have generally similar flow regimes. Processes of storage of precipitation either as snow or in lakes are second level processes that control flow regimes. These storage processes are determined by topography. The topography of the catchment, therefore, causes more specific differences in flow regimes. Differences in topography determine the amount of precipitation that is stored as snow or in lakes. These storage processes modify the catchment response to climate and act as a second level control on flow regimes. Thus the Source-of-Flow level of the REC uses the factors Climate and Topography to subdivide rivers into groups that contrast with respect to their flow regimes such as seasonal variation, and frequency and severity of floods and low flows.

Table 1.2 Levels of the REC hierarchy that describe particular physical processes and characteristics in rivers

Factor	Processes being described by this classification level	Physical characteristics that are discriminated at this level
Climate	Climate influences precipitation (how much rain an area receives), the amount of evapotranspiration occurring in the catchment, and the air temperature and the amount of sunshine the river receives, which together influence heating and cooling of water.	Seasonality of flow and thermal regime. High and low flow frequencies. Very broad discrimination of water chemistry (quality).
Topography	Catchment topography strongly influences how precipitation is stored (due to snow pack and lakes) and released from a catchment as well as erosion and transport of sediment. Topography also influences small-scale climate variation within a catchment.	Further (more specific) discrimination of the seasonality of the flow and thermal regimes, frequency of high flows. General discrimination of sediment transport regimes.
Geology	Catchment geology influences rates of erosion and chemical weathering of underlying rocks including nutrient release. Catchment geology influences aspects of hydrology, including groundwater storage and release (i.e. base flow conditions)	The Geology level discriminates: low flow magnitude, sediment supply, water chemistry (e.g. inorganic nutrient status, pH and dissolved and suspended inorganic matter) and channel substrate.
Land-Cover	Catchment land cover influences surficial erosion of soil, supply of soil derived water column constituents during rainfall and surface runoff including nutrients and sediments	The land cover level further discriminates the frequency and duration of low flow and water chemistry including total nutrients and organic matter.
Network-Position	Attenuation of many fluxes (e.g. flow, sediment) by catchment storage	Flux of sediment, water, and hydro-chemicals. Distribution of flow rates. Flood intensity.
Valley-Landform	Local hydraulic processes of erosion and deposition.	Valley-Landform influences channel shape and thus, hydraulic conditions (water velocity and depth), bank-full discharge, habitat volume, local flood power, sediment size range, and riparian conditions. The exact characteristics are, in part, determined by the higher order factors.

Processes of erosion and transport broadly determine sediment regimes. Flow regimes provide the power to transport eroded material down the river channel. Topography controls the erosion of sediment. Climate and topography are, therefore, high-level factors controlling sediment regimes. The Source-of-Flow level of the REC groups rivers that are broadly similar with respect to sediment regimes. However, within each of these large groups of rivers there will be some variation in the sediment regimes because of differences in the erodabilty of the surface material. The type of rock in the catchment is therefore a lower order controlling factor that causes variation in sediment supply at smaller spatial scales. The REC subdivides each high-level group into smaller groups based on catchment geology. The processes controlling sediment regime are increasingly well described moving down the levels of the factor hierarchy. Reducing the classification level is expected to provide more specific characterisation of the sediment regime.

Another example of a process hierarchy is the concentration of chemical constituents of water, such as nutrients, in a river. The flow regime determines the transport of the chemical constituents and influences their potential concentrations. The Climate and Source-of-Flow levels of the REC can very broadly subdivide rivers into groups with different water quality. The chemical constituents at base flow (periods when flow is supplied by groundwater rather than rainfall) are largely determined by weathering of the underlying geological material. By including Geology, the rivers can be subdivided into smaller groups that are more specifically similar in terms of their water quality than the previous larger groups defined by the Source-of-Flow level. During periods of rainfall, surface runoff mobilises chemicals and sediment from the surface soil layer and adds to the total flux of chemicals. So, the inclusion of land cover in the classification adds increasing detail about the processes involved in determining water chemistry, breaking the groups into even smaller units and providing increased discrimination of water chemistry.

An example of increasing the discrimination of water chemistry by grouping sites at increasingly lower REC levels is illustrated in Figure 1.5. Figure 1.5 shows the range in mean concentration of soluble inorganic nitrogen (SIN) at 70 water quality monitoring sites throughout New Zealand based on five years of monthly samples. The sites have been grouped by the REC class of the river section on which the site is located. Groups are defined at three levels of the REC: Climate, Source-of-Flow and Land-Cover. The range in the mean concentration of SIN within each class is shown by ‘box and whisker plots’. These plots show the median value for concentration as a small square, the 25th to 75th percentiles are enclosed within the rectangular box and the full range is shown by the ‘whiskers’. The plots show that the variation in mean concentration among sites is successively reduced by grouping them at lower levels of the classification.

Note that the y-axis covers a decreasing range in successive graphs. The first plot shows wide variation in nitrogen concentrations within each of three climate classes (CX = Cool-Extremely-Wet, CW = Cool-Wet, CD = Cool-Dry). This variation is reduced by the Source-of-Flow level where the median concentration of nitrogen is quite different for Cool-Wet Mountain (CW/M), Hill (CW/H) and Low-Elevation (CW/L) classes. Finally, at the REC Land-Cover level the effect of different catchment Land-Cover is shown within the CW/H class with Hard-Sedimentary geology (HS) and Pastoral (P) and Indigenous-Forest (IF) classes. Section 7 has a full discussion of all the REC categories and naming conventions.

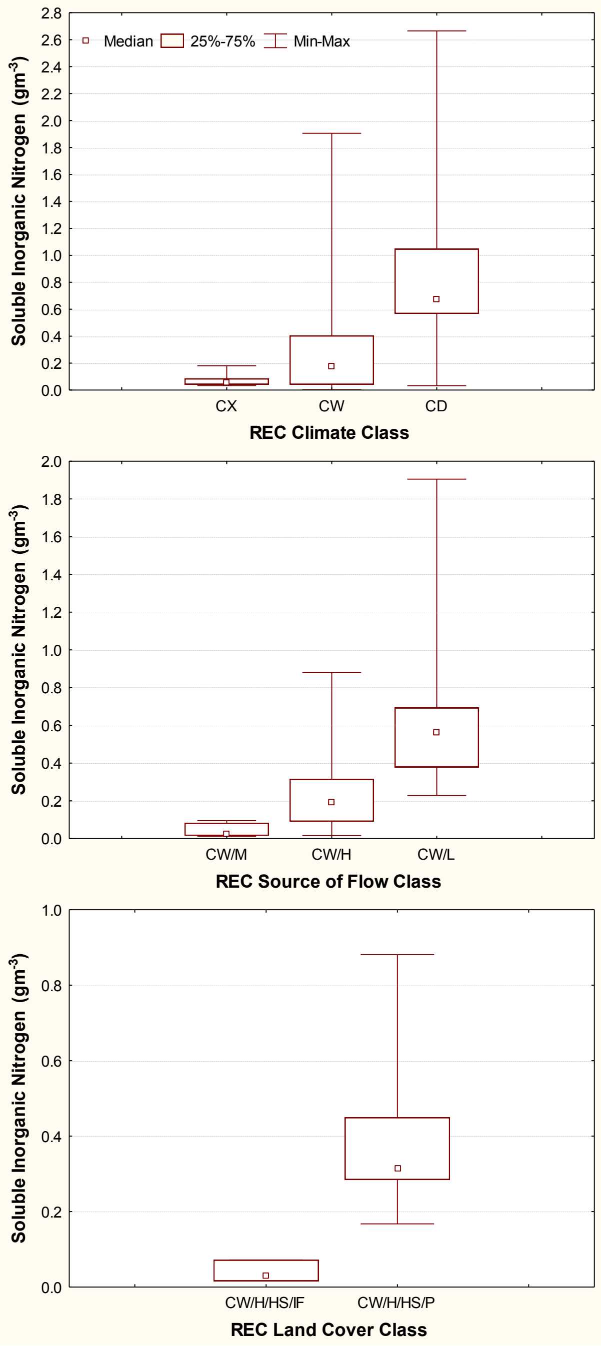
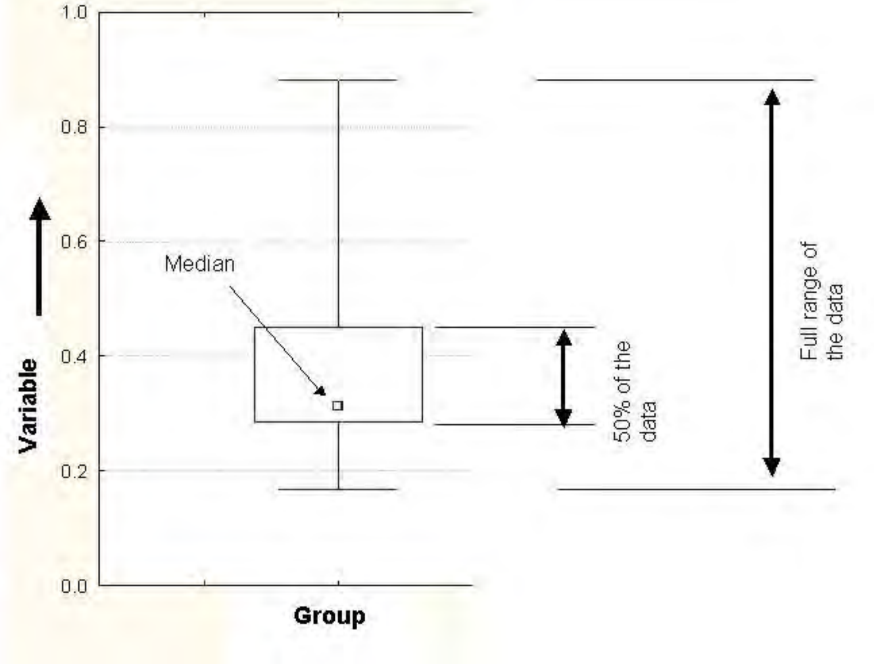


Figure 1.5 **Graphs of mean soluble inorganic nitrogen concentration at 70 locations belonging to a subset of REC classes throughout New Zealand based on 5 years of monthly samples. (Adapted from MFE 2002).**

Box 1. Explanation of Box and whisker plots

Box and whisker plots show the range in a variable, such as a nutrient concentration, for grouped data. The central square is the median concentration; the upper and lower boundaries of box are the 25th and 75th percentile; and the whiskers are the range of all the data.



The fifth level of the classification is defined by the factor of Network-Position. Groups of rivers (in fact groups of sections of rivers) that have the same Climate, Source-of-Flow, Geology and Land-Cover categories are subdivided at the fifth level of the REC by Network-Position categories. Network-Position is the location of a section of river in the catchment network, (for example, a headwater stream, a tributary or a main stem). Network-Position describes processes involved in transport down the network. In headwater streams, the network has very little storage capacity and there is a short delay in flood flows or material moving down the network. However, in main stems the network upstream has appreciable storage capacity. This storage affects movement of water and materials, effectively delaying and smoothing sharp spikes in flow and transported material such as sediment and chemical constituents.

The lowest classification level, Valley-Landform, describes hydraulic process, essentially processes involved in in-channel erosion and deposition of sediment. These processes lead to differences in channel characteristics. Where the valley slope is high, erosion dominates, resulting in coarse substrate (bed material). Where the valley slope is low, deposition dominates and fine sediments are deposited. Hence this lowest level of the classification discriminates channels that are broad, shallow and gravel or cobble bottomed with swift moving water from those channels that are deep with slow moving water and muddy bottoms. The inclusion of the factors controlling these channel characteristics greatly increases the discrimination of the biological communities of rivers – or enables a more detailed explanation or prediction of the animals likely to occur in a particular section of river.

An understanding of processes is vital when considering how resource use affects river ecosystems. The fundamental effect of resource use is to change certain processes, leading to changes in the characteristics and potentially a loss of certain valued characteristics. For example, a change in concentration of nutrients (as a result of discharges) or a change in the flow regime (as a result of abstraction, dams or diversions) may result in a change in biological characteristics. Because certain characteristics of rivers have *value*, policy makers and resource managers should focus on the processes affecting these characteristics. An understanding of the characteristic scale of processes allows management to be carried out at appropriate scales and recognition of spatial variation allows realistic expectations in terms of achievable conditions.

6 REC factor categories and their characteristics

SUMMARY

This section outlines how each REC factor is subdivided into categories and what physical characteristics each category represents.

Each section of the REC river network has been classified by assigning each section of river a factor category based on a set of criteria. The process of assigning each section of network to a class so that the REC can be mapped as classified river lines was carried out using various spatial databases of *mapping characteristics* that allowed the factor categories to be evaluated for each network section (see Table 1.9 for each mapping characteristic). Climate classes were assigned using criteria related to mean annual precipitation, evaporation and air temperature of the catchment of each network section. The climatic data were provided by Landcare Research and are consistent with the climate data underlying the Land Environments of New Zealand (LENZ) classification system[7]. Source-of-Flow categories have been assigned based on the elevation within which more than 50 percent of total annual rainfall occurs. Geology is based on geological attributes contained within the *Land Resources Inventory (LRI).* Land cover is based on Land-Cover categories contained within the 1997 version of the *Land Cover Database (LCDB).* Network-Position is based on the stream order of each network section and Valley-Landform categories are assigned based on various valley slope criteria. The assignment criteria are detailed in Table 1.9.

Environmental attributes of catchments are generally heterogeneous, (e.g. topography of catchment generally involves higher areas such as mountains or hills as well as Low elevation areas; Geology may comprise Soft-Sedimentary and volcanic rocks). For the first four levels of the REC hierarchy (that is, the first four factors in the REC hierarchy) the categories are based on an evaluation of each mapping characteristic for the catchment as a whole. The criteria recognise that some factor categories have a disproportional effect on characteristics. For example, a geological category may dominate the characteristics of a river even when it comprises only a small proportion of the total catchment area. For example, REC criteria categorise Geology as 'Soft-Sedimentary' if 'soft' rocks such as siltstone, mudstone and limestone, exceed 25% of the total catchment area. This criterion recognises the proportionally greater contribution of Soft-Sedimentary geology to sediment and nutrient supply[8].

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[7] Leathwick et al (2003)

[8] Hicks, et al. (1996) Biggs (1990; 1995) Biggs and Gerbeaux (1993)

The last two factors in the REC hierarchy do not propagate their effects downstream and are concerned with processes that are 'local' to the section itself. The categories for Network-Position and Valley-Landform are based on features of the section itself.

6.1 Climate

The Climate level of the REC is based on a subdivision of New Zealand into six categories (Table 1.3) at the macro-scale (i.e. homogeneous areas with a characteristic size of 10^3 to 10^5 km^2). The spatially averaged climate of the catchment of each network section is used to define Climate categories producing the largest scale REC patterns.

Large-scale patterns in climate cause patterns in hydrological and thermal regime of rivers as well as broad patterns in water quality. Precipitation and potential *evapo-transpiration* control hydrological cycles including frequency of flooding and low flow periods. Rivers with higher rainfall have high flows, relative to their catchment area and flood more frequently. Temperature modifies the watershed response to precipitation and, with solar radiation, sets the potential thermal regime of rivers. Rivers whose catchments have low temperatures have consequently lower maximum water temperatures. Higher flows have greater dilution potential and thus rivers whose catchments have high rainfall tend to have higher water quality (see Figure 1.5).

Table 1.3 The REC's six Climate categories along with notations

Climate category	Notation
Warm-Extremely-Wet	WX
Warm-Wet	WW
Warm-Dry	WD
Cool-Extremely-Wet	CX
Cool-Wet	CW
Cool-Dry	CD

In New Zealand, precipitation is strongly related to elevation with maximum precipitation in the Southern Alps occurring at 1200 to 1700 metres[9]. Precipitation extremes generally reflect the pattern of annual precipitation – the heaviest and most intense falls tend to occur where annual totals are highest, and dry periods and droughts where annual totals are least[10]. However, rain-shadow areas occur on the eastern side of the mountains. Because these rain-shadow areas are also subject to warm Föhn winds, the relationship between topography and 'effective annual precipitation' (i.e. precipitation minus potential evapotranspiration) that produces

[9] Tomlinson (1992)

[10] Mosley and Pearson (1997)

stream flow is not simple[11]. Because of this partial independence of climate and topography, the REC uses direct measures of precipitation minus potential evapotranspiration and temperature to assign each network section to a climate category.

6.2 Source-of-Flow

The second factor in the REC hierarchy broadly subdivides topography into eight categories (Table 1.4) at the meso-scale (i.e. 10^2 to 10^3 km^2). Five of these Source-of-Flow categories (Mountain, Glacial-Mountain, Hill, Low-Elevation, and Lake) are assigned using GIS based topographic data and appear in the REC GIS coverage. A further three categories are not able to be determined using GIS techniques and have to be subjectively assigned to sections of the river network manually. This is made by overwriting the category in the GIS database, which is discussed in Part II of this manual. These topographic categories subdivide the Climate class patterns into smaller Source-of-Flow level classes and mapped patterns.

The eight categories are:

- Glacial-Mountain
- Mountain
- Hill
- Low-Elevation
- Lake
- Spring (manually assigned)
- Wetland (manually assigned)
- Regulated (manually assigned).

Topography is the dominant cause of patterns in flow regime at meso-scales. In high elevation areas such as Mountains the amount and intensity of rainfall and discharge are greater than in Low elevation areas. Topography is also the dominant cause of patterns in sediment regimes. Erosion and sediment transport processes are more intense in Mountain catchments, resulting in higher flood frequency and sediment supply. Less steep catchments tend to have more attenuated (slowed) runoff and less intense erosion and, as a result, sediment supply and flood frequency tend to be generally lower in Hill and Low-Elevation Source-of-Flow categories.

Whether precipitation is stored as snow and ice is also important. Snow pack storage and spring and summer high flows due to snow melt are characteristics of Glacial-Mountain, Mountain and Hill Source-of-Flow categories (Figure 1.6). Rivers belonging to the Low-Elevation category follow the effective rainfall regime; flows are high in winter when rainfall is high and evapotranspiration is low (Figure 1.6). A

[11] Tomlinson (1992)

further Source-of-Flow category ‘Lake’ distinguishes catchments on the basis of their hydraulic storage. Lakes attenuate flood flows, resulting in stable flow regimes. In addition, the Lake Source-of-Flow category has low sediment supply as lakes act as ‘sinks’ for sediment.

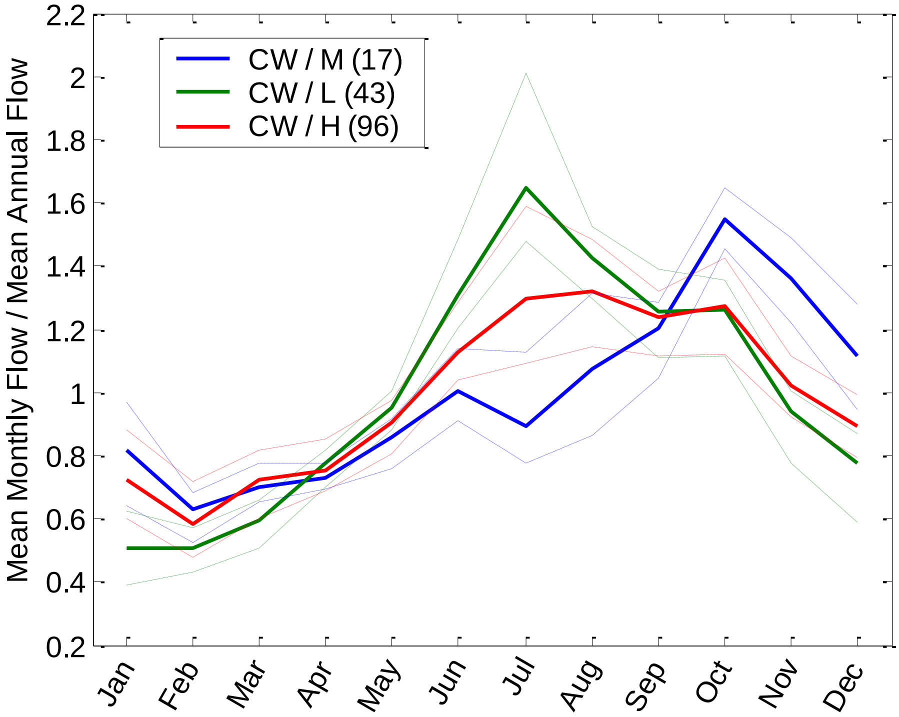


Figure 1.6 Seasonal pattern of flow in three Source-of-Flow classes.

This figure is based on mean monthly flows recorded at 156 long-term flow-monitoring sites. The number of sites in each Source-of-Flow class is shown in brackets in the legend. The solid line shows the class median of mean flow (expressed as a ratio of the mean annual flow) and the dotted lines show the 25th and 75th percentiles. The number of individual sites used to characterise each class is shown in brackets in the key.

Flood frequency and sediment supply are processes that are the major determinants of the general form and character of river channels at scales of hundreds of metres to kilometres. This is a scale at which river channels appear as features in a landscape. Thus, different classes at the Source-of-Flow level are generally quite visually distinctive. Figures 1.7 to 1.10 show the typical general form of river channels in Glacial-Mountain, Mountain Hill and Low-Elevation classes.

The conceptual framework underlying the REC also recognises a further three Source-of-Flow categories as significant determinants of flow and sediment regimes - Spring, Wetland and Regulated. These categories cannot be assigned using GIS data and need to be assigned manually by overwriting the default REC category for individual network sections (see Part II). Regulated rivers are those where flow regime is dominated by dams and artificial flow control such as power station discharges. Catchments that have significant flow contributions from spring or wetlands have similar characteristics to Lake Source-of-Flow classes, that is, relatively stable flow regimes and low sediment supply. These Source-of-Flow categories may also have significant effects on water chemistry characteristics. For example, Wetland Source-of-Flow can have high organic material content often exhibiting dark, tannin-stained water. Spring sources of flow may be relatively lower temperature and temperature regimes may show little seasonal variation.

Box 2. Variation of Source-of-Flow within catchments

Source-of-Flow classes may vary considerably within a single catchment. Figure 1.4 illustrates how separate tributary streams may have a different classification to the main stems they meet. Collectively, tributaries may change the classification of the main stem. In Figure 1.4 the main stem changes from a Mountain to Hill Source-of-Flow category as the upstream catchment becomes dominated by Hill rather than Mountain topography. This has major implications for catchment management. Values or issues are unlikely to be able to be considered as consistent within a catchment because the difference of Source-of-Flow within the catchment will mean the physical and biological characteristics of these sections of rivers will vary.

Figure 1.7 An example of a Glacial-Mountain Source-of-Flow category. Rakaia River, Canterbury. (Photo by Nelson Bousted, NIWA)

Figure 1.8 An example of a Mountain Source-of-Flow category. Eglington River, Southland. (Photo courtesy of Environment Southland)

Figure 1.9 An example of a Hill Source-of-Flow category. Mataura River, Southland. (Photo courtesy of Environment Southland)

Figure 1.10 An example of a Low-Elevation Source-of-Flow category. Mokau River tributary (Photo courtesy of Jody Richardson, NIWA)

Table 1.4 Characteristics and notations for the eight topography categories which define the Source-of-Flow level of the REC.

Source-of-Flow category	Notation	Characteristics of category
Glacial-Mountain	GM	Similar to the Mountain category. Low flows in winter, high flows extend further into summer. High turbidity due to fine glacial sediment.
Mountain	M	Strong seasonal pattern of flows: low flows in winter, high flows in summer. High suspended solids and sediment load. Very frequent high flood flows lead to unstable substrates and channels with wide, active gravel bed flood plains.
Hill	H	Strong seasonal pattern: low flows in late summer, high flows in spring due to rainfall and snow melt. High to medium sediment loads depending on catchment geology and land use. Where the valley is broad so that the river channel is unconstrained, the channel morphology is characterized by unstable substrates and wide, active gravel bed flood plains.
Low-Elevation	L	Very marked seasonal flow patterns: high in winter, low in summer (see Figure 1.6). Low sediment supply. Stable, Low-Gradient, entrenched channels with low flow velocity and silty-sandy substrates. Flood flow velocities are low due to low channel slope.
Lake	Lk	Stable flow regime. Low suspended solids and sediment load. Stable channel and substrates, which may be 'armoured' (i.e. large stable stones due to winnowing of fine material and lack of sediment supply).
Spring	Sp	Stable flow regime. Low suspended solids and sediment load. High nutrient status from catchments draining pastoral areas, otherwise low nutrient status in hill and mountain areas. Stable flow regime with no or negligible flood flows.
Wetland	W	Relatively stable flow regime. Low sediment load. Humic staining (dark brown/yellow colour) due to a high dissolved organic carbon. Stable, substrates and channels.
Regulated	R	Flow regime significantly altered from natural state. Hydroelectric power generation may cause short-term fluctuations in flow and longer-term seasonal changes. Diversions may significantly increase or decrease base flows. Flood peaks generally less frequent. Sediment supply generally reduced due to dam and diversion structures.

6.3 Geology

Geological categories further subdivide the patterns that are defined by the Source-of-Flow level. Geology broadly describes the rock types present in the catchment of each network section. The REC has been developed from the 'toprock' geology category[12] provided by the New Zealand Land Resources Inventory (LRI). Seven geological categories are used to differentiate New Zealand at a scale of 10 to 100 km^2 (i.e. 'meso-scale') (Table 1.5).

Catchment geology controls groundwater storage capacity and transmissivity. These are dominant influences on base flow at the meso-scale. Catchment geology is also the dominant controller of hydro-chemical processes, particularly at base flow. The geology level, therefore, provides increased discrimination of water chemistry. Catchment geology strongly influences erosion rate and the geology level provides increased discrimination of sediment supply. Geology categories are also expected to discriminate patterns in the architecture of material forming channel substrates (e.g. platy versus rounded) and sediment particle size.

[12] Note that where the LRI toprock category was loess, alluvium, or peat, the LRI baserock category was used.

Table 1.5 The REC's seven Geology categories including notations and characteristics.

Geology category	Notation	Characteristics of category
Alluvium	Al	Rainfall infiltration is high which tends to reduce flood frequency. There tends to be a high degree of surface water and ground water interaction. Base flows may be sustained by seepage or springs or may reduce in the downstream direction as water flows into the groundwater system. Water chemistry reflects the nature of the parent material. Note that the source information on catchment geology, the LRI, does not discriminate the parent material for alluvium. This makes the geochemistry of the Alluvium category variable.
Hard sedimentary rocks (greywacke, schist)	HS	Infiltration of rainfall is variable. Where geology is fractured, infiltration is high, resulting in infrequent floods but sustained base flow. Low natural nutrient concentration. Low suspended sediment. Relatively coarse substrates (cobble, gravel, sands) depending on local morphology.
Soft sedimentary (siltstone, mudstone and limestone)	SS	Low infiltration resulting in increased floods and low base flow. High natural phosphorus concentration. Because of the relatively soft parent material suspended sediment concentrations tend to be high. In addition, substrates tend to be relatively fine (silts and mud).
Volcanic basic	VB	This is a broad category within which considerable variation may exist. Phosphorus concentration tends to be high relative to other geology categories. Substrates tend to be angular, well packed and stable.
Volcanic acidic	VA	This is a broad category within which considerable variation may exist. Very high infiltration in areas of tephra or scoria resulting in low flood frequency and sustained base flow. Concentration of phosphorus tends to be high. Substrates tend to be fine (sands, silts and mud), unless the stream channel is steep and eroding.
Plutonics	Pl	Infiltration of rainfall tends to be low. Low natural nutrient concentration. Low suspended sediment. Substrates tend to be 'bimodal', either large (boulder to cobble) or fine (sands) depending on local morphology.
Miscellaneous	M	This class covers a number of rock types that occur infrequently including peat. The hydrology and water chemistry characteristics of this category are therefore variable. The miscellaneous geology category in urban areas where the LRI did not properly determine rock type.

6.4 Land-Cover

Seven major categories of Land-Cover are used to differentiate New Zealand at a characteristic scale of approximately 1 to 10 km^2 (i.e. 'micro-scale') (Table 1.6). The REC has been developed from land cover data provided by the New Zealand Land Cover Database (LCDB). Catchment land cover is the dominant control of rainfall capture or runoff, as well as potential evapotranspiration at the micro-scale. For example if land is covered by dense forest, rain interception and evapotranspiration is higher than rain falling on impervious urban surfaces. Catchment land cover is also the dominant control of erosion and runoff processes at the micro-scale. As a result, Land-Cover categories discriminate differences in flow regime, nutrient and sediment supply and the type of sediment reaching the stream, forming the channel substrate.

Box 3. Explanation of pastoral land cover

Pastoral Land-Cover refers to all intensive agricultural use and includes pasture, cropping and also includes the LCDB horticulture category. The REC used the 1997 version of the Land Cover Database (LCDB) to provide mapping characteristics for land cover. The LCDB has relatively limited resolution of agricultural land use and does not separate, for example, different levels of land use intensity. Future versions of the LCDB may make this discrimination and these could be incorporated as additional Land-Cover categories by the REC.

Box 4. Partitioning of water quality data by Land-Cover classes

Land cover may explain why rivers that are otherwise similar, that is, having the same Climate, Source-of-Flow and Geology classification, may have different water quality characteristics. Figure 1.5 (lower panel) shows that rivers whose catchment characteristics differ only with respect to land cover have distinctly different ranges in soluble inorganic nitrogen. Many other water quality variables such as water clarity, faecal indicator bacteria, phosphorus and biological oxygen demand are high in catchments dominated by pastoral Land-Cover relative to natural Land-Cover categories (see MFE 2002).

Table 1.6 The REC's seven Land-Cover categories including notations and characteristics.

Land-Cover category	Notation	Characteristics of river environment
Bare ground	B	The Bare Ground category tends to occur over large areas only in mountainous catchments. The hydrological and water chemistry characteristics of this class tend to accentuate the characteristics of the Mountain Source-of-Flow category. Runoff response is rapid, low nutrient concentration and suspended sediment tends to be high.
Indigenous forest, Scrub, Tussock (Natural land cover)	IF S T	Flood peaks are attenuated by vegetation, and low flows are generally more sustained than Pastoral or Bare Ground Land-Cover categories. Nutrient concentrations tend to be low. Suspended sediment concentrations tend to be low resulting in high water clarity.
Pastoral	P	Flood peaks tend to be higher and recede faster. Low flows are generally more extreme relative to catchments with natural land cover. Nutrient concentrations are high relative to natural Land-Cover categories. Erosion rates tend to be high, resulting in low water clarity and fine substrates (silts and mud) compared to natural land cover.
Exotic forestry	EF	Flow regime dependent on the age of the forest. Mature forests display a regime relatively similar to that found in native forest; recently logged forests display a regime similar to pastoral sites. Variable nutrient and suspended sediment concentrations depending on the cutting cycle of the forest. Nutrients for mature forests are typically lower than for rivers with a Pastoral Land-Cover category.
Urban	U	Flood peaks are very 'peaky' and recessions return quickly to base flow. Base flows are very low. High concentration of many contaminants. High suspended sediment load during development and typically low afterward. Fine substrates (silts and mud) relative to natural Land-Cover categories.

6.5 Network-Position

Network-Position describes the location of a section of river in the network (*stream order*). Three Network-Position categories (Table 1.7) subdivide rivers into sections, which are typically 1 to 10 km long.

This level characterises variation in fluxes of water, sediment and other constituents of the flow along the network due to increasing catchment area. Network-Position also characterises changes in river environments caused by attenuation of flood flows, homogenisation of flow constituents and changes in the relative contribution of flow from groundwater storage. Network-Position therefore discriminates patterns in aspects of flow including the intensity of flood flows, fluxes of sediment and fluxes of chemicals including nutrients.

Box 5. Explanation of the stream order concept

Stream order is the numerical position of a tributary or section of a river within the entire network. Headwater streams are assigned a stream order of 1. When two tributaries of the same stream order meet, the order increments by one for the next section downstream. However, if two sections meet where one section has higher order than the other, the next section downstream has the same order as the highest upstream section. This is illustrated on the diagram below where the numbers are the stream order of the adjacent network sections.

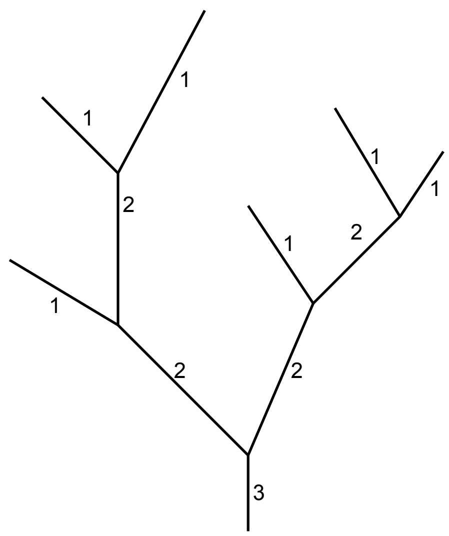


Table 1.7 Three Network-Position categories with notations and characteristics.

Network-Position category	Notation	Characteristics of river environment
Low-Order	LO	Headwater streams (Stream order 1 and 2) with little upstream storage. Fluxes of water and water borne constituent (e.g. sediment) move rapidly through with little attenuation.
Middle-Order	MO	Tributaries (Stream order 3 and 4)
High-Order	HO	Main stems (Stream order greater than 4). Main stems have large upstream catchments with appreciable storage. The response of the river to rainfall is 'damped' and variation in concentrations or fluxes of inputs, such as sediment or other contaminants are smoothed by the homogenising effect of catchment storage and upstream mixing.

6.6 Valley-Landform

The final factor in the REC classification hierarchy is Valley-Landform. The Valley-Landform level subdivides the river network into three categories with characteristic lengths of 100 to 1000 metres. Valley-Landform recognises the influence of geological conditions and various aspects of valley shape on geomorphic and hydraulic process at this scale. REC, however, simplifies what in reality are complex factors by assigning Valley-Landform categories only on the basis of valley slope (Table 1.8).

Because higher levels of the classification constrain lower levels, the characteristics of Valley-Landform categories cannot be well described in isolation from the other higher level REC categories. However, the three Valley-Landform categories broadly separate small sections of river on the basis of differences in hydraulic processes ranging from erosive (High-Gradient category) to depositional (Low-Gradient category).

Table 1.8 Three categories of Valley-Landform including notations and characteristics.

Valley-Landform category	Notation	Characteristics of river environment
High-Gradient	HG	Steep channels with high water velocities. Substrates tend to be coarse relative to the lower gradient Valley Land form classes.
Medium-Gradient	MG	Medium-Gradient channels. These are typically broad and shallow with some meandering pattern resulting in varied morphology typically a pool-riffle-run sequence. The characteristics are, however, dependent on higher order classes.
Low-Gradient	LG	Low-Gradient channels. For given higher order classes, LG categories are characterised by relatively greater meandering, greater depth relative to width and lower water velocities.

6.7 Category mapping criteria

Table 1.9 below contains a summary of categories and their notation, the mapping characteristics used to assign a category to each network section and the assignment criteria. A more complete discussion of how the REC was made is contained in Part II, Section 5.

Box 6. Explanation of Lake Source-of-Flow category mapping characteristic

The variable 'effective precipitation' is calculated by subtracting the mean annual precipitation from the mean annual potential evapotranspiration. The 'lake index' (LI) includes; V_{LW}, the volume of annual rainfall in the catchment of each lake; A_L the area of each lake; A_{LW} the area of each lake's catchment, and V_W the volume of annual rainfall in the upstream catchment, and has the form:

$$LI = \frac{\sum V_{LW} . \sum \frac{A_L}{A_{LW}}}{V_W}$$

A rule assigns a 'Lake' class to all nodes where the value of LI exceeds a specified value (see Table 1.9). These and other mapping characteristics are more thoroughly explained in Snelder and Biggs (2002).

Table 1.9 Summary of categories, mapping characteristics and category membership criteria for application of REC to New Zealand rivers. Note that the mapping characteristics are described in greater detail in Part II.

Classification level	Classes	Notation	Mapping characteristics	Category assignment criteria
1. Climate	Warm-Extremely-Wet Warm-Wet Warm-Dry Cool-Extremely-Wet Cool-Wet Cool-Dry	WX WW WD CX CW CD	Mean annual precipitation, mean annual potential evapotranspiration, and mean annual temperature.	Warm: mean annual temperature ≥ 12°C Cool: mean annual temperature < 12°C Extremely Wet: mean annual effective precipitation ≥ 1500 mm Wet: mean annual effective precipitation 500 - 1500 mm Dry: mean annual effective precipitation ≤ 500mm
2. Source-of-Flow	Glacial-Mountain Mountain Hill Low-Elevation Lake Spring Regulated Wetland	GM M H L Lk Sp R W	% permanent ice, catchment rainfall volume in elevation categories, lake influence index.	GM: M and % permanent ice > 1.5% M: > 50% annual rainfall volume above 1000m ASL H: 50% rainfall volume between 400 and 1000m ASL L: 50% rainfall below 400 m ASL Lk: Lake influence index* > 0.033 Sp, R and W are manually assigned.
3. Geology	Alluvium Hard-Sedimentary Soft-Sedimentary Volcanic-Basic Volcanic-Acidic Plutonic Miscellaneous	Al HS SS VB VA Pl M	Proportions of each geological category in section catchment.	Class = the spatially dominant geology category unless combined Soft-Sedimentary geological categories exceed 25% of catchment area, in which case class = SS.
4. Land-Cover	Bare Indigenous-Forest Pastoral Tussock Scrub Exotic-Forest Wetland Urban	B IF P T S EF W U	Proportions of each Land-Cover category in section catchment.	Class = the spatially dominant Land-Cover category, unless P exceeds 25% of catchment area, in which case class = P, or unless U exceeds 15% of catchment area, in which case class = U
5. Network-Position	Low-Order Middle-Order High-Order	LO MO HO	Stream order of network section	Stream order 1 and 2 Stream order 3 and 4 Stream order ≥ 5
6. Valley-Landform	High-Gradient Medium-Gradient Low-Gradient	HG MG LG	Valley slope of section based on Euclidian length.	Valley slope > 0.04 0.02 ≥ Valley slope ≤ 0.04 Valley slope < 0.02

* See explanation in Box 6

7 Defining the REC classes and conventions for naming

SUMMARY

This section explains how the sequence of categories at each level in the REC hierarchy identifies a REC class and also explains the naming conventions.

A full classification follows the form Climate/Source-of-Flow/Geology/Land-Cover/Network-Position/Valley-Landform. Potential classes at each classification level are all possible combinations of factor categories at that and all subsequent levels. The shortened notation for factor categories is summarized in Table 1.9 and is included on the page at the back of this manual.

Figure 1.11 is an abbreviated tree diagram showing how classes are formed at each level of the REC. The full classification of a section of river at any level is denoted by the categories at each of the preceding levels separated by a slash (/) for clarity. In Figure 1.11 the full classification of the lowest and leftmost box at the Land-Cover level is CW/M/HS/B. This is the notation for Cool-Wet Climate / Mountain Source-of-Flow / Hard-Sedimentary Geology / Bare Land-Cover.

The number of classes depends on the level in the REC hierarchy that is used to subdivide the rivers of an area (for instance in a region). The number of potential classes increases down the hierarchy. For instance, at the Climate level of the classification there are six possible classes. At the Source-of-Flow level there are five categories; thus at the second level of the REC there are 6 x 5 = 30 potential Source-of-Flow classes. However, the number of actual classes occurring in any one region is limited because environmental variability is restricted within a region. Typically 40 to 60 classes will occur at the Geology level of the classification within a jurisdictional region.

Special software (GROUPER) provided with the REC allows the classes at any level to be aggregated together to further simplify the REC (see Part II of this manual). For example, Land-Cover categories such as Indigenous-Forest and Tussock may be grouped and referred to as ‘Natural’. GROUPER also allows the user to construct purpose built classifications from any combination of the REC factors. Purpose built classifications and maps are created to suit individual applications. This is discussed further in Part II.

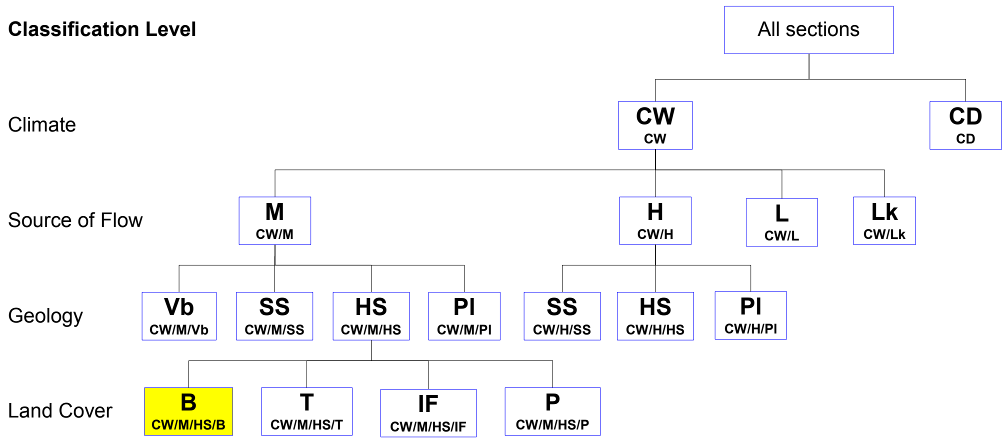


Figure 1.11 An abbreviated classification diagram showing the formation of selected classes to the Land-Cover level of the REC classification.

The large font is the factor category and the small font is the full class at each level. See Table 1.9 for the notation key.

8 Using the REC to identify patterns in biological and resource values

SUMMARY

The REC enables resource managers to identify patterns in physical and biological characteristics (including resources and values) of rivers. The REC can be used to directly organise empirical data or as a framework to incorporate expert knowledge. Characteristics can be associated with particular classes and all river sections within the class can be treated as if they possessed those characteristics.

Patterns in many river characteristics are strongly influenced by the REC factors and are, therefore, delineated by the REC classes. At each successive lower level REC factors discriminate physical characteristics in greater detail. For example, hydrological regimes and water quality are increasingly well-defined at the Source-of-Flow, Geology and Land-Cover levels of the REC. Because physical conditions are strong determinants of biological characteristics, the REC's hierarchy of classes characterises, in successively greater detail, the biological communities of rivers. For example, climatic conditions broadly determine the potential pool of species that a river type could be expected to include. This is because thermal regime is an important factor determining suitability for species. For example, brown trout are not a characteristic of Warm Climate classes. The Source-of-Flow level further discriminates differences in potential biological communities by defining water temperature and the physical growing conditions (essentially water velocity and variation in water velocity over time caused by the flow regime). For example, invertebrate species such as snails are long-lived and need stable stream flows and stable bed sediment, whereas mayflies are short-lived with high immigration rates making them successful colonists of flood prone rivers. The Source-of-Flow level of the REC broadly discriminates differences in flood frequency and substrate stability. As a result there are significant differences in the invertebrate communities inhabiting rivers with different sources of flow such as Mountains, Hill and Low-Elevation[13].

The REC classes can be used in conjunction with existing databases or expert knowledge to delineate patterns of characteristics and values. REC provides a framework for the analysis of existing empirical data such as water quality or biological databases. For instance, the information shown in Figure 1.5 was derived by classifying sites in a water quality database and analysing patterns associated with REC classes. Figure 1.12 shows a similar process where sites are grouped by the REC classes at various levels of the REC to show patterns in invertebrate communities. In Figure 1.12 the invertebrate data was converted to a Macro-invertebrate Community Index (MCI) score. Grouping sites using successive REC levels reduces the variation

[13] MFE (2000c)

in this score, indicating the biological characteristics of classes becomes more specific at lower levels of the REC. Case studies 1, 2 and 3 in Part III of this manual discuss the monitoring sites by the REC class and the use of data from multiple sites to characterise REC classes.

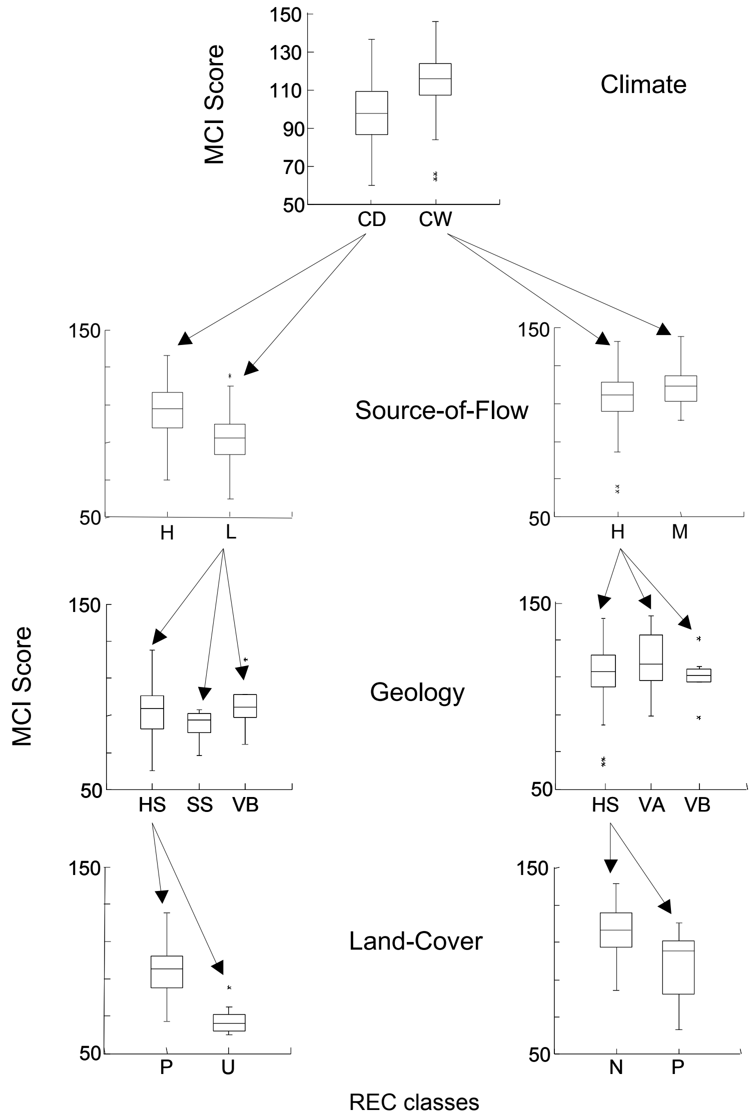


Figure 1.12 Macro-invertebrate Community Index (MCI) score for sites grouped by REC classes at Climate, Source-of-Flow, Geology and Land-Cover levels (source: Snelder et al. 2004a).

The REC can also be used as a framework to incorporate expert knowledge of the valued characteristics such as biological communities, cultural, recreational, and natural character values as well characteristics of rivers that provide resource values. Expert knowledge is often derived from small-scale studies that have provided insights into the causes of distributions of particular characteristics such as hydrological regimes or biological communities. This understanding of processes can be used to associate different classes with specific characteristics and, therefore, scale-up the site-specific information. The influence of large scale factors on the generally smaller scale characteristics must be understood to scale-up information. The preceding sections on the process hierarchy that is described by the REC's Controlling Factors (see Part I, Section 5) and the resulting characteristics of each factor category (see Part I, Section 6) are relevant to this understanding.

An example of definition of values for management units is provided by the use of expert knowledge to describe potential fish community groups in core management units for Canterbury in Table 1.10. These expert predictions were tested by looking at the frequency of occurrence of each species in the New Zealand Freshwater Fish Database and was found to be broadly consistent with the predicted patterns (see MFE 2000b).

The REC provides a useful tool for defining ecological patterns because it is based on the drivers of ecosystem pattern. However, classes based on environment alone ignore the historic context that may influence the current biological community. At short timescales temporally varying factors such as disturbance and dispersal may blur the expected relationships between environmental and ecosystem patterns. At longer time scales biogeographic factors such as glaciation and volcanism may control the genetic pool at a location. Thus, the REC delineates patterns in biological potential but must be combined with additional information if all unique and rare ecosystems are to be delineated.

Table 1.10 Definition of potential fish communities based on expert knowledge of habitat requirements and physical characteristics of REC classes in Canterbury.

REC classes	Potential fish community
CD/M, CW/GM CW/M, CX/GM CX/M	Clean, cold and swiftly flowing water and coarse, clean substrates provide habitats suitable for: bluegill bully, alpine galaxias, rainbow trout, longfin eel, chinook salmon, torrent fish and long jaw galaxias. Chinook salmon spawn in spring-fed tributaries.
CD/H, CW/H CX/H	Inland areas with swifter flows and gravel substrates support Canterbury galaxias, brown trout, longfin eel and upland bully. Alpine galaxias in tributary streams. Koaro habitat provided by steeper boulder tributaries.
CD/L, CW/L WD/L	Low-Gradient, fine substrates, incised channels, instream debris and undercut banks relatively close to the coast provide habitat for weak swimming species such as common bully, smelt, giant bully, and inanga. Finer substrates and undercut banks provide habitat for short fin eel. Mudfish habitat in ephemeral tributaries with mud banks. Brown trout, upland bully and longfin eels where channels are steep and substrates are gravel. Brown trout are most common where streams have a large component of flow from cool groundwater with high water quality and where catchment geology is Hard-Sedimentary rocks that provide for their preferred gravel substrates.
CD,H/VB, CD/L/VB CW/H/VB, CW/L/VB	Steep topography provides coastal streams that tend to have forest and scrub riparian vegetation, and step-pool morphology. This provides habitat for banded kokopu and lamprey, which are able to 'climb' but prefer Low-Gradient pool habitat. Volcanic geology results in tightly packed stable substrates that do not provide spawning gravel for trout. Long jaw galaxias is particularly prevalent in this management unit. Low-Gradient coastal stream habitat provides habitat for weak swimming species such as common bully, smelt, giant bully, and inanga. Finer substrates, macrophytes and undercut banks provide habitat for shortfin eel.

Patterns in the value of rivers as water resources are illustrated by the flow regimes that are shown in Figure 1.6. This graph of seasonal pattern in flows indicates that flows in rivers in the Glacial-Mountain and Mountain Source-of-Flow classes are sustained at relatively high levels in summer, whereas Hill and Low-Elevation classes are relatively lower in summer and are less likely to provide reliable sources of water supply. This is discussed in more detail in Part III Case Study 2.

9 Assessment using the REC

SUMMARY
Assessment using the REC is based on defining groups of rivers (management units) and their specific characteristics. Assessments can be carried out at a range of scales and levels of precision. The scale of analysis is reduced, and the precision of the characterisation is increased, by moving to lower levels of the REC to define the management units. The appropriate level of precision is a pragmatic decision that is made by considering the trade-off between the complexity of the assessment with the level of specificity, justifiability and certainty that is required.

9.1 Key components – management units and characteristics

The REC is designed to be flexible and be applicable to a wide range of river management issues. The ability of the REC to group and map rivers at a variety of classification levels allows analysis, reporting and planning at different levels of detail and associated spatial scales. When the classification is used to group rivers, or parts of rivers, at specific scales for management purposes, the resulting groupings are termed *management units*.

The REC is used in assessment to ensure that spatial variation in characteristics and relevant processes are accounted for in developing an understanding of spatial patterns in characteristics (e.g. water quality) and ultimately, issues and options for management responses. The first step in any assessment is to subdivide the region's rivers into groups that are expected to have fundamentally different characteristics due to differences in controlling factors. Management units define large groupings of rivers (or parts of rivers) that are likely to have similar characteristics including potentially similar values. If the assessment is attempting to derive management options, the characteristic values (including environmental and resource values) are identified for each management unit using combinations of data analysis and expert assessments as described in Section 8 as well as public consultation.

There are a large number of potential classes that can be used to discriminate differences between rivers. For example, Geology and Land-Cover are each classified into six and eight categories respectively, giving a potential for forty-eight unique classes from combinations of these two factors alone. Classification at this level of detail would be unworkable for many management applications. The hierarchical structure of the REC allows the user to choose the number of classes and thus choose management units that discriminate differences between rivers at a resolution that suits the analysis being carried out. Classifications can be made by selecting any particular level of the classification or by selecting one or a combination of factors to produce purpose built classifications.

9.2 Deriving a set of management units

Grouping rivers of a region by Source-of-Flow or Geology level REC classes provides a useful set of management units for national and broad scale regional analyses. The Source-of-Flow or Geology levels of the REC define classes that strongly discriminate potential differences in the environmental and resource values of a river irrespective of the effect of human uses such as land use. There are generally only a few Source-of-Flow classes in a jurisdictional region, and groups defined by these classes are quite readily accepted as being different from one another. Source-of-Flow is a good starting point for defining management units. In addition, management units may group some factor categories together where differences between categories are negligible for a specific resource or issue. For instance, sites in the Cool-Extremely-Wet Climate class may have very similar water quality despite belonging to different classes at the subsequent Source-of-Flow level of the REC (see Figure 1.5). However in the Cool-Dry Climate class the variation is quite large (see Figure 1.5). Classes at the Source-of-Flow level achieve better discrimination of water quality and may provide a better set of management units for rivers in the Cool-Dry class. Figure 1.13 defines eight management units for the Southland Region. Some of the management units were formed by aggregating two or three classes at the Source-of-Flow level.

Using classes at the Geology level has also been found to produce a useful set of management units. Classes at the Geology level can be quite distinct with respect to water quality and ecological values. For example, trout and salmon tend not to be abundant in rivers that have Soft-Sedimentary Geology categories as these do not provide suitable gravel substrates for spawning. Environment Canterbury's Draft Natural Resources Regional Plan (ECan 2001) provides an example of development of management units. The Draft Plan subdivides the region into five river types that comprise the majority of the region's rivers. The five main types are: alpine sourced rivers, hill country sourced rivers, lake-fed rivers, lowland rivers, volcanic rivers. The physical similarity of rivers within each of Environment Canterbury's five types means they share broadly similar resource use and environmental values. As a result rivers in each of the five types share management issues and may be treated as management units. The REC was used to assign all the region's rivers to one of these five management units. The management units were given the same names in the Draft Plan to allow easily understood descriptions rather than use of the REC's generic naming system. The Source-of-Flow category (i.e. ignoring Climate) was used to assign the alpine sourced rivers, hill country sourced rivers, lake-fed rivers, and lowland rivers (see Figure 1.14). The volcanic geology category (VB) that produces distinctive stream types on Banks Peninsula was used to assign rivers to the volcanic rivers management unit. This volcanic geology recurs in other locations within Canterbury so this management unit is not solely restricted to Banks Peninsula.

Increasing the number of classes reduces the scale of management units – the areas being considered get smaller – and the similarities among rivers (and sections of rivers) within the group become more specific. For some analyses greater discrimination of characteristics may be required. The factors that exert influence on the characteristics can be identified and used to form contrasting management units. For example, the management units defined for Canterbury may be further subdivided by including Climate to better separate rivers with respect to their flood frequencies or Geology and Land-Cover to better discriminate differences in nutrient and sediment concentrations (see Part III, Case Study 1). Thus, the user can increase the number and reduce the spatial scale of management units by introducing further levels of the hierarchy. For example, Figure 1.5 shows that the inclusion of Geology and Land-Cover levels of the REC greatly increased discrimination of soluble inorganic nitrogen concentrations within the higher level Cool-Wet/Hill (CW/H) class.

The trade-off with introducing a larger number of management units is that the increase in detail also increases complexity. Too many classes may make management unwieldy. Expert knowledge of river related issues must be used to derive classifications that are practical, useful and technically defensible. There is no easy formula for deciding on the appropriate number of management units and use of the REC to date suggests iterations will usually occur.

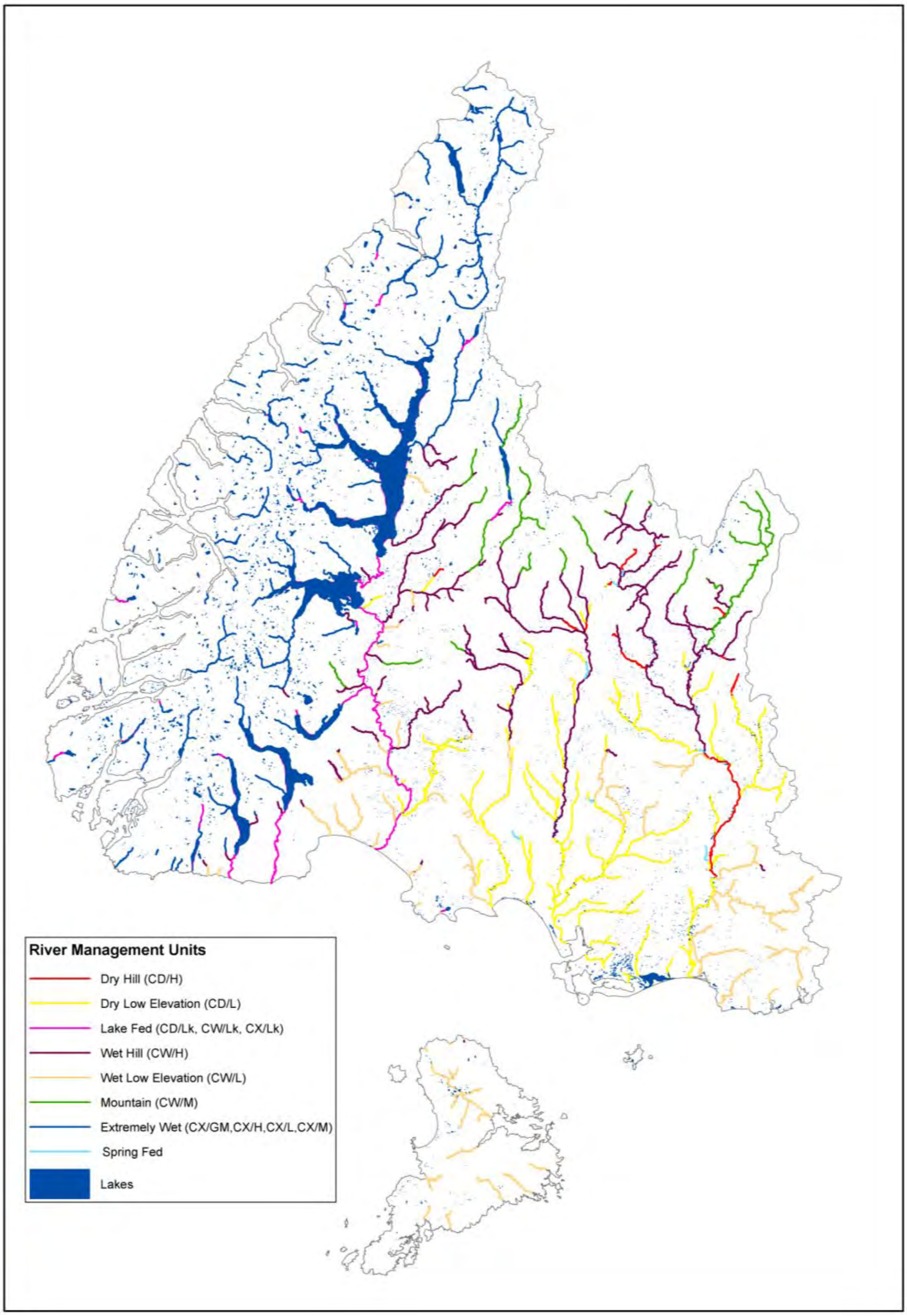


Figure 1.13 Grouping of classes to define eight management units for the Southland Region.

Some of the management units are formed by aggregating two or three classes at the Source-of-Flow level. The Source-of-Flow level classes that make up each management unit are shown in parentheses in the legend.

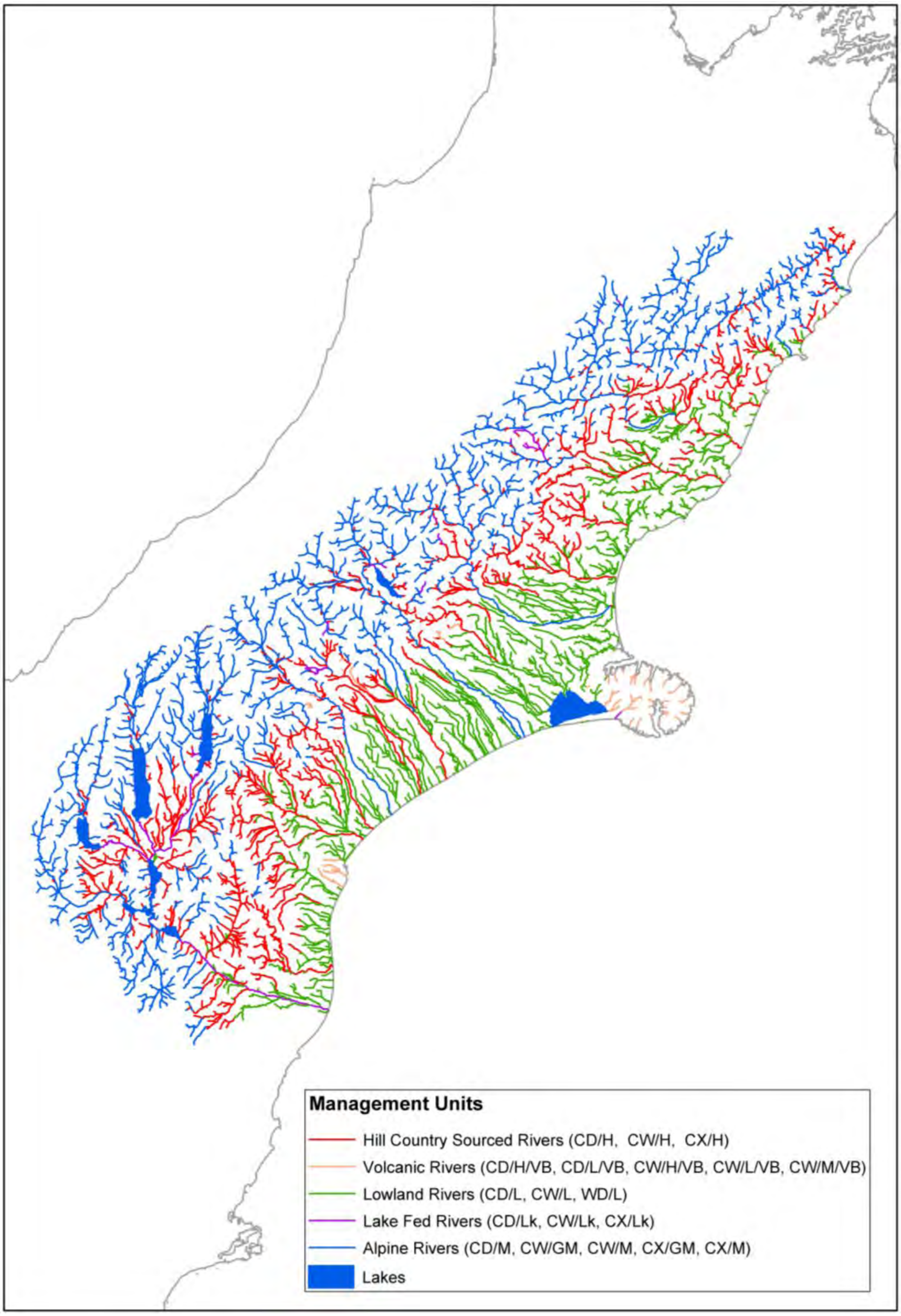


Figure 1.14 Management units for Canterbury.

PART II Using the REC with GIS

1 Introduction

Part II of this manual gives a brief introduction to the use and manipulation of the REC using ESRI's ArcView 3.2 GIS software and provides a summary of how the REC's GIS components were produced. This section assumes that the user has a basic understanding of ArcView (e.g. how to add layers and display maps).

2 Using the REC

Displaying the REC

The REC is delivered as GIS features in ESRI Shapefile format (e.g. Figure 2.1). This format is used because ESRI's ArcView software is the most commonly used GIS in New Zealand. However, other GISs such as MapInfo will import shapefiles.

In general terms, a GIS data layer is made of two components: the geospatial data describing the position of the features such as lines, points or polygons, and the attributes of the individual features. In the case of the REC, rivers are broken up into sections at every confluence. Each section has a set of data related to it consisting of the classification at each level and some auxiliary data such as section length, upstream catchment area and stream order. The attribute data is stored as a standard dBase 4 file (*.dbf) which can be loaded into other analysis packages such as Microsoft Excel.

WARNING! Manipulation of the dBase file using a 3rd party package (such as Microsoft Excel) could result in the file becoming unreadable by ArcView. It is advisable to make a copy of the file before analysis.

Table 2.1 The basic components of an ESRI Shapefile.

File Name	Description
Layer1.shp	Main file: contains the geospatial data for each feature
Layer1.shx	Index file: used internally for locating features within the *.shp file.
Layer1.dbf	dBase file: contains the attribute information for each feature

Note that there may be additional files associated with the shape file that have other extensions depending on how the shapefile has been used. These may include default legends, other indexes and metadata.

In the REC shapefile each river section has two unique identifiers. The first relates to the number within the regional council region and is called 'ReachID'. The second identifies the river section within the whole country and is called 'NZReach'. All REC layers follow a RegionName_REC.* naming convention, so for the Taranaki region, the REC layer is called Taranaki_REC.*.

Note: the use of the word 'reach' in the identifiers is due to internal naming systems generated during the development of the REC. In this document we have used the term 'section' because 'reach' can be misleading with regards to the scale of the individual river sections. In the case of the REC, sections are typically several hundred metres long, while the term 'reach' is generally used to refer to riffle-pool-run sequences which are often of a much smaller scale.

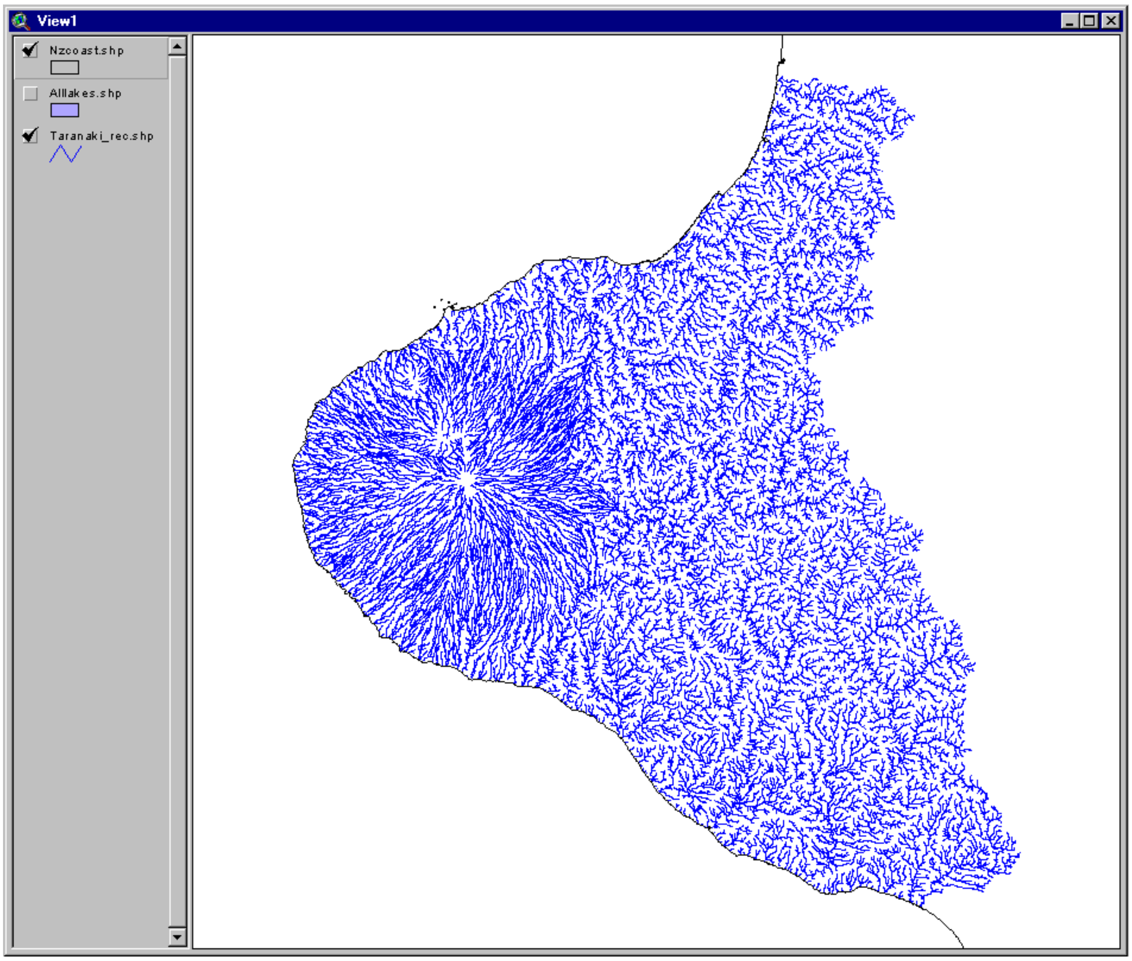


Figure 2.1 The Taranaki REC.

The REC encapsulates information at a range of scales with each level being nested within the preceding level (see Section 3, Part I). The highest level of the REC is defined by a series of factors: Climate, followed by Source-of-Flow then Geology, Land-Cover etc (see Figure 1.2 in Section I). The classes at each level are defined by the concatenation of the categories for each factor separated by a forward slash. Thus, at the Source-of-Flow level the classes take the form Climate/Source-of-Flow e.g. Warm-Wet-Low-Elevation and Cool-Dry-Hill. The categories are represented by short codes, e.g. Cool-Extremely-Wet-Mountain is coded CX/M. Table 1.9 in Section I lists all the categories for each factor and the short codes used.

In the REC shapefile, each river section has a class for each level of the classification and also the individual categories for each factor. This is detailed in Table 2.2. You can view the attribute table by using the **Open-Theme-Table** button.

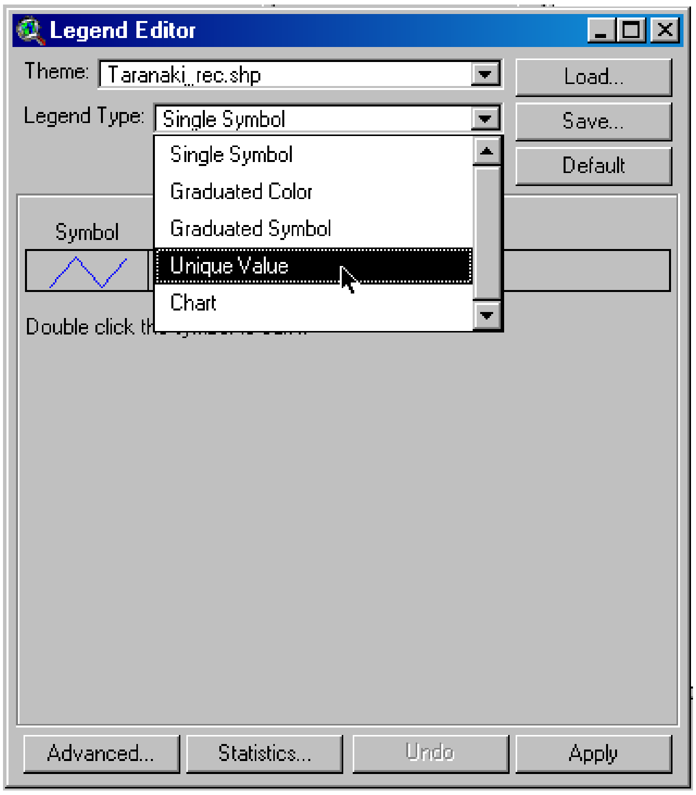
Table 2.2 The major fields contained within the REC attribute table.

Field	Description
NZReach	Unique national identifier
ReachID	Unique regional identifier
Tnode	To node – used for network direction
Fnode	From node – used for network direction
Length	Length of river section (m)
Climate	Climate level class
CSoF	Source-of-Flow level class
CSoFG	Geology level class
CSoFGL	Land-Cover level class
CSoFGLNP	Network-Position level class
CSoFGLNPVL	Valley-Landform level class
Src_of_flw	Source-of-Flow factor category
Geology	Geology factor category
Landcover	Land-Cover factor category
Net_posn	Network-Position factor category
Vly_Lfrm	Valley-Landform factor category
Order	Stream order

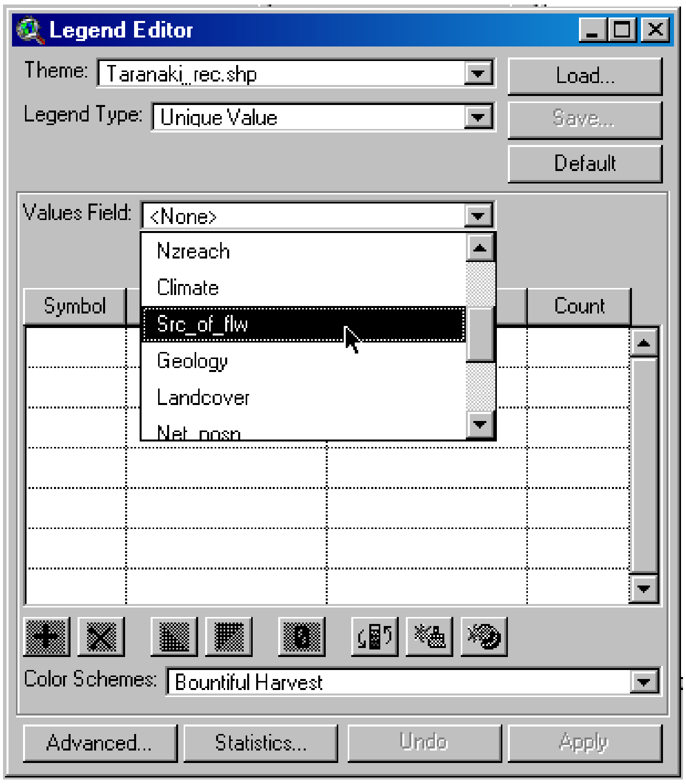
The easiest way to use the REC is to colour the lines according to the classes at any level. For example, a whole region may be usefully viewed at the Climate or Source-of-Flow level.

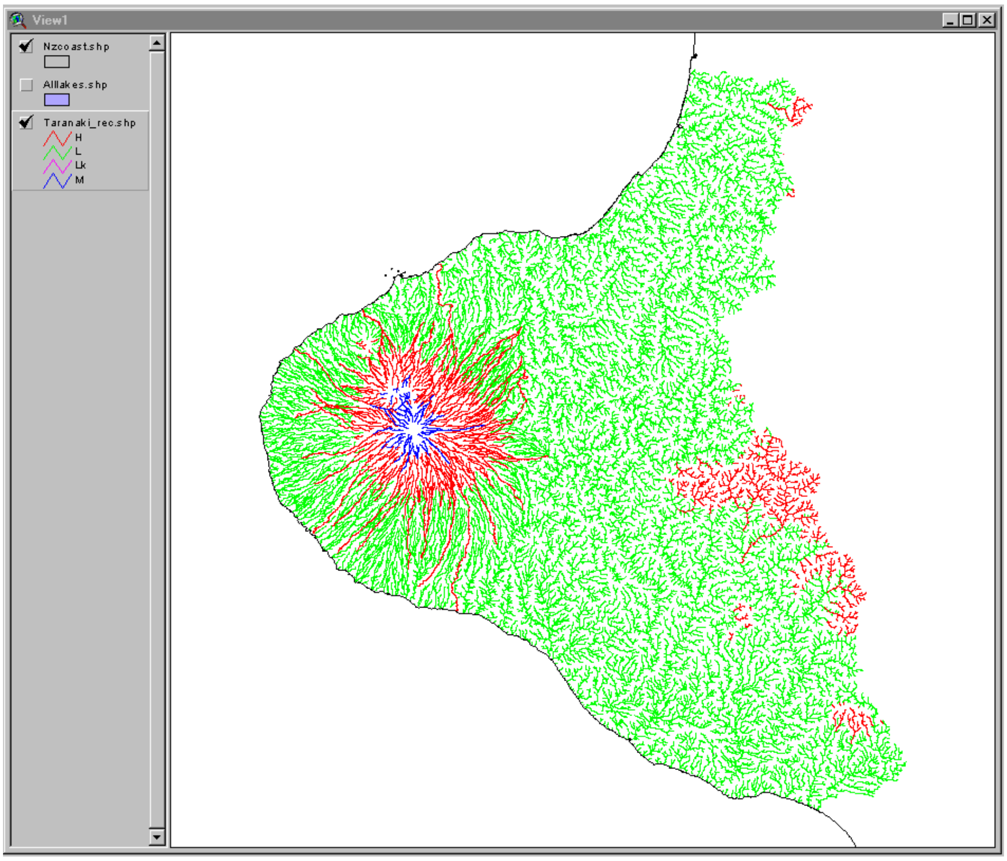
1. Select the **Edit Legend** button.

2. Change the legend type to **Unique Value**.



3. Select the field that you want to use (in this case the Source-of-Flow factor). The fields available are from the attribute table.

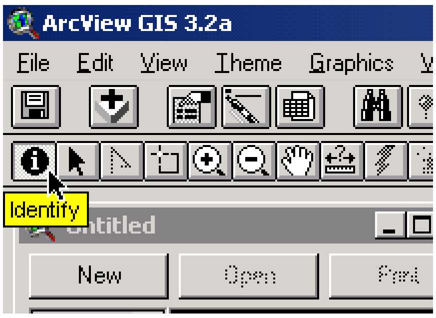


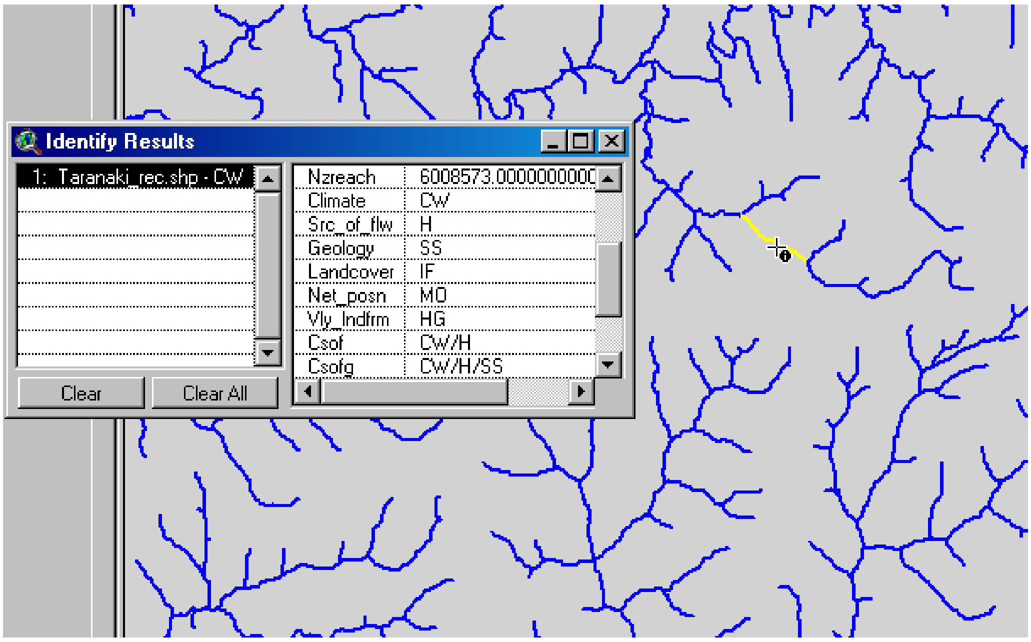


2.1 Querying the data

2.1.1 Individual river sections

Another way of using the REC is query a specific point in the river network, for example a water-quality monitoring site. The simplest way of doing this is to use the **Identify** tool, which displays the attribute information for any feature selected.

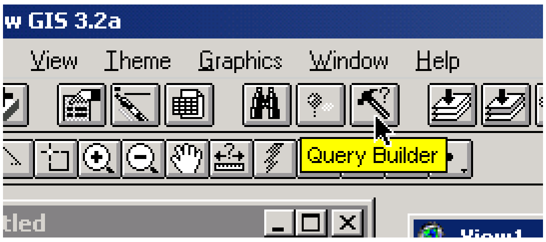




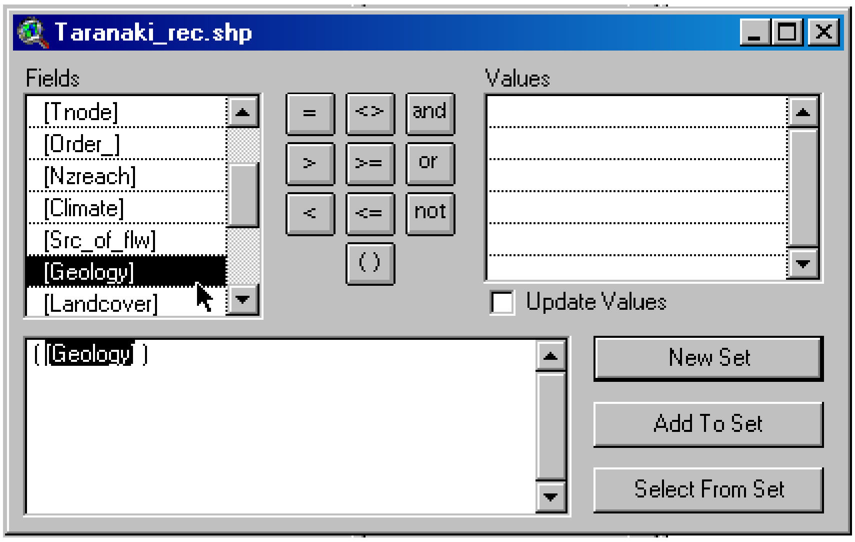
2.1.2 More advanced queries

A more advanced query selects all rivers with a specific attribute or attributes. For example, select a subset of the larger rivers by choosing all sections of order 3 and above. A fast way of doing this is to use the **Query Builder** tool.

1. Select the **Query Builder** button from the tool bar.

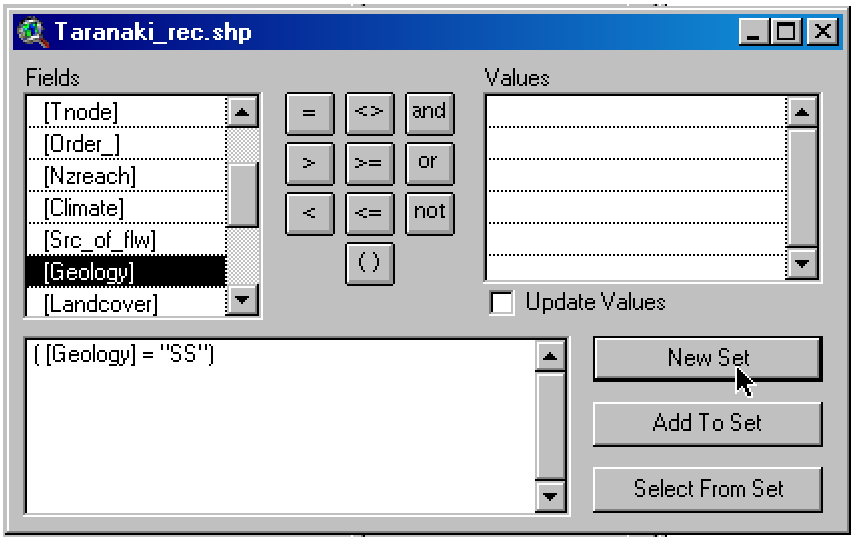


2. Build the query statement by simply double clicking on the field of interest (in this case Geology), then the operator, and then enter the value you want to select. For values stored as text (like the REC classes) the values must be enclosed in double quotes, e.g. to select Soft-Sedimentary geology the code is SS.

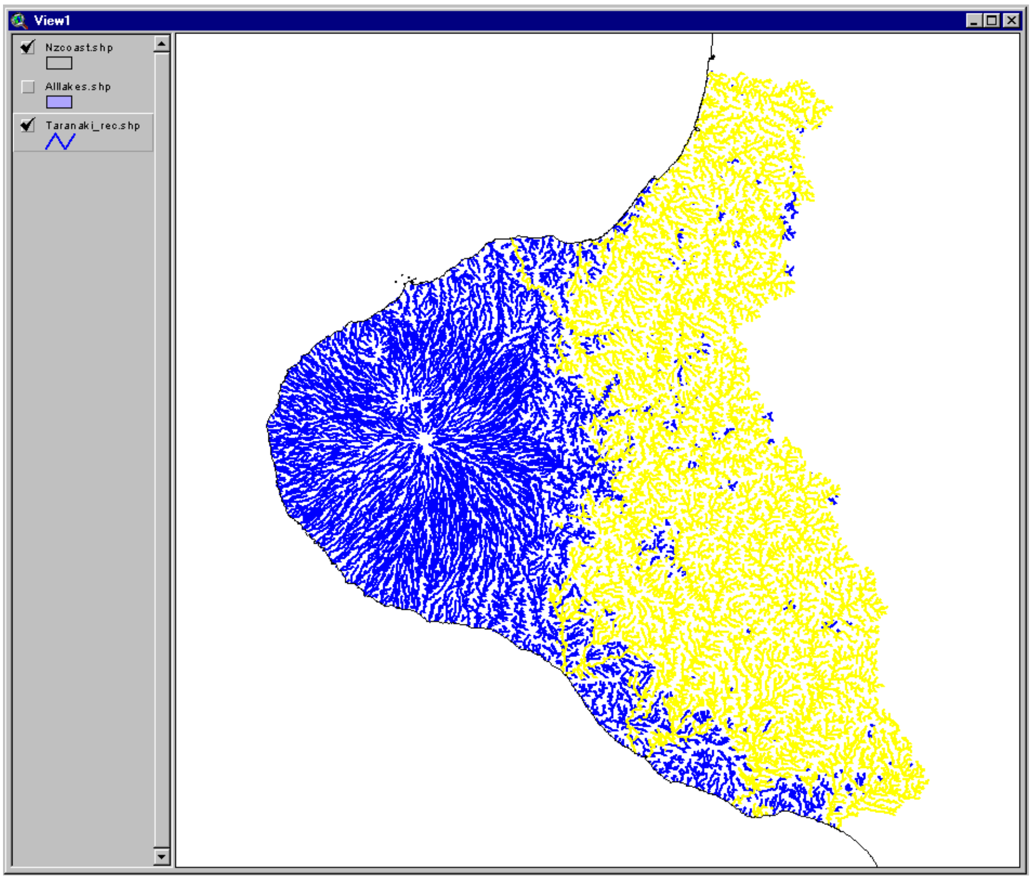


> **Note**: If the REC file has 32765 or fewer river sections then ArcView will give the option of listing the valid values for the selected field. This option can be enabled using the **Update Values** check box. When the box is selected ArcView will query the attribute table, which may take quite some time depending on the size of the file.

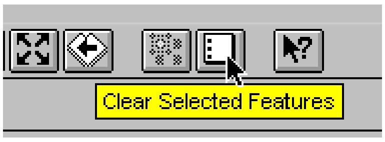
3. Click the **New Set** button to run the query.



4. The resulting selection will be highlighted in yellow. You can then save the selection as a new shapefile by selecting **Theme | Convert to Shapefile**.



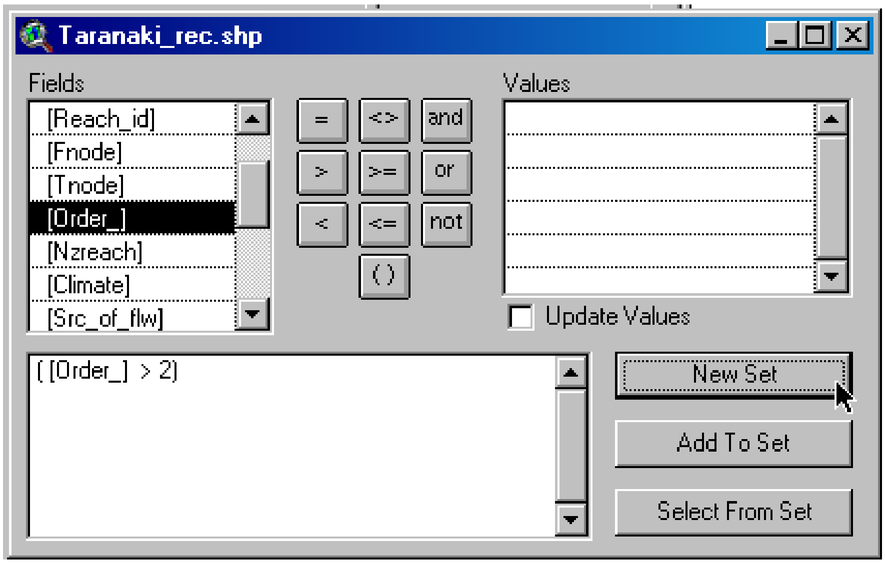
5. The selection can be cleared using the **Clear Selected Features** button on the toolbar.



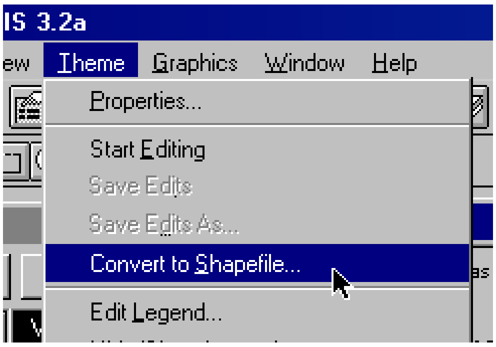
2.1.3 Saving queries as shapefiles

Queries can be saved as new shapefiles. An example is to simplify the river network by selecting the higher order rivers and creating a new shapefile.

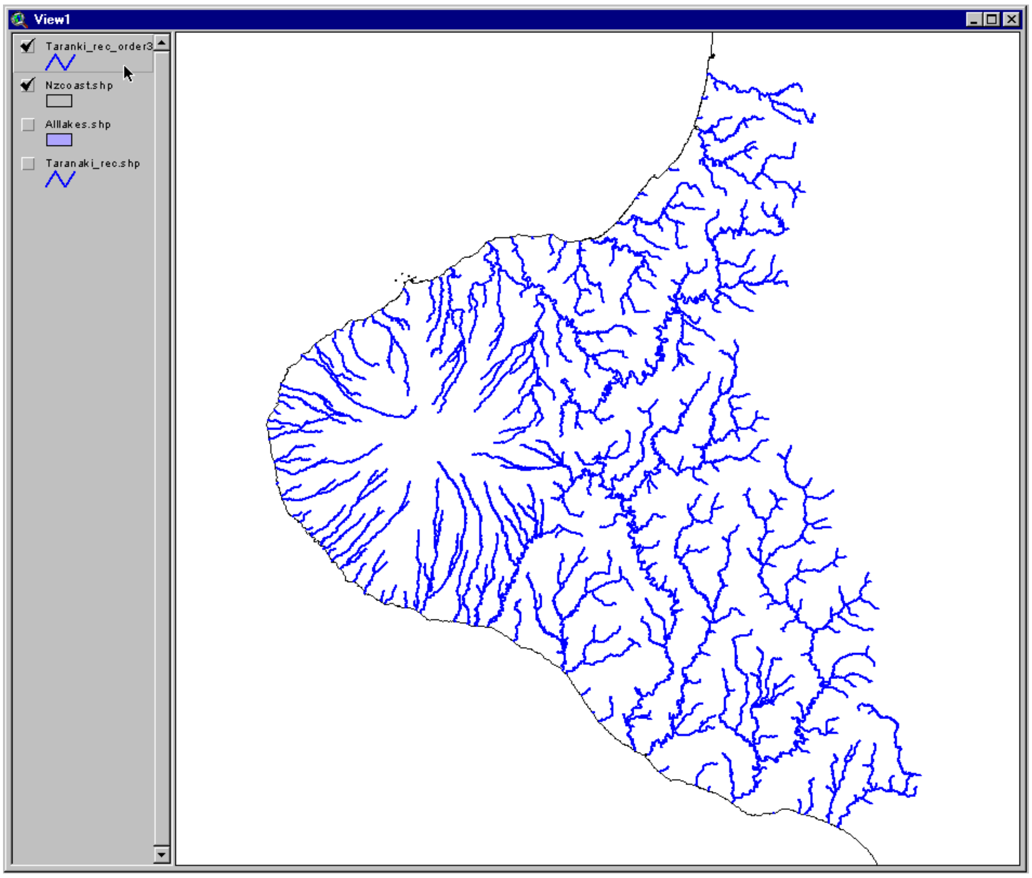
1. Create the query using the query builder and select a new set. In this case we want the Order field. Note that as this is a numeric field we don't need the double quotes.



2. Convert the selection to a new shape file using **Theme | Convert to Shapefile**.



3. Add the new theme to the view to display it.



2.1.4 Tracer

In addition to the standard querying functions provided by ArcView, the REC is provided with a network querying tool called Tracer. Tracer allows the user to run queries based on the river network. There are three options available:

- The first option allows the user to choose a section of river and Tracer will select all sections upstream from that point. This is useful for selecting whole river, or subcatchments of rivers.
- The second option allows the user to choose a section of river and have Tracer select the most direct route from that point to the sea. This is useful to identify parts of a river potentially impacted by a point discharge.
- The third option is a variation on option 2 and allows the user to trace downstream to a second selected section. This is used to select sections downstream of a specific point to another point, for example a lake.

For all options, Tracer allows the watersheds of the selected sections to also be selected (Figure 2.2 for example). This is combined with option 1 to identify the catchment area upstream of any point in the river network.

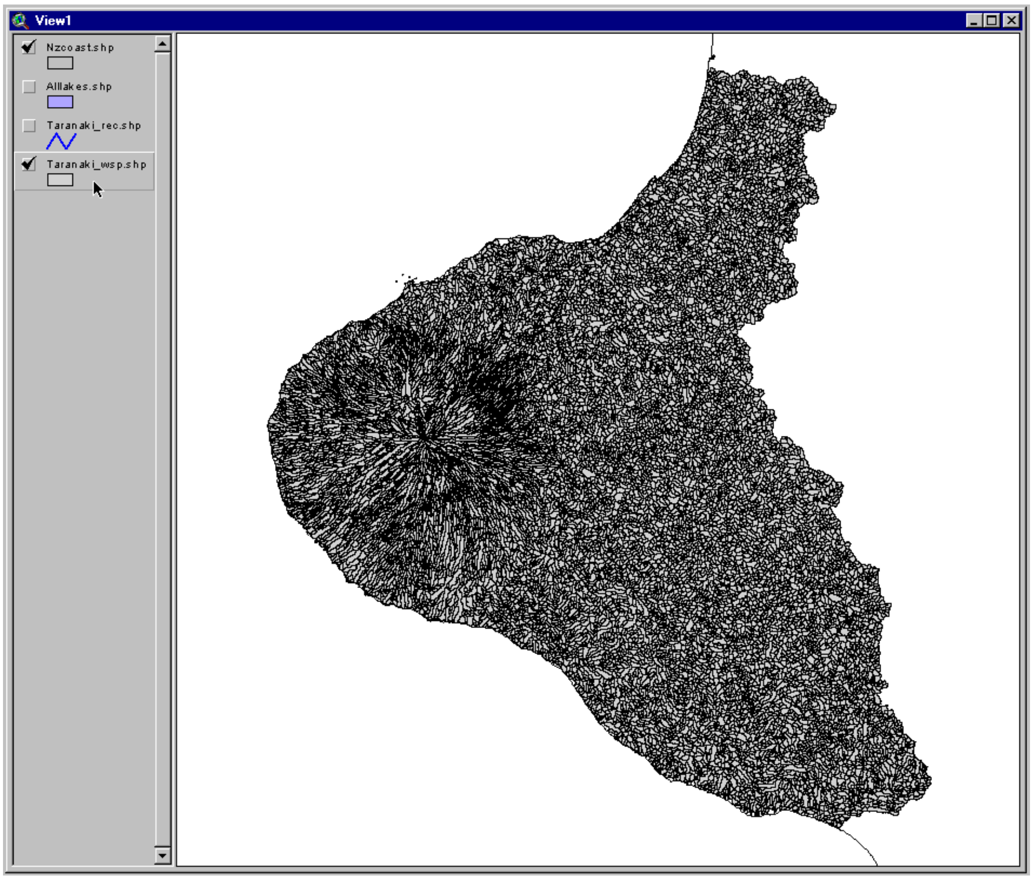
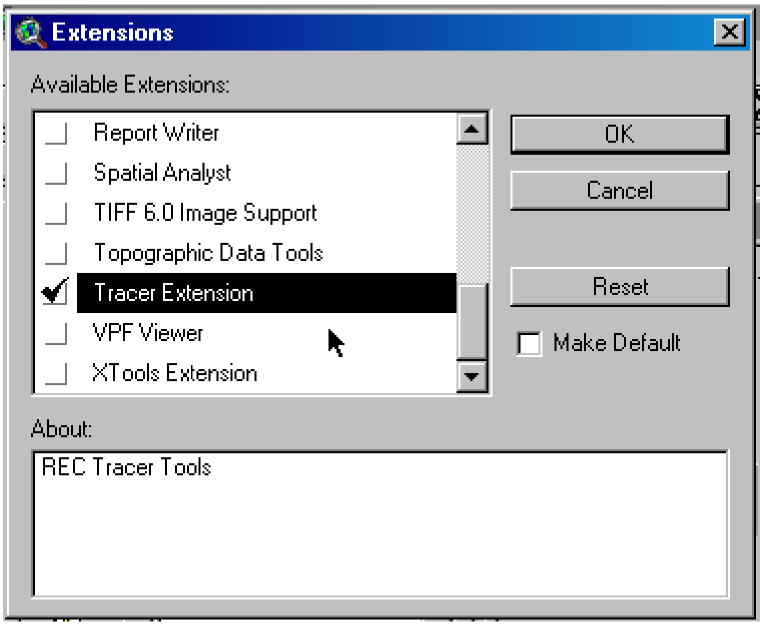


Figure 2.2 The Taranaki watershed layer.

All watershed layers are named as RegionName_wsp.*, so for example the Taranaki region watershed layer is named Taranaki_wsp.*.

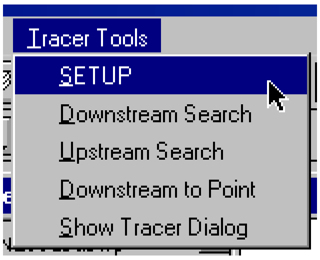
Tracer is supplied as an ArcView extension called tracer.avx. To use this file the extension must be copied from the REC CD into the $HOME/Ext32 directory (usually c:\esri\arcview_30\Ext32). For more information on installation see the readme.txt file in the Tracer directory of the REC CD.

To enable the extension, select **File** | **Extensions** and check the **Tracer** option. This will provide a new choice on the main toolbar

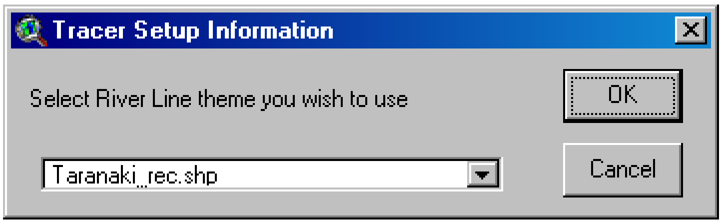


Before beginning analysis the Tracer extension has to be initialised. First select **Tracer Tools | SETUP**.

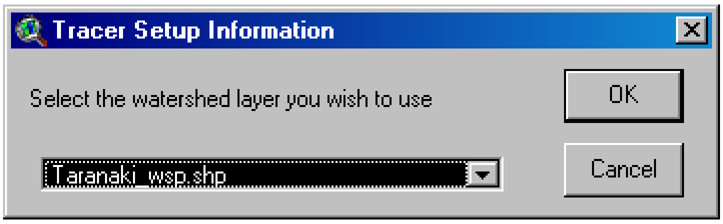
1. Before beginning analysis the Tracer extension has to be initialised. First select **Tracer Tools | SETUP**.



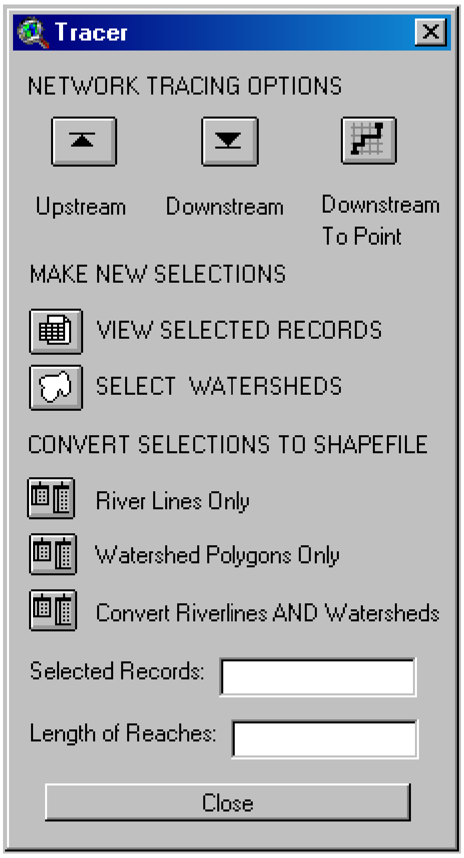
2. Select the river line layer (i.e. the REC layer) and click **OK**.



3. Select the matching watershed file. Note that if you don't want to be able to select watersheds you can skip this step by clicking on the **Cancel** button.

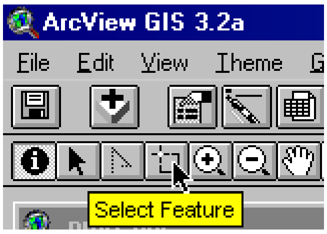


4. A new window (the Tracer dialog box) will appear presenting the options available.

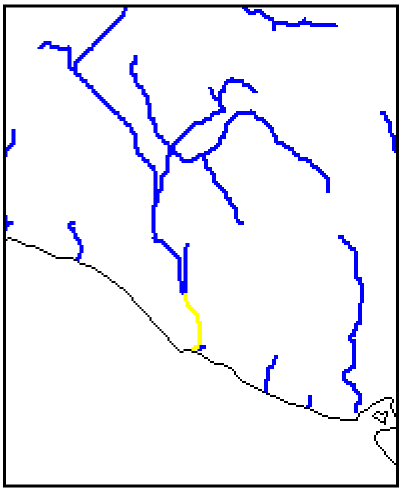


To perform an **Upstream** query.

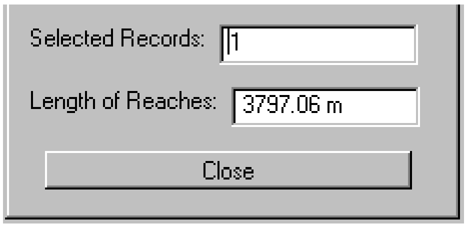
1. Click on the **Select Feature** tool.



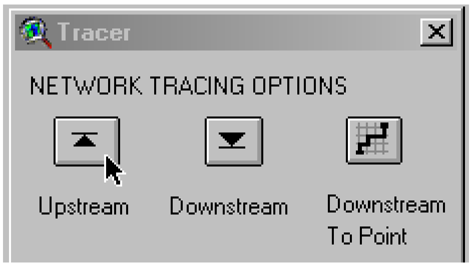
2. Select the most down stream river section required, for example to select an entire river system the last section of the network before the coastline is selected.



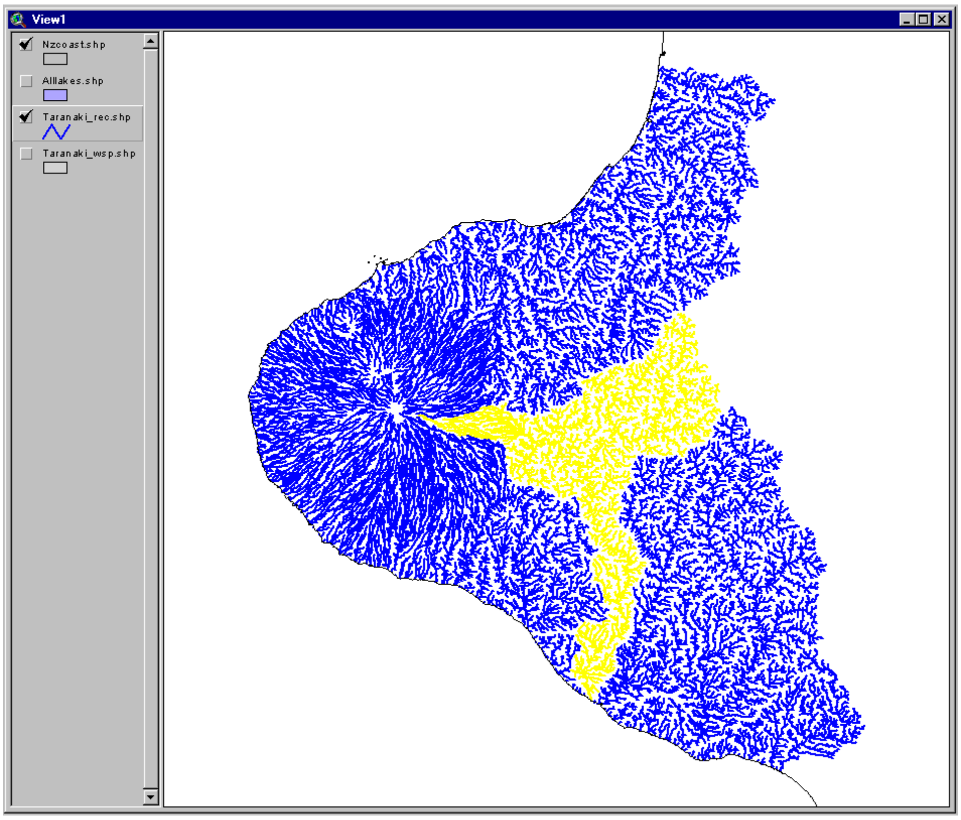
3. The Tracer dialog box will display the number of river sections and the total length of river selected. Check that only *one* section is selected.



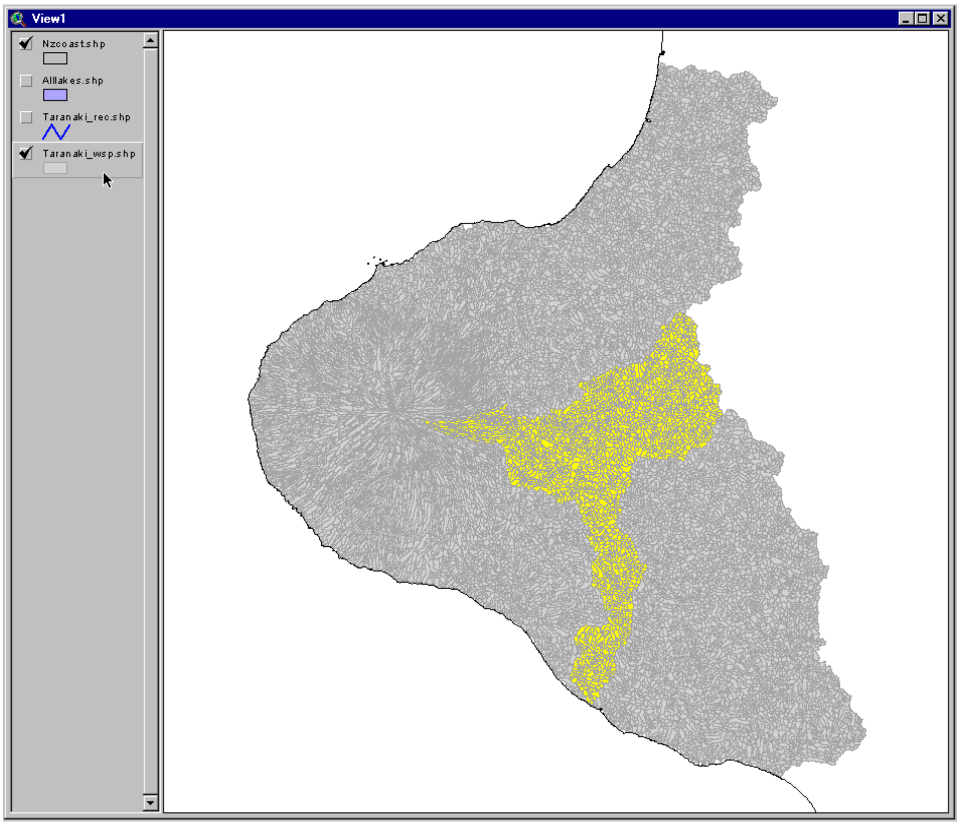
4. Click on the **Upstream** button on the Tracer dialog. The upstream query may take a few minutes to complete depending on the size of the region, the processing power of the computer, and the speed of the data connection.



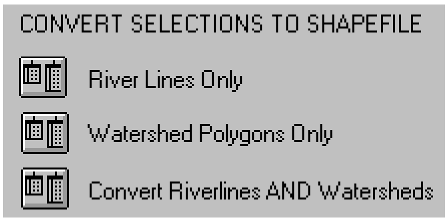
5. The selected sections will then be displayed.



6. If the catchment of the selected river is of interest then click on the **Select Watersheds** button on the Tracer dialog. Tracer will select all of the watersheds in the catchment.

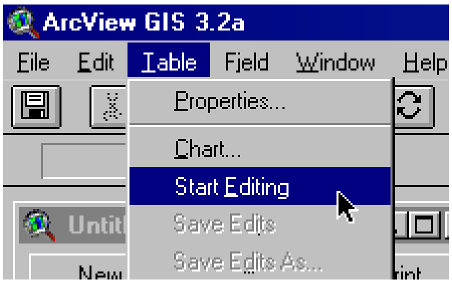


7. The resulting selections can then be converted to new shapefiles using the options on the Tracer dialog.

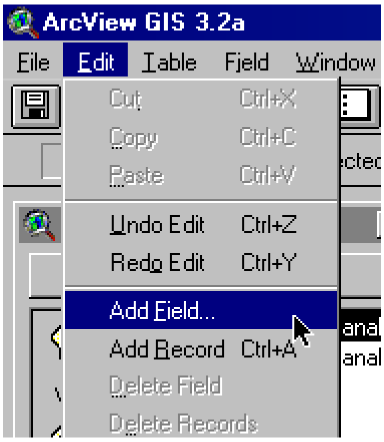


Once the watersheds have been converted to a new shapefile it can be useful to merge the individual watersheds into one large polygon delineating the entire catchment. This process is called dissolving and can be done using the Geoprocessing Wizard extension that comes with ArcView.

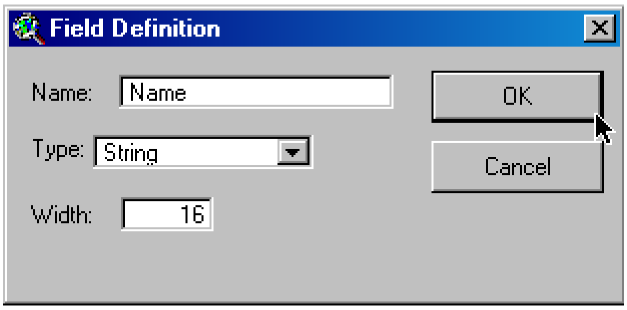
1. Before dissolving the watersheds some pre-processing is necessary as ArcView requires that the polygons that are to be dissolved have an attribute in common. Start by opening the attribute table of the new shapefile. To begin editing the table select **Table** | **Start Editing**.



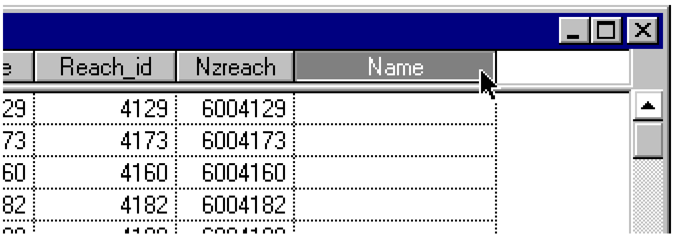
2. Create a new field to hold the new attribute by selecting **Edit | Add Field**.

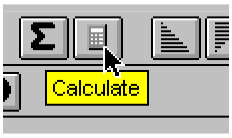


3. A dialog box will appear and allow the creation of the new field name and data type. The data type is unimportant because the field is populated with any consistent number or character. In this case, however, the river name is used so the dissolve adds useful information. The new field is called 'Name' and the data type is 'String' containing 16 characters.

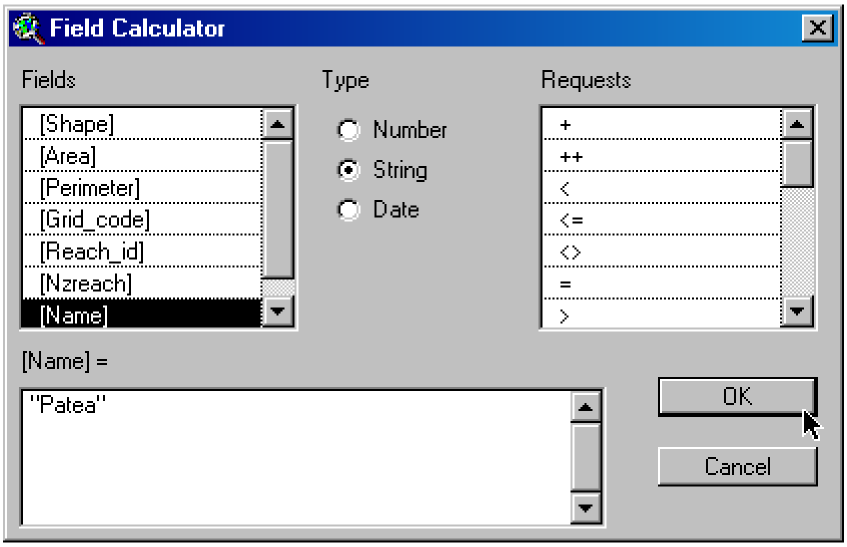


4. The new field will appear in the table. The new field is populated using the Calculate tool. Select the new column by clicking on the title and then select the **Calculate** button from the tool bar.

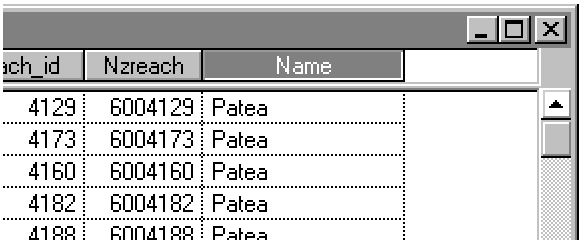




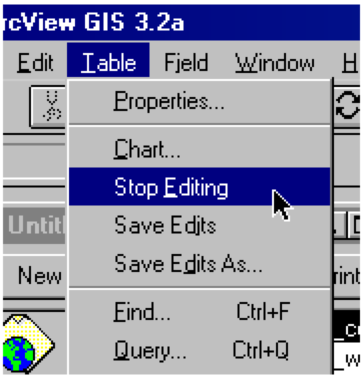
5. The Field Calculator dialog box will appear. Enter the name of the catchment in the text box on the lower left (using double quotes) and click on the **OK** button.



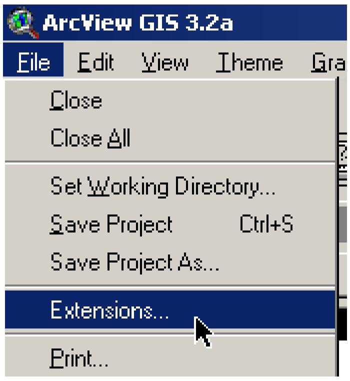
6. The new field will be populated.



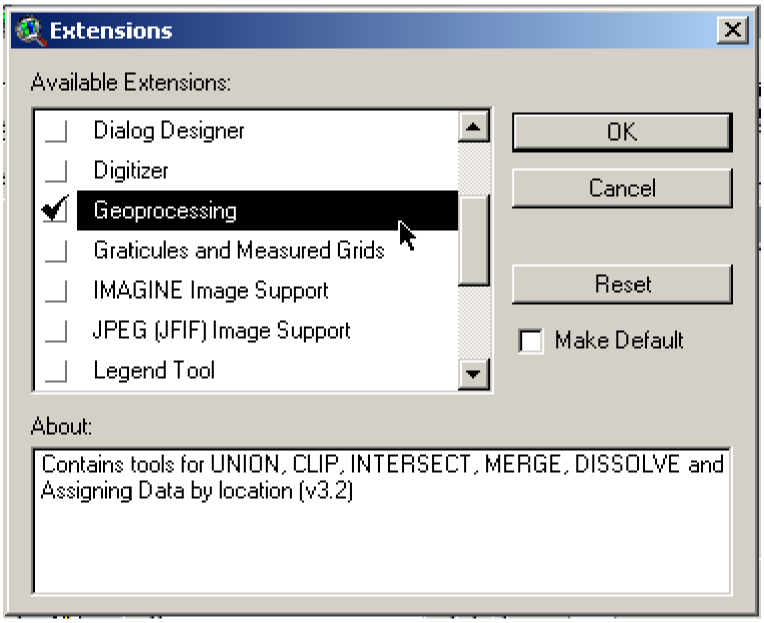
7. Finish editing by selecting **Table | Stop Editing** and accept the changes.



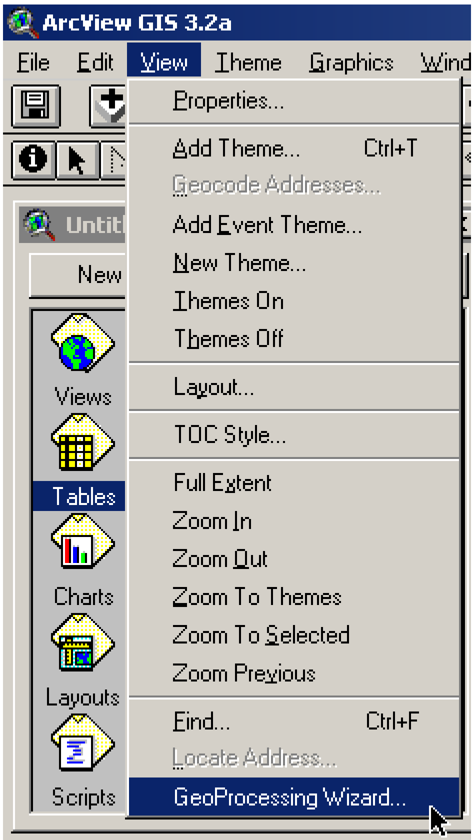
8. Now the dissolve can be carried out. First turn on the Geoprocessing extension by selecting **File | Extensions**.



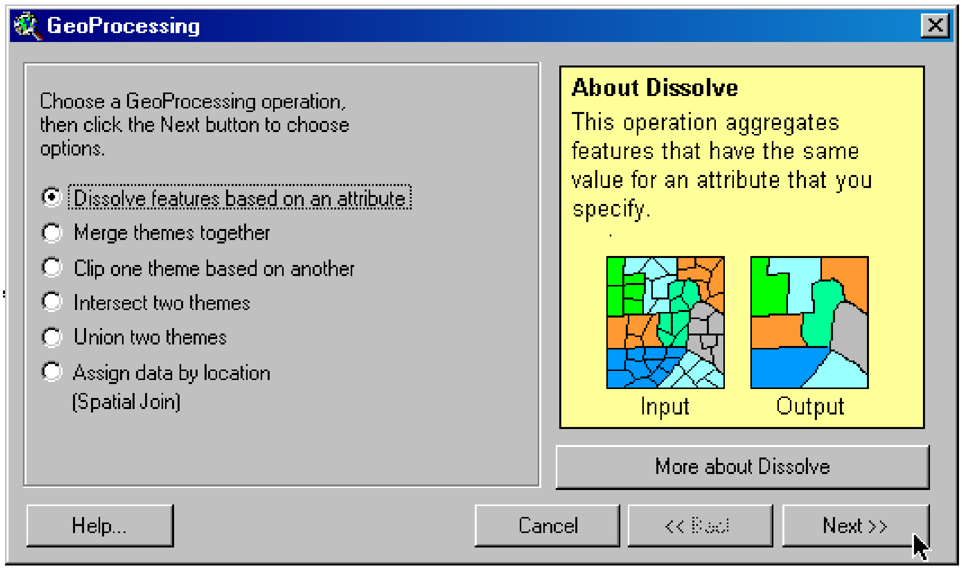
9. Make sure that the Geoprocessing option is checked and click **OK**.



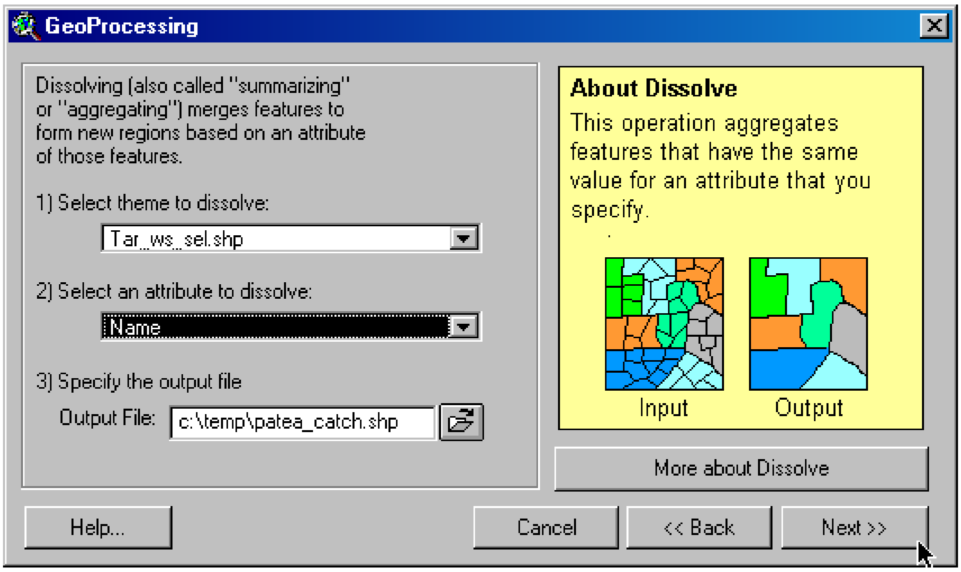
10. Click on the view window. There will now be a new menu option available through **View** | **GeoProcessing Wizard** which provides several operations.



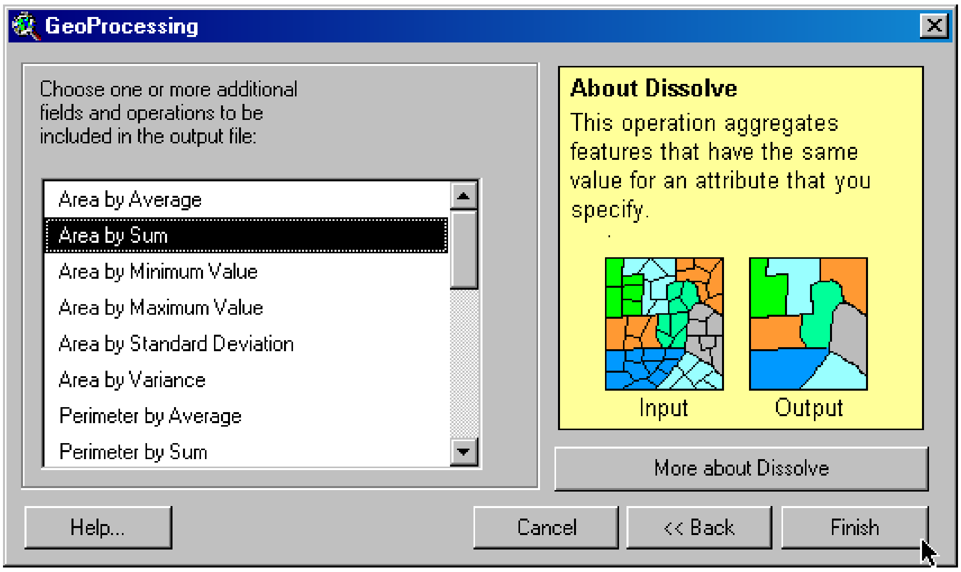
11. Select **Dissolve features base on an attribute** and click **Next**.



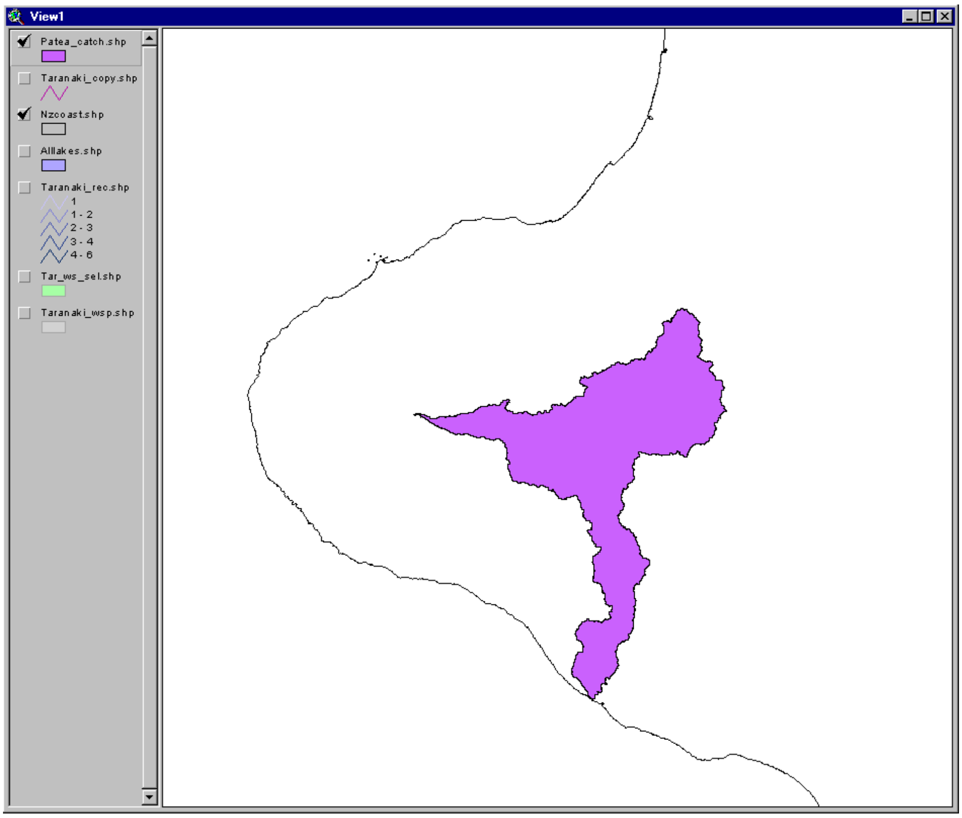
12. Choose the watersheds subset shapefile as the theme to dissolve, choose the new field name (in our case 'Name') as the attribute to dissolve on, decide on the name and location of the output shapefile, and click on **Next**.



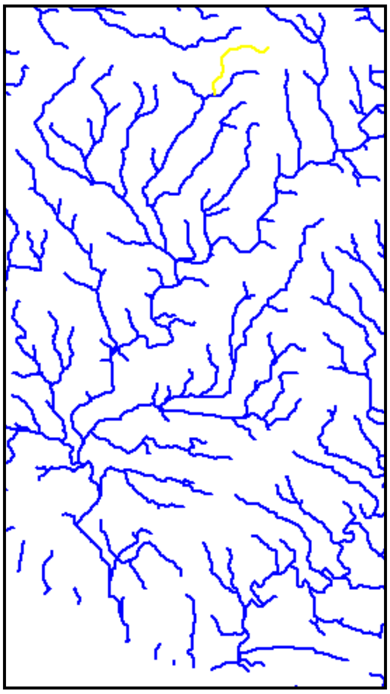
13. Finally, select one or more summary statistics. A useful number might be the total area of the catchment. Make a choice and click on **Finish**.

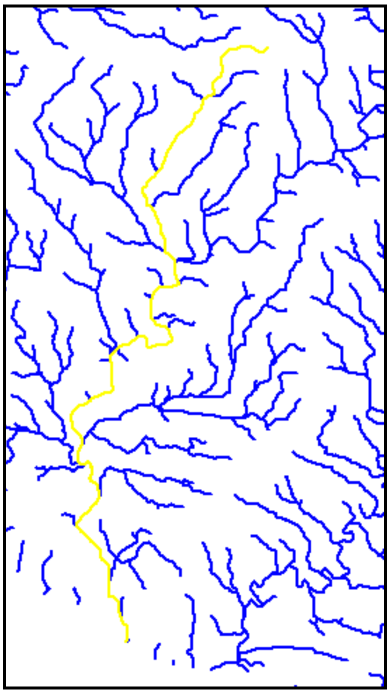


14. ArcView will then dissolve the features and generate a new shapefile containing a single polygon.

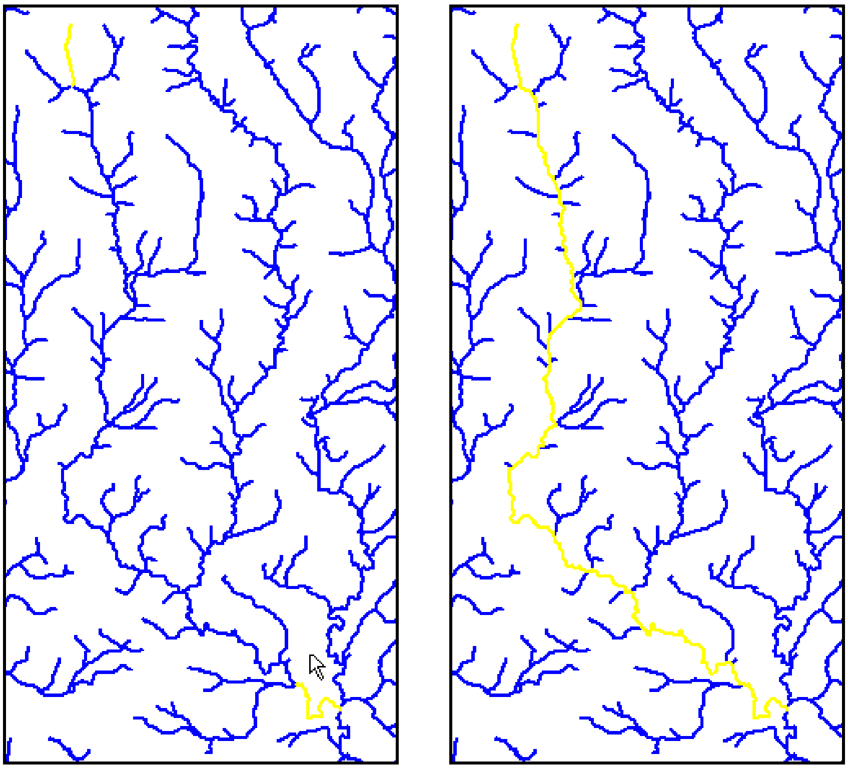


Tracer's other query options work in the same way as the upstream trace. For the Downstream query simply select the most upstream section and then click on the **Downstream** button.





The third option is to trace downstream to a point. In this case select both the most upstream and the most downstream points required and click on the **Downstream to Point** button.



> **Note**: Tracer was written to provide basic network analysis functionality for users of ArcView 3.2. For users of ArcGIS 8.x a better option is to use the **Arc Hydro** tools available from www.esri.com. This set of tools provides improved hydro processing capabilities for *advanced* GIS users.

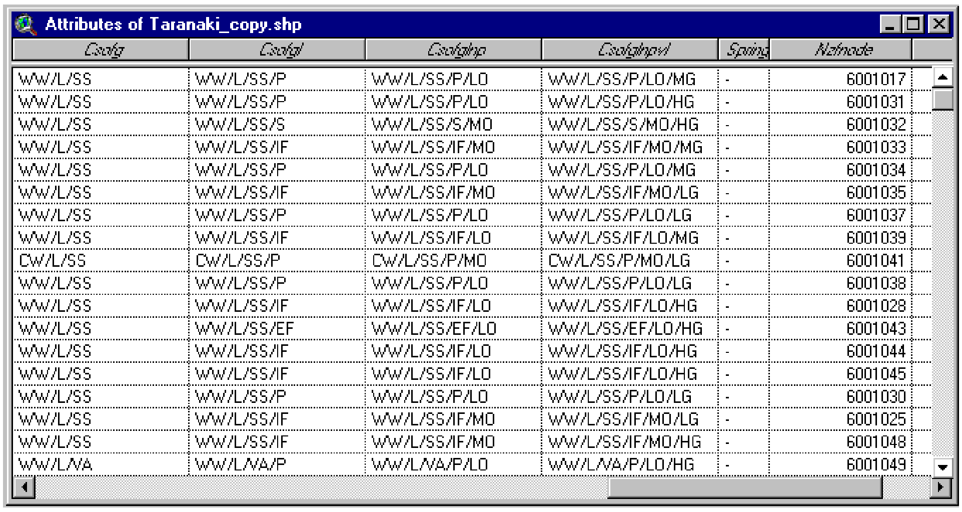
2.2 Adding data to the REC table

It is possible to add additional fields to the REC database so that this information is available to anyone using the REC. For example it may be desirable to flag sections of river that have specific management issues such as reserve status (this is purely for example purposes only).

> **Note**: This section deals with modifying the REC database. It is possible to damage the file by inadvertently overwriting data. We recommend that an experienced GIS user carry out any direct modification of files and a backup copy is kept.

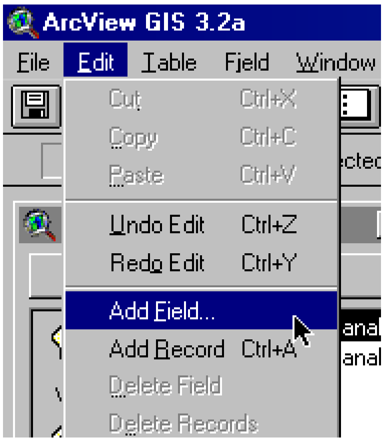
1. Open the theme table for the REC shapefile using the **Open Theme Table** button.

2. To create a new field to hold the new information, put the table into Edit mode by selecting **Table | Start Editing**.

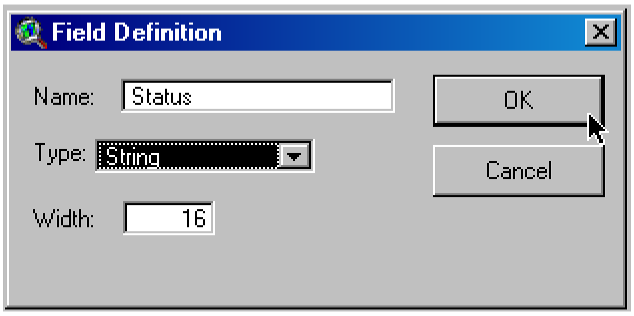

Attributes of Taranaki_copy.shp

Csofg	Csofgl	Csofglnp	Csofglnpvl	Spring	Nzfnode
WW/L/SS	WW/L/SS/P	WW/L/SS/P/LO	WW/L/SS/P/LO/MG	-	6001017
WW/L/SS	WW/L/SS/P	WW/L/SS/P/LO	WW/L/SS/P/LO/HG	-	6001031
WW/L/SS	WW/L/SS/S	WW/L/SS/S/MO	WW/L/SS/S/MO/HG	-	6001032
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/MO	WW/L/SS/IF/MO/MG	-	6001033
WW/L/SS	WW/L/SS/P	WW/L/SS/P/LO	WW/L/SS/P/LO/MG	-	6001034
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/MO	WW/L/SS/IF/MO/LG	-	6001035
WW/L/SS	WW/L/SS/P	WW/L/SS/P/LO	WW/L/SS/P/LO/LG	-	6001037
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/LO	WW/L/SS/IF/LO/MG	-	6001039
CW/L/SS	CW/L/SS/P	CW/L/SS/P/MO	CW/L/SS/P/MO/LG	-	6001041
WW/L/SS	WW/L/SS/P	WW/L/SS/P/LO	WW/L/SS/P/LO/LG	-	6001038
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/LO	WW/L/SS/IF/LO/HG	-	6001028
WW/L/SS	WW/L/SS/EF	WW/L/SS/EF/LO	WW/L/SS/EF/LO/HG	-	6001043
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/LO	WW/L/SS/IF/LO/HG	-	6001044
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/LO	WW/L/SS/IF/LO/HG	-	6001045
WW/L/SS	WW/L/SS/P	WW/L/SS/P/LO	WW/L/SS/P/LO/LG	-	6001030
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/MO	WW/L/SS/IF/MO/LG	-	6001025
WW/L/SS	WW/L/SS/IF	WW/L/SS/IF/MO	WW/L/SS/IF/MO/HG	-	6001048
WW/L/VA	WW/L/VA/P	WW/L/VA/P/LO	WW/L/VA/P/LO/HG	-	6001049

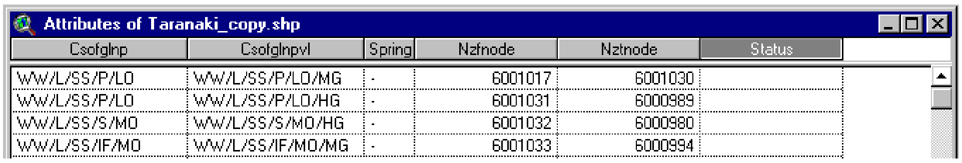
3. Now create the new field by selecting **Edit | Add Field**.



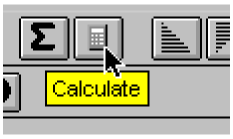
4. A dialog box will appear that allows the new field name and data type to be assigned. In this case the new field is named ‘Status’ and will contain text data with a maximum length of 16 characters.



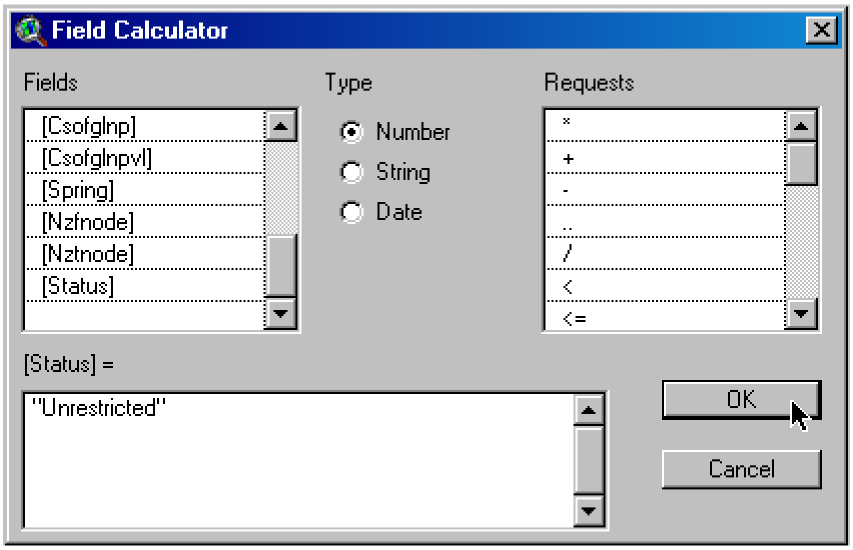
5. The new field will appear in the table and initially will contain no data.



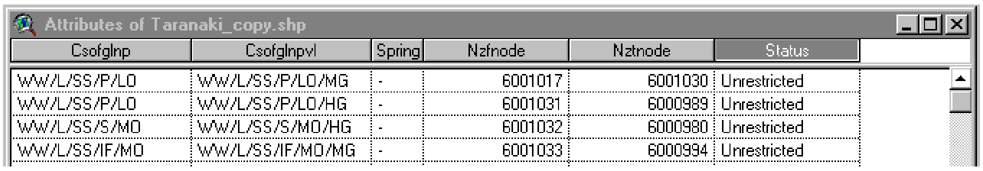
6. It is a good idea to populate the new field with the default value (even if the default value is 'No Data'). To do this click on the top of the column and select the **Calculate** tool.



7. The Field Calculator dialog box will appear. In the case of this example the default value is 'Unrestricted'. Enter this in the text window and click **OK**.



8. ArcView will populate the field and the new data will appear in the table.

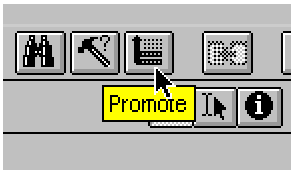


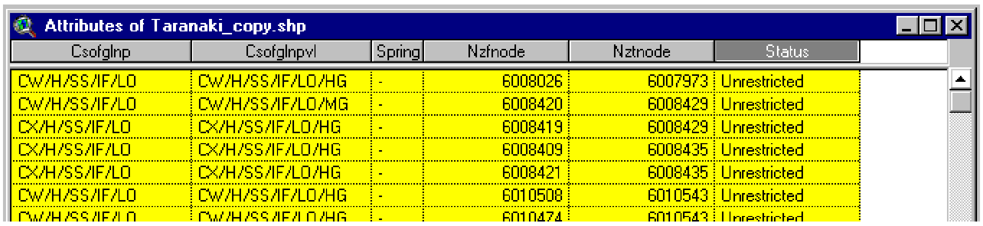
Attributes of Taranaki_copy.shp

Csofglnp	Csofglnpvl	Spring	Nzfnode	Nztnode	Status
WW/L/SS/P/LO	WW/L/SS/P/LO/MG	-	6001017	6001030	Unrestricted
WW/L/SS/P/LO	WW/L/SS/P/LO/HG	-	6001031	6000989	Unrestricted
WW/L/SS/S/MO	WW/L/SS/S/MO/HG	-	6001032	6000980	Unrestricted
WW/L/SS/IF/MO	WW/L/SS/IF/MO/MG	-	6001033	6000994	Unrestricted

9. To assign rivers to an alternative status, use Tracer, the Query Builder, or manually select river sections. In the case of this example a whole river was selected using Tracer.

10. Once some river sections have been selected the matching records in the attribute table will also be selected and highlighted in yellow. These records can be brought to the top of the table using the **Promote** button.

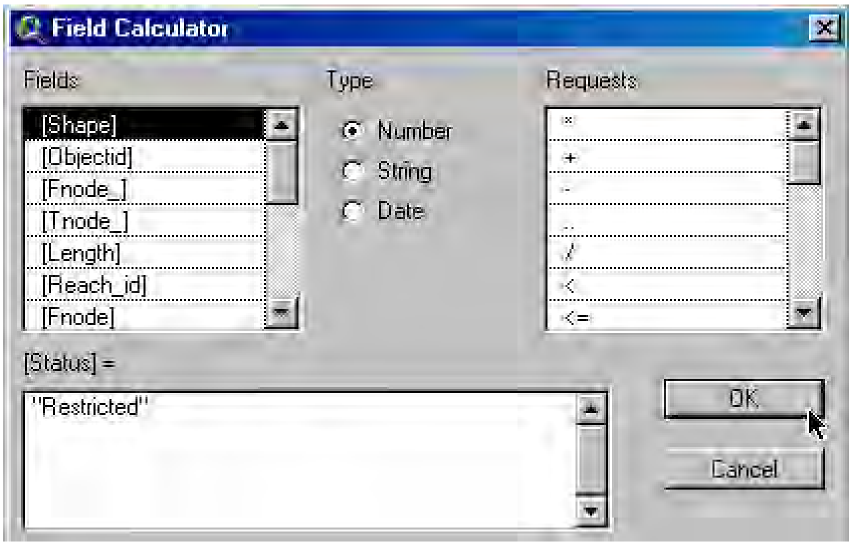




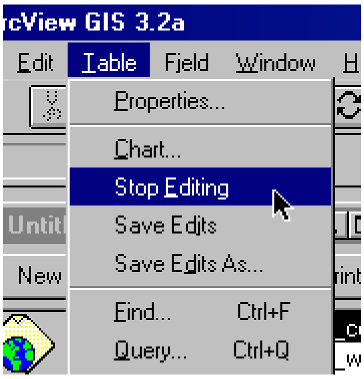
Attributes of Taranaki_copy.shp

Csofglnp	Csofglnpvl	Spring	Nzfnode	Nztnode	Status
CW/H/SS/IF/LO	CW/H/SS/IF/LO/HG	-	6008026	6007973	Unrestricted
CW/H/SS/IF/LO	CW/H/SS/IF/LO/MG	-	6008420	6008429	Unrestricted
CX/H/SS/IF/LO	CX/H/SS/IF/LO/HG	-	6008419	6008429	Unrestricted
CX/H/SS/IF/LO	CX/H/SS/IF/LO/HG	-	6008409	6008435	Unrestricted
CX/H/SS/IF/LO	CX/H/SS/IF/LO/HG	-	6008421	6008435	Unrestricted
CW/H/SS/IF/LO	CW/H/SS/IF/LO/HG	-	6010508	6010543	Unrestricted
CW/H/SS/IF/LO	CW/H/SS/IF/LO/HG	-	6010474	6010543	Unrestricted

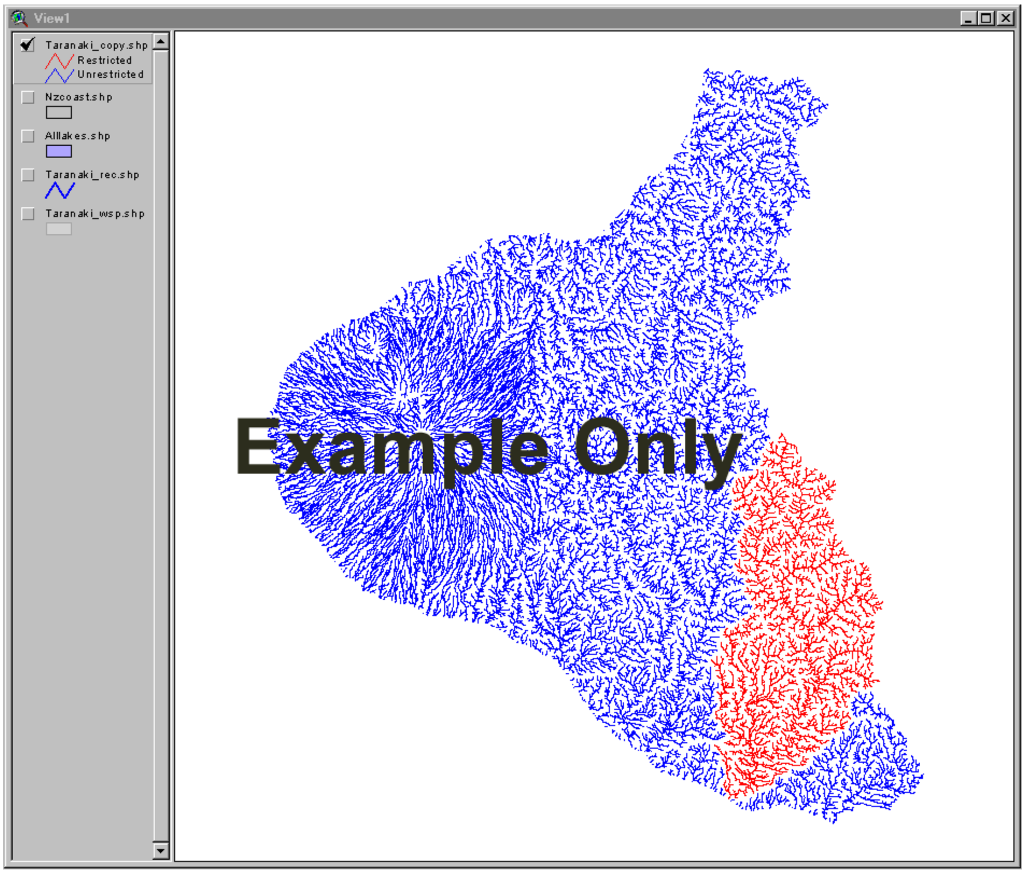
11. Use the Field Calculator to assign a new value to the selected reaches (in this case the status is changed to 'Restricted'). Note that if any features are selected then the Field Calculator will *only* operate on the selected data.



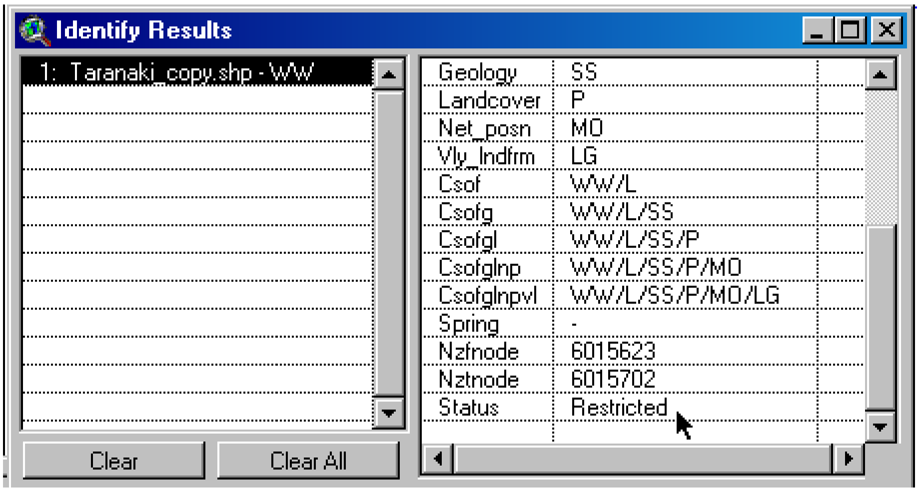
12. When editing is completed, select **Table | Stop Editing** and click **OK** to accept the changes.



The new field and data are now part of the shapefile and can be mapped and queried as usual. For example a map can be produced showing the river lines coloured according to their status.



The value of the new field can be seen using a query. Adding data to the REC may be useful for day-to-day use. For example, an officer processing a resource consent application could quickly check whether there are any outstanding issues regarding the river in question.


Identify Results
1: Taranaki_copy.shp - WW
Geology SS
Landcover P
Net_posn MO
Vly_lndfrm LG
Csof WW/L
Csofg WW/L/SS
Csofgl WW/L/SS/P
Csofglnp WW/L/SS/P/MO
Csofglnpvl WW/L/SS/P/MO/LG
Spring -
Nzfnode 6015623
Nztnode 6015702
Status Restricted
Clear
Clear All

3 Classifying individual sites

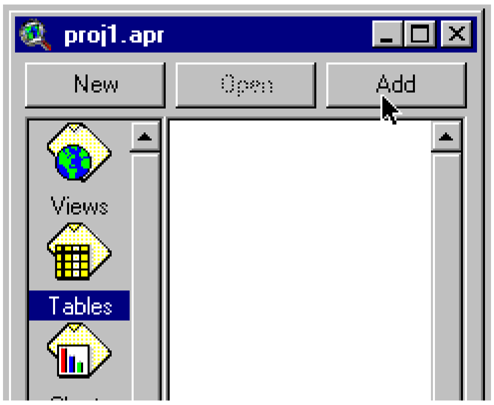
REC classes can be assigned to other data sets to facilitate analysis. For example, water quality monitoring sites can be assigned REC classes. A fast method is to match sites to the closest REC river sections. This works quite well if the geographic references of the sites are accurate.

1. First arrange the site data for import to ArcView. A table containing at least a Site ID and the location of the sites in Eastings and Northings is needed, preferably to metre accuracy. Typically this would be done using a spreadsheet application such as Microsoft Excel. If the geographic location information is only available in another reference system (for example as a map reference or a latitude and longitude) there is a utility available to make conversions (at a cost) from the Institute of Geological and Nuclear Sciences through the website below:

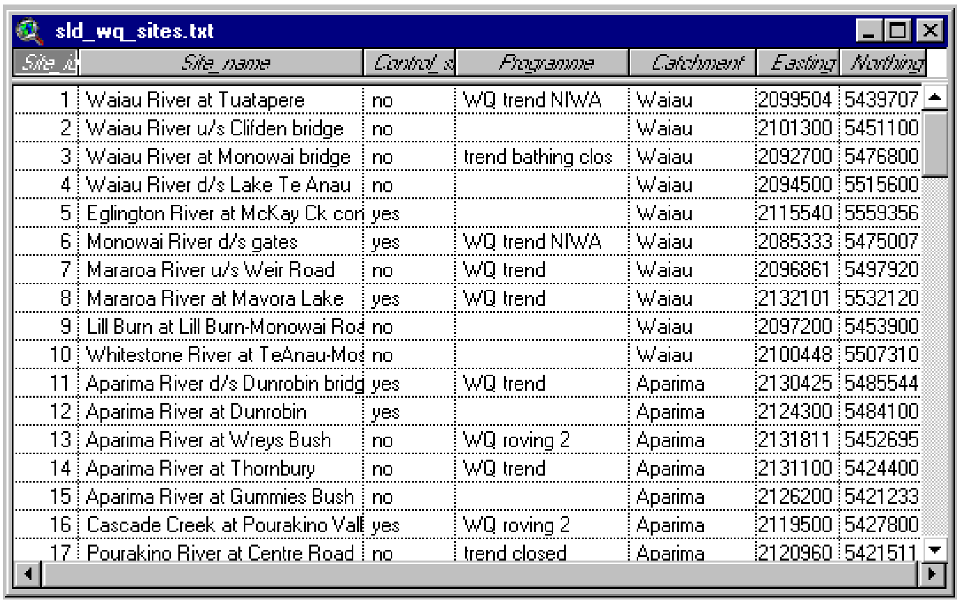
   http://www.gns.cri.nz/help/publications/software/convert.htm

2. The site data must then be exported to either a delimited text or dBase IV file. Note that field names must not contain spaces and long field names will be truncated. Also, numeric fields can sometimes be strangely formatted in Excel. For this reason text files are usually safest.

3. Import the table by first selecting the **Tables** option on the project window and then clicking the **Add** button.



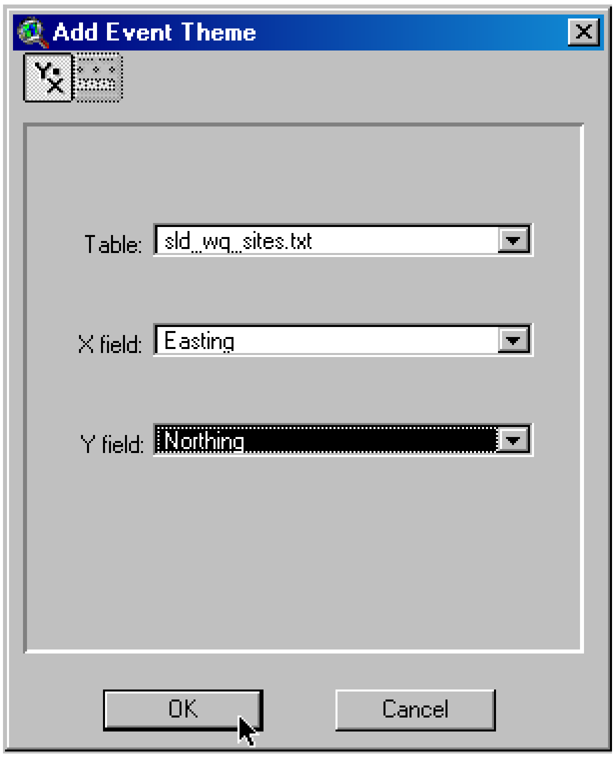
4. Open the table and check that all of the columns have imported correctly. If the data has not imported correctly then go back to step 2 and export in an alternative format.



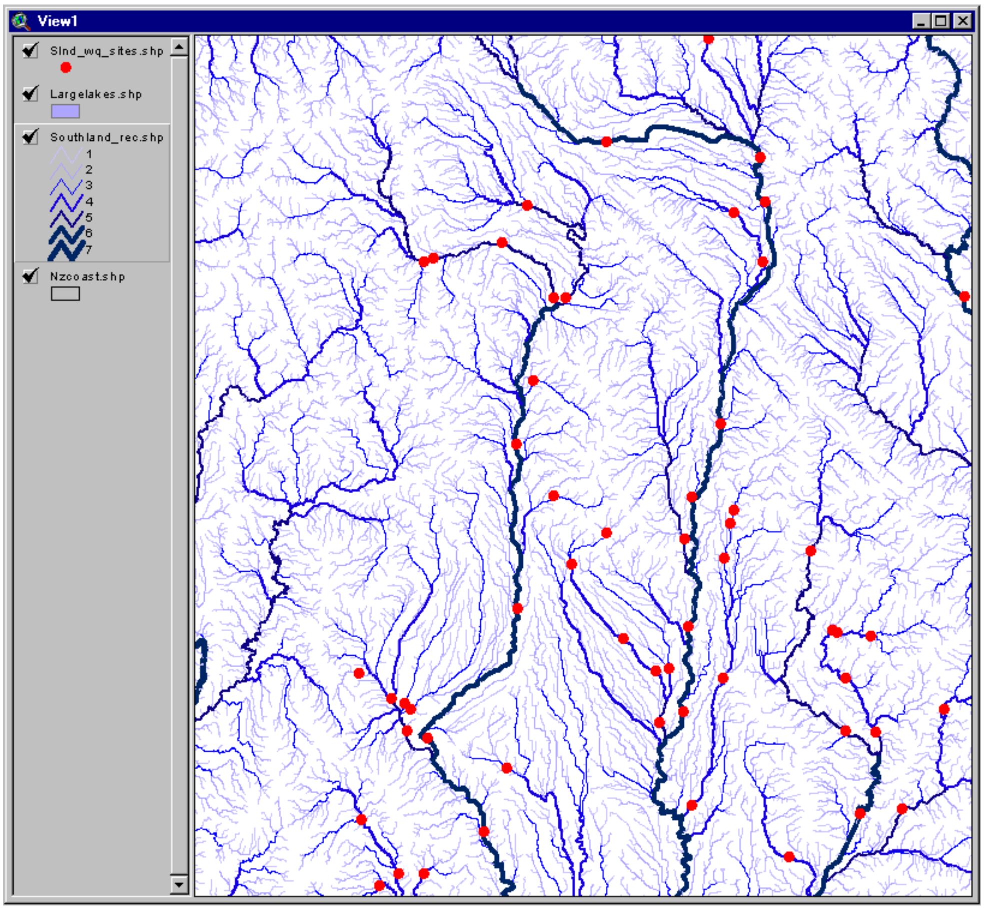
sld_wq_sites.txt

Site_i	Site_name	Control_s	Programme	Catchment	Easting	Northing
1	Waiau River at Tuatapere	no	WQ trend NIWA	Waiau	2099504	5439707
2	Waiau River u/s Clifden bridge	no		Waiau	2101300	5451100
3	Waiau River at Monowai bridge	no	trend bathing clos	Waiau	2092700	5476800
4	Waiau River d/s Lake Te Anau	no		Waiau	2094500	5515600
5	Eglington River at McKay Ck cor	yes		Waiau	2115540	5559356
6	Monowai River d/s gates	yes	WQ trend NIWA	Waiau	2085333	5475007
7	Mararoa River u/s Weir Road	no	WQ trend	Waiau	2096861	5497920
8	Mararoa River at Mavora Lake	yes	WQ trend	Waiau	2132101	5532120
9	Lill Burn at Lill Burn-Monowai Roa	no		Waiau	2097200	5453900
10	Whitestone River at TeAnau-Mos	no		Waiau	2100448	5507310
11	Aparima River d/s Dunrobin bridg	yes	WQ trend	Aparima	2130425	5485544
12	Aparima River at Dunrobin	yes		Aparima	2124300	5484100
13	Aparima River at Wreys Bush	no	WQ roving 2	Aparima	2131811	5452695
14	Aparima River at Thornbury	no	WQ trend	Aparima	2131100	5424400
15	Aparima River at Gummies Bush	no		Aparima	2126200	5421233
16	Cascade Creek at Pourakino Vall	yes	WQ roving 2	Aparima	2119500	5427800
17	Pourakino River at Centre Road	no	trend closed	Aparima	2120960	5421511

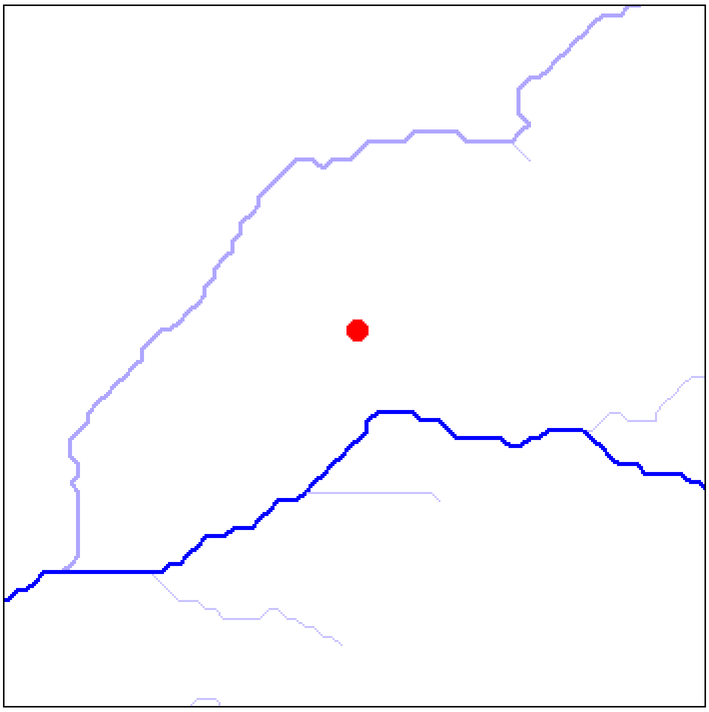
5. The points are displayed by selecting **View | Add Event Theme**… A dialog box will appear. Simply select the name of the table, and assign the Easting column to the **X field** and the Northing column to the **Y field**.



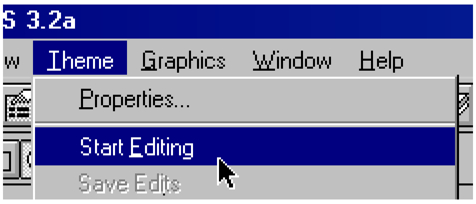
6. The points will then be displayed on the view. At this stage the points can be converted into a shapefile by clicking the new event theme in the legend panel and then selecting **Theme | Convert to Shapefile**…



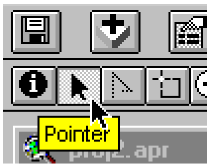
7. It is a good idea to stop at this stage and check the location of the sites and move any misplaced points to their correct locations. Moving points involves editing the shapefile which must always be done with caution. If your points look to be correctly located then skip to step 12.



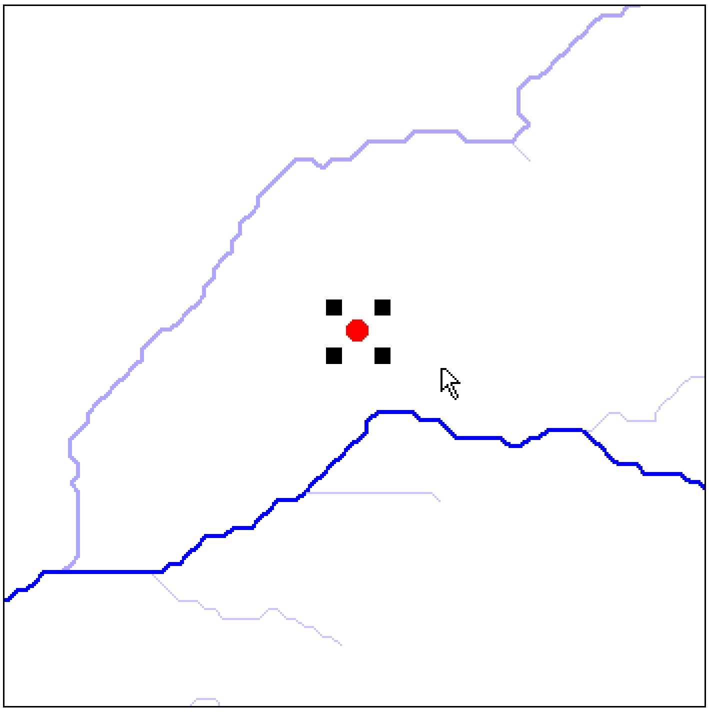
8. To edit a point select the new site location theme in the view window and select **Theme | Start Editing**.

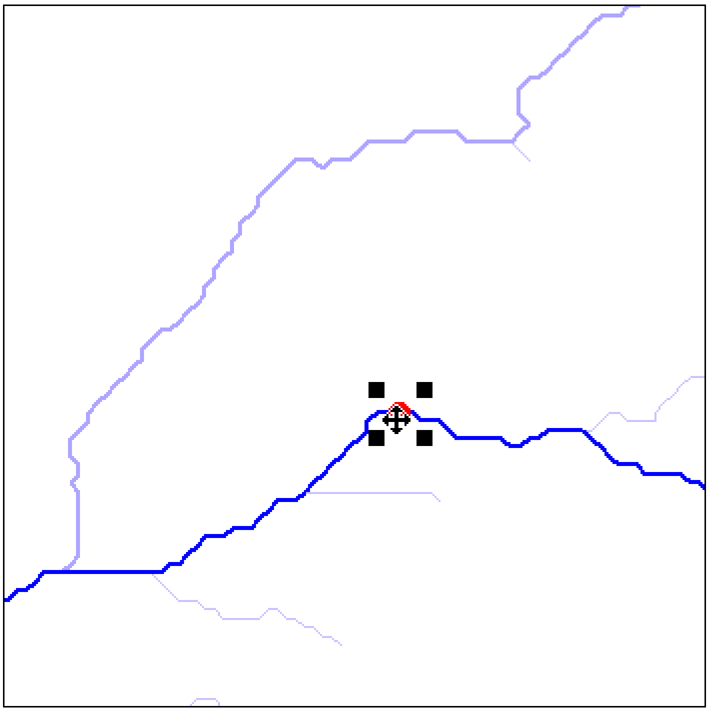


9. Select the **Pointer** tool if it is not already selected.

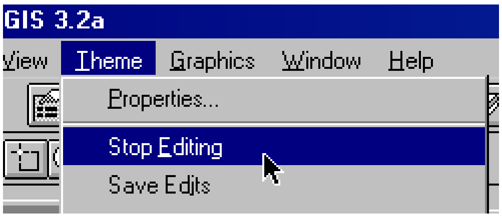


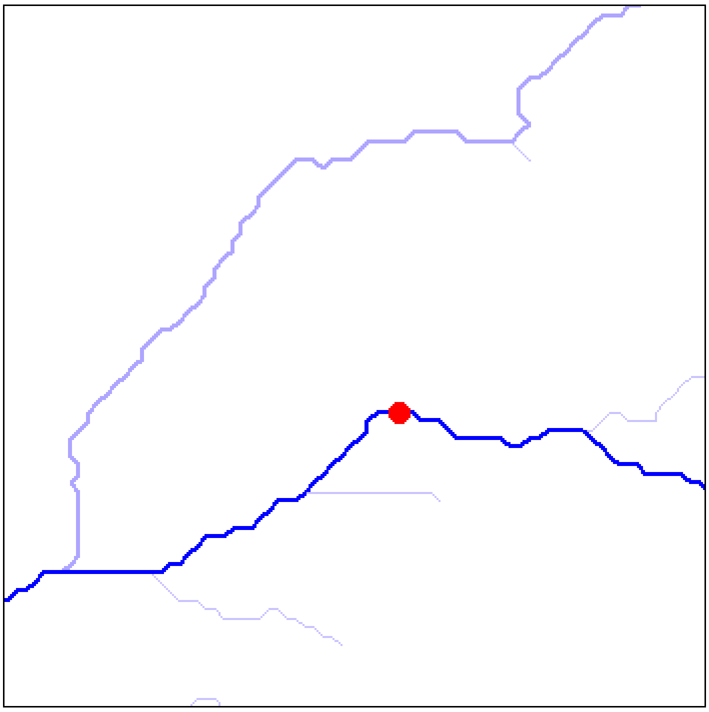
10. Select the point you want to move using the pointer and then click and drag it to the desired location. Continue moving points until they are all correctly located. This process can be made easier by loading other GIS layers (such as roads and towns) as a navigation guide. The best option is to underlay Topo Map images.



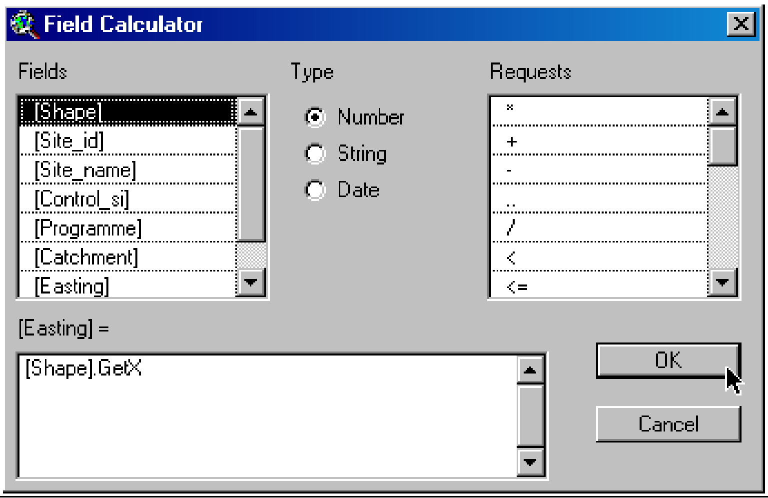


11. When editing is complete select **Theme | Stop Editing** and save the changes.

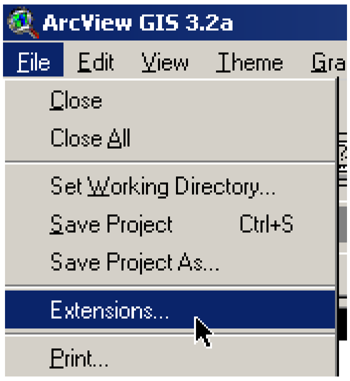




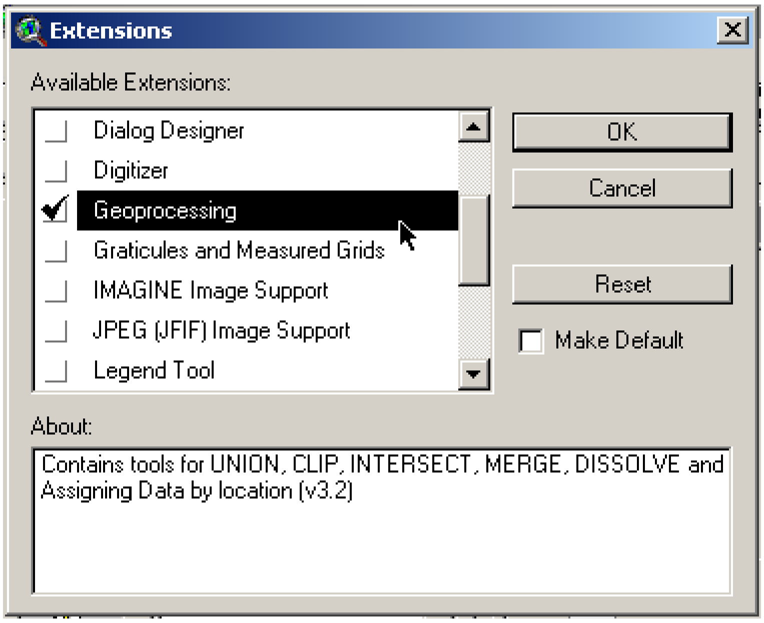
Note: Existing Easting and Northing values stored in the attribute table will NOT be automatically updated by ArcView when points are shifted. This data can be updated with the Field Calculator using the function [Shape].GetX or [Shape].GetY on the Easting and Northing field respectively. It is best to do this when all of the points have been moved.



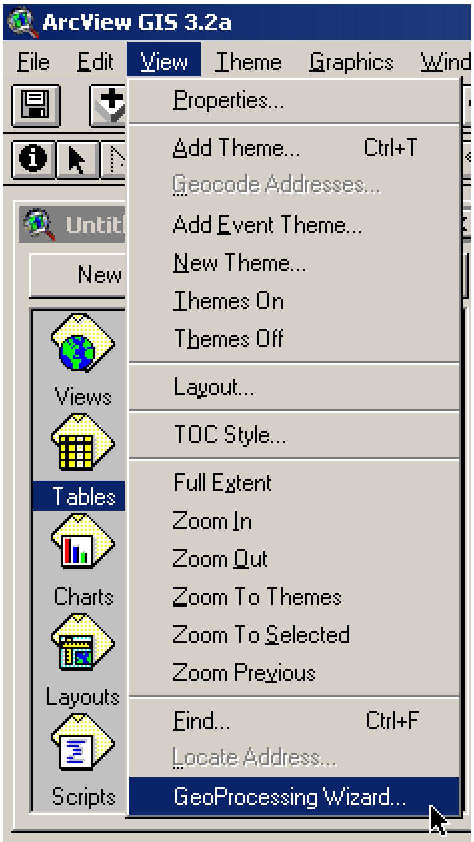
12. A spatial query is used to assign REC class to each site. This is carried out by using the Geoprocessing extension that comes with ArcView. This can be loaded by selecting **File | Extensions**…



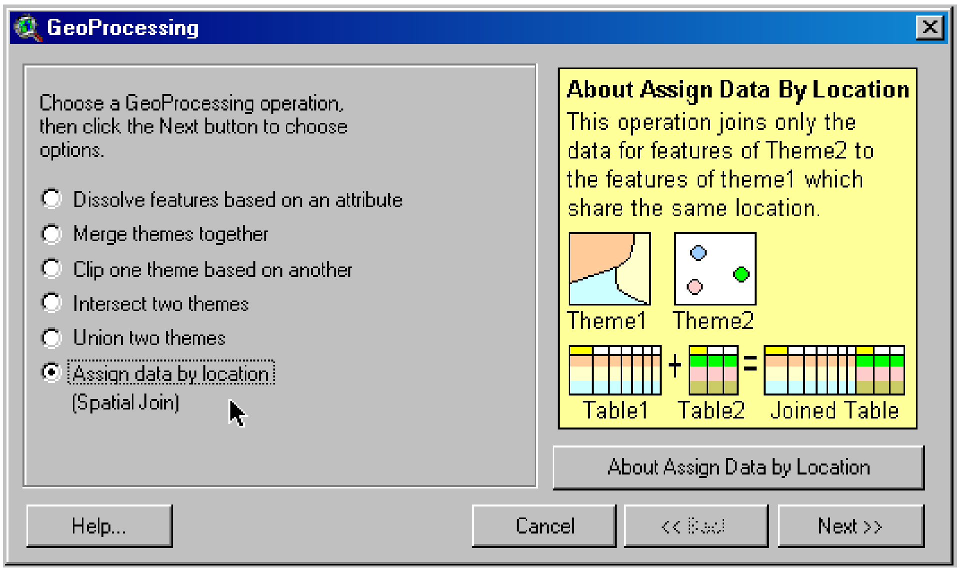
13. Make sure that the Geoprocessing option is selected and click **OK**.



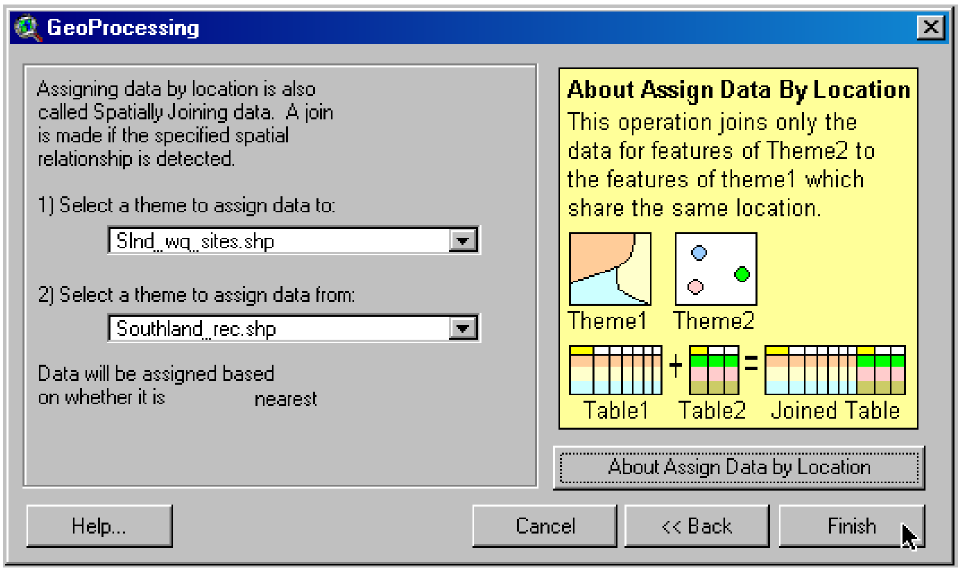
14. A new menu option is available through **View** | **GeoProcessing Wizard**, which provides several operations.



15. Select the **Assign data by location** option and click **Next**.



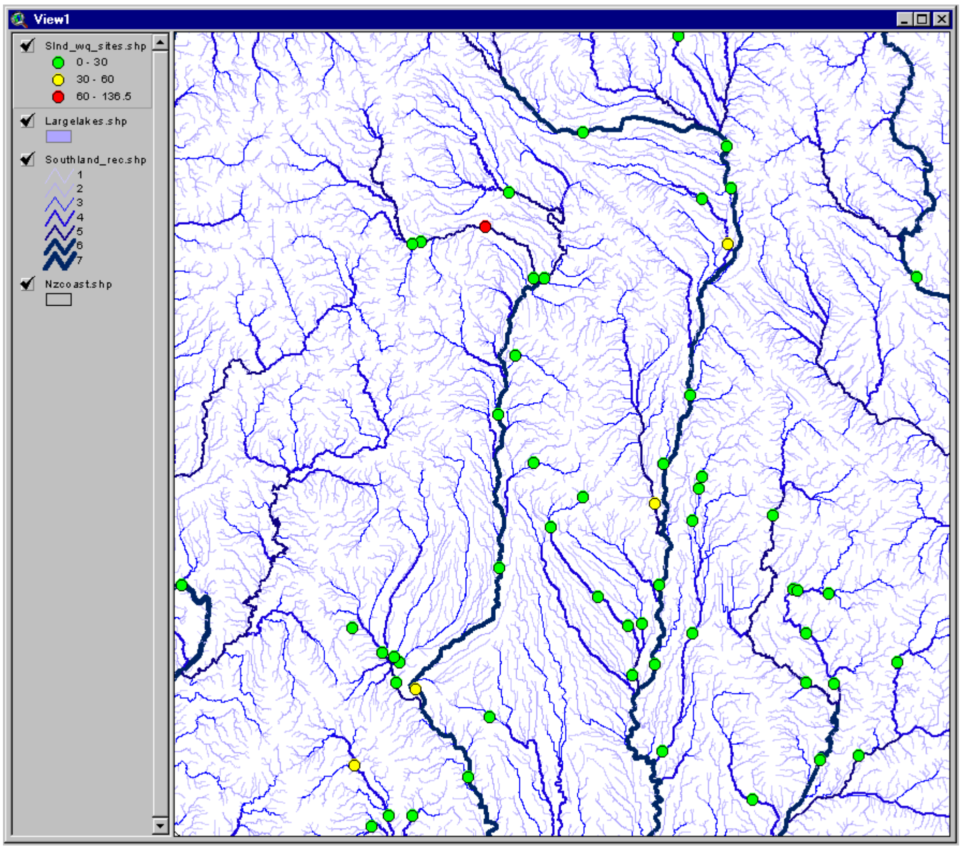
16. Choose the sites shapefile as the **theme to assign data to** and the REC shapefile as the **theme to assign data from** and click on **Finish**.



17. The table for the points shapefile will now have all the data from the nearest river section attached to each point. Note that this is a temporary join; in order to make it permanent, the points must be saved as a new shapefile. In addition to the REC classes, ArcView will have also added a column called ‘Distance’ that gives the distance in metres to the nearest river section. This provides an additional way to check the legitimacy of the spatial join as those points that have a large distance value will be a long way from the nearest river and may be more likely to have been mis-classified. If points are mis-classified then they need to be moved by going back to step 8. Points are most commonly mis-classified if they are close to a confluence, and so these situations need to be checked carefully.

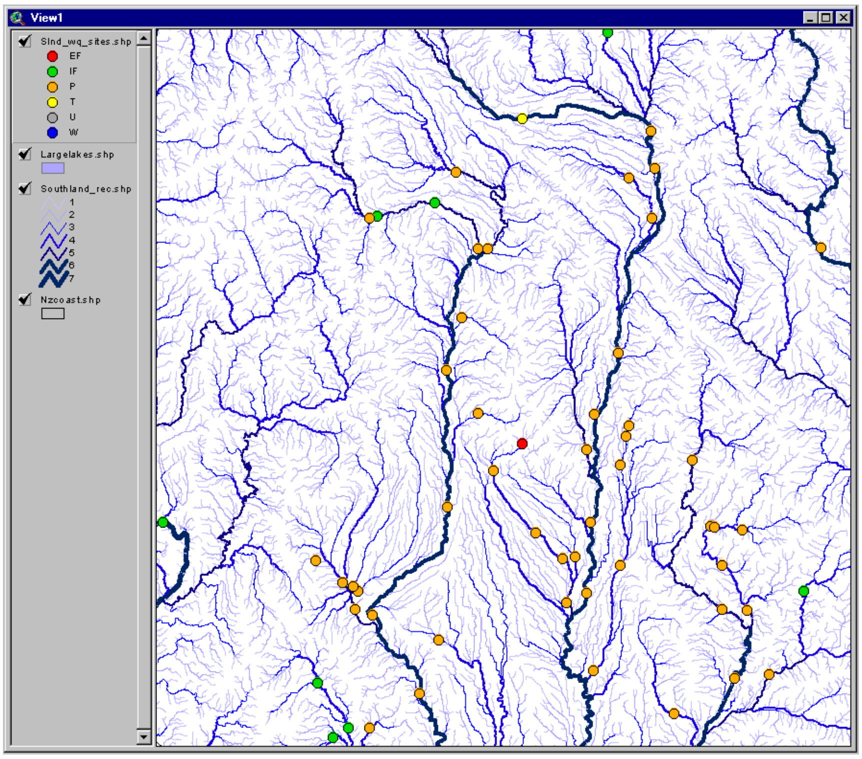
Attributes of Slnd_wq_sites.shp

Distance	Fnode_	Tnode_	Length	Reach_id	Nzreach	Fnode	Tnode	Order_	Climate	Src_of_flw	Geology	Landcover	Net_
0.500	53527	53817	1016.98485	52505	15052505	53672	53969	7.00000000000	CX	Lk	PI	IF	HC
22.274	49345	49587	1028.52814	48469	15048469	49551	49779	7.00000000000	CX	Lk	PI	IF	HC
22.274	38972	39053	259.70563	38197	15038197	39126	39210	7.00000000000	CX	Lk	PI	IF	HC
6.010	23244	23536	911.54329	22730	15022730	23395	23682	6.00000000000	CX	Lk	PI	IF	HC
1.061	10218	10241	162.42641	9956	15009956	10240	10271	5.00000000000	CX	M	VB	IF	HC
1.000	39762	39713	319.70563	38952	15038952	39916	39859	5.00000000000	CW	Lk	HS	IF	HC
25.102	29964	30607	2130.36580	29370	15029370	30114	30751	6.00000000000	CW	H	Al	P	HC
12.500	16719	16900	517.27922	16464	15016464	16951	17129	5.00000000000	CW	Lk	HS	T	HC
12.000	48226	48448	1426.69048	47441	15047441	48399	48641	5.00000000000	CW	L	SS	IF	HC
14.500	26571	27107	1574.55844	26001	15026001	26713	27242	5.00000000000	CW	H	SS	P	HC
66.000	35620	35627	1226.98485	34889	15034889	35765	35773	5.00000000000	CW	H	HS	IF	HC
2.000	36181	36158	1046.98485	35443	15035443	36330	36316	5.00000000000	CW	H	HS	IF	HC
2.500	48041	48713	2205.80736	47179	15047179	48214	48935	6.00000000000	CD	L	HS	P	HC

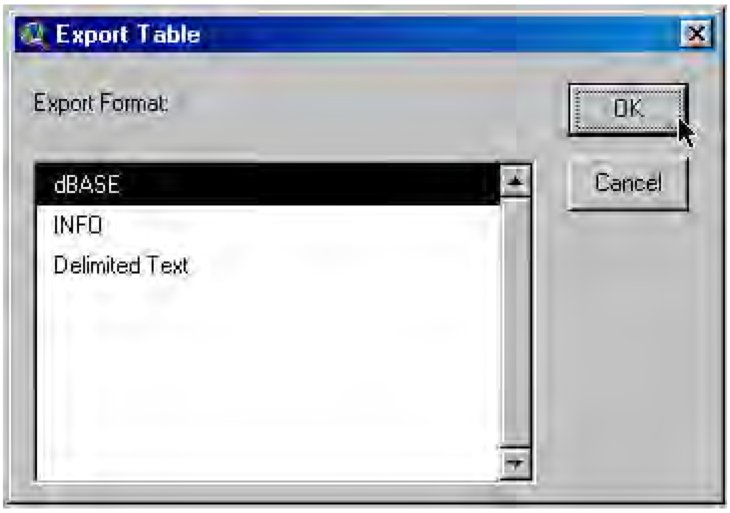


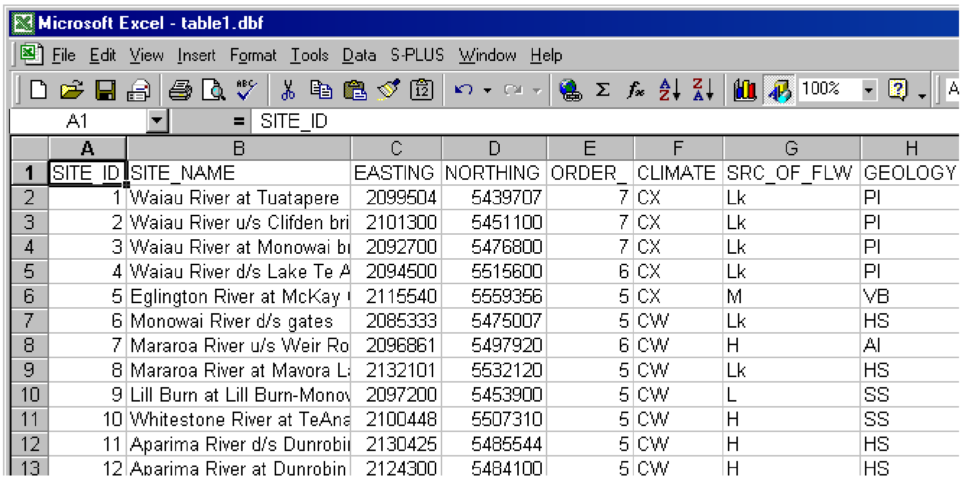
Note: In the figure above the sites have been coloured according to their distance (in metres) from the nearest river section.

18. The sites can now be mapped according to REC classes, for example by Land-Cover.



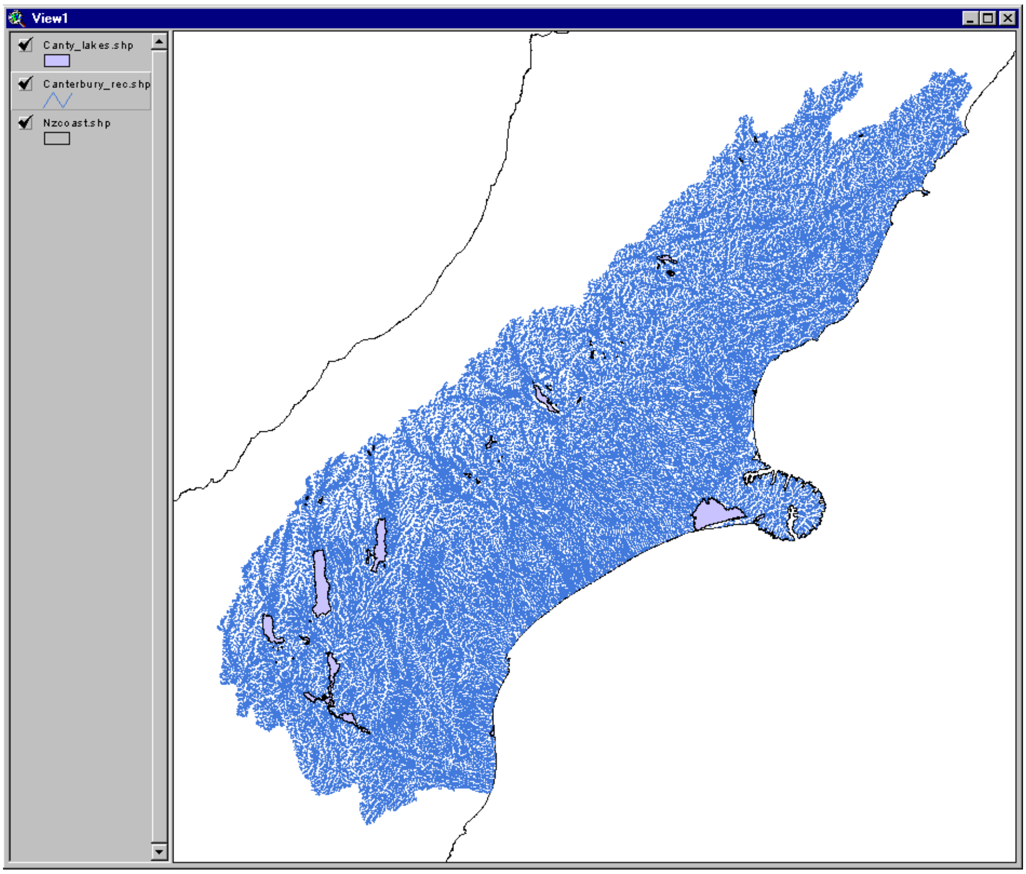
19. The classified site data can be exported to another piece of software by clicking on the table and then selecting **File | Export**…





4 Grouper

In certain circumstances it is useful to simplify the classification by grouping together classes from one or more levels, for example when defining management units. To help facilitate this process a tool called Grouper has been developed. Grouper is simple to use, however, the decisions that need to be made regarding which classes should be put together can be quite difficult and rely on the user having a good working knowledge of the theoretical basis for REC. In this example the management units developed in Part I of this manual for Canterbury will be created.

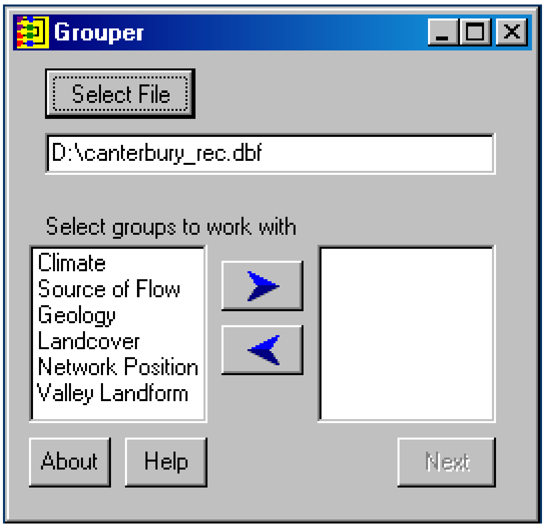


1. Install Grouper by running Setup.exe in the Grouper directory of the REC CD.

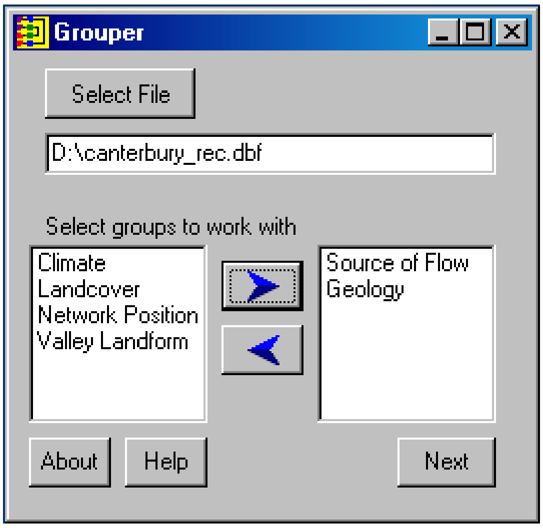
2. Run grouper by activating C:\Program Files\Grouper\grouper.exe

3. When the Grouper program is started, the first step is to select the REC file by clicking on the **Select File** button and then navigating to the correct file.

> **Note**: The REC file *must* be stored in a directory that has write-access, as Grouper needs to create temporary files. Grouper only reads the REC attribute file and does not alter it.

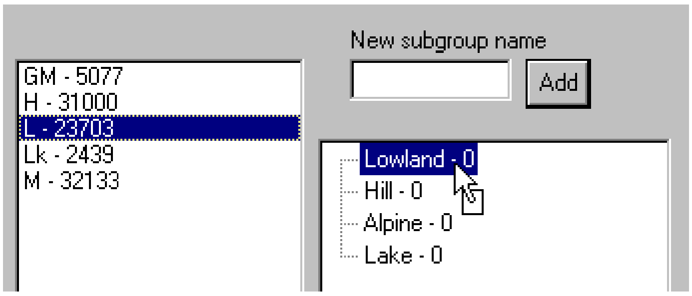


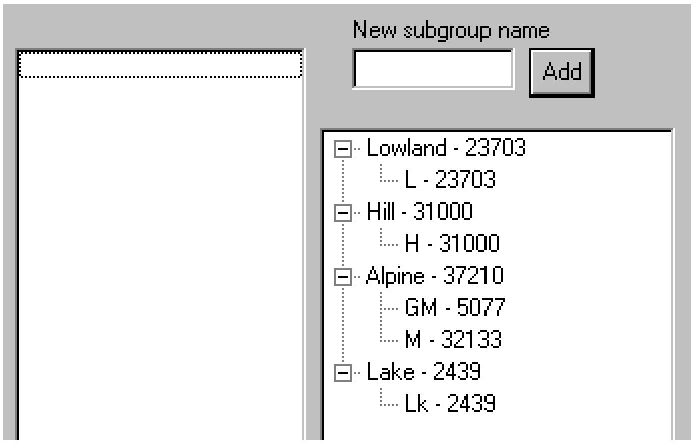
4. Next select the Factors to group together. For this example grouping is carried out on Source-of-Flow and Geology. Select the factors in the left hand window and move them to the right hand window using the arrow button. Click **Next** to continue.



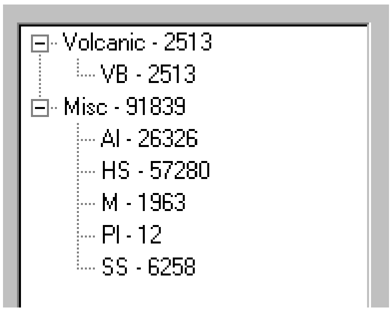
5. A new window will appear with a tab for each of the factors chosen at the previous step. For each factor create a new set of groups to assemble the classes. In this example, Source-of-Flow is re-categorised into groups named Lowland, Hill, Alpine, and Lake. Type each name one at a time into the **New subgroup name** box and press the **Add** button.

6. When the new groups are added click and drag classes from the panel on the left and drop them onto the new group name. Once the new Source-of-Flow groups are assigned click on the Geology Tab

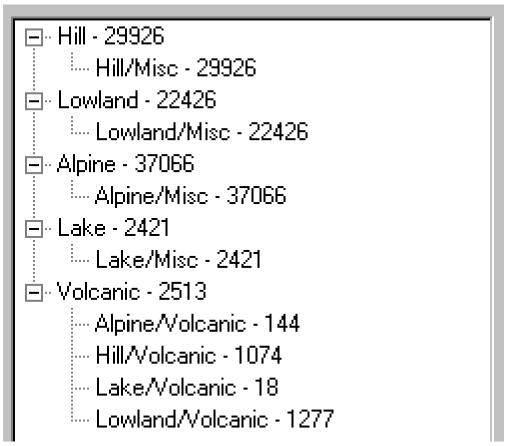




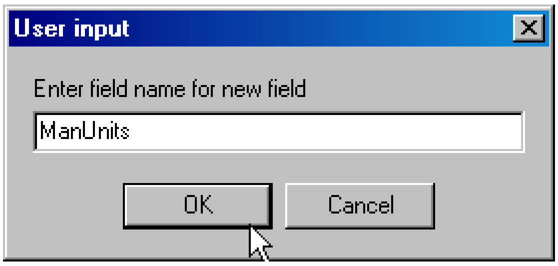
7. In this example only the Volcanic geology category is used to define a new group named Volcanic. All the other rock types are placed into a miscellaneous group by clicking on the **Rest -> Misc** button. When complete press the **Next** button.



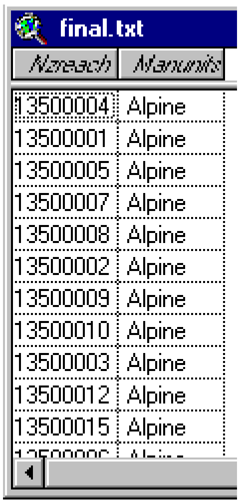
8. Grouper assigns all the REC data into the new groups. The next window shows all the existing combinations and provides the chance to further group these. This last grouping creates five groups named Lowland, Hill, Alpine, Lake, and Volcanic. All of the Source-of-Flow categories with a Volcanic geology are assigned to the new Volcanic group. The remainder are assigned to the appropriate groups according to their Source-of-Flow.



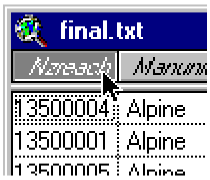
9. Finally click the **Finish** button. Grouper will prompt for a new field name for the groups. In this example the field is named ManUnits. Grouper then writes a new text file into the working directory named final.txt. This lists the NZReach number and new group for each river section.



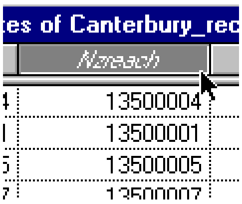
10. Switch to ArcView to use these new groups by loading the REC file and adding final.txt as a new table.



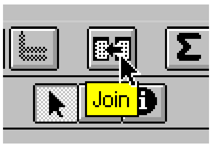
11. Attach the new field to the REC file with the **Join** tool. First select the NZReach column on the final.txt table.

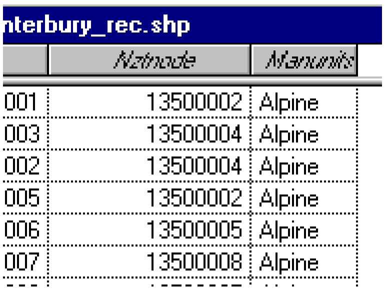


12. Open the attribute table for the REC file and select the NZReach column. Note that the order of selection is important, you must select the *From* table (final.txt) first and the *To* table (REC) second. It is also important that no records are selected in either table otherwise ArcView will only join those records. This can be checked by clicking on the **Clear Selected Features** button.

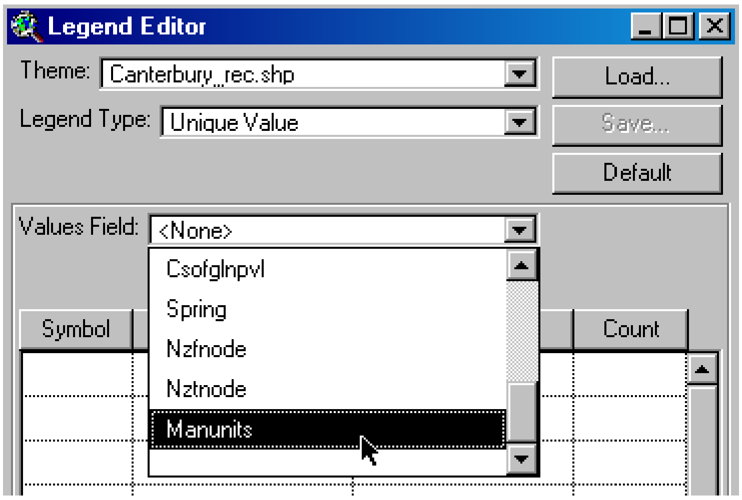


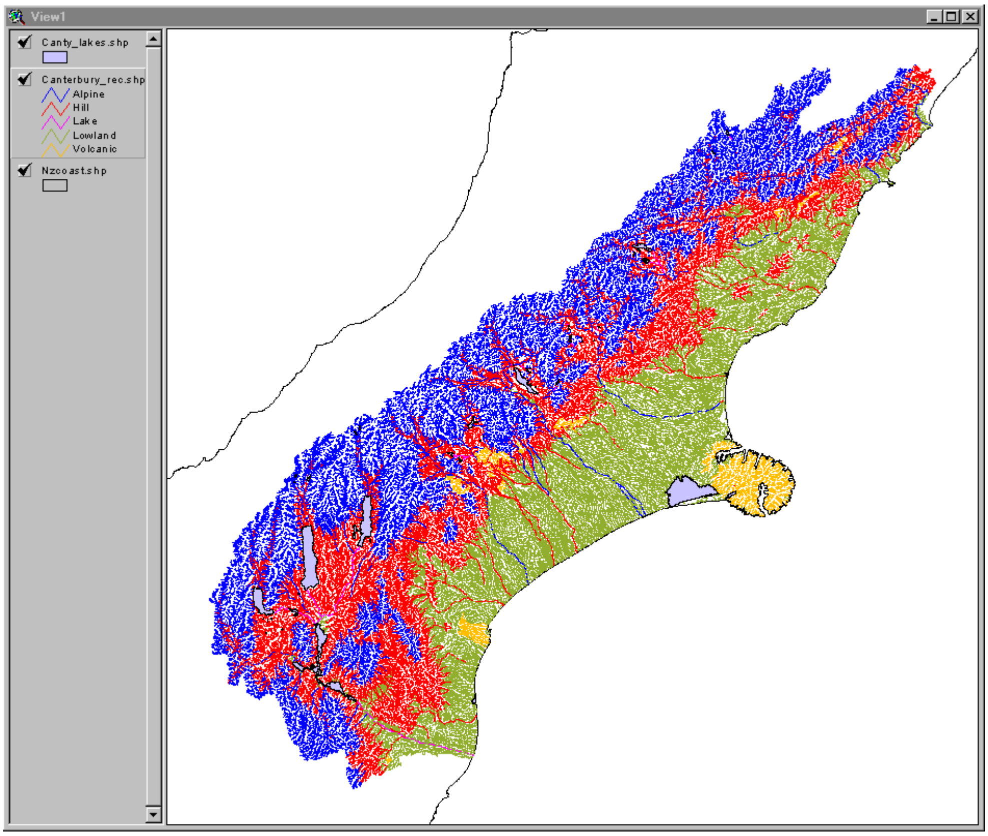
13. Click the **Join** button on the toolbar. ArcView will attach the ManUnits column to the REC attribute table. Note that this is not a permanent join; to make a permanent join save the REC file to a new shapefile.





14. The new column can be used as normal. For example, here the river lines are coloured according to their management unit.





In addition to Final.txt, Grouper also writes a log file called log.txt. This contains a record of which original REC categories were grouped to form the new categories (see the example below). This file shows all the selections made and also shows how many river sections were put into each new group to give the user some information on how the region was reclassified. It is useful to save a copy of this file in case the procedure needs to be repeated.

```
Grouper log file
28 Nov 2002 at 05:18 PM
Input file = D:\canterbury_rec.dbf
Output file = D:\\Final.txt

Classifications used:
  - Source-of-Flow
  - Geology

Subgroups chosen:
  - Source-of-Flow
    - Lowland - 23703
      - L - 23703
    - Hill - 31000
      - H - 31000
    - Alpine - 37210
      - GM - 5077
      - M - 32133
    - Lake - 2439
      - Lk - 2439
  - Geology
    - Volcanic - 2513
      - VB - 2513
    - Misc - 91839
      - Al - 26326
      - HS - 57280
      - M - 1963
      - Pl - 12
      - SS - 6258

New groups created:
  - Hill - 29926
    - Hill/Misc - 29926
  - Lowland - 22426
    - Lowland/Misc - 22426
  - Alpine - 37066
    - Alpine/Misc - 37066
  - Lake - 2421
    - Lake/Misc - 2421
  - Volcanic - 2513
    - Alpine/Volcanic - 144
    - Hill/Volcanic - 1074
    - Lake/Volcanic - 18
    - Lowland/Volcanic - 1277
```

5 How the REC was made

The basis of the REC system is a synthetic river network derived from a hydrologically correct digital elevation model (DEM). The DEM used was built at a 30m-pixel size by NIWA using 20 m contour data from the NZMS260 map series. The DEM was then hydrologically corrected using the river lines from the NZMS260 maps as a guide. The river lines themselves had been manually corrected by hand by NIWA based on expert advice from representatives from every regional authority.

During the river synthesis process, the river sections and related watersheds were simultaneously delineated (see Figure 2.3).

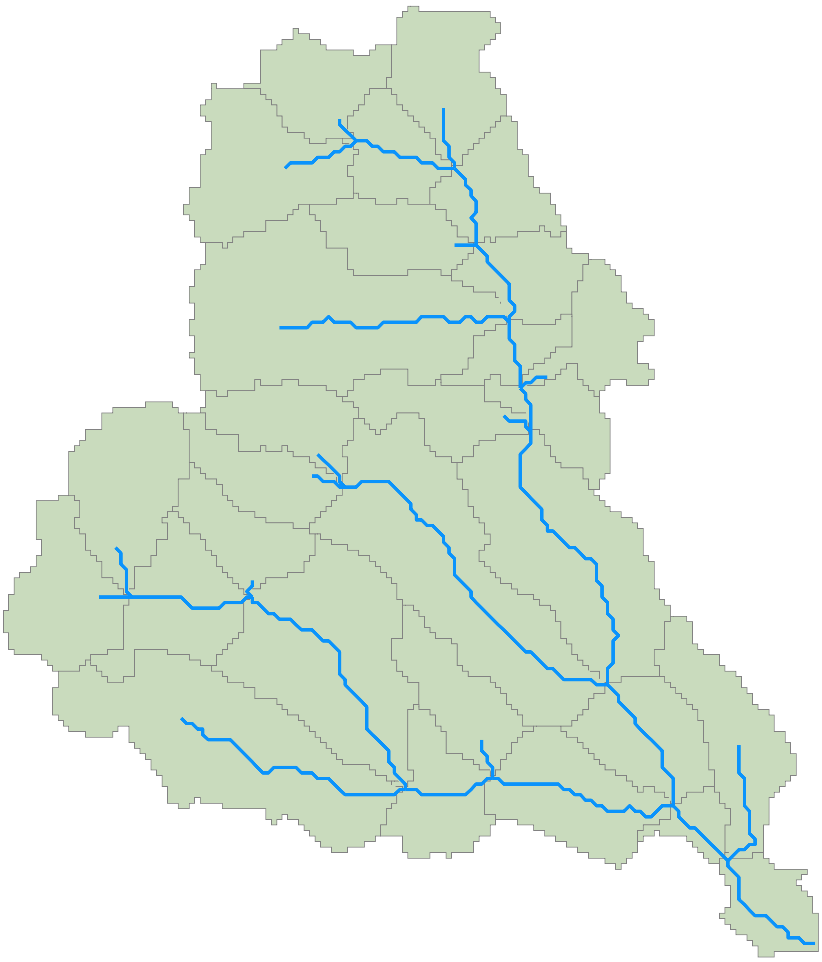


Figure 2.3 REC river network sections and their watersheds.

Note that the jagged edges on the watersheds reflects the scale of the 30 m DEM pixels.

The watersheds were then used to interrogate the GIS layers used to develop the mapping characteristics. For example, for Geology the area in m^2 of each rock type occurring in each watershed was extracted, and this data was then used as a mapping characteristic (see Part I, Table 1.9).

The data was handled in two ways depending on the factor. For factors that act at a catchment scale (for example climate or geology) the data was accumulated for the entire upstream catchment (i.e. all the individual watersheds that flow to that point), for local scale factors (for example valley slope) the data was only processed for the individual river section. Figure 2.4 illustrates this.

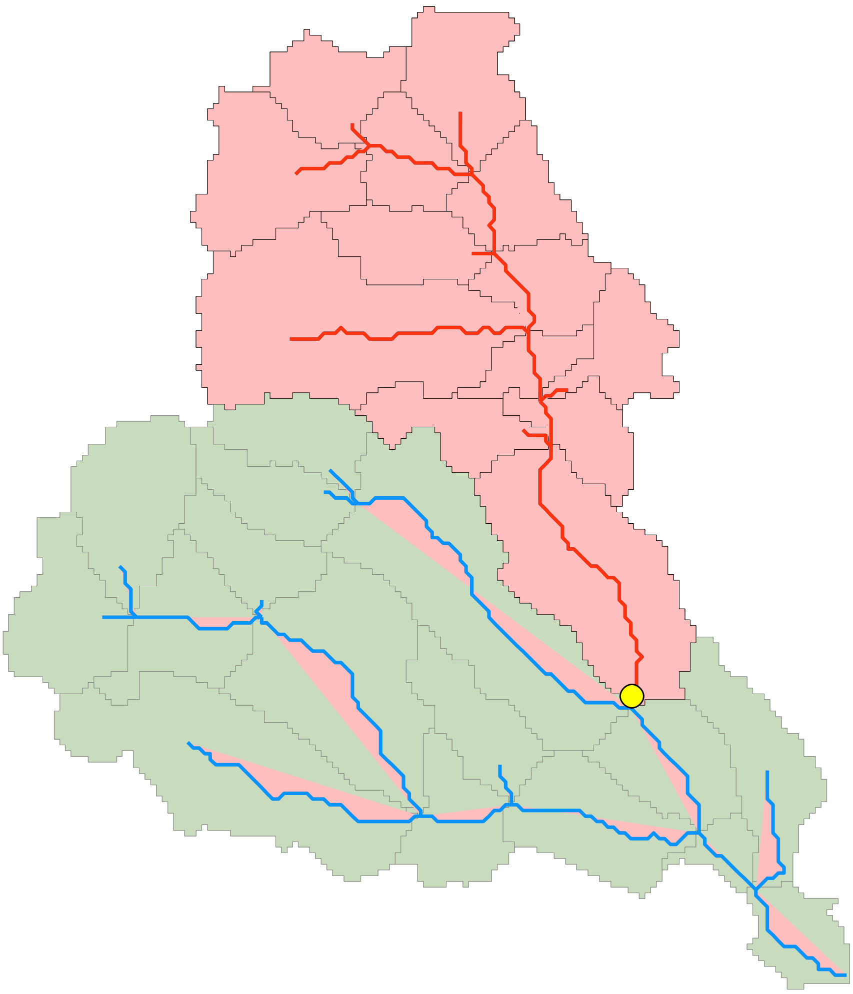


Figure 2.4 Accumulation example.

The catchment scale data (i.e. Climate, Source-of-Flow, Geology, and Land-Cover) was processed for every section of the river network by accumulating the information for each watershed flowing to that section. In this example the river section flowing to the yellow circle is characterised by all of the watersheds flowing to that point (shown in pink).

The processed data was fed through custom written software that applied the classification rules and produced the REC class for each river section. The rest of this section of the manual details the classification procedure for each factor.

5.1 Climate

The Climate classification procedure was based on two pieces of information, Mean Annual Temperature (Figure 2.5) and Effective Rainfall (Figure 2.6) which is total rainfall minus potential evaporation. The GIS layers used were supplied by Landcare

Research and are the same as those used for the Land Environments of New Zealand (LENZ) classification system. The surfaces were based on long-term average climate data.

As the Climate factor operates at the catchment scale, spatially averaged values of the climatic variables were derived for the entire upstream catchment of each river section. The rules used for climate categorisation of river sections are simple: river sections with integrated catchment temperatures greater than or equal to 12°C were designated as Warm, while those with temperatures less than 12°C were categorised as Cool; rivers with effective rainfall less than 500 mm per year were categorised as Dry, those with rainfall between 500 and 1500 mm were categorised as Wet, and the rivers exceeding 1500 mm categorised Extremely-Wet. These two sets of categories were then put together to produce six possible climate classes detailed in Table 2.3.

Table 2.3 The REC's six Climate categories along with notations and classification rules.

Climate category	Notation	Temperature	Eff. Rainfall
Warm-Extremely-Wet	WX	≥ 12°C	> 1500 mm
Warm-Wet	WW	≥ 12°C	500 – 1500 mm
Warm-Dry	WD	≥ 12°C	< 500 mm
Cool-Extremely-Wet	CX	< 12°C	> 1500 mm
Cool-Wet	CW	< 12°C	500 – 1500 mm
Cool-Dry	CD	< 12°C	< 500 mm

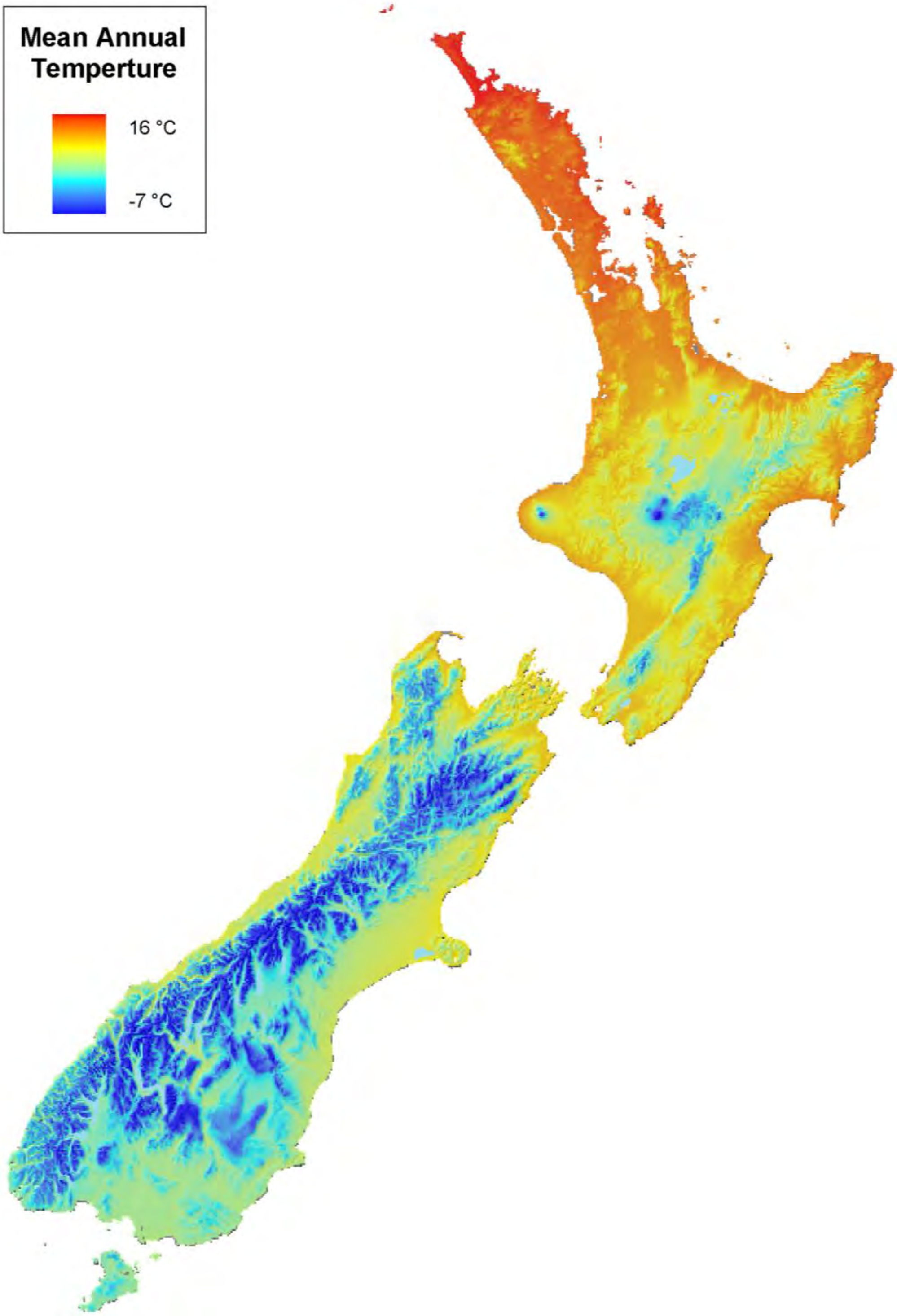


Figure 2.5 The mean annual temperature data set used for the Climate factor classification.

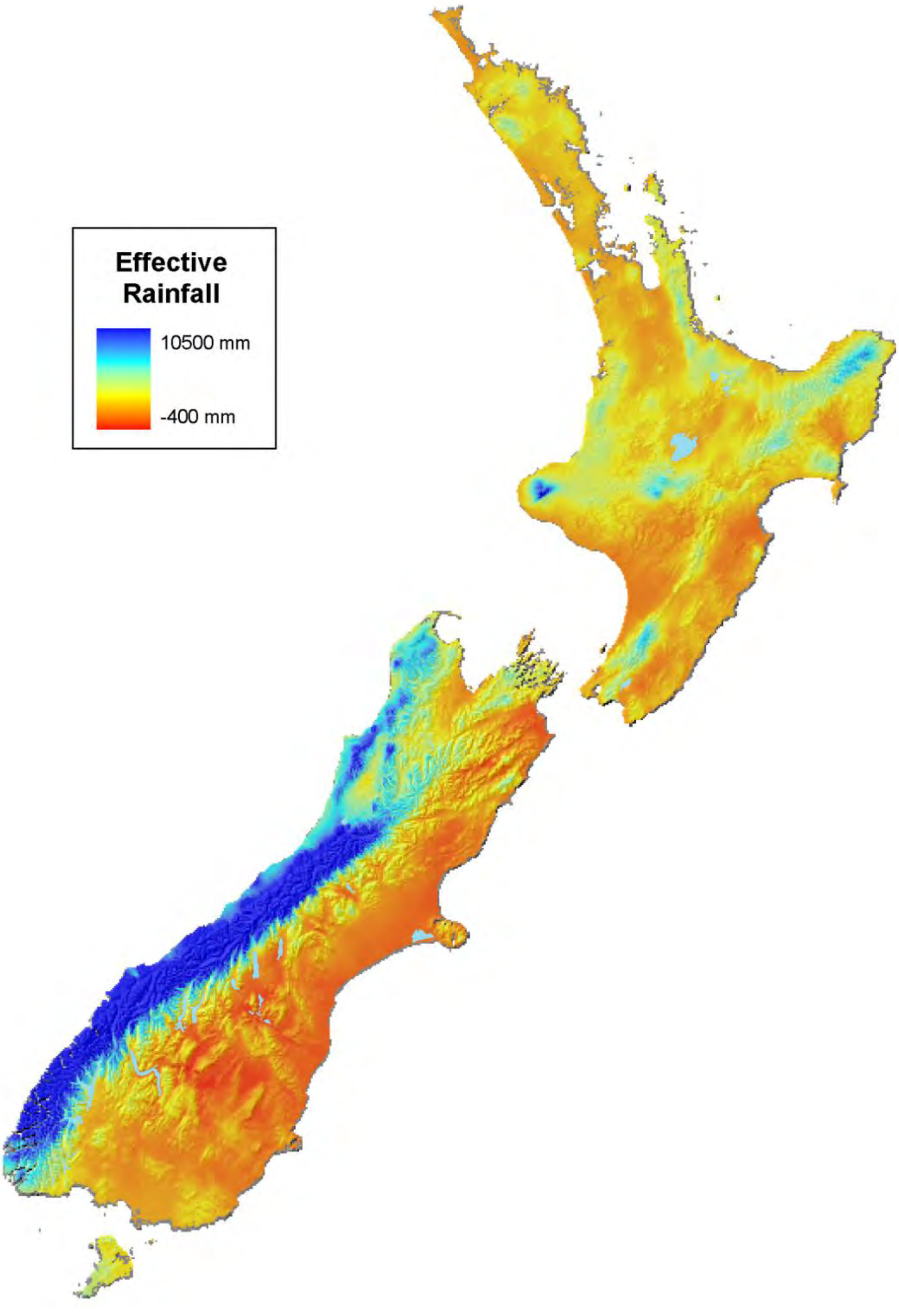


Figure 2.6 **The effective rainfall (rainfall minus potential evaporation) dataset used for the Climate factor classification.**

5.2 Source-of-Flow

The classification of the Source-of-Flow factor for each river section was based on two sets of information: an estimate of the distribution of rainfall within the upstream catchment and an estimate of the influence of lakes. The rainfall surface used for Source-of-Flow was different from the one used for Climate as the Source-of-Flow calculations were done much earlier in the REC project before the LENZ surfaces were available. However, both surfaces were based on the same climate station data. The major difference between the Source-of-Flow and Climate calculations is that for Source-of-Flow potential evaporation was not taken into account.

The rainfall surface was divided into elevation bands and for every river section the percentage of the total rainfall volume occurring in each band was calculated. The river sections were then classified by examining the elevation at which 50% of the cumulative rainfall fell (see Figure 2.7). If 50% fell at 400 m or lower, the river section was categorised as Low-Elevation, if the elevation was between 400 and 1000 m then the section was categorised as Hill and if it was greater than 1000 m then the river was categorised as Mountain.

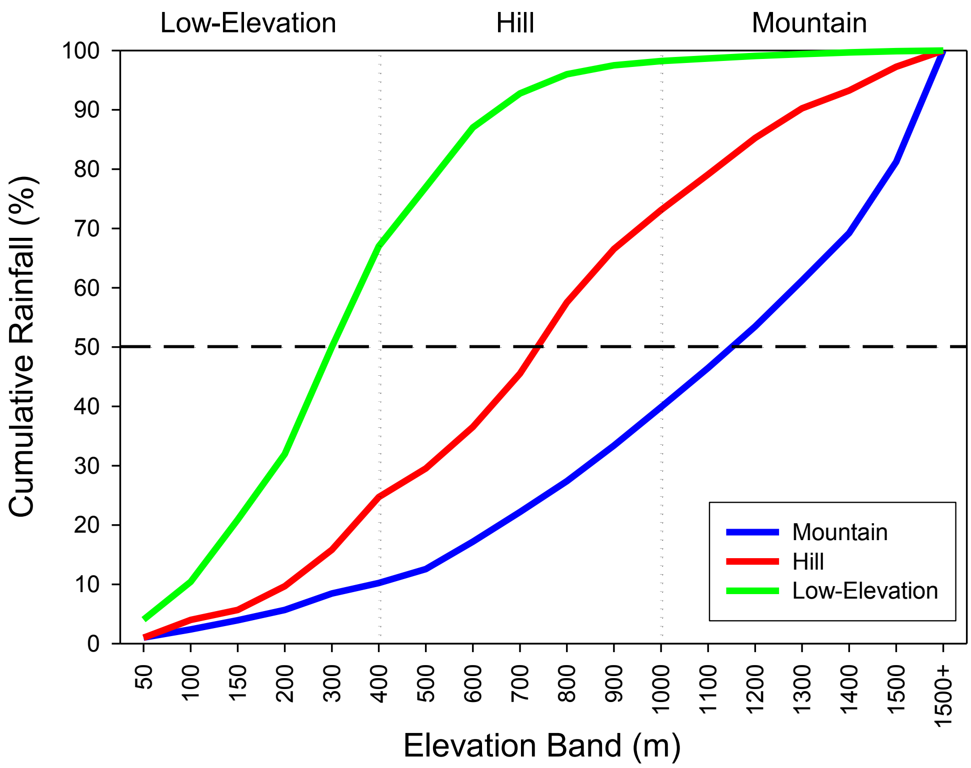


Figure 2.7 Rainfall accumulation curves for three example rivers.

If 50% of the rainfall fell below 400 m then the river was categorised as Low-Elevation (shown in green), if 50% fell between 400 and 1000 m then the river was categorised as Hill (in red), and if 50% fell over 1000 m elevation then the river was categorised as Mountain (blue).

After this initial classification two further steps were taken. For rivers that were Mountain an assessment was made of the percentage area of permanent ice in the catchment. If this value exceeded 1.5% then the category was changed to Glacial-

Mountain. The second step was to assess the influence of lakes. An index of lake influence was calculated taking into account both the size of the lake itself and volume of water passing through the lake in relation to the total volume coming from the catchment. The lake index was calculated as follows:

$$LI = \frac{\sum V_{LW} . \sum \frac{A_L}{A_{LW}}}{V_W}$$

where V_{LW} = the volume of annual rainfall in the catchment of each lake; A_L = the area of each lake; A_{LW} = the area of each lake's catchment, and V_W = the volume of annual rainfall in the upstream catchment. The lake index was calculated for every river section and where this index exceeded 0.033 the river section was categorised as Lake. The Source-of-Flow classification process is summarised in Figure 2.8.

In addition to the five automatically assigned classes, there are three classes that can be assigned manually; Spring, Wetland, and Regulated (Table 2.4). During the course of development of the REC a few regional councils provided information about spring fed streams in their region. Because this information was not always provided it was decided not to automatically create a Spring class, but to include an attribute called SpringFlag which contains the value '+Sp' if a river section was indicated as spring fed by the regional council.

Table 2.4 The eight REC Source-of-Flow categories along with notations and classification rules

Source-of-Flow Categories	Notation	Criteria
Glacial-Mountain	GM	50% rainfall > 1000 m, Ice > 1.5%
Mountain	M	50% rainfall > 1000 m, Ice ≤ 1.5%
Hill	H	50% rainfall 400 - 1000 m
Low-Elevation	L	50% rainfall < 400 m
Lake	Lk	Lake Index > 0.033
Spring	Sp	Manually set
Wetland	W	Manually set
Regulated	R	Manually set

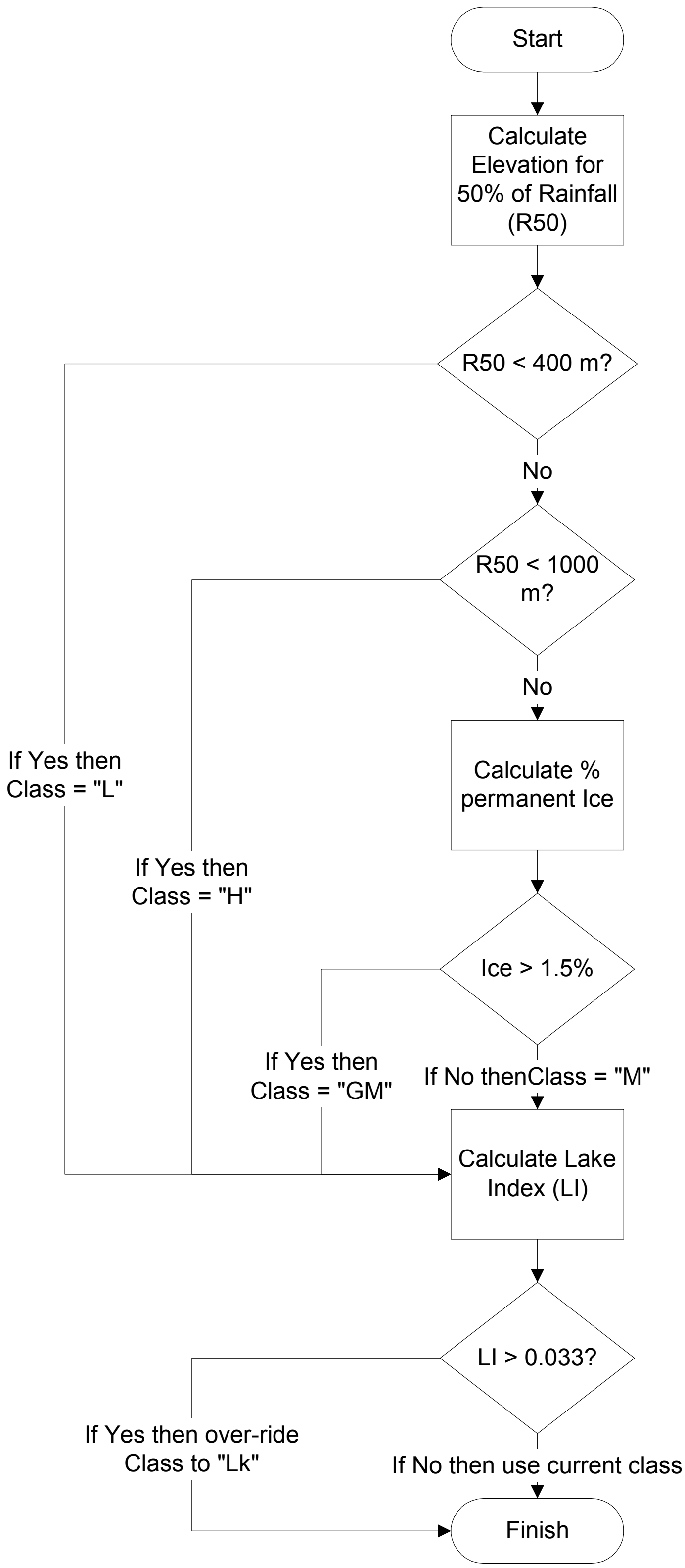


Figure 2.8 The decision tree for the Source-of-Flow classification.

5.3 Geology

The classification procedure for the Geology factor was based on an assessment of catchment rock type using the New Zealand Land Resource Inventory (LRI) database. The LRI contains two rock type attributes called TopRock and BaseRock with many rock types delineated.

LRI rock type categories were lumped into seven groups (see Table 2.5). The percentage area for each group was calculated for the upstream catchment of each river section. If the TopRock type was Alluvium, or Miscellaneous then the BaseRock type was used. If Soft-Sedimentary rock type exceeded 25% then the river section was categorised SS, otherwise the river section was classed according to the rock type that had the greatest extent. Figure 2.9 shows the simplified geology classes used in the procedure.

Table 2.5 The simplified Geology categories used for REC and the LRI rock types that were grouped into each category.

Geology Category	Notation	LRI Rock Types	
		North Island	South Island
Alluvium	Al	Wb, Gr, Al	Al, Wb
Hard-Sedimentary	HS	Ar, Ac, Gw	Ar, Gw, St1, St2, Ma
Miscellaneous	M	Lo, Pt	Lo, Pt
Plutonic	Pl	Gn	Gn, Gs
Soft-Sedimentary	SS	Us, Mm, Mb, Mj, Me, Sm, Sb, Cg, Li	Ms, Ss, Fy, Cw, Hs, Cg, Ls
Volcanic-Acidic	VA	Ng, Ta, Rm, Kt, Mo, Lp, Tp, Ft, La, Sc, Vo, Vu	
Volcanic-Basic	VB	Um	Tb, Vo, In, Um

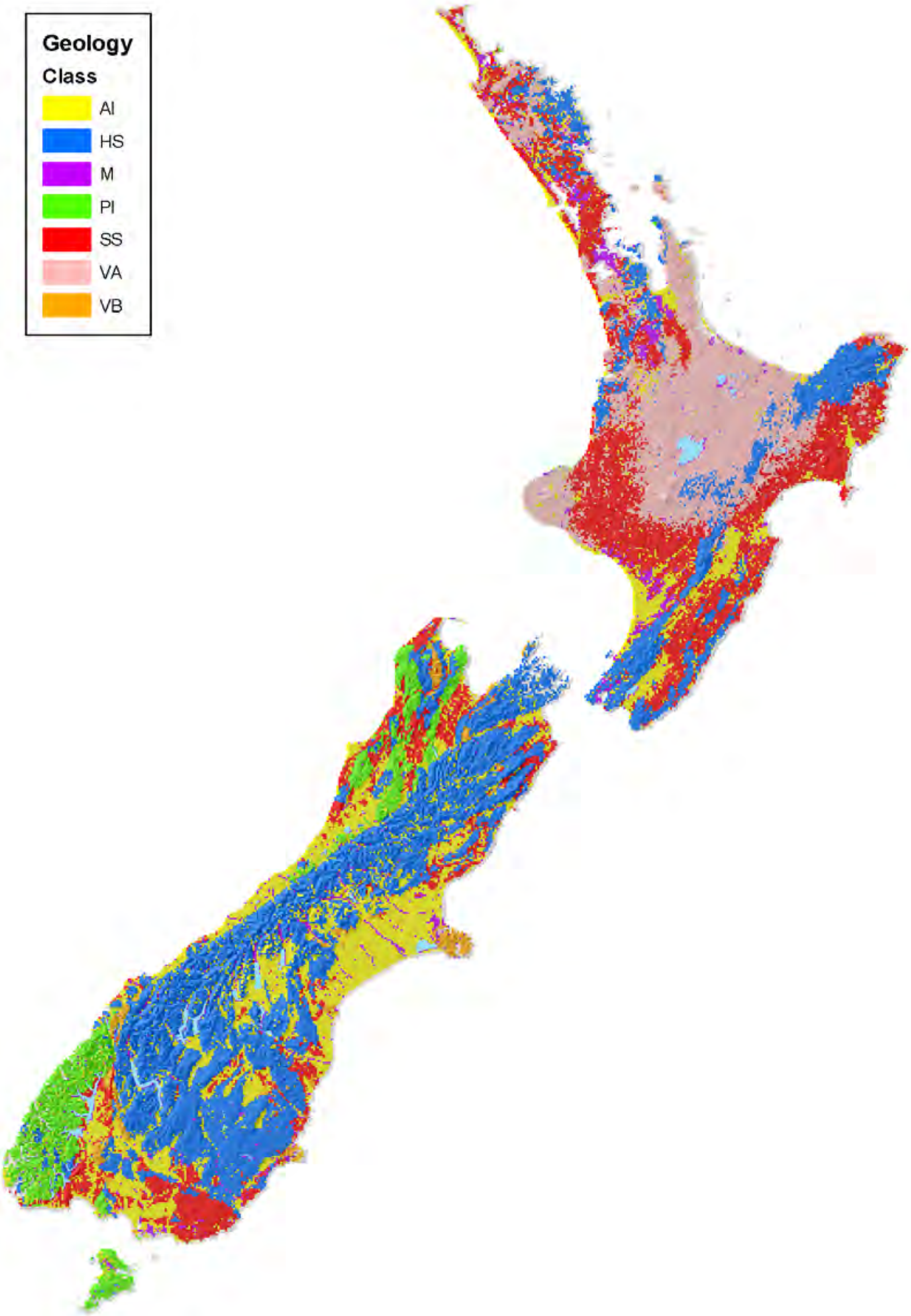


Figure 2.9 The simplified rock types used for the REC Geology classification.

5.4 Land-Cover

The Land-Cover classification was based on information derived from the New Zealand Land Cover Database (LCDB). The LCDB classes were simplified slightly by grouping similar LCDB types together (see Table 2.6). The percentage of each Land-Cover type for the upstream catchment of each river section was calculated. The Land-Cover type that was present in the greatest percentage was deemed to be the dominant land cover unless Pastoral exceeded 25% in which case the class was set to P or if Urban exceeded 15% in which case the class was set to U. If both Pastoral and Urban exceeded their respective thresholds then Urban was assumed to be the most dominant. Figure 2.10 shows the distribution of the simplified Land-Cover categories.

Table 2.6 The simplified Land-Cover categories used for REC and the associated LCDB classes.

Land-Cover Category	Notation	LCDB Types
Bare-Ground	B	Bare Ground
Indigenous-Forest	IF	Indigenous-Forest
Scrub	S	Scrub
Tussock	T	Tussock
Wetlands	W	Inland Wetlands, Coastal Wetlands
Exotic-Forest	EF	Planted Forest
Pastoral	P	Primarily Pastoral, Primarily Horticultural
Urban	U	Urban, Urban Open Space
Miscellaneous	M	Mangrove, Riparian Willows, Coastal Sands

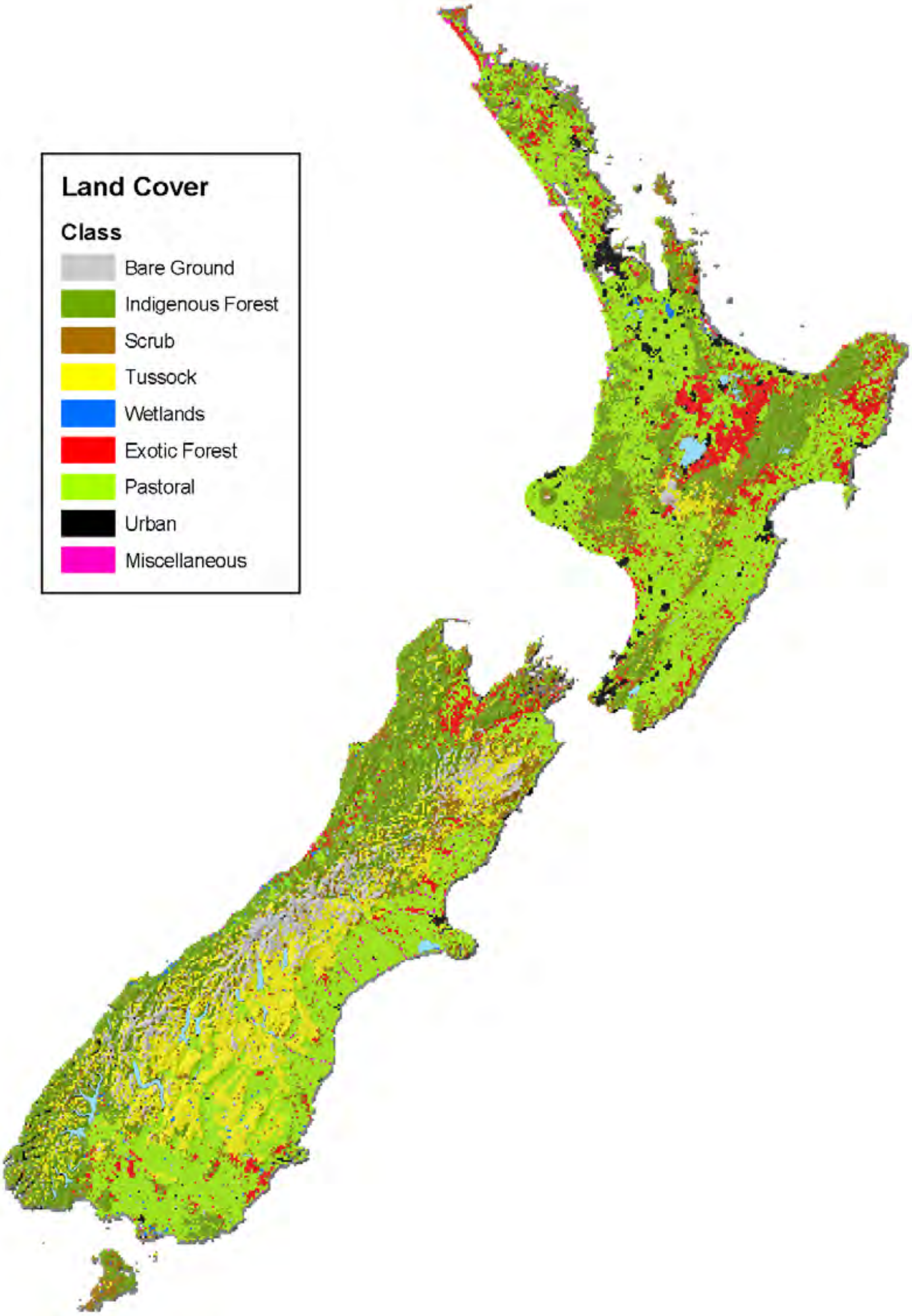


Figure 2.10 The simplified Land-Cover types used for the REC Land-Cover categories.

5.5 Network-Position

The Network-Position factor operates at the scale of the individual river section. The mapping characteristic we used was stream order, which was automatically calculated during the stream delineation process. River sections of order 1 or 2 were categorised Low-Order, those of order 3 or 4 were categorised Middle-Order, and those greater than order 4 were categorised High-Order (Table 2.7).

Table 2.7 Mapping characteristics of the REC Network-Position factor.

Network-Position Category	Notation	Stream Order
Low-Order	LO	1 or 2
Middle-Order	MO	3 or 4
High-Order	HO	> 4

5.6 Valley-Landform

The Valley-Landform factor operates at the individual river section scale. The mapping characteristic used for this factor was the slope of the valley the river section was flowing through. For each river section we extracted the elevation and spatial position of the upstream and downstream ends. The valley slope was calculated as the difference between the upstream and downstream elevations divided by the straight-line distance between the two ends. If the slope was less than 0.02 the section was categorised as Low-Gradient, if the slope was between 0.02 and 0.04 the category was Medium-Gradient and if slope was greater than 0.04 the category was High-Gradient (Table 2.8).

Table 2.8 Mapping characteristics used for the REC Valley-Landform factor.

Valley-Landform Category	Notation	Valley Slope
Low-Gradient	LG	< 0.02
Medium-Gradient	MG	0.02 – 0.04
High-Gradient	HG	> 0.04

PART III Case Studies

1 Case Study 1 – Use of the REC for state of environment reporting

1.1 Introduction

A powerful state of environment analysis is able to report spatial patterns in both state, relative to guidelines, and temporal trends. Because patterns are scale dependent, state of environment analysis should also characterise conditions at a variety of levels of detail and associated spatial scales. The River Environment Classification (REC) is a framework that assists detection of spatial patterns in water quality and biological variables at multiple scales. In this case study[14], the REC was used by the Ministry for the Environment to examine national patterns in water quality of rivers using a selection of water quality and biological variables collected at long term river monitoring sites. The objective of this study was to characterise patterns in water quality and biological indicators of the state of rivers in New Zealand at varying spatial scales. The Ministry contracted NIWA to carry out the study and to prepare a technical report. The results of the study are being used by the Ministry for environmental reporting.

1.2 Methods

1.2.1 Source of data

The analysis used long-term river water quality and biological data from two monitoring networks, National Rivers Water Quality Network (NRWQN), and the Environment Southland Water Quality Network (ESWQN). The NRWQN includes 77 sites, distributed throughout the North Island (44 sites) and South Island (33 sites), at which river flow and 12 other physico-chemical variables have been measured monthly since 1989. NRWQN sites were selected to reflect both baseline conditions (32 upstream sites) and impact conditions (45 downstream sites).

1.2.2 Management units

All of the NRWQN and ESWQN monitoring sites were classified into management units by assigning the REC Source-of-Flow, Geology and Land-Cover level classes for the section of river on which they are located. This process is carried out using GIS maps of the REC and geographic locations of all sites as described in Part II of this guide.

1.2.3 Analysis

To characterise the general or long-term state at a site, measures of the central tendency (means and medians) of each variable were calculated for all sampling

[14] MFE (2002a)

occasions within a specified time period. Box and whisker plots of these aggregated data were used to characterise the median state and the variation among sites within each REC class. See Box 1, Part I for an explanation of how to interpret box and whisker plots. Some classes are represented by a single site. In this case the data is shown on the box and whisker plots by a single square. The classification of the monitoring network provides insights into which classes may be under or over-represented and this could be a step in designing, or redesigning, a representative monitoring network.

1.3 Results

First the analysis considered the state of various Climate level classes. Water clarity (see Figure 3.1), soluble reactive phosphorus (SRP), soluble inorganic nitrogen (SIN) (see Part 1, Figure 1.5), total ammonia, 5-day biological oxygen demand (BOD_5) and *Escherichia coli* (*E. coli*) concentrations vary among the REC climatic classes with water quality tending to increase as rainfall increases. The biological variables showed a similar but less consistent relationship with climate. Macroinvertebrate Community Index (MCI) scores generally decreased as rainfall decreased (see Figure 3.2).

Classifying sites at the Source-of-Flow level of the REC further increased the discrimination of patterns in water quality and biological variables. Rivers with Dry Climate categories and Low-Elevation Source-of-Flow categories had lower clarity (see Figure 3.1) and higher concentrations of SIN, and *E. coli* in general than rivers with Wet and Extremely Wet climate categories and Hill and Mountain Source-of-Flow categories. MCI scores were generally higher in Mountain and Hill Source-of-Flow rivers than Low-Elevation Source-of-Flow categories (see Figure 3.2).

The Land-Cover level increased the discrimination further. Water quality (clarity and *E. coli*) was consistently poorer in classes with Pastoral Land-Cover categories (see Figures 3.3 and 3.4). Significant differences in water quality variables among Geology level REC classes are also apparent. Mean clarity was lower (Figure 3.3) at sites with a Cool-Dry Low-Elevation Soft-Sedimentary class (CD/L/SS) compared with sites with Hard-Sedimentary geology (CD/L/HS). This difference may be attributable to higher erosion and weathering rates associated with Soft-Sedimentary geology.

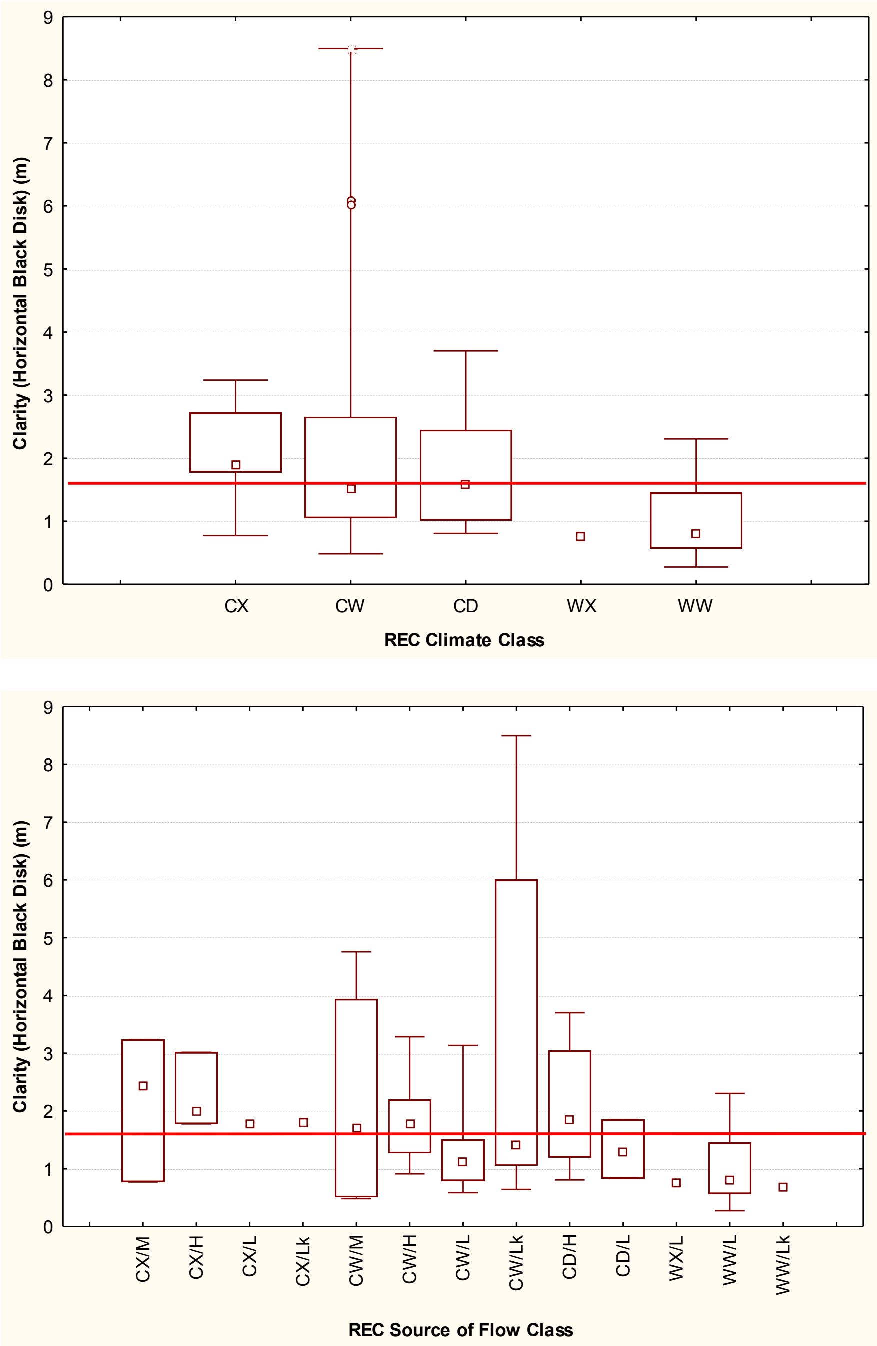


Figure 3.1 **Summary of analysis of mean monthly clarity of NRWQN sites classified by REC Climate and Source-of-Flow class.**

The red line is a clarity guideline for contact recreation[15]. (Source: MfE 2002a)

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[15] MFE (1994)

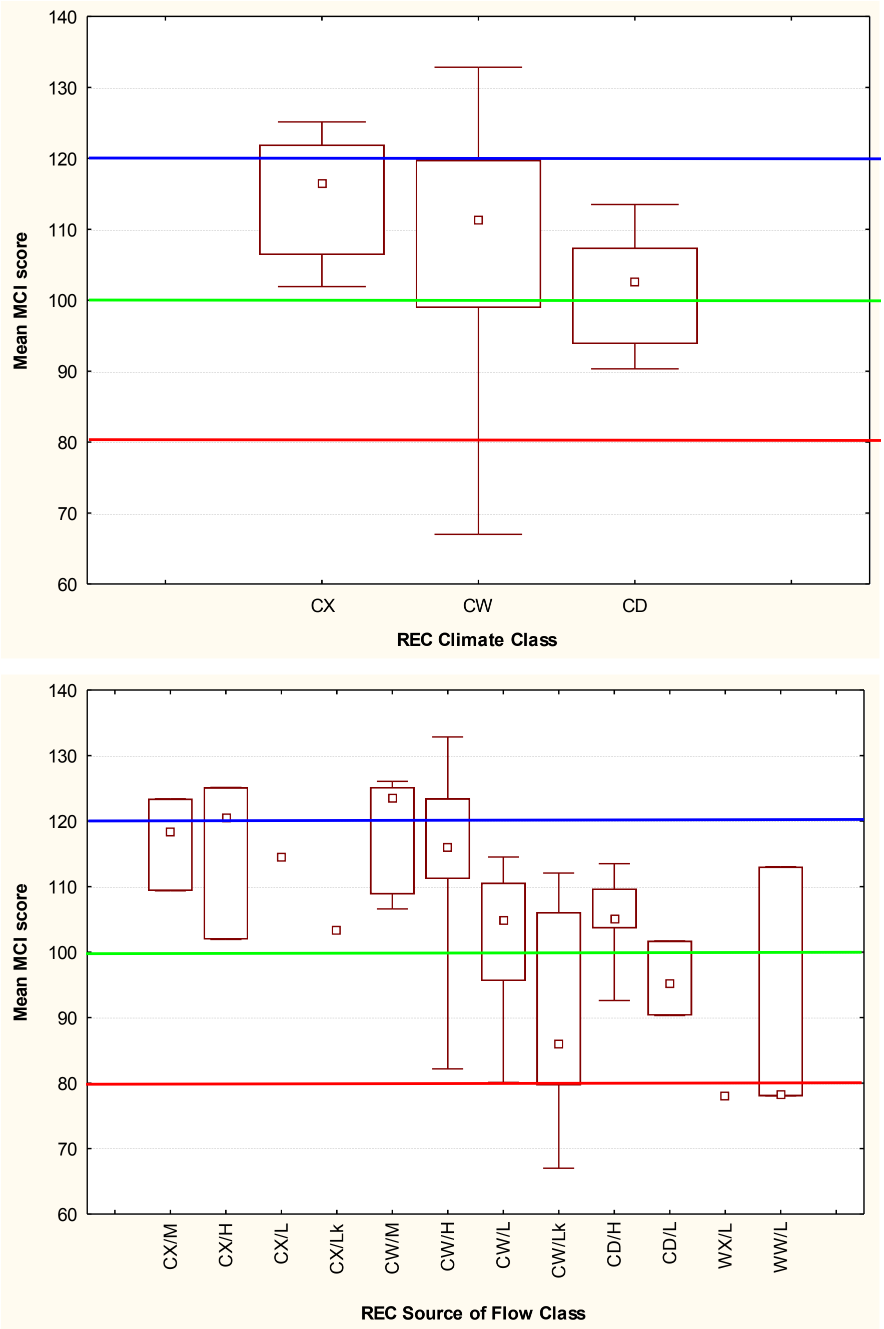

Figure 3.2 Mean MCI scores at 59 NRWQN sites grouped by REC Climate and Source-of-Flow classes.

The blue, green and red lines are indicative of low, medium and high pollution levels[16]. (Source: MfE 2002a)

[16] Stark (1998)

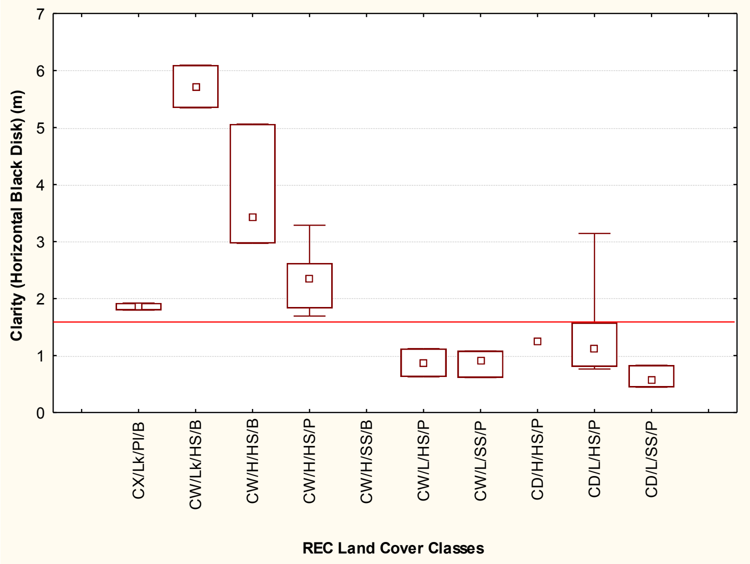

Figure 3.3 Mean monthly water clarity by REC Land-Cover class for selected Environment Southland water quality network sites.

The red line is the clarity guideline for contact recreation[17]. (Source: MfE 2002a)

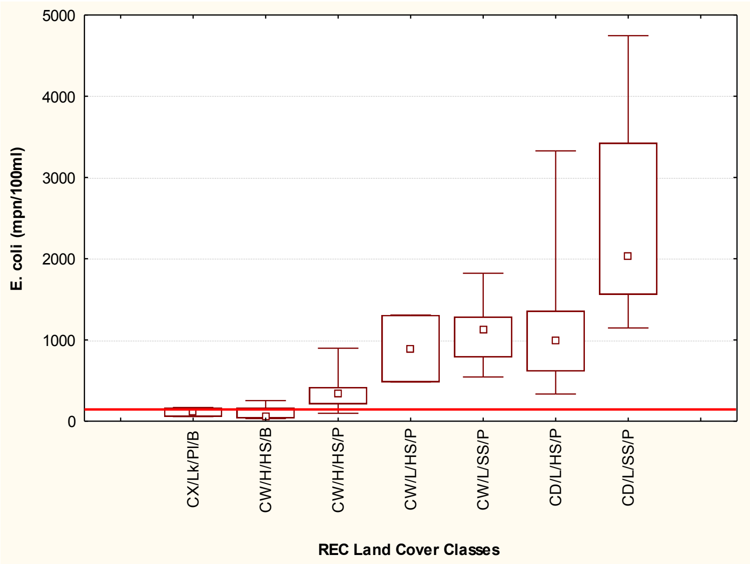

Figure 3.4 Concentration of *E. coli* from monthly samples measured at Environment Southland microbiological sites in the year period 2000/2001 and classified at the REC Land-Cover level.

The red line is the nominated guideline of 144 mpn/100ml for contact recreation[18]. (Source: MfE 2002a)

[17] MFE (1994)

[18] MFE (2002a)

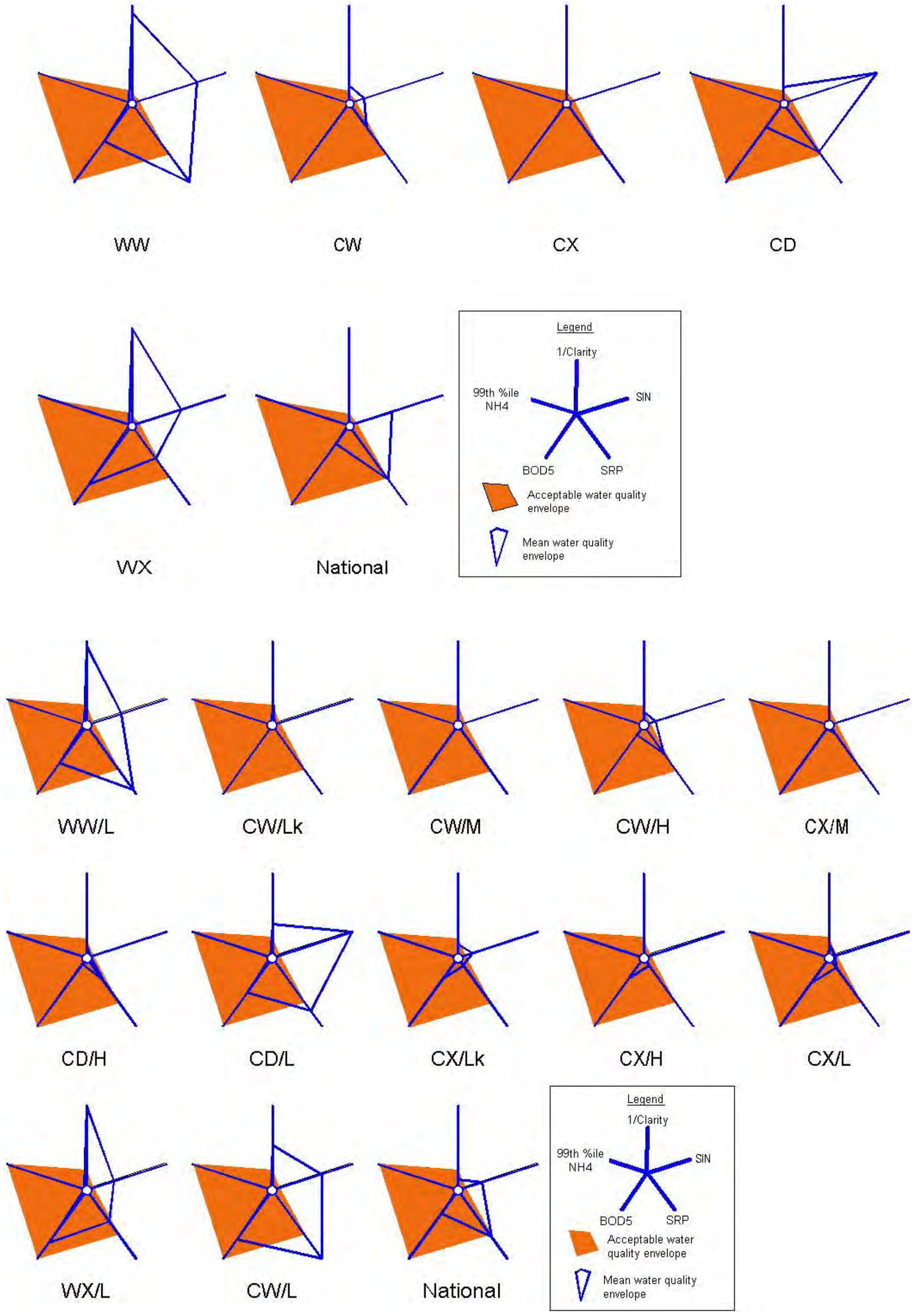

Figure 3.5 **Sunray diagrams for water quality for the period 1995-2001 based on monthly samples from 69 NRWQN sites. Sites have been classified at the REC Climate (5 classes) and Source-of-Flow (12 classes) levels. (Source: MfE 2002a)**

Sun ray diagrams were used to summarise national water quality patterns for five water quality variables at two scales. Data from 69 NRWQN sites was aggregated by REC classes at the Climate and Source-of-Flow levels. The median of clarity, SIN, SRP, BOD_5 was used to represent water quality in each class. The 99^{th} percentile of Total Ammonia was used because the guideline is based on acute toxicity. The diagrams (Figure 3.5) were constructed by calculating the mean value of the five water quality variables for all monthly samples in the period 1995 to 2001 for each site. The means for each site are then aggregated by class and the median of these variables is then plotted on one of five Rays. The reciprocal of clarity was used so that the relative plotting position is the same as for the other variable (i.e. the number increases as water quality decreases). Blue lines linking the plotted positions form a polygon which allows the relative water quality among classes to be compared.

Various guidelines[19] for each water quality variable have also been plotted on each ray. Joining these points provides an acceptable water quality envelope (the orange polygon). When a class complies with all guidelines, the actual mean state (blue) polygon lies entirely within the red polygon. Exceedence of guidelines is seen as the actual mean state protruding from the acceptable water quality envelope. The information shown on the sunray diagrams has also been interpolated to all rivers that share a similar class (Figure 3.6). The map indicates the extent of classes that characteristically comply with, or exceed, the guidelines and should not be interpreted as a prediction of water quality in any particular river.

[19] see MFE (2002a) for a discussion

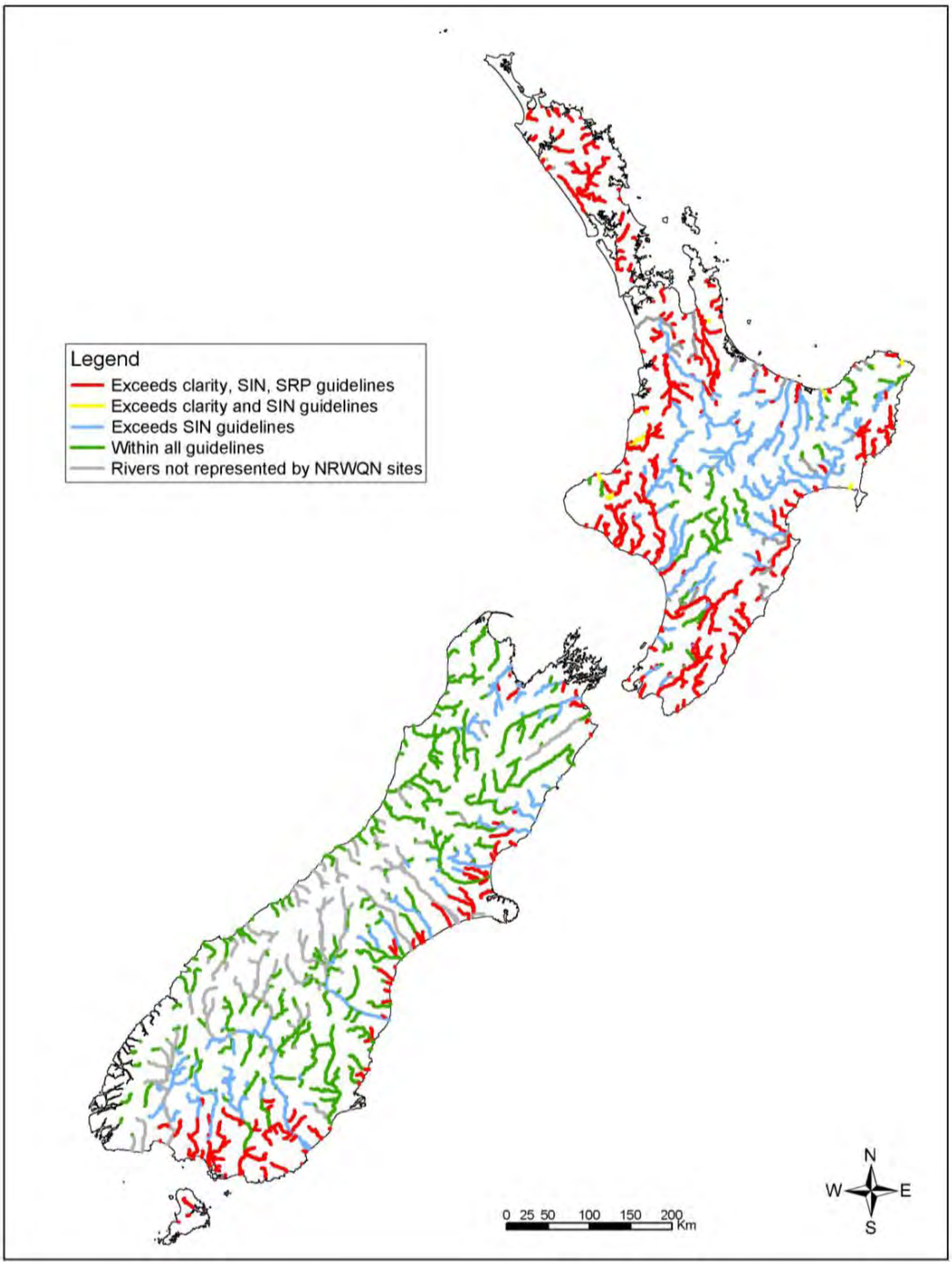

Figure 3.6 **Characteristic patterns in the quality of large New Zealand rivers for the period 1995 to 2001, based on a synthesis of NRWQN data aggregated by REC Source-of-Flow class.**

2 Case Study 2 – Assessment of eutrophication and development of nutrient criteria

2.1 Introduction

This case study considers the issue of eutrophication – the increase in nutrients (nitrogen and phosphorus) and consequent increased plant biomass in the rivers of the Canterbury region[20]. Canterbury's rivers support many environmental values, including biological and recreational resources as well as providing a resource for diluting, assimilating and transporting excess nutrients. The region's rivers are potentially nutrient enriched due principally to non-point sources from intensification of pastoral land use.

Some increase in nutrients in rivers can increase productivity. Nutrient enrichment, however, may become an issue when it results in an unacceptable level of plant biomass in a river ecosystem. Plant biomass in rivers takes two forms; periphyton (algae growing on cobbles and gravel in riverbeds) and macrophytes (rooted plants that grow in rivers with fine silt or sand substrates). High plant biomass affects the values of rivers in several ways, including causing large fluctuations in dissolved oxygen and pH due to plant photosynthesis and respiration; smothering of invertebrate habitat; and reduced food for fish. Increased algae, particularly algae growing on the substrates of gravel and cobble bed rivers (periphyton) is an issue in Canterbury. Algal biomass can exceed levels that are sustainable for healthy ecosystems and can also have undesirable effects for aesthetics and recreational activities (see Biggs 2000). Establishing plant biomass limits and nutrient concentration criteria is, therefore, a regional management issue.

2.2 Management units and values

The definition of management units for Canterbury is discussed in Part I, Section 9. For this case study only fish species are considered as values, although in a full assessment all other values would need to be considered. The valued fish communities in each of Canterbury's management units were identified by expert knowledge (see Part I, Section 8) and are listed in Table 3.1.

The most sensitive value to eutrophication in each management unit was nominally used as a basis for setting criteria. Salmon and rainbow trout are confined to Alpine Sourced rivers and are highly valued as recreational fish species. The Hill Country Sourced and Lowland Sourced rivers are valued as brown trout fisheries as well as being significant habitats of native fish species.

[20] This case study is based on Snelder et al. (2004b).

The banded kokopu, ranked by the Department of Conservation as a category C priority threatened species, is found almost exclusively in the Volcanic Rivers management unit in Canterbury whereas trout are not abundant in this management unit. The banded kokopu was, therefore, specifically identified as the most sensitive species.

2.3 Issue analysis

The original management units were further subdivided into issue-management-units to increase the resolution of the analysis. A simple model of the processes controlling algal biomass involves two processes: the supply of nutrients that stimulate growth, and the time between flood events which controls the maximum biomass that can accrue on the riverbed (see Biggs 2000 for a more detailed discussion). The frequency of floods is characterised by the Source-of-Flow level of the REC. Nutrient concentrations are better discriminated by the Land-Cover level of the REC (see Part I, Section 5). Thus, the Hill Country sourced rivers were subdivided into three issue management units: Hill Country Hard-Sedimentary Natural Land-Cover and Hill Country Hard-Sedimentary Pastoral Land-Cover and Hill Country Soft-Sedimentary. Because there was insufficient data to characterise the various classes, the Hill Country Soft-Sedimentary management units were not broken up by Land-Cover categories. The Alpine rivers are dominated by natural Land-Cover and a pragmatic decision to not further subdivide these management units was made because nutrient concentrations are unlikely to be better discriminated by further subdivision. The Lowland rivers are dominated by pastoral Land-Cover but two geological categories dominate: Hard-Sedimentary and Soft-Sedimentary. Thus, the Low-Elevation rivers were subdivided into two smaller management units. Lowland Hard-Sedimentary and Lowland Soft-Sedimentary.

At this point the characteristic values for the initial management units were reconsidered. The Soft-Sedimentary geology of the Hill Country and Lowland Soft-Sedimentary management unit does not provide suitable habitat for trout. Thus, the values for these smaller scale issue management units is exclusively native fish.

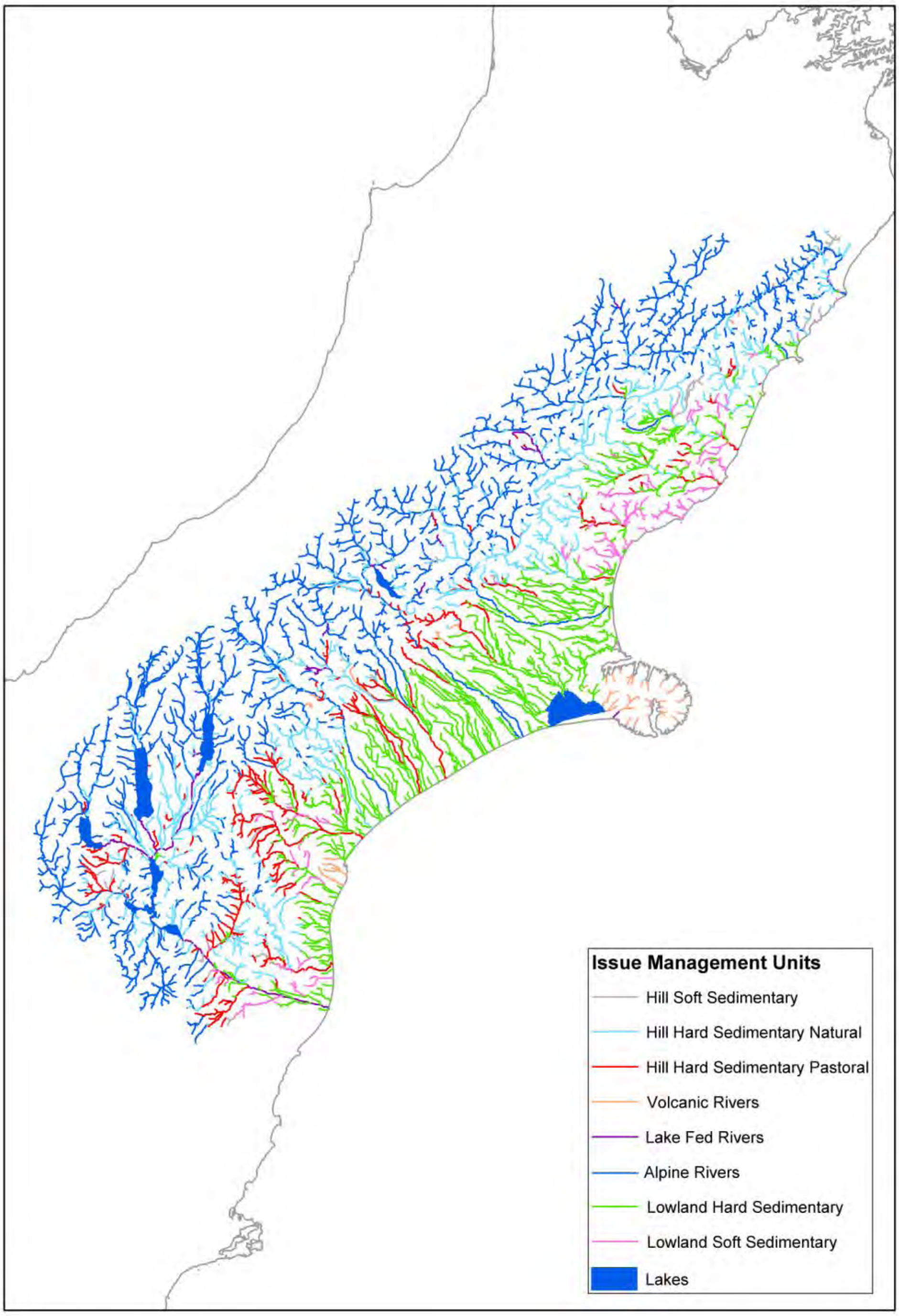

Figure 3.7 Map of water quality management units used for the assessment of eutrophication and derivation of nutrient criteria.

2.3.1 Derive options for trophic state

The term trophic state is used to describe a range of environmental criteria for plant biomass. Biggs (2000) uses periphyton biomass to represent three trophic states: oligotrophic, mesotrophic and eutrophic. The oligotrophic state is defined as maximum monthly periphyton biomass lower than 60 mg/m^2 of chlorophyll a (chl*a*). This trophic state is a low plant biomass associated with very high water quality and ‘clean’ substrates. An oligotrophic state provides a high level of protection for the most sensitive ecosystem values. The mesotrophic state is defined as a maximum periphyton biomass of between 60 mg/m^2 and 200 mg/m^2 chl*a*. The mesotrophic ecosystem has an appreciable periphyton biomass and produces water quality that provides a medium level of protection for ecosystem values. The eutrophic ecosystem has a maximum periphyton biomass of greater than 200 mg/m^2 chl*a*. The eutrophic ecosystem has high plant biomass and has relatively degraded water quality, providing a low level of protection for ecosystem values.

The trophic states define a graduated range of levels of protection that provide options for environmental objectives. Table 3.1 proposes a set of trophic states for the management units. The trophic states for each management unit are sensible given the sensitivity of the selected fish species of each management unit to water quality impacts. It should be borne in mind, however, that the levels of protection implied by the trophic states are ultimately political decisions.

Table 3.1 Fish species most sensitive to effects of eutrophication and proposed trophic states for each management unit.

Management unit	Most sensitive fish species	Proposed trophic state
Alpine Sourced rivers	Salmonids	Oligotrophic
Hill Country Hard-Sedimentary Natural rivers	Natives and Brown Trout	Mesotrophic
Hill Country Hard-Sedimentary Pastoral rivers	Native fish and Brown Trout	Mesotrophic
Hill Country Soft-Sedimentary Pastoral rivers	Native fish	Mesotrophic
Lowland Soft-Sedimentary rivers	Native fish	Mesotrophic
Lowland Hard-Sedimentary rivers	Native fish and Brown Trout	Mesotrophic
Volcanic rivers	Native fish	Mesotrophic

2.4 Assess the severity and extent

The severity of the eutrophication issue is now assessed by comparing the actual trophic state in each management unit with the trophic states proposed in Table 3.1. The most direct method would be to compare measured periphyton biomass with the proposed trophic states. This type of data was not available, however, the regional council had measured nutrient concentrations in many rivers and this data was used in the assessment.

Biggs (2000) provides mean monthly nutrient concentration criteria for the two main periphyton nutrients, soluble reactive phosphorus (SRP) and soluble inorganic nitrogen (SIN), which will retain river ecosystems in each of the three trophic states. Where nutrient concentration criteria are exceeded the relevant trophic state threshold may be breached from time to time. It should also be recognised that other factors such as light, substrate availability and the presence of invertebrate grazers may limit biomass. These nutrient criteria take into account different flood frequencies which alter the time available for growth. To derive the criteria for Canterbury's management units the time available for growth was estimated by examining hydrological records for the frequency of floods using the flow statistic FRE3 (see Biggs 2000). The value of FRE3 was calculated from hydrological data that was available for a number of sites in each management unit. The median value of FRE3 in each management unit was used to characterise the time available for growth (see Table 3.2).

Table 3.2 Definition of nutrient criteria to achieve trophic states (from Biggs 2000)

	Management units					
	Lowland source drivers		Foothills sourced rivers		Alpine sourced rivers	
Average time available for growth (days)	70		25		14	
Trophic threshold	Mesotrophic	Oligotrophic	Mesotrophic	Oligotrophic	Mesotrophic	Oligotrophic
Maximum periphyton biomass (mg m^{-2} chl*a*)	200	60	200	60	200	60
Mean monthly SRP criteria (g m^{-3})	0.0009	Not achievable	0.019	0.002	0.06	0.018
Mean monthly SIN criteria (g m^{-3})	0.009	Not achievable	0.190	0.02	0.6	0.18

Environment Canterbury's water quality database was used to characterise the existing nutrient concentration for each management unit from monthly data using the methods discussed in Case Study 1. Note that some management units had insufficient data to be adequately characterised and have been omitted from this part of the analysis. This result in itself is useful because it points to a possible need for more monitoring. The nutrient concentration for each management unit was compared with the water quality criteria by plotting the range in mean monthly SIN and SRP on a box and whisker plot and overlaying the criteria for each management unit as shown on Table 3.2 (Figure 3.8).

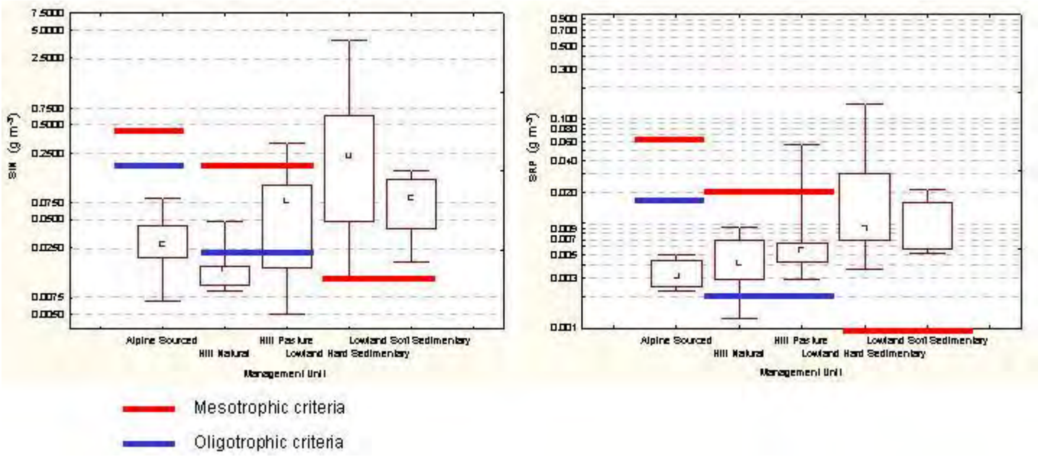

Figure 3.8 **Box and whisker plots for soluble inorganic nitrogen and dissolved reactive phosphorus data for management units for Canterbury rivers and compared to nutrient criteria to meet the proposed trophic state.**

For simplicity, the state of each management unit was compared with the single trophic state proposed in Table 3.1. The regions on the graphs show the potential trophic state based on the nutrient concentration criteria shown in Table 3.2. Below the blue line indicates an oligotrophic state, between the blue and red lines indicates a mesotrophic state, above the red line indicates a eutrophic state. Because the nutrients nitrogen and phosphorus are required for plant growth, concentrations for each nutrient must be within a region for the ecosystem to potentially achieve that trophic state. Where both nitrogen and phosphorus exceed the nutrient concentration criteria, there is potential for algal biomass to exceed biomass corresponding to the relevant trophic state, at least occasionally. Where one nutrient concentration exceeds the criteria and the other does not, the ecosystem is susceptible to increases in the non-exceeding nutrient. Thus, the Alpine Sourced rivers are all well within the oligotrophic state. The Hill Hard-Sedimentary Natural rivers are all within the nutrient criteria to achieve a mesotrophic state. However, some Hill Hard-Sedimentary Pastoral rivers show exceedance of the nutrient criteria for a mesotrophic state criteria, particularly for nitrogen where the median concentration for SIN is close to the nutrient criteria. These rivers are therefore potentially phosphorus limited, that is additional phosphorus could lead to a eutrophic state. The Lowland rivers all dramatically exceed the water quality criteria, indicating these rivers are potentially eutrophic.

A representation of the potential extent of the river eutrophication issue in Canterbury is shown in Figure 3.9 below. The map represents the general trophic state by characterising each management unit by its median nutrient concentration relative to the criteria. Note that the potential trophic state is determined by the limiting nutrient. Thus, although SRP for Hill Hard-Sedimentary Natural exceeds oligotrophic/mesotrophic criteria, SIN is below this and therefore the management unit is characterised as oligotrophic.

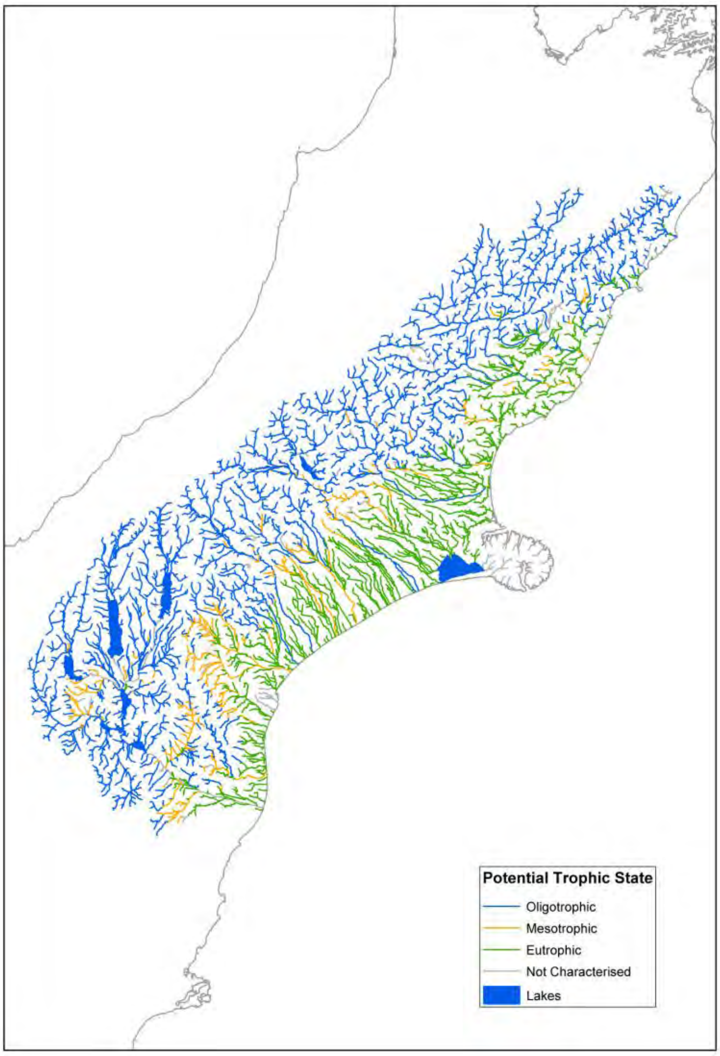

Figure 3.9 Characteristic trophic state of rivers in Canterbury based on the median nutrient concentration of each of the management units.

(see Figure 3.8) and nutrient criteria (see Table 3.2).

2.5 Developing objectives and policies for nutrient management

The analysis could be used to derive policy options, for example. Examples of options for objectives and policies for four of the most contrasting management units are outlined below. The objectives are based on the single set of trophic states proposed in Table 3.2. The objectives and differences in time available for growth of each management unit mean that policies vary for each management unit. For example, in the Lowland rivers policies seek to achieve the objectives by mitigating the effects of high nutrient levels by shading to reduce plant biomass growth. However, this policy is not appropriate in the Hill rivers management units where frequent floods and high sediment loads result in wide channels that cannot be shaded effectively. In the Hill Country rivers management unit policies focus on avoiding the discharge of nutrients at levels that will stimulate excessive plant growth from point and non-point sources.

Issue Management Unit - Alpine rivers

Options for plan provisions		Explanation
Valued fish species	Salmon, rainbow trout, native species	
Most sensitive fish	Salmonids	
Objectives	**Option 1.**: Oligotrophic state (defined by a maximum periphyton biomass of 60 mg m^{-2} chl*a*)	This state provides water quality to support salmon at a high level of protection. Existing nutrient concentrations are well within the criteria required to maintain this trophic state. This objective allows for increases in nutrient discharges so long as the oligotrophic threshold is not breached.
	Option 2: Natural state	The existing state of the mountain management units is well above the oligotrophic threshold. It may be unacceptable to allow an increase in nutrients up to the oligotrophic/mesotrophic *threshold,* as this is a degradation of the existing ('natural state') water quality conditions. A 'natural state' objective would allow no change to the existing water quality
	Option 3.: Nominated periphyton biomass selected between existing natural state levels and the oligotrophic threshold.	This represents an intermediate option between the reasonably restrictive option of maintaining the natural state and the more permissive option of allowing degradation down to the oligotrophic/ mesotrophic threshold. Depending on the nominated environmental state, this option could maintain a high quality environment while being more permissive of discharges than Option 2.
Policies	**For Objective Options 1 & 3**: Control point-source discharges to ensure specified water quality (nutrient concentration) criteria are not exceeded. Criteria to achieve option 1 are: DRP = 18 mg m^{-3} SN = 180 mg m^{-3}	Current land uses are not having a significant adverse effect on nutrient levels in mountain rivers. Point source discharges are the most likely cause of nutrient transgressions. Plant growth in mountain rivers can only be restricted by limiting nutrient concentrations. This option would allow some discharge of nutrients provided that specified nutrient concentrations were not exceeded.
	For Objective Option 2: Allow no change in water quality	This policy allows only minor discharges, the effects of which should not be able to be measured downstream of a specified mixing zone.

2 Issue management unit – Hill Hard-Sedimentary Natural rivers

Options for plan provisions		Explanation
Valued fish species	Brown trout, native species	
Most sensitive fish	Brown trout	
Objective	Mesotrophic state (defined by a maximum periphyton biomass of 200 mg m^{-2} chla)	The Hill Country Natural management unit currently meets the mesotrophic criteria. Some exceedance of the nitrogen criteria occurs meaning the management unit is sensitive to increases in phosphorus. This objective would allow some discharge of nutrients and land use change provided that nutrient concentration criteria were met.
Policies	Achieve Objective by using water quality (nutrient concentration) criteria to limit plant growth. DRP = 2 (mg m^{-3}) SN = 20 (mg m^{-3}).	Hill Country rivers tend to have wide channels that are typified by wide gravel – cobble channels that provide ideal substrate for algal proliferation. This means that the low flow channel cannot be shaded by riparian vegetation. To continue to achieve the desired environmental state, nutrient concentration must be managed to limit plant growth. Policies therefore focus on achieving nutrient criteria in relation to existing and future point source discharges, particularly phosphorus. To continue to achieve the desired environmental state, existing and future point and non-point source discharges, particularly phosphorus, would be carefully managed to meet nutrient criteria. Options could retain objectives by prohibiting point source discharges and land use change.

Options for plan provisions		Explanation
Valued fish species	Brown trout, native species	
Most sensitive fish	Brown trout	
Objective	Mesotrophic state (defined by a maximum periphyton biomass of 200 mg m^{-2} chla)	Concentrations of phosphorus are generally well below the nutrient criteria required to meet the threshold for a mesotrophic state. The nitrogen criteria, however, is close to being exceeded in some rivers. Phosphorus is, therefore, the limiting nutrient and excessive algal growth is generally avoided. Note that algal proliferations do occur in some rivers from time to time verifying some exceedences of the nitrogen and phosphorus criteria (see Figure 3.5)
Policies	Control point, and possibly non-point, discharges (particularly of phosphorus), to ensure specified water quality (nutrient concentration) criteria are not exceeded. DRP = 2 mg m^{-3} SN = 20 mg m^{-3}	Plant growth in Hill Country rivers cannot generally be restricted by shading the low flow channel as these rivers tend to have wide channels and are typified by gravel–cobble channels that provide ideal substrate for algal proliferation. Objectives can therefore only be achieved by limiting nutrient concentrations. Applications for discharge consents will require tight controls, especially of phosphorus. Consideration should be given to limiting land use change / management practices (such as fertiliser application rates/ timing, pastoral intensification) to ensure nutrient criteria are not breached. At the least, the consequences of land use changes should be monitored to determine the need for further management attention.

Options for plan provisions		Explanation
Valued fish species	Native species	
Most sensitive fish	Native species	
Objective	Option 1: Improve water quality to achieve a mesotrophic state (defined by a maximum periphyton biomass of 200 mg m^{-2} chla)	Nutrient criteria are severely exceeded. It will be difficult to manage land use to control non-point sources of nutrients to levels required to meet the objective of a mesotrophic state. The infrequency of floods in this management unit means that even very low nutrient concentrations could potentially promote excessive plant growth.
	Option 2: Retain the existing eutrophic state	Accept the currently degraded environmental state and lower the level of protection for values, but do not allow this to worsen.
Policies	For Objective Option 1: Seek to limit plant biomass by shading.	The most effective way to limit plant biomass is likely to be through the use of riparian vegetation to shade streams where excessive plant growth is occurring. The narrow entrenched streams that characterise the morphology in this management unit make shading the stream channel a viable option. Channels are narrow compared to depth allowing trees to grow to the water edge. Riparian zones may be able to be relatively narrow as sufficient foliage to shade the stream channel is all that is required.
	For Objective Option 2:	In order to merely retain the existing state, further increase in nutrient concentrations would need to be avoided. Actions could include prohibiting further point source discharges and/or limiting land use intensification and/or tightening conditions on existing discharge consents.

2.6 Conclusion

The key feature of the analysis is the definition of specific criteria including environmental objectives, (trophic states) and nutrient concentration criteria that are specific to different river environments. The specificity of the analysis means that the criteria would provide a more precise focus for management. Under the proposed criteria, discharge consents could be managed to achieve a consistent and specific environmental objective and nutrient concentration criteria provide a basis for monitoring and state of the environment reporting.

3 Case Study 3 – Assessment for Water Quantity Management

3.1 Introduction

This case study uses the REC to define water allocation management regimes with a focus on water supply for irrigation[21]. The case study demonstrates how the REC can make better use of available data and produce an assessment that provides greater information concerning both environmental values and resource use.

A water allocation management regime sets a minimum flow and total allocation (the total allowable sum of all takes from a river) for a river. The details of an allocation regime have implications for instream values (i.e. the level of protection both in terms of instantaneous minimum flow and the characteristics of the residual flow) and the reliability of supply for water users. Setting allocation regimes for management units provides a framework for issuing individual water use consents. Importantly, the methodology described here enables the effects of the allocation management regimes on both instream values and reliability of supply to be understood in advance. This allows for more transparent decision-making and better management of cumulative effects of allocation on both environmental values and existing water users.

There were two specific objectives of this study. First the study determines whether significant differences in water allocation management regimes are appropriate among different management units. Second, the study determines if application of a consistent water allocation management regime for all rivers within a management unit results in consistent implications for water reliability and residual flows within that management unit.

The analyses carried out in this case study involve a number of assumptions that are essentially policy options. These options would require scrutiny by affected parties and a political decision making process, such as that used to prepare a regional plan, to ratify them. The assessment made specific choices for: management objectives, minimum flow setting method, water demand over the irrigation season, and supply reliability criteria in order to produce one set of water allocation management regimes for the management units.

3.2 Management units and values

The same management units as Case Study 2 were adopted. Although a full evaluation of values was not conducted, recreation and natural character values were included. In particular, braided channels are identified as a particular natural character value in the Alpine Sourced rivers management unit.

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[21] Adapted from MFE (2001a)

3.3 Issue analysis

Water abstraction from rivers affects in-stream values through a variety of mechanisms that are detailed in Flow Guidelines for Instream Values[22]. Minimum flows are a commonly used regulatory mechanism that seeks to retain sufficient water instream to support environmental values. Minimum flows are environmental criteria and in this case study are developed using the same rationale as the trophic state environmental criteria in Case Study 2.

The choice of minimum flow has implications for the reliability of the water resource for abstractors; the higher the minimum flow the more frequently abstraction is restricted and the less reliable the resource will be. Another important regulatory mechanism is the total allocation. This is a rate (i.e. litres or m^3 per second) which is equal to the sum of all individual allowable takes from a river. For any given minimum flow the higher the total allocation the greater probability of being restricted. As a consequence, as more users are granted consents to take water the existing users have their reliability reduced. Ideally, therefore, minimum flows and total allocation are determined in advance so that the effects of both these regulatory mechanisms can be determined on instream and out-of-stream values.

A regional plan is the ideal framework for establishing minimum flows and total allocation. A plan can provide a management framework that guides future consenting of takes while establishing how the cumulative effect of these consents will be managed. Ideally the minimum flows and total allocation are set by considering and assessing how these interact with the natural flow regime of the river and influence both the residual flow supporting the instream values and the reliability of supply. This type of assessment is complex because natural flow regimes are very variable and can only be characterised by statistical analysis of actual flow records. A regional assessment of minimum flows and total allocation becomes even more difficult because there is generally only flow information for a number of sites. Figure 3.10 shows the selection of flow sites in Canterbury for which long-term natural flow records were available.

The assessment first developed management units. The assumption was made that the geology level of the REC provides good discrimination of rivers on the basis of natural flow regime because the processes of precipitation, catchment storage and release of water are reasonably well described at this level of the REC. This results in a similar set of management units as used by Case Study 2. However, the Alpine Sourced rivers were subdivided into the constituent REC Source-of-Flow categories; Glacial-Mountain and Mountain. The Glacial-Mountain class was considered an important distinction because rivers in this class have the most sustained high flows during summer due to snow melt and thus, are the most reliable source of irrigation water. This analysis was carried out prior to implementing the Climate level of the

[22] MFE (1998c)

REC. Thus, the Geology level classes are based only on topographic and geologic categories. Better results may have been achieved had climate been included in the analysis.

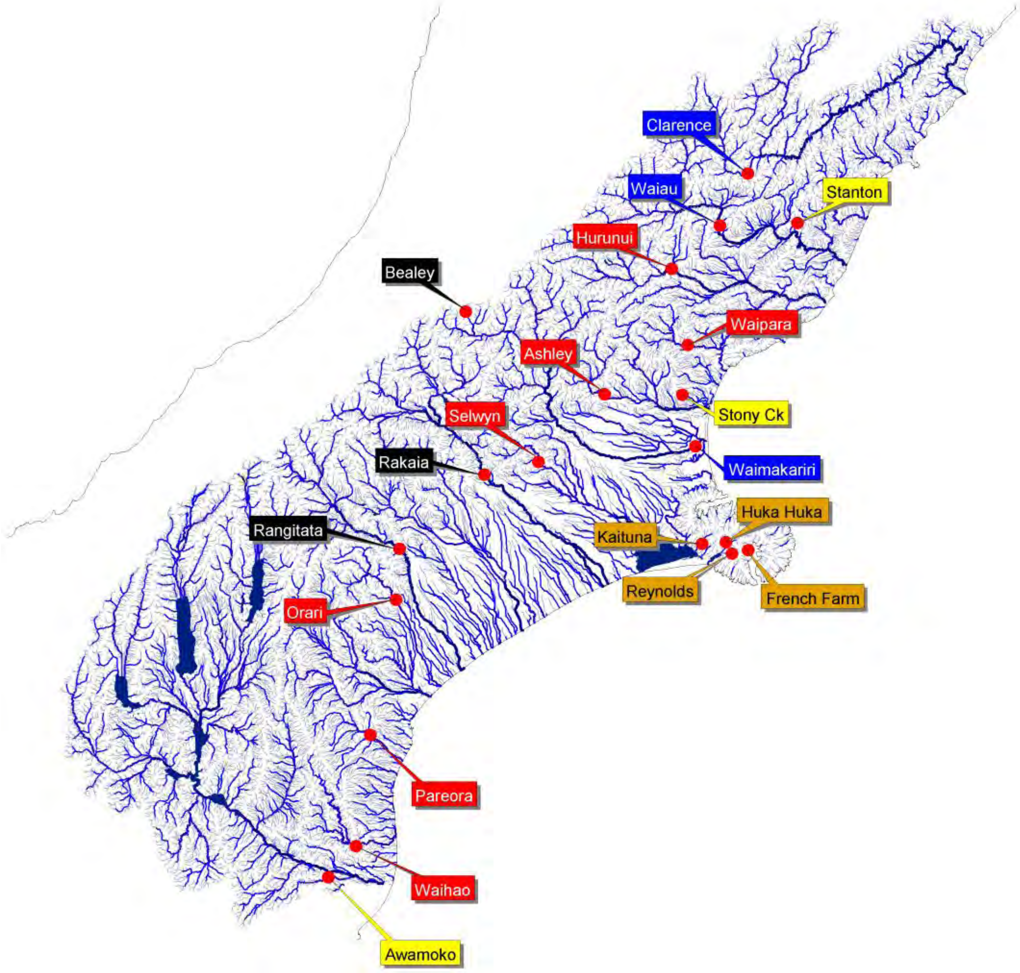

Figure 3.10 Locations of flow sites used in the study.

The site names are colour coded according to the management units they represent, black = Glacial-Mountain, blue = Mountain, yellow = Lowland Soft-Sedimentary, red = Hill Country Sourced, brown = Volcanic rivers.

The values that were most sensitive to abstraction (i.e. flow reduction) were identified for each management unit. For Mountain and Glacial-Mountain rivers the assumption was made that natural character, as defined by the number of braids, was the most sensitive value. Minimum flows were set to retain a 90 percent of the minimum depth occurring at mean annual low flow (*MALF*) and thus, retain a similar level of braiding as that occurring at MALF. Brown trout habitat was assumed to be the most sensitive value for Hill Country Sourced rivers. Minimum flows were set to retain 2/3rds of the brown trout habitat at MALF. The channel morphology and abundance of plants in Lowland and Volcanic rivers means water quality aspects, rather than hydraulic or habitat, becomes the limiting factor as flows are reduced. In particular, as flows are reduced to MALF the reduction in water volume can cause dissolved oxygen (DO) problems due to plant respiration. A minimum flow of MALF was adopted in order to meet a general ecological DO requirement of 6 mg/L.

Once minimum flows are set, the effect of abstraction on residual flows and reliability depends on the total allocation. Reliability of supply criteria were developed based on the acceptability of abstraction restrictions. Below is one of a set of possible criteria that the study assumed defines thresholds above which irrigators start to experience difficulty:

- Restriction, on average, no more than 10% of days for the irrigation season
- Restriction of no more than 20% of days in the most restricted month
- Restriction on average, for only one event of 7 consecutive days per year.

The effect of various levels of total allocation on the reliability of supply and residual flows were then analysed by running statistical tests[23] for individual flow recorder sites. The results for individual sites were then grouped by management unit, and a line of best fit was plotted through the points to determine a mean result for each management unit and show the difference among units. In order to account for differences in the size of rivers within a management unit the total allocations are expressed in terms of proportions of MALF[24].

3.4 Results

The study highlighted a common problem facing water managers at a regional level, that hydrological data is limited. The data was sufficient to consider five management units: Glacial-Mountain Sourced, Mountain Sourced, Hill Country Sourced, Lowland Soft-Sedimentary and Volcanic. There was insufficient data to analyse the Lowland Hard-Sedimentary management unit. The study demonstrated that there are predictable differences in the natural flow regimes among these management units (see Figure 3.11). These differences are justification for managing the water resources of different management units differently. The study suggested options for general flow management regimes for each management unit. One option for each management unit is summarised in Table 3.3. These management regimes suggest minimum flows and total allocations for each management unit that will meet the reliability criteria discussed above. Note that the last column in Table 3.4 also provides information about the effect of the management regime on residual flows by characterising the increase in time that flows are less than MALF.

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[23] These analyses were carried out using LOWFAT (MFE 1999). This software has been specially developed for water allocation analysis and is freeware that can be downloaded from http://www.niwa.co.nz/ncwr/tools

[24] The minimum flows are expressed as proportions of MALF in order to carry out an analysis that is consistent across rivers of different size. Note, however, that these minimum flows were generally developed from hydraulic and habitat methods and not historic flow methods (MFE 1998c).

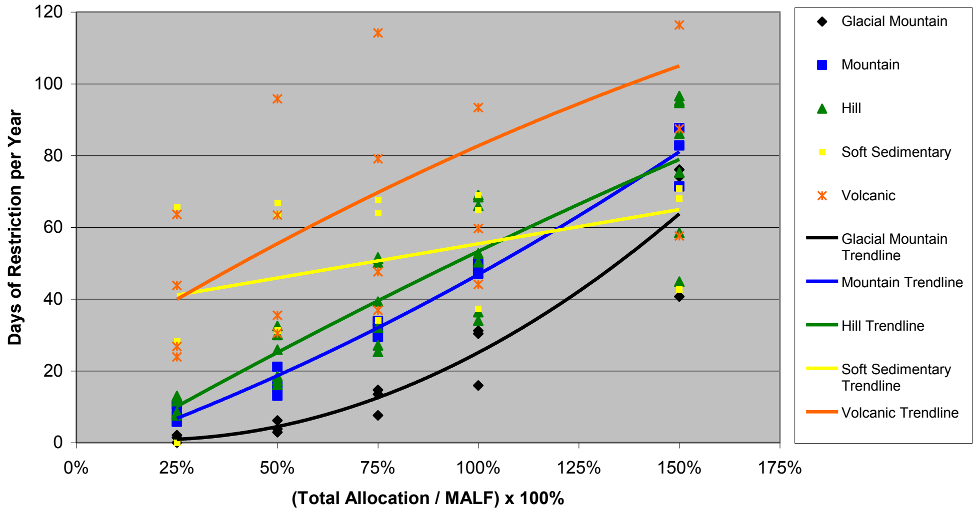

Figure 3.11 Days of restriction per year assuming a constant minimum flow and various levels of total allocation for all rivers organised by management unit.

The outputs from the analysis allows minimum flows and allocations to be transferred from flow sites to rivers without detailed flow data and for the consequence of this for reliability of supply and residual flows to be estimated. The results for the Volcanic and Soft-Sedimentary management units were less convincing than other management units with wide variation in reliability of supply among rivers within the same management unit. The analysis does, however, provide some general guidance on the acceptable size of the total allocation for all the management units considered.

Water availability is highest in the Glacial-Mountain management unit. Total allocation of up to 100% of MALF can occur in these rivers without exceeding the supply reliability criteria. Mountain and Hill management units have the next highest water availability. Allocations of 50% of MALF can be made without exceeding the reliability criteria. Water availability is lowest in Soft-Sedimentary and Volcanic management units. These management units must have total allocation not exceeding 25% of MALF in order to meet the reliability criteria.

It should be borne in mind that the exact implications are dependant on, and sensitive to, the details of the assumptions made for minimum flow and reliability criteria as well as the assumed seasonal pattern of water demand. The results of the analysis show that total allocation should be managed differently among management units and provide a clear justification for a regional framework for water allocation that varies minimum flows and total allocation between management units.

Table 3.3 Summary of general flow management regimes and consequences for supply reliability and residual flows.

Management unit	Management objective	Level of protection	Minimum flow	Total Allocation	Days of restriction per season (average & range)	Number of events per year of greater than 7 days of restriction (average & range)	**Increase in time flows are below MALF (average & range)**
Glacial-Mountain	Natural character	Retain 9/10ths of depth at MALF	68% MALF	MALF	25.9 16.0 – 31.3	1.18 0.53 – 1.65	15.1% 8.8% – 18.8%
Mountain	Natural character	Retain 9/10ths of depth at MALF	68% MALF	50% MALF	16.7 13.2 – 21.2	0.61 0.52 – 0.74	7.97% 7.2% - 8.4%
Hill	Brown Trout	Retain 2/3rds of habitat at MALF	67% MALF	50% MALF	24.4 16.1 – 32.3	1.02 0.57 – 1.32	1.93% 0.0% - 8.1%
Volcanic	Ecosystem protection	DO criteria 6 mg/l	100% MALF	25% MALF	39.6 23.9 – 63.6	2.01 1.15 – 3.69	0.18% 0.0% - 0.4%
Lowland Soft-Sedimentary	Ecosystem protection	DO criteria 6 mg/l	100% MALF	25% MALF	31.4 0.0 – 65.7	0.82 0.00 – 1.36	0.0% 0.0% - 0.0%

APPENDICES

1 Abbreviations/Glossary

ARCView. A proprietary GIS that can be used with the REC. The REC tool TRACER is an ARCView 3.X Extension.

Categories. Each factor is subdivided into categories that discriminate variation in characteristics.

Class. A group of sections of river that share similarities due to similarities in their factors.

Controlling factor. Physical component of the environment that has a profound effect on the existence and development of the physical and biological characteristics of rivers. The REC comprises six controlling factors: Climate, Source-of-Flow, Geology, Land-Cover, Network-Position and Valley-Landform.

Evapo-transpiration. Total moisture loss from evaporation off surfaces and soil and plant transpiration.

Factor. Controlling Factor

Fluvial. Relating to a river or stream.

Flux. The amount of something flowing through a specified surface per unit time.

Geographically independent. Classification schemes that describe similar ecosystem types that may show wide geographic dispersion[25]. When mapped, geographically independent classifications result in a mosaic pattern that depicts the geographic recurrence of particular set of characteristics. Geographically independent schemes provide a basis for transfer of environmental data information to other locations.

GIS. Geographic Information Systems – information as data to be viewed as mapped information.

Hydraulics. Aspects of movement of water in the river channel including its depth and velocity.

Hydrology. Study of water on or under earth surface and uses, availability, conservation etc.

Hydrological regime. The characteristic variation of flow over time.

LCDB. Land Cover Database (1997). Note that the REC was developed using the first version of the LCBD (LCBD1).

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[25] Detenbeck (2000)

Level. The position of a class in the REC hierarchy. REC classes can belong to one of six levels, named: Climate, Source-of-Flow, Geology, Land-Cover, Network-Position and Valley-Landform. Classes at each level are defined by the factor categories for that and all preceding levels (see Figure 1.4). Thus, a Geology level class includes the Climate, Source-of-Flow and Geology categories (e.g. CW/H/HS).

Linear mosaic. The linear features appearing in a map of the REC where the line represents the river channel. When classified an assortment of REC classes recur across the landscape producing a mosaic effect.

LRI. New Zealand Land Resource Inventory.

MALF. Mean Annual Low Flow. This hydrological statistic is an estimate of the flow that a river descends to or below, on average, once every two years.

Management units. A grouping of rivers or parts of rivers that are delineated at specific scales by the REC and used for management purposes.

Mapping Characteristics. Spatial databases (Topography, LRI, LCDB and climatic data) that were used to assign each network section to a factor category at each level of the REC.

Morphology. The characteristic shape of an object. Referred to here as the channel morphology meaning the characteristic shape of the river channel.

Network. The REC's structure of linked catchments and channels.

NZReach . Unique identifier for each river section at a national scale.

Reach. Internal numbering system for identifying river sections on a regional basis.

REC. River Environment Classification

Sediment regime. The characteristic variation in the flux, or load, of sediment moving past a specific point on a river over time.

Spatial Framework. A spatial framework delineates areas within which ecological characteristics are distinct from adjoining areas. Spatial frameworks are abstract depictions of ecological pattern that are developed by classification and mapping of spatial units based on multiple ecological characteristics and which support ecosystem-based resource and conservation management.

Shapefile. An ArcView (ESRI) standard file type for GIS data layers. In general terms a GIS data layer is made of two components: the geospatial data describing the position of the lines, points or polygons on the Earth's surface, and the attributes of the individual elements. The shapefile is actually made up of three files containing the geospatial data, the attribute data, and an index.

Stream order. Numerical position of a section of a river within a river network.

Substrate. River channel bed material.

Temperature regime. The characteristic variation of river water temperature over time.

Values. A characteristic or aspect of a river that is considered to have some worth (e.g. as a habitat for fish), a use (e.g. for swimming or irrigation water), or a rated importance (e.g. for human visual, spiritual or cultural satisfaction).

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3 Summary of classification levels and categories

Tabulated overview of classes for quick reference.

Classification Level	Classes	Notation
1. Climate	Warm-Extremely-Wet	WX
	Warm-Wet	WW
	Warm-Dry	WD
	Cool-Extremely-Wet	CX
	Cool-Wet	CW
	Cool-Dry	CD
2. Source-of-Flow	Glacial-Mountain	GM
	Mountain	M
	Hill	H
	Low-Elevation	L
	Lake	Lk
	Spring	Sp
	Regulated	R
	Wetland	W
3. Geology	Alluvium	Al
	Hard-Sedimentary	HS
	Soft-Sedimentary	SS
	Volcanic-Basic	VB
	Volcanic-Acidic	VA
	Plutonic	P
	Miscellaneous	Ml
4. Land-Cover	Bare	B
	Indigenous-Forest	IF
	Pastoral	P
	Tussock	T
	Scrub	S
	Exotic-Forest	EF
	Wetland	W
	Urban	U
5. Network-Position	Low-Order	LO
	Middle-Order	MO
	High-Order	HO
6. Valley-Landform	High-Gradient	HG
	Medium-Gradient	MG
	Low-Gradient	LG