Development of a GIS-based decision support model for riparian zone ecological restoration at two spatial scales: a case study for the Waihi River, Canterbury, New Zealand

Entwicklung eines zweistufigen GIS-basierten Entscheidungsfindungssystems für Uferzonenrevitalisierung anhand einer Fallstudie entlang des Waihi Flusses, Canterbury, Neuseeland

Diplomarbeit

im Rahmen des Studiums der Landschaftsplanung und Landschaftspflege

eingereicht von Gerhard Gruber

Supervisor: O.Univ.Prof. Dr. Florin Florineth (University of Natural Resources and Applied Life Sciences, Vienna, Austria)
Prof. Ian Spellerberg (Lincoln University, New Zealand)

Co-Supervisor: DI Dr. Hans Peter Rauch (University of Natural Resources and Applied Life Sciences, Vienna, Austria)
Brad Case (Lincoln University, GIS)

Institut für Ingenieurbiologie und Landschaftsbau

der Universität für Bodenkultur

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Abstract

Human activities related to land use and land development (e.g. intensification of dairy farming and irrigation) are key factors involved in the alteration, and destruction of aquatic and related ecosystems in rural regions. The results of degrading human activities in aquatically-dependent ecosystems include higher nutrient inputs caused by stock entering riparian areas; insufficient shading of the channels for temperature, reduced in-stream plant control because of land clearing at riparian areas; and the subsequent stream-bank erosion and instability.

Restoration as a means to re-establish functions and related physical, chemical and biological characteristics of a degraded and disturbed system (Cairns, 1988), can have a considerable role in minimizing the effects of human activities on streams and downstream aquatic systems (Ministry for the Environment, 2000). Additionally, restoration can result in the enhancement of stream habitat and water quality.

Efforts have been taken to develop new approaches for assessing, evaluating, managing, and restoring riparian areas. However, these efforts have either lacked a model that offers the application for various projects, or the models that have been developed are limited to one spatial scale. Few have used a GIS framework or similar tool for facilitating restoration efforts.

The aim of this research was to develop a GIS-based decision support system that facilitated and improved both stream-reach ($10^3 - 10^5$ m) and onsite (10^2 m – 10^1 m) riparian restoration efforts. The support system had a further goal of prioritising sections and sites with respect to their suitability for restoration efforts specifically in the New Zealand context. Using two spatial scales in the analysis took into account the importance of scale for dealing with restoration issues. First, the stream-reach scale allowed a broader scaled strategic planning of restoration efforts; and second, the onsite scale analysis supported the restoration work at which scale the restoration ultimately occurs (Harris et al., 1997).

The application of stage one of the GIS-based decision support system at the Temuka Catchment, and stage two at the Waihi River in the Temuka Catchment, demonstrated that this research successfully implemented an ecological restoration mapping challenge into a GIS system. By testing different criteria weights in four scenarios, at stage one of the decision support system, a range of degradation was found in the total riparian area. Concentrated efforts can then be directed to those areas consistently analysed as low or not degraded. At stage two of the GIS-based decision support system a 300 meters long section (2.875 hectares) of the Waihi River north of Geraldine, was assessed. 17.39% of the area (0.5 hectares) was rated with a low grade of degeneration.

The multi-scaled, GIS-based model approach suits a variety of institutions and people such as Regional Councils, District Councils, farmers, restorations groups, and other institutions or organisations which have to make scale-dependent decisions.

Keywords: riparian, ecological restoration, GIS, decision support system, Waihi River, Temuka Catchment

Zusammenfassung

Anthropogene Landnutzungsaktivitäten und der stetig steigende Bedarf an Bauland sind entscheidende Faktoren für eine Veränderung und Zerstörung von aquatischen und davon abhängigen Ökosystemen wie Uferzonen eines Fliessgewässers.

Gemäß Cairns (1988) entspricht eine Revitalisierung solcher Ökosysteme einer Wiederherstellung aller charakteristischen physikalischen, chemischen und biologischen Funktionen. Eine Revitalisierung von Uferzonen kann die Einflüsse der anthropogenen Aktivitäten auf die aquatischen Ökosysteme flussabwärts entscheidend vermindern, und die Wasserqualität von Flüssen verbessern.

Das Ziel dieser Diplomarbeit ist es, ein zweistufiges GIS-basiertes Entscheidungsfindungssystem (DSS) zu entwickeln, welches sowohl eine Revitalisierung auf regionaler und auf lokaler Ebene ermöglicht und verbessert. Ein weiteres Ziel ist, mithilfe des entwickelten GIS-DSS Flussabschnitte bezüglich ihrer Eignung für eine Revitalisierung zu klassifizieren. Das Verwenden von 2 Maßstäben berücksichtigt die Wichtigkeit des Maßstabes bei Revitalisierungsprojekten. Der Flussabschnittsmaßstab (Stufe 1 des DSS) erlaubt eine breitere und strategischere Planung der Revitalisierungsarbeiten. Stufe 2 des DSS (lokaler Maßstab) unterstützt eine Revitalisierung auf einer Ebene, auf der die Arbeiten schlussendlich durchgeführt werden (Harris et al., 1997).

Die Anwendung von Stufe 1 des GIS-basierten DSS am überregionalen Temuka Einzugsgebiet, und Stufe 2 am Waihi Fluss selbst, hat gezeigt, dass diese Arbeit erfolgreich eine Revitalisierung von Uferzonen und deren digitale Analyse/Darstellung in ein GIS System implementieren konnte. Das Testen von diversen Gewichtungen der Kriterien auf Stufe 1 des GIS-basierten DSS zeigt unterschiedliche Verteilungen der Degradationsklassen. Basierend auf den Ergebnissen von Stufe 1 können Revitaliserungsarbeiten gezielter auf Abschnitte gelenkt werden, die in allen Szenarien maximal als gering degradiert klassifiziert werden.

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1 General introduction

Human activities and land use have altered, threatened and destroyed once-balanced natural ecosystems. Riparian zones as part of the river ecosystem are no exception. In rural areas, changes in land use have put pressure on aquatic ecosystems like rivers. The stress of altered land use, for example through intensification of agriculture in general and an increase in destructive agricultural methods such as dairy farming and extended use of irrigation, can be traced through the changing health of related rivers and ecosystems. Further examples of the deterioration of ecosystem health can be found in ecosystems that have also undergone physical modification and degradation, such as channelisation and drainage of former floodplains, which are vital to stream corridor ecosystems (aquatic and riparian ecosystems). Agricultural development harms those ecosystems in various ways. A higher nutrient input, alleviated denitrification, and increased riverbank damage caused by stock entering riparian buffers are only some of the examples of various threats for aquatic ecosystems and their related riparian zones (Petersen, 1992; Quinn, 2003).

Riparian zones provide critical biophysical and ecosystem functions, such as streambank stability, denitrification of groundwater and runoff inflows, shading of the channels for temperature, in-stream plant control, downstream flood control and enhancement of habitat diversity (Boone Kauffman et al., 1997; Naiman et al., 2005; Quinn, 2003; Quinn et al., 2001a). Ecological restoration of degraded riparian zones is an essential part of complete river restoration and is an approach to mitigate negative developmental impacts by supporting and restoring riparian functions and the related ecosystem functions. Although difficult to achieve, riparian restoration attempts to return those riparian zones as closely as possible to pre-disturbance functions and processes (Boone Kauffman et al., 1997).

The classification approach to managing and restoring riparian areas is that most widely supported internationally by the literature in this field (Boon et al., 1998; Fry et al., 1994; Harris et al., 1997; Petersen, 1992; Russell et al., 1997; United

States Department of Agriculture, 1992). In New Zealand, an example of this approach is the Riparian Management Classification (RMC) (Quinn, 1999; Quinn, 2003; Quinn et al., 2001a) which groups riparian areas based on similar values for the biophysical functions they provide, for example stream bank stability, filtration of nutrients, or shading.

A holistic and successful restoration approach must not be limited to one scale because either it would exclude and neglect the geomorphic and hydrological aspects by just operating on an onsite scale, or the single scale would support restoration work inadequately by disregarding the importance of the onsite scale for restoration work. A holistic and successful restoration approach needs both a broader scale for strategic planning and an onsite scale for supporting the specific restoration work adequately.

The important riparian classification, management and restoration approaches include the Riparian, Channel and Environmental Inventory (RCE) developed by (Petersen, 1992), the United States Department of Agriculture (USDA) Forest's Service Integrated Riparian Evaluation Guide (1992), the Riparian Evaluation and Site Assessment (RESA) by Fry et al. (1994), the Harris et al. (1997) two-staged prioritizing stream reaches and riparian communities for restoration, the System for Evaluating Rivers for Conservation (SERCON) by Boon et al. (1998), and Rosgen's classification (1994). Relevant classification systems in New Zealand are the River Environment Classification (REC) by NIWA (Snelder, 2004) and the Riparian Management Classification (RMC) by Quinn et al. (1999, 2001a, 2003).

Although they were strong initial attempts either as multi-scaled approaches, or approaches based on GIS-data, none of the approaches mentioned above fulfil the criteria explained in chapter 2.4.2 and illustrated in Table 1 and Table 2 to support ecological restoration efforts on various spatial scales, or as a GIS-based decision support system. They all lack a model that offers the application for various projects, are limited to one spatial scale, or do not use GIS as a framework or tool for facilitating restoration efforts.

Based on these findings, the aim of this dissertation was to overcome these limitations by developing a GIS-based decision support system that operates at two scales. The three objectives were:

To find the riparian areas with the highest potential of improvement regarding to their biophysical and ecological functions (as support for proposed riparian restoration efforts) at a stream reach scale (10^3 m- 10^2 m).

At its first stage, this GIS decision support system uses the RMC as framework and criterion to classify riparian areas regarding their suitability for ecological restoration at a stream-reach scale (10^2 m).

Objective two: Development of the second stage of the GIS-based decision support system to find the riparian areas with the highest potential of improvement with regard to their biophysical and ecological functions (as support for proposed riparian restoration efforts) on an on site scale (10^2 m – 10^1 m).

By adding data collected during fieldwork, stage two of the analysis model refines the results of the first stage analysis by using the additional collected onsite data as criteria for classifying riparian areas on a finer onsite scale (10^2 m – 10^1 m).

Objective three: Collecting onsite data to prove and test if the model is going to deliver reasonable and helpful results to support and improve such on site restoration efforts by running the model with the collected data.

A test survey, collecting data at the Waihi River in the Temuka catchment, South Canterbury, New Zealand, is the tool to show whether or not the model delivers sensible and useful information. To verify stage two, one section, based on the classification from stage one of the model, was chosen to do the assessment. The assessment was done for every 25 x 25 m grid along this section.

The model is intended to be complementary to the RMC to support and enhance restoration efforts at the onsite scale (10^2 m – 10^1 m) at which the restoration ultimately occurs (Harris et al., 1997). In contrast, the RMC stops at a stream-reach scale (10^3 m- 10^2 m) and is more a general tool for managing riparian areas than specialised on restoration.

2 Riparian zone management and restoration worldwide and in New Zealand – A literature review

This chapter contains a brief description of riparian areas, the functions they provide, and a review about both international and New Zealand river and riparian classification, management and restoration approaches. In addition the chapter attempts to illustrate the meaning of ecological restoration for riparian areas.

2.1 Riparian zones – An overview

Riparian areas (Appendix A - Glossary) such as floodplains have been a preferred area of agricultural activities because of the highly fertile soil deposited after frequent flood events. This land use has been noted since the agricultural revolution began. Many settlements were built on those floodplains because associated rivers had been an essential transport medium for many settlements around the world (Cairns, 1988). This use of land for agriculture was especially true in the lower regions along a river where the floodplains and riparian areas were more widespread and had a lower gradient, and the sediment deposition rate was at its highest. Increased human population and activities such as agriculture, housing and the hydropower generation caused a loss or disturbance of those important ecosystems. The result of altering and destroying riparian areas have been a decrease in habitat diversity, biophysical functions, and productivity of riparian and aquatic ecosystems which limit the future integrity, value and use of riparian zones.

Natural riparian areas as ecosystems are highly dynamic in terms of space and time, and "normally extending from the edges of water bodies to the edges of upland communities" (Naiman et al., 2005; p. 1). Due to their location as such a three-dimensional zone of direct interaction between aquatic and terrestrial ecosystems, riparian areas can have a disproportionately large role in controlling the effects of human activities on streams and downstream aquatic systems (Gregory et al., 1991). Figure 1 demonstrates a cross section of a riparian area.

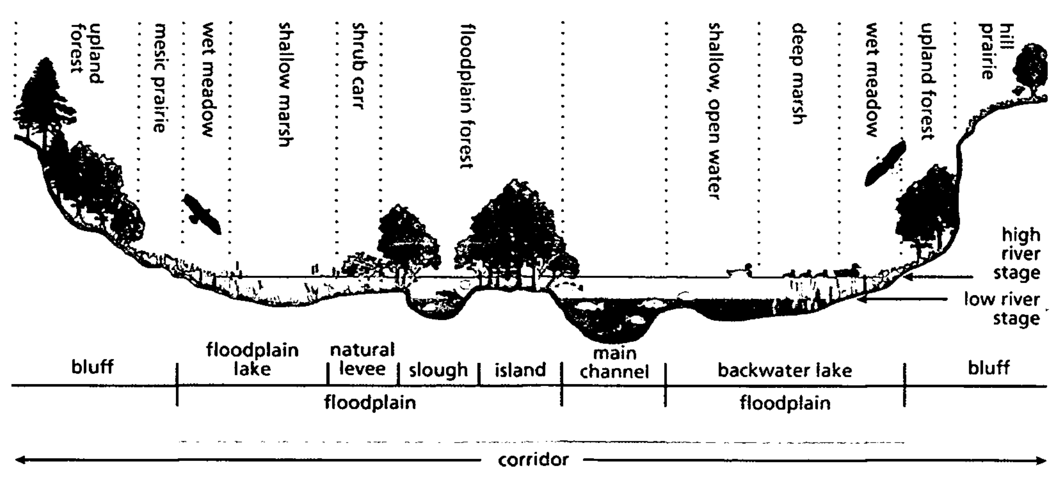

Figure 1 A cross section of a river corridor including riparian areas Sparks, Bioscience, Vol. 45, p.170; March 1995; cited in US Federal Interagency Stream Restoration Working Group, 1998)

Riparian areas are also *ecotones* (Appendix A) and therefore they affect habitat diversity positively. Because of their ability to perform various functions to mitigate results of human activity, due to their location and their character as ecotones, it is essential to look after such very specific and ecological important areas.

Furthermore, riparian areas change their appearance along the longitudinal gradient of rivers (US Federal Interagency Stream Restoration Working Group, 1998). This is related to the sediment export and deposition that changes along a river, and contributes to a vast diversity of ecological complexity along the river. Figure 2 demonstrates the three longitudinal profile zones of a river system.

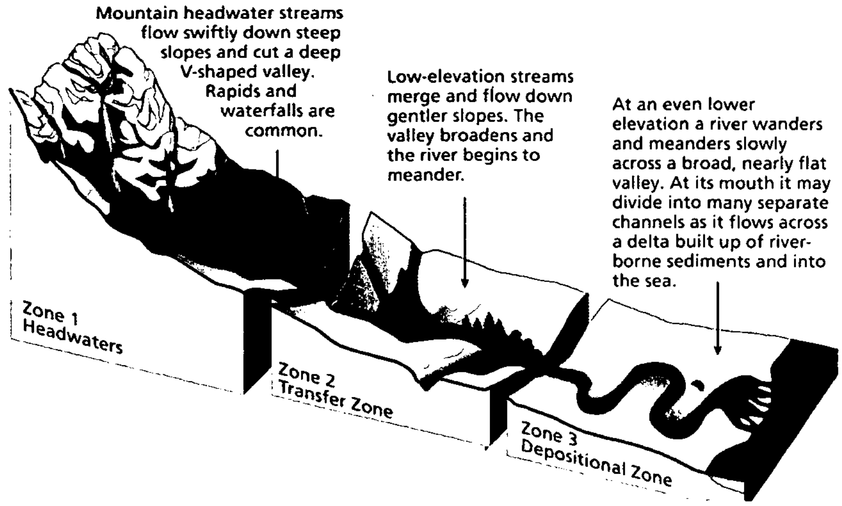

Figure 2 Three longitudinal profile zones. Characteristics of the riparian areas and the channel change along the river from headwaters to mouth (Miller, 1990; cited in US Federal Interagency Stream Restoration Working Group, 1998)

A very helpful theory to illustrate the change of appearance of riparian areas related to changing geomorphic and hydrological preconditions is the *river continuum concept* (Appendix A - Glossary) (Figure 3). This conceptual model can be seen as an approach to explain longitudinal changes in stream ecosystems. According to the US Federal Interagency Stream Restoration Working Group (1998), this concept helps to describe how biological communities develop and change from the headwaters to the river mouth. The approach further identifies the relationships between the catchment, riparian areas, in general, and the stream systems.

Rivers have three stages. At stage one, which includes headwater streams (first to third-order, after *Strahler* (Appendix A - Glossary), shading plays a significant role. Shading has an impact on the growth of aquatic plants, such as algae or periphyton. Their need for energy in form of sunlight to perform photosynthesis is limited by the grade of shading. Hence they are highly dependent on allochthonus materials. These are materials that are an input from outside the channel (e. g. debris, leaves and wood). Stage two includes streams that are fourth to six order streams, after Strahler. As the channels get wider, more sunlight can enter the stream and primary production of energy through photosynthesis in stream vegetation becomes possible. Streams of seventh to twelfth order build stage three of the concept. According to the US Federal Interagency Stream Restoration Working Group (1998), large rivers undergo significant changes in structure and biological function because those rivers have a higher reliance on primary production and gain additional amounts of ultra-fine organic particles from upstream. Figure 3 demonstrates the graphical concept of the River Continuum Concept.

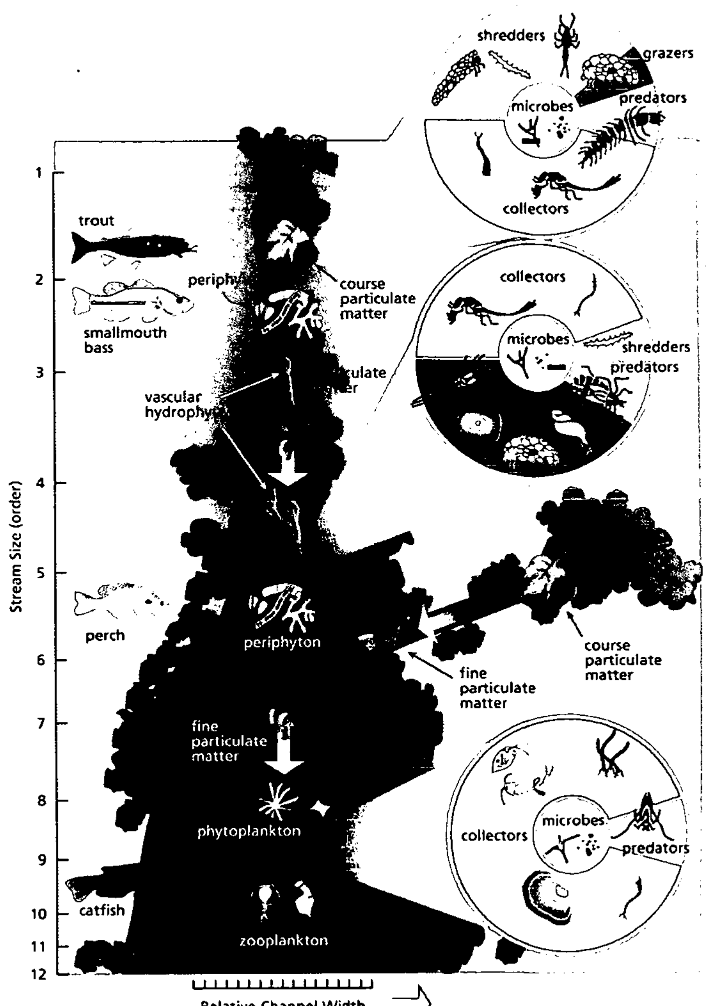

Figure 3 illustrates the River Continuum Concept. It hypothesis a relationship between stream size, relative channel width and the progressive shift in structural and functional attributes of the river and its riparian areas (Vannote et al., 1980; cited in US Federal Interagency Stream Restoration Working Group, 1998)

Vegetation at riparian areas, their distribution and formation, is mainly determined by the geomorphic, hydrological and soil conditions. According to the manual of the US Federal Interagency Stream Restoration Working Group (1998) plant communities play a significant role in determining stream corridor condition, vulnerability, and potential for (or lack of) restoration. Hence it is essential to consider the type, extent and distribution, soil moisture preferences, elevation, species composition, age, vitality and rooting depth in the planning, designing and undertaking of restoration work at river corridors and their riparian areas.

Vegetation as inherent part of riparian areas in almost every biogeographic zone worldwide is an essential part of a riparian zone in a natural state. Vegetation along a riverbank and in the channel itself fulfils various important ecosystem functions in general and many specific ecological purposes. The following three sections illustrate the biophysical, ecological, and social functions riparian areas and their vegetation provide and perform.

2.2 Riparian zones - Functions

Riparian areas fulfil a wide range of biophysical, ecological, economic and social functions, but there are complications in assessing these roles. First, scientists are far from understanding all the relationships, functions and developments from such a highly dynamic ecosystem as a riparian area. Secondly, it is very difficult to classify the functions because the boundaries are fluid and many functions fulfil more than one role within different boundaries. However, because this project's topic includes ecological restoration of riparian areas, a definition must follow. Thus the functions are classified in biophysical, ecological, and social functions.

2.2.1 Biophysical functions

2.2.1.1 Filter function

Ungrazed, well planted riparian zones act as filters which settle out sediments for absorption into the soil. Riparian plants use some of the nutrients for growth. To filter effectively, contaminants from overland flow riparian areas have to slow the flow of surface runoff, enhancing settling of particulates and/or increasing infiltration into the soil, which enhances the filtration of suspended particulates (Philips, 1989a,b; Smith 1989; Cooper et al. 1995; Williamson et al. 1996; Lowrance et al. 1997; cited in Quinn, 2003). To fulfil this function, riparian areas need a dense ground cover of grassy vegetation or debris and litter under riparian forests that increase surface roughness, provide a flat topography, and contribute to soil characteristics that increase hydraulic conductivity, such as low compaction, high sand content, abundant *macropores* (Appendix A) (Quinn, 2003).

2.2.1.2 Nutrient uptake by riparian plants

Riparian vegetation takes up nutrient input with respect to their size. Larger trees and shrubs have a greater biomass and can obviously store more nutrients in plant tissue than smaller plants. Furthermore, larger trees and shrubs have deeper roots and can therefore intercept deeper groundwater. According to (Quinn, 2003), this function is important since infiltration surface runoff or shallow groundwater passes through the root zone before entering the stream. Removing those plants, for example, harvesting the timber, means removing this function, which contributes to a long-term removal of the nutrients that were once stored in that biomass.

2.2.1.3 Erosion control and stream bank stability

The roots of riparian vegetation provide erosion control and stream bank stability. Trees, shrubs and grasses have the ability to improve the stability of stream banks through a strengthening of their root network (Rutherfurd et al. 1999; Lyons et al. 2000; cited in Quinn, 2003). Erosion control is also performed through providing a well-developed turf or a dense root system that protects against surface soil attrition (Murgatroyd and Ternan, 1983; Dunaway et al. 1994; cited in Quinn, 2003). Furthermore vegetation has the ability to pump out water from the soil, and provide *macropores* for drainage and lowering so the potential of erosion.

(Environment Canterbury, 2005) suggested that plants with flexible, multi-stemmed growth forms should be used on the margins at the waterway's normal flow level. Such flexible, multi-stemmed plants provide additional erosion protection for steam banks and the soil layer. This is especially true in the case of a flood when the flexible stems lying down, act as an additional layer above the soil layer and help to protect the stream bank from shear failure (Thorne 1990; cited in Phillips et al., 2004).

2.2.1.4 Mitigation of flood events

Higher runoff and flood peaks are a consequence of a number of causes such as forest clearance in riparian zones and specifically in New Zealand, the development of tussock grasslands to improve pasture land in former riparian areas.

Riparian zones can store and retard drainage water flow which mitigates flood peaks in duration and amount in down stream-reaches (Environment Canterbury, 2005; Quinn, 2003). This is supported by the ability of riparian vegetation to intercept precipitation, which helps to retard the amount of water that enters the soil and hence the stream itself. Also, the higher hydraulic roughness of riparian vegetation retards the progress of flood flows by reducing the velocity and hence the amount of flow (Q). According to Quinn (2003) this water retention can cause increased local flooding of the riparian area and adjacent land, but is expected to reduce the peak flow in downstream-reaches. Hence, several important factors influence the ability of mitigation of flood events and control of down stream flooding, for example, the extent and size of the riparian area, floodplain and wetlands, and the roughness (stem height in relation to the flow depth, stem diameter, stem spacing, and resistance to flattening) of the riparian vegetation (Darby, 1999).

2.2.1.5 Denitrification

Denitrification (Appendix A) is a chemical process that provides a permanent nitrogen removal from the water bodies through decomposition of nitrates.

2.2.2 Ecological functions

Riparian areas are rich ecosystems in terms of biological diversity, unique biogeochemical processes, and productivity (Boone Kauffman et al., 1997). They fulfil and provide essential and varied ecological functions and processes such as food supplies and habitat, buffers to the upland, and interface areas between the terrestrial and aquatic ecosystems.

One of the most important ecological or biological functions riparian areas provide is the function known as *habitat* (Appendix A - Glossary). Wildlife in riparian zones is dependant upon vegetation for shelter, shade and food (Environment Canterbury, 2005).

2.2.2.1 Habitat diversity

Because of its highly dynamic character, if not channelised, regulated or heavily altered by human activities, riparian areas provide a wide range of various habitats. The variety of habitats supports many ecological niches for many species ranging from micro-organisms, insects, birds, fish, invertebrates up to vertebrates and mammals.

Riparian vegetation provides cover and stream enhancement for fish habitats and also encourages the input of terrestrial insect food items from overhanging vegetation (Main and Lyon, 1988; Jowett et al. 1996; cited in Quinn, 2003). Riparian areas also provide spawning areas for many fish species. Several examples of New Zealand species which use this are the banded kokopu, and short jawed kokopu that spawn in leaf litter and woody debris during high flows, and inanga that spawn in riparian grasses in tidal lowland reaches (Michtell and Eldon, 1991; Mitchell and Penlington, 1982; cited in Quinn, 2003). Additionally, eels feed in riparian areas during flooding.

According to Environment Canterbury (2005), riparian vegetation provides tree cover, perching and nesting for kingfishers and game birds, seasonal food sources for the kereru (the New Zealand native wood pigeon), and provides moist conditions and insect life the native frogs and kokopu (whitebait) species depend on.

2.2.2.2 Connectivity

Connectivity (Appendix A) is one of the most important ecological functions riparian areas can provide for flora and fauna. There is a necessity for a high degree of connectivity among natural communities providing and supporting valuable functions, including transport of materials, food and energy but also movement of flora and fauna in times of large human impact. Figure 4 illustrates two landscapes with a different degree of connectivity.

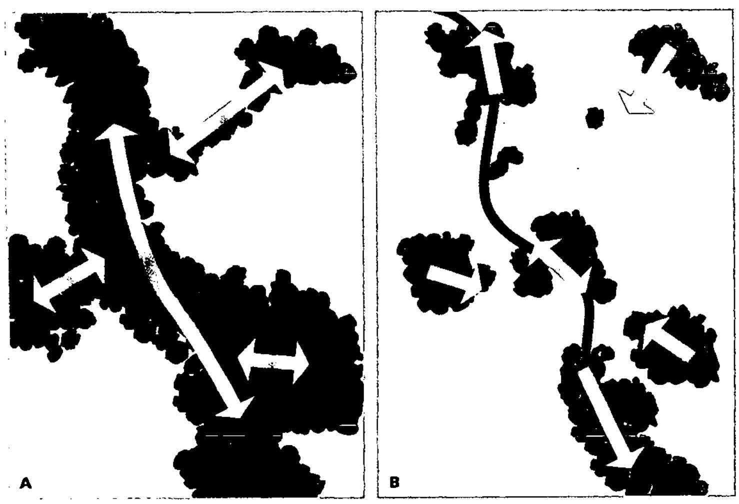

Figure 4 Landscape A show a high and landscape B a low degree of connectivity (US Federal Interagency Stream Restoration Working Group, 1998)

2.2.2.3 Shading

Riparian vegetation prevents, or at least attenuates, a heating of stream water by absorbing or reflecting the incident solar radiation. According to Quinn (2003) shading by riparian vegetation can have two aspects. These include shading for in-stream temperature control as well as shading for in-stream plant control.

Shading for in stream temperature control is essential for many chemical and biological in stream processes, and for in stream fauna and flora. It is connected to the stream depth as a higher mass of water means more radiation can be absorbed without heating up the water and the canopy riparian vegetation can thus build on itself. The ability of riparian vegetation to shade the stream decreases with stream width and the height of the vegetation (Davies-Colley and Quinn, 1998; cited in Quinn, 2003).

The second ecological aspect of shading is the in stream plant control feature. This shade control of in stream primary production helps to reduce the in stream processing of nutrients in terms of an uptake of dissolved nutrients into plant biomass (Quinn et. al.1997b; cited in Quinn, 2003). According to Wilcock et al. (1998; cited in Quinn, 2003) 90% shading is needed to prevent growth of some emergent *macrophytes* (Appendix A - Glossary) in low gradient streams and 60 to 80% shading is needed to prevent proliferation of filamentous green algae (Quinn et al. 1997a; Davies-Colley and Quinn, 1998; cited in Quinn, 2003). Controlling in stream plant growth through shading by controlling the solar radiation that can enter the stream water body helps to maintain or reach a higher biodiversity and desirable functions that plants provide (Briggs, 2000; cited in Quinn, 2003).

2.2.2.4 Leaf litter, debris and large wood input

Leaf litter, debris and large wood as input can play an important role in rivers. On the one hand they are a food resource, and on the other hand they can improve habitat diversity (Collier and Halliday, 2000; Quinn et al. 2000b; cited in Quinn, 2003).

Large wood can be a key habitat-forming feature and increase habitat diversity in stream and in riparian areas close to the stream by providing cover for various invertebrates and fish, and can help to form the needed deeper pools (Quinn, 2003). This aspect is strongly related to the ecological function of providing habitat diversity as described in 2.2.2.1.

According to Collier and Halliday (2000; cited in Quinn, 2003) wood is particularly important as invertebrate habitat in sandy and silty bedded streams. In addition, Maser et al. (1994) found that for rivers in the Pacific Northwest logs and woody debris from the headwaters forests are among the most ecologically important features supporting food chains in the in stream habitat structure.

In general the biophysical and ecological functions riparian areas fulfil can be summarised as followed. Riparian areas interact with rainwater runoff from hill slopes and with stream water when this overflows onto the flood plain. A forested or well-vegetated riparian zone affects the stream by intercepting runoff, providing shade that keeps water temperatures cool, providing leaf matter and wood for habitat and food, and stabilising stream banks (Parkyn et al., 2003). By doing so they are, whether recognised by human beings or not, a fundamental component in the human life-support system (Boone Kauffman et al., 1997).

2.2.3 Social functions (economic value, aesthetics and recreation)

Riparian areas, as any type of landscape, are both "natural" and "cultural" places (Naiman et al., 2005). Riparian areas have a long history as areas of human activity and interaction. Apart from their fertility based on deposition and their use for agriculture and fishing, they also have a long history as areas for human settlements. As an example of the Australasian region, the Maori in New Zealand (Ministry for the Environment, 2001) and the Aborigines in Australia have been using riparian areas as source of food (e.g. fishing), building and weaving materials (e.g. flax), and for medicines, and housing. (Naiman et al., 2005) pointed out that Aboriginal populations focused on floodplains, locate villages in strategic locations for exploiting floodplain fisheries and other biotic resources, particularly edible plants as well as rushes and trees for building shelter. The Maori in New Zealand have strong cultural, spiritual, traditional and historic links with waterways and wetlands and see themselves as the *kaitiaki* (guardians) (Appendix A - Glossary) of those natural resources to protect the integrity of the valued freshwater resources. Waterways and wetlands also have been a source of pride and identity for the people (Ministry for the Environment, 2001).

Naiman et al. (2005) stated that the way people see and value riparian areas changes with time. Hence aesthetics that are based on mind settings or ideals people have of how a certain landscape has to look, undergo changes through time. Other criteria that influence that mind settings are the social group the people belong to and where they are from. Populations use landscapes for building identification within a certain area and over time people tend to build a connection or attachment to a certain landscape, for example, their area where they grew up or used to spend their free time when they where younger.

However, riparian areas have always had an economic value for people, although this aspect has decreased over the last 100 years in the western countries. In many western countries, the economic value of riparian areas has dropped almost to zero because there is no longer the need to use riparian vegetations as supplies for firewood and timber or use riparian areas as a supplier of food.

Riparian areas provide for, and influence, human recreation such as fishing, swimming, boating, walking, biking or having picnics if clear access is provided.

2.3 Ecological restoration of riparian zones

Restoration aims to re-establish valued functions. Focusing on ecological functions gives the restoration effort its best chance to recreate a self sustaining system. This property of sustainability is what separates a functionally sound stream that includes the riparian areas, from an impaired watercourse that cannot sustain its valued functions and may remain a costly, long-term maintenance burden (US Federal Interagency Stream Restoration Working Group, 1998).

Successful and sustainable restoration of riparian zones is based on the understanding of the relationships and connections among physical (geomorphic and hydrological), chemical and biological (ecological) processes at varying time scales. According to (Boone Kauffman et al., 1997) ecological restoration can be described as the reestablishment of processes, and related biological, chemical, and physical linkages between the aquatic and associated riparian ecosystems. The National Research Council (NRC) defined restoration, in its 1992 report (National Research Council, 1992) as "the return of an ecosystem to a close approximation of its condition prior to disturbance".

Human activities related to land use and land development activities, for example the intensification of dairy farming, or the increasing demand on land for urban growth or hydropower generation, are the key factors in altering, threatening and destroying aquatic and related riparian ecosystems in rural and urban areas (United States Department of Agriculture, 1992). The result of altering and destroying riparian areas is a decrease in habitat diversity, biophysical functions, and productivity of riparian and aquatic ecosystems which limit the future integrity, value and use of riparian zones. In the United States an estimated 70 – 90 % of all natural riparian areas have been extensively altered (Hirsch and Segelquist 1978, cited in Boone Kauffman 1997, p. 13) and 53 % of all U.S. wetlands have been lost since the 1780s (Dahl 1990, cited in Boone Kauffman et al., 1997).

As pointed out in section 2.1, riparian zones can have a disproportionately large role in controlling the effects of human activities on streams and downstream aquatic systems due to their location (Ministry for the Environment, 2000). Restoration of riparian zones can thus be an appropriate approach for the improvement and support of biophysical functions such as streambank stability, in-stream temperature control through shading, or denitrification of groundwater. Riparian areas provide shelter and can have an extensive effect on enhancing stream habitat and water quality for organisms dependent on them (Quinn, 2003).

Besides the character as interface between aquatic and terrestrial ecosystems and their supply with critical biophysical and ecosystem functions, riparian areas are highly dynamic and heterogeneous areas that are in constant in flux, which makes it difficult to define a pre-disturbance state as the goal for restoration efforts. Additionally, the ever-changing environmental conditions must be considered when trying to define a pre-disturbance state of the riparian ecosystem. Hence, according to Boone Kauffman et al. (1997) these changes, sometimes supported or strengthened through irreversible human impacts (i.e. soil loss, biotic invasions, air pollution, land use and land clearing) may preclude the capability to precisely re-create ecosystem structure and functions that previously existed. The preclusion may be especially true if upstream conditions have been heavily modified (e. g. by a dam). That means that the goal of every restoration project has to include the maintenance of the dynamics of natural ecosystem processes so that they again can operate efficiently for both ecosystem structure and function to be recovered (National Research Council, 1992)

Ecological restoration of riparian areas has to focus on geomorphic, hydrological and biotic processes and functions. The aim of every restoration work is to restore the state of the whole ecosystem in order to bring all three aspects (biological, geomorphic and hydrological) as close as possible to the natural conditions at least to a level where this ecosystem can start or improve self recovery and can nourish itself without additional help (Boone Kauffman et al., 1997).

An important aspect of restoring biotic processes and structures is the re-vegetation of riparian areas. According to abiotic location factors (e.g. soil, temperature, longitudinal and lateral location along the water body) needed by plants, a re-vegetation of riparian areas with indigenous flora can be seen as an approach to restore riparian areas and their functions, values and benefits. It helps to achieve improvements in habitat diversity, water quality and to enhance the integrity of the whole stream corridor ecosystem.

Re-vegetation with site specific indigenous plants is just one aspect of ecological restoration of riparian areas. Other aspects that may have to be considered in an integrated restoration are geomorphic and hydrological processes. Both are highly influenced by human land use such as irrigation and farming, as well as land development such as the need for space for housing, industry and agriculture. Although vegetation is mainly determined by those two processes and re-vegetation as ecological restoration approach does not consider those influential aspects, re-vegetation has however impacts on the geomorphic and hydrological processes and functions.

Riparian vegetation promotes geomorphic stability via increased flow resistance and, therefore, reduces near-bank flow velocity (Thorne, 1990; cited in Darby, 1999). And it also increases the strength of bank materials via buttressing, arching, and root reinforcement (Waldron 1977; Gray and Leiser 1982; cited in Darby, 1999).

Furthermore, riparian vegetation reduces soil moisture content through enhanced evapotranspiration and reduced infiltration (Darby, 1999). The specialized vegetation also contributes to a higher habitat quality, aesthetics, and water quality (Brookes and Shields, 1996; cited in Darby, 1999).

Hence, at its best, riparian restoration should consider all three parts and aspects; those include the geomorphic, the hydrological and the biological (Erwin 1990; Misch & Gosselink 1993; cited in Russell et al., 1997; Rosgen, 1994; Boone

Kauffman et al., 1997). Therefore, restoration has to be planned on a larger scale to cope with their larger scaled influences and effects. But re-vegetation can be a first and initial step for riparian restoration where other approaches are too expensive, not feasible, or not desired.

However, the success of re-vegetation as a restoration approach at locally confined sites can be limited in terms of inefficiency because the grade of improvement and effect on a broader scale compared to the effort put into such a project. Hence, re-vegetation as an ecological restoration approach also has to be planned on a larger scale to allow a strategic planning on a catchment down to a stream-reach scale.

The aim of the GIS-based decision support model is to provide a tool for helping to locate the most suitable sections and sites in a catchment for re-vegetation with native vegetation at two spatial scales. Re-vegetation efforts have to consider the potential vegetation regarding to the position along the river system.

Although riparian plant communities look quite similar throughout the country and across quite broad elevation gradients, the appearance and formation of riparian vegetation varies most along the riparian gradient. From aquatic subspecies (spp.) and emergent reeds in and on the edge of water, tall tussock spp on the bank edge, shrubs and small trees on the levee, flaxland and tall sedgeland or swamp forest in the backswamp, and bush on the terraces above. This upper terrace bush will vary most geographically as this will depend on the basic climate (arid or rain forest) (C. Meurk, personal communication, August 3, 2006). For detailed riparian species lists and riparian plant communities in Canterbury, New Zealand see the Environment Canterbury "Guide for riparian zones" (Environment Canterbury, 2005), the Christchurch City Council guide for "Streamside Planting" (Christchurch City Council, 2005), and the planter guide on the homepage of NZERN (www.bush.org.nz). They all provide detailed information about species most suitable for a re-vegetation or riparian areas in

Canterbury regarding to their requirements for specific site factors such as moisture, sun light and location at rivers.

It is often mentioned in the literature that the management of riparian zones (Phillips et al., 2003; Bowden, 2001; Quinn, 2003) and ecological restoration of riparian areas (Boone Kauffman et al., 1997; Goodwin et al., 1997; Russell et al., 1997; US Federal Interagency Stream Restoration Working Group, 1998) and their site selection (Kondolf et al., 1995; Harris et al., 1997; Boone Kauffman et al., 1997) should take place on a broader scale such as a catchments scale or stream reach scale because of two main reasons. First, riparian ecosystems largely have been degraded and altered by larger scaled and off-channel activities and hence cannot be restored by focusing solely on manipulations within the channel or onsite scale. Second, holistic management or restoration of those areas has to take into account that the most influential processes on riparian areas; that is, the larger scaled hydrological and geomorphic processes must be considered on a broad scale because of their broad influence. These forces mainly determine the morphology and development of riparian areas and their inherent fauna and flora in a whole catchment.

2.4 River and riparian classification and management approaches worldwide and in New Zealand

The classification approach, highly accepted in the literature, has a long history of being an appropriate management and restoration tool to deal with the high complexity and dynamic character of river ecosystems. In 2005, Naiman et al. (2005) suggested that classification systems are intellectual constructs in which objects with similar relevant attributes are grouped together to meet the purposes of the classifier to understand, plan and deal with nature or the environment itself. Naiman et al. (2005) added that classification systems can be seen as an approach to use similarities of form and function to create reasonably homogenous units.

Many efforts have been undertaken to develop classifications and approaches for assessing, evaluating, and managing riparian areas (Table 2). Stream corridor classifications have long been of scientific interest. The first efforts towards stream classification were undertaken in the 19^{th} century by Surell (1841), and furthered by Dana (1850), by recognising differences between mountain and lowland channels and Powell (1875), Gilbert (1877) and Davis (1890) by broadly delineating geomorphic channel types. The emphasis of those studies was more on the classification stream channels rather than the adjacent riparian areas. However, Leger's classification (1909) was one of the first approaches that also considered biophysical stream environment and riparian vegetation in its approach. Since then a myriad of stream corridor and riparian areas classification approaches and systems have been developed worldwide, with a wide range of criteria and approaches to define, assess and evaluate riverine areas. This study focuses specifically on the classification and management approaches for riparian areas and their restoration.

2.4.1 International riparian management and classification approaches

In general riparian classification and assessment systems can be divided into two main groups: geomorphic and the biotic (plants and wildlife); though some also use criteria from both approaches. Riparian restoration approaches proposed by Petersen (1992), Fry et al. (1994), Boon et al. (1998) SERCON (System for Evaluating Rivers for Conservation), the USDA Forest Service (1992), and Harris & Olson (1997) are all representatives of the biotic classification approach. These systems all assess, evaluate and classify riparian zones according to criteria, values, benefits and physical or biological functions such as width, completeness and type of vegetation, aquatic invertebrates and naturalness of the channel and its riparian zone (Table 2).

However, Harris & Olson (1997) acknowledged the association between vegetation and geomorphology by defining geomorphic reference conditions for specific plant communities. Their approach to prioritising locations such as sites and sections (reaches) for riparian restoration is based on a spatially two-staged analysis. In the first stage, the mainstream was stratified into reaches, then the reaches were classified based upon how present conditions compared to reference conditions. The boundaries of those units were determined by geomorphic, topographic and data on geology (e. g. channel slope, floodplain width). Land cover within each reach was mapped from current aerial photography. Reference criteria were developed based on percent cover of natural vegetation, land use, connectivity between patches of riparian vegetation, and connectivity between the floodplain and upland vegetation. The criteria were used to evaluate the condition of a reach and to classify it for protection/preservation, for review within the current management or permitting system, or for further study to establish restoration needs.

Stage two examined the reaches identified for further study to establish restoration needs and to identify sites. Data on vegetation, landform and surficial substrate were collected in a field study. The data were analysed to identify the plant communities associated with each landform/substrate class and to define reference conditions. Finally, restoration needs were determined for each reach by evaluating the plant community occurrence, structure, and composition relative to the reference conditions defined for each landform/substrate class (Kentula, 1997).

Rosgen's Classification (1994) is included among the geomorphic classification and assessment approaches because it assesses geomorphic and in-channel characteristics such as channel gradient, sinuosity, width-to-depth ratio and soil erodibility and stability. It is not indisputable in the literature. However, it is an important contribution to the field of river classification and it is also basis for various riparian classification and assessment approaches.

Russell et al. (1997) approach is a mixture of both main classification groups. Because they used a modelling approach within Geographic Information Systems (GIS) to identify areas for riparian preservation and restoration based on combining on the one hand watershed-level information on basin topography for developing a wetness index based on upslope contributing area and surface slope to classify areas within a watershed according to the potential for saturation by excess runoff ("wetness potential"). On the other hand, they used land cover and land use as second layer to rank the potential suitability of all sites within the watershed. The result of combining both layers was a classification of the potential suitability for all sites within the watershed for either preservation or restoration of riparian areas and wetlands. The criteria were based on vegetation type, land use, patch size, and proximity to existent riparian habitat (Kentula, 1997).

A GIS based approach to identify those riparian areas of high quality and diversity which are at risk or which have a high potential for conservation or restoration was the subject of the California Riparian Evaluation System (CARES). This was developed by the California Rivers Assessment (CARA) staff at the University of California, Davies, in 1997. The aim was to use this goal for support the decision making process for how riparian habitat restoration funds should be allocated. That GIS tool used five data layer such as Land Use/ Land cover, Land Management Status, Flow Regime (Natural or Altered), potential plant species richness, and potential vertebrate species richness (Beardsly/Willett et al., 1997).

2.4.2 New Zealand approaches

In New Zealand, Quinn et al. (1999, 2001a, 2003) developed the Riparian Management Classification (RMC) for assessing and classifying riparian areas. This was due to a need for a technique from catchment scale down to a stream-reach scale (10^2 m). The RMC was created by surveying relevant site characteristics at reaches and then by using statistical analysis tools to group sites with similar function and physical attributes. It is based on the River Environment Classification (REC) developed by NIWA in 2002 (Snelder, 2004). This approach is a GIS-based and multi-scaled classification of rivers in New Zealand for river management issues such as policy development, monitoring and reporting. The inventory of 426,000 km of river network in New Zealand was done at a 1:50000 mapping scale.

Other approaches in New Zealand have included "The Motueka Riparian Typology Assessment" for the Integrated Catchment Management (ICM) study in the Motueka Catchment, New Zealand (Phillips et al., 2004). This approach is mainly based on the RMC and illustrates the recognition of riparian management as an essential part of an integrated approach to manage a whole catchment in a sustainable way.

The guide "Managing Waterways on Farms: A guide to sustainable water and riparian management in rural New Zealand" published by the Ministry for Environment in 2001 (Ministry for the Environment, 2001) can be seen as a support and helping tool for people who advise farmers. But it is also a tool for the farmers themselves to manage their land in a sustainable way and educate them on the values and importance riparian areas have regarding water quality, biodiversity in and around the water bodies and how they can successfully mitigate agricultural impacts on waterways.

Selecting catchments for streamside management assistance by the Greater Wellington Regional Council (River Environment Group) is an report published in 2005 and describes an approach to identify, by applying five criteria out of their Riparian Management Strategy, the streams in the Wellington Region that would most benefit from stream side management (Forsyth et al., 2005). The main intention for this approach is the lack of financial power to restore or rehabilitate the thousands of kilometres of streams in the Wellington region that would benefit from such a management approach. Thus, prioritising always has an economical background driver.

Riparian Use of Land and its Effects on Streams (RULES), developed by the New Zealand National Institute of Water and Atmospheric Research Ltd. (NIWA), is another approach of catchment planning and managing regarding the connections and relationships between rivers, riparian areas and their influence on shading and chemical in stream processes based on nutrient input from agricultural activities. The aim of this model is to overcome the common disadvantages of models such as high complexity, long running times and the need for an experienced modeller, in order to be a user-friendly decision support system. It allows the user to run various management scenarios in a catchment by changing the impacts (criteria) of land use, the amount of nutrient removal in the groundwater and the riparian zone and stream shade (Rutherford, 2002).

2.4.3 Summary of approaches and linkages with GIS

There are significant differences among those approaches (Table 2). The advantage of such a variety is the ability to choose the appropriate tool for a specific environment, such as for lowland areas or the headwater areas of a river. However, all those approaches for river and riparian classification, management or restoration share a lack either in one or more of the following criteria to be a GIS based decision support model facilitating riparian restoration efforts (Table 1).

None of them fulfil all the criteria, shown in Table 1, to be a useful two-staged and GIS-based decision support model. But they offer the possibility to use the suitable criteria or parts of them for the proposed GIS decision support system. The aim of the proposed GIS decision system is to fulfil all three criteria by providing a multi-scaled GIS decision support model. It is based on criteria and parts developed and applied in one or more of already existing approaches but it will integrate within a multi-scaled GIS-based decision support system.

There are two main issues with integrating the RMC with a multi-scaled GIS-based decision support system. First, the RMC is limited by scale for using it as a GIS decision support system for onsite restoration efforts. The scale of operation and applying is limited to the stream-reach scale (10^2 m). Secondly, its character is basically more statistical than a GIS tool although visualisation and GIS analysis is possible on principle if the data from the surveys are linked to the sections in the REC (River Environment Classification for New Zealand) accordingly to the NZREACH-NUMBER both exhibit as attribute.

Although Harris & Olson's (1997) approach would fulfil two criteria it fails to fulfil the third criteria. Their approach to determine the upstream and downstream-reach boundaries on their susceptibility to erosion or deposition during peak flows and cross valley reach boundaries determined by the geomorphic defined valley floor is impossible to implement into a model because it requires human editing work and site mapping.

Also Russell et al.'s (1997) approach would fulfil two criteria to be a two-staged GIS-based decision support model, at least partly. But to facilitate onsite restoration efforts it lacks the ability to fulfil the important criterion of also applicable at a site scale. This approach is limited to the catchments scale. Like the Riparian Use of Land and its Effects on Streams (RULES) developed by NIWA and the California Riparian Evaluation System (CARES). Both would fulfil the GIS criteria but also lacks the ability to fulfil the criterion of also applicable at a site scale.

Systems	Criteria can be derived from GIS-data	applicable also at a site scale ($10^1 - 10^2$ m)	Potential for integration into a GIS decision support model
RCE (Petersen, 1992)	**No**	**No**	**Low**
RESA (Fry et al., 1994)	**No**	**very limited**	**Low**
Harris & Olson (1997)	**Limited**	**Yes**	**Low**
USDA (1992)	**No**	**Yes**	**Low**
Russell et al. (1997)	**Yes**	**No**	**Limited**
RMC (Quinn et al., 1999, 2001a, 2003)	**limited**	**No**	**Medium**
SERCON (Boon et al., 1998)	**very limited**	**No**	**Low**
Rosgen (1994)	**No**	**No**	**Low**
RULES (2002)	**limited**	**No**	**high**
CARES (1997)	**Yes**	**No**	**high**

Table 1 illustrates various riparian classification systems and their ability being a GIS-based decision support model to facilitate on-site restoration effort

Biotic or geomorphic classification	Country	Name	Author	Objectives	What was measured (Criteria)	Scale/GIS use
Biotic	Sweden	RCE (Riparian, Channel and Environmental Inventory)	Petersen (1992)	Assessment of the physical and biological conditions of small (< 3 m wide) stream channels in low gradient, agricultural landscapes	16 characteristics (Adjacent land-use pattern, width of riparian zone, completeness of riparian zone, vegetation of riparian zone, retention devices, channel structure, channel sediments, stream-bank structure, Bank undercutting, stony substrate/feel and appearance, stream bottom, riffles/pools or meanders, aquatic vegetation, fish, detritus, macrobenthos)	Assessment for 100 m sections Recommendation for using a 1: 10000 topographical map No GIS use
Biotic	United States	USDA Forest's Service Integrated Riparian Evaluation Guide	USDA (1992)	Evaluation of the integrity of riparian areas to categorize and prioritise riparian areas for restoration and monitoring	Criteria (Stream type after Rosgen, Cover types, Soil, aspect and elevation, wildlife and fish species presence, land use activities and influence, bank stability, vegetation community type composition, area extent or riparian area, aquatic habitats, valley bottom type, stream type/channel morphology, woody species regeneration, foliage height/volume)	Level 3 is operating on a site specific level (10^1 to 10^0 m) similar to level two of the proposed two-staged GIS decision support system to find the most suitable riparian sites for restoration GIS application unknown
Biotic	United States	RESA (Riparian Evaluation and Site Assessment)	Fry et al. (1994)	Assessment and evaluation to rank river segments to facilitate appropriate land-use decisions Determine appropriate buffer widths for stream corridor protection	Natural functions, values and benefits 3 criteria (perennial riparian, intermittent riparian and ephemeral riparian) and 10 site-specific attributes (vegetative cover density and diversity, channel morphology, state of erosion, habitat diversity, local land use, surface water quality enhancement factors, groundwater recharge enhancement factors, recreation potential, upland condition)	Only onsite assessment applied by cross sections (transect) Application for GIS not mentioned
Biotic	United States		Harris & Olson (1997)	Prioritizing stream reaches and riparian communities for restoration by acknowledging the association between geomorphology and riparian vegetation	Criteria are land cover (vegetation), land use and geomorphology (valley floor, width and slope, substrate and gradient) Ranking based on previous defined reference conditions varies from protection (reference sites) to restoration (lowest ranking)	Two-staged system; operates on a stream reach scale (10^2 to 10^3 m) and on a onsite scale (10^2 to 10^0 m)

					Criteria for the reference conditions are: Percent canopy cover of tree, shrub and herb communities, percent of urban and other irreversible land use, percentage of floodplain-upland boundary – connectivity to upland, number of patches of native riparian communities, mean size of those patches	Use of aerial photos (stage one) and grids or transects (stage two)
Biotic and geomorphic	United States		Russell et al. (1997)	Ranking sites regarding their potential for preservation or restoration of riparian areas and wetlands within a watershed	Land cover – land use, Topography of the watershed and a calculation of a relative wetness (consideration of the hydrological factor), size of the sites and the proximity to existing riparian vegetation	Operates on a watershed (catchments) level Use of GIS
Biotic	United Kingdom	SERCON (System for Evaluating Rivers for Conservation)	Boon et. al. (1998)	Assessment of the conservation value of a river corridor Tool for strategic river corridor management	Criteria: Naturalness, physical diversity, representativeness and species richness	Using 'Evaluated Catchment Sections' (ECS) as units (between 10 and 30 km length) SERCON includes an own computer software to calculate the results
Geomorphic	United States	Rosgen's Classification	Rosgen (1994)	Stream type classification	Geomorphic and in-channel characteristics (Landform, valley morphology, soil, river profile, width to depth ratio, channel material, sinuosity, bank erodibility, riparian vegetation)	Ends at the stream or channel reach scale (10^2 to 10^3 m) GIS application unknown
Biotic and geomorphic	New Zealand	RMC (Riparian Management Classification)	Quinn et al. (1999, 2001a, 2003)	Assessment and classification or riparian areas according to their functional roles in improving stream habitat, controlling contaminant input and enhancing aesthetics, biodiversity and recreation RMC as tool for planning and prioritising riparian management actions	Criteria (bank stabilisation, filtering contaminants from overland flow, nutrient uptake by riparian plants, denitrification, shading for instream temperature and plant control, input of large wood and debris, enhancing instream fish habitat and fish spawning areas, controlling downstream flooding, human recreation)	Assessment for 100 m sections Use of GIS for analysis and presentation of the results possible

Table 2 illustrates a summary of various riparian classification systems developed throughout the world

3 Development of the GIS decision support system (DSS)

3.1 Study area description

The Waihi catchment covers an area of 166 km^2 (Hudson, 2005) and is a sub catchment of the Temuka catchment (577.35 km^2). Figure 5 illustrates the location of the Temuka catchment. The Waihi River flows a distance of 43 km in a southerly direction and joins the Hae Hae Te Moana River about 11 km from the coast to form the Temuka River at the northern end of Temuka settlement. The Temuka River flows into the Opihi River about 4 km from the sea (Hudson, 2005).

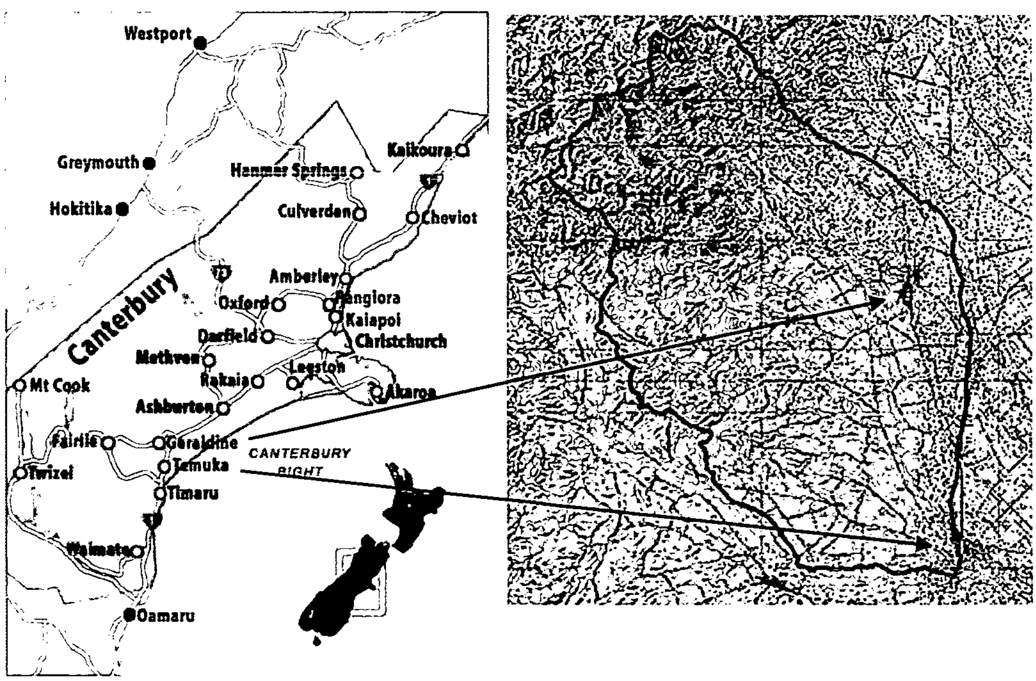

Figure 5 illustrates the location of the Temuka catchment

The water from the rivers in this area is used for irrigation, stock and domestic water supply, dairy use, effluent dilution, industrial use, and recreation such as fishing, swimming, picnicking, camping and passive recreation. The water, especially in the coastal plains from Geraldine to Timaru, is used to irrigate pasture, crops and berry fruit (De Joux, 1981).

Throughout the catchment, wetland areas (including backwaters and swampy areas) are inhabited by native pukeko (New Zealand swamp hen), herons, and bitterns, which feed and nest in the damp areas of riparian areas and wetlands. However, extensive land drainage has destroyed many former wetlands and consequently the abundance of those birds (De Joux, 1981).

The headwaters of the Waihi River are in the Canterbury Foothills (40 km^2), flowing from the Four Peaks Range. The foothills are typified by moderately steep ranges with alpine vegetation, bare rock and scree above 1200 m. Elevation ranges from ~300 at the gorge to 1,653 m (Tripps Peak). With only 40 km^2 of catchment above 335 m, a significant portion of the water resource of the Waihi river comes from the spring-fed creeks of Worners, Raukapuka, Dobies and Smithfield (De Joux, 1981). In the hills, the contextual forest consists of podocarp forest or beech forest. Above an elevation of about 1200-1400 m, the surrounding vegetation would be snow tussock grassland. Under an elevation of 1200 m, *Hebe cupressoides*, an endangered native shrub, and, *Coprosma robusta*, also a native shrub, are typical plants that can be found in riparian areas (C. Meurk, personal communication, August 3, 2006).

The lower 30 km of the Waihi flows through the Canterbury Plains. The lower gradient, and hence a slower mean flow velocity, increases sediment deposition and contributes to broader floodplains, and thus a greater water volume. The plains consist of coalescing alluvial fans with a cover of short tussock grasses and intensive land use pattern. Rainfall varies from ~700 m near the river mouth to 1,100 mm in the foothills (De Joux, 1981; cited in Hudson, 2005). At the water edge or lower banks, typical plants in the Canterbury Plains are tussocks, sedges (*Carex sectra*, Carex *virgata)*, Ferns, harakeke (NZ flax, *Phormium tenax*), Cabbage Tree (*Cordyline australis*), and Manuka (*Leptospermum scoparium*). At the top end of the upper bank or terrace typical plants in the Canterbury Plains are lowland Ribbonwood (*Plagianthus regius*), Kanuka (*Kunzea ericoides*), and Totara (*Podocarpus totara*). For a more detailed species list see the planting guides provided by Environment Canterbury (Environment Canterbury, 2005), Christchurch City Council (Christchurch City Council, 2005), and NZERN (www.bush.org.nz).

According to Lynn et al. (1997), extensive channel clearing, stopbanking and berm planting commenced in 1956 to provide 100 year return period flood protection. Southeast of Geraldine (Figure 6) the river is largely confined by stopbanks built on the natural boundary banks on both sides of the river. This has led to a reduction of the river meander width from ~ 700 m to an active channel width of ~ 50 m. Moderate floods occur mainly in the winter when successive depressions migrate from the south bringing low intensity rain, for 3 or 4 days at a time. Flash floods in small tributaries can occur as a result of local convective storms.

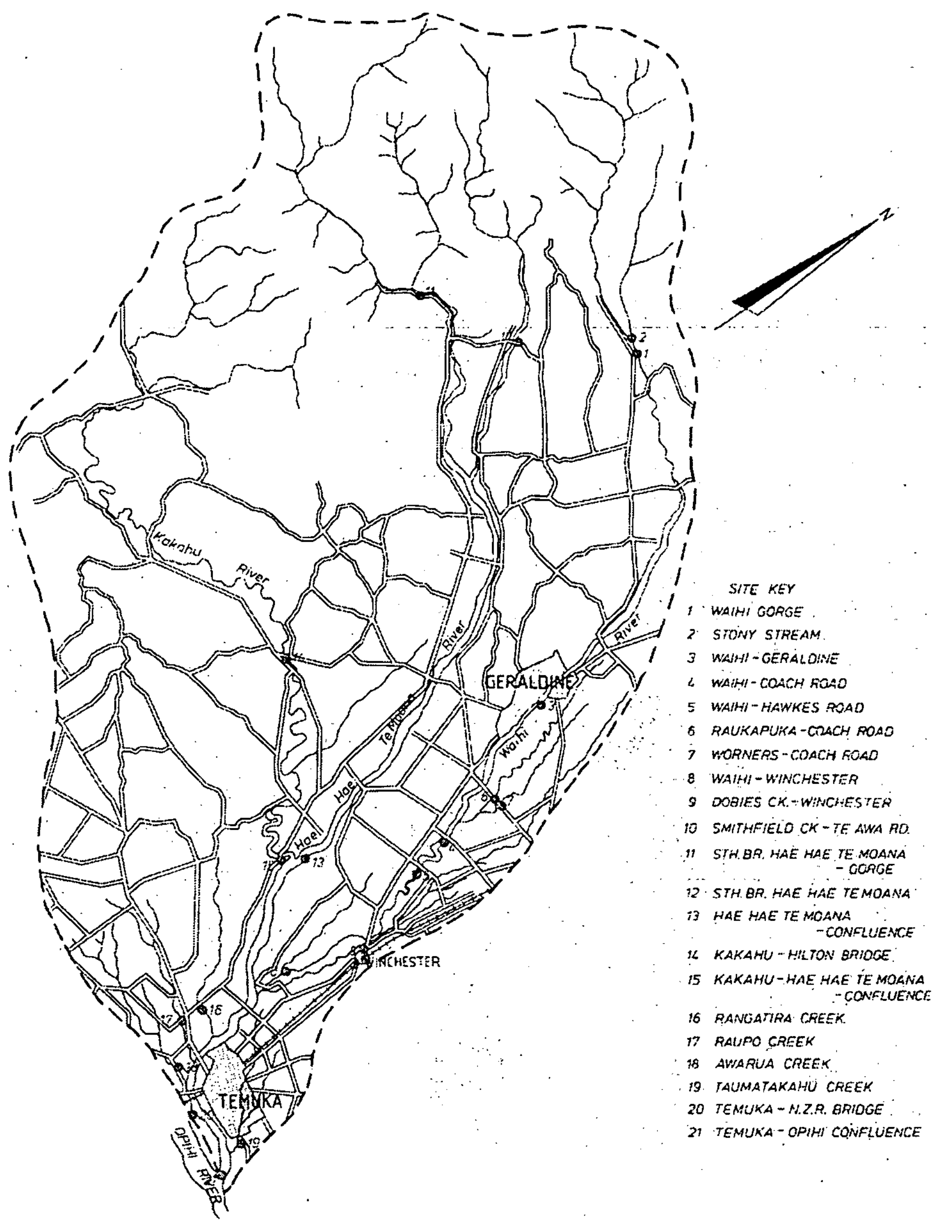

Figure 6 illustrates the Temuka catchment and the Waihi river as part of the catchment (De Joux, 1981)

At the Waihi River, a restoration group has been working for more than 10 years, resulting in some restoration work along the river in the area of Geraldine (Figure 8). The Waihi River Working Group, a member of NZERN, is a community based group formed in 1995 with a mission of restoring the Waihi North section, a 1.2 km section north and upstream to the Geraldine traffic bridge. All participants of the Waihi River Working Group agreed on native ecosystem restoration as a complement to the Talbot Forest adjacent to the area. The Waihi Working Group identified the potential key use of the riparian land along this section in terms of enhancement of habitat diversity and extent, and, therefore, an improvement in local native biodiversity should result.

The initial reasons for starting with restoration work at this section of the Waihi River were the heavy flood event in 1986, and the Canterbury Regional Council's flood protection work to stabilise the river banks. Figure 7 shows a floodplain stabilisation project by ECAN after the flood in 1986.

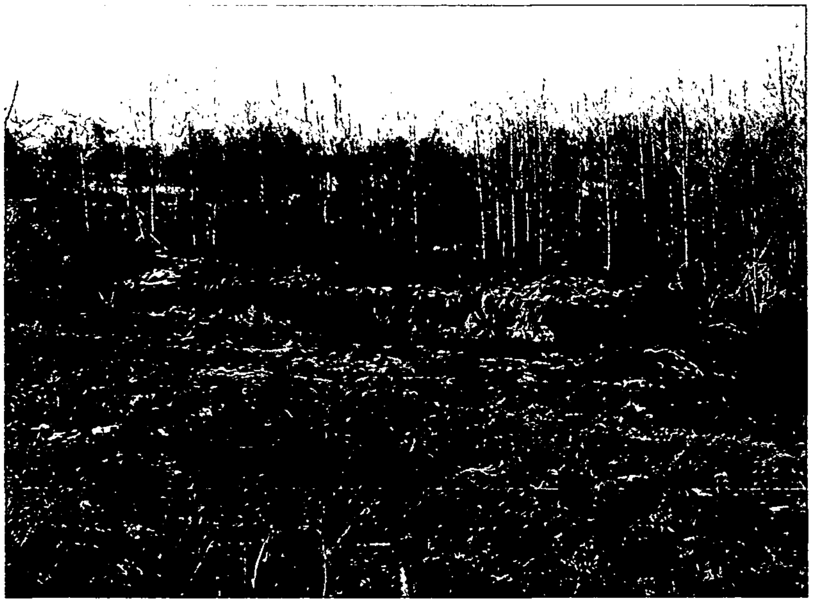

Figure 7 illustrates the poplars planted by ECAN for stabilising the floodplain near Geraldine (upstream); Picture taken by Gerhard Gruber on June 30, 2006;

Thus far, the Waihi Working Group has focussed on the re-vegetation and planting aspect of native species restoration. The reason for focussing on this aspect is to improve the ecologically very important connectivity and corridor function of the riparian areas, especially the linkage to the Talbot Forest (a main goal of the Working Group). The selection of the plants for the re-vegetation of the riparian areas is based on experience, knowledge, and the work of Colin Meurk. The plans of the Working Group for the future are more restoration work at the restoration site and monitoring of the previously restored areas (I. Stäger, personal communication, June 30, 2006).

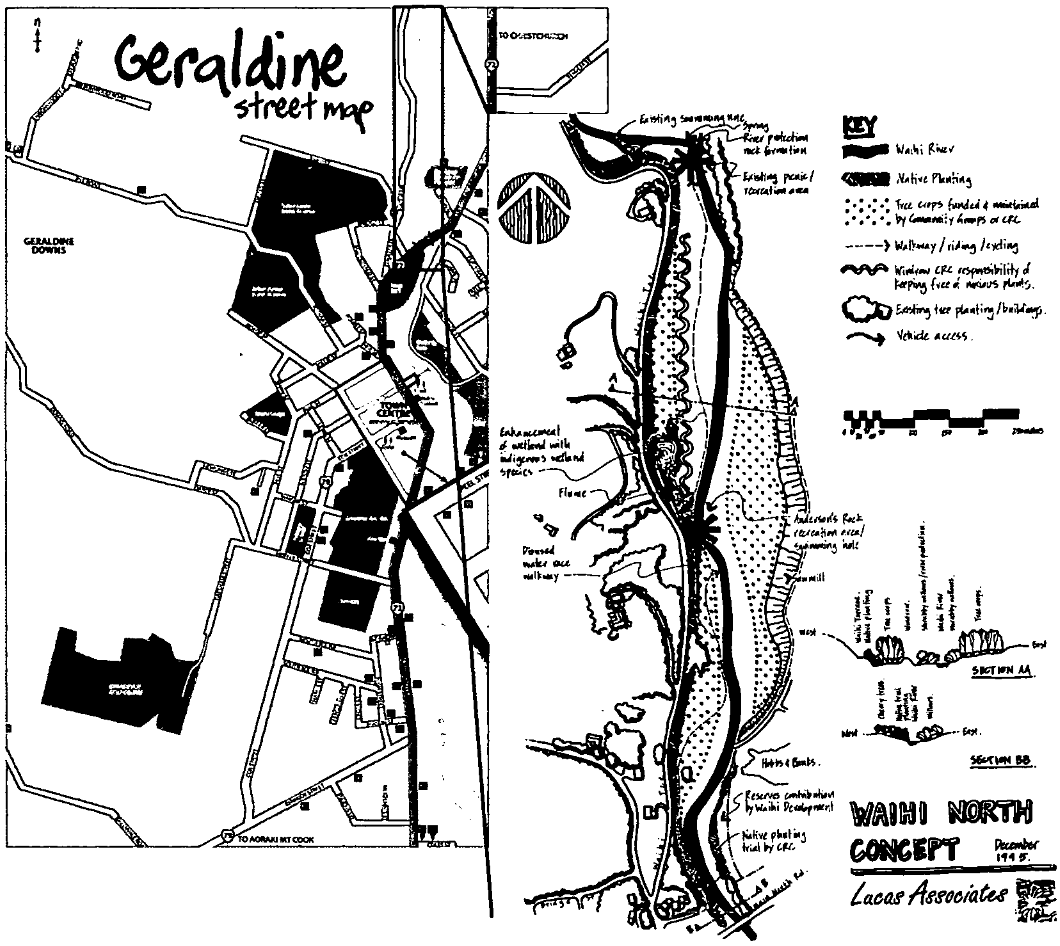

Figure 8 illustrates the location of the restoration site in Geraldine

3.2 Overall description of the GIS-based DSS

The proposed two-staged *GIS*-based decision support system (Appendix A - Glossary) is essentially a suitability model created using the ESRI ArcGIS 9.1 software. The model analysed, calculated, ranked and mapped riparian areas with respect to their level of degradation at two spatial scales. The first stage of the model assessed the level of degradation at a stream reach scale. The second stage of the model analysed the grade of degradation of riparian areas at a finer scale, the onsite scale (25 by 25 m grids). Both stages can be used independently and the results are not directly linked. However, the two stages can be applied together for locating the most suitable sites for riparian restoration at two different spatial scales.

Model creation was carried out directly in ArcGIS 9.1, using its "Model Builder" environment (Figure 9), enables automation of GIS work flow and offers the possibility to run different scenarios by changing the values for the parameter or criteria, and allow experimentation with the different outcomes (McCoy, 2004).

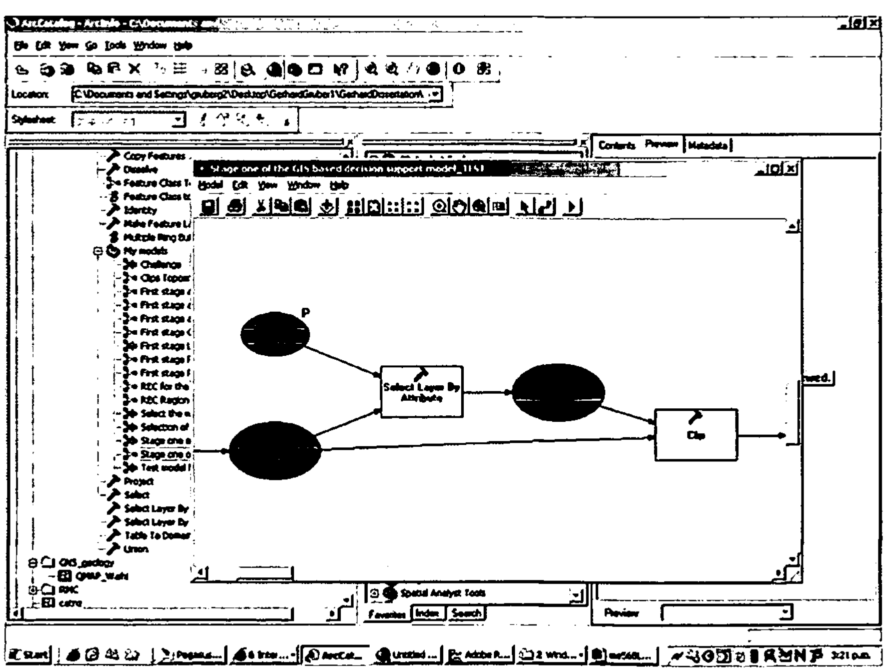

Figure 9 illustrates the model builder window a graphical environment for building models in ArcGIS 9.1

3.3 GIS decision support system – stage one

The stage one model objective is:

To find the riparian areas with the highest potential of improvement regarding to their biophysical and ecological functions (as support for proposed riparian restoration efforts) at a stream reach scale (10^3 m- 10^2 m).

3.3.1 Justification

The successful management of riparian zones (Phillips et al., 2003; Bowden, 2001; Quinn, 2003) and ecological restoration of riparian areas and their site selection (Kondolf et al., 1995; Harris et al., 1997; Boone Kauffman et al., 1997) need take place on a broader scale. In order to take into account the most influential processes occurring in an ecosystem, such as hydrological and geomorphic processes, a catchments scale or stream reach scale should be used.

Further, the main reasons for a broadly scaled planning framework include, first, that restoration work cannot be done everywhere along rivers in a catchment or region. The reasons for this include private land ownership, closeness to urban areas, a higher priority for flood security that does not allow a restoration and some other types of intensive land use such as dairy farming areas. Secondly, single (small-scaled) restoration efforts without strategic planning do not consider the larger scaled off-channel activities, such as land use of the upland which largely have degraded and altered riparian ecosystems. In other words, every single effort is, at least from an ecological point of view desirable, but needs to be put into a bigger picture to enhance the success of such efforts. Not until all the single efforts have been coordinated and are a part of a strategic plan, will those efforts become effective over the long term.

Based on this knowledge, stage one of the proposed GIS-based DSS provides the opportunity to look for the most suitable riparian areas for restoration at a stream-reach scale by incorporating factors operating at scales coarser than the stream-reach scale such as land cover and land use. This broader scaled analysis enhances onsite-scale restoration work in two ways. First, the initial broad scale search for potential sites eases the selection of locations for restoration efforts that will ultimately occur at an onsite scale, by ensuring that broad scaled goals are met (Harris et al., 1997). Second, stage one allows stage two of the decision model to be considered in the context of a holistic ecosystem.

Riparian areas change in appearance in various sections along rivers. In general the natural state of riparian areas in headwater reaches of rivers differs substantially from areas in the transfer zone or the depositional zone including estuaries and river mouths. This change in appearance and formation is based on changing hydrological and geomorphic conditions regarding elevation (stream slope, stream flow velocity and discharge (Q) (Schumm 1977; cited in US Federal Interagency Stream Restoration Working Group, 1998; p. 1-24). Hence the restoration goals have to be adapted to the location of riparian areas along the river.

Restoration projects always aim for an outcome similar to the pre-disturbance state of an ecosystem. Based on the fact that riparian areas as part of the river corridor ecosystem are complex and highly dynamic areas, and the mutually influencing effects of environmental and human induced alterations, defining a pre disturbance or 'natural' state or goal is often difficult and time intensive. However, it is possible to estimate natural states of riparian areas and their natural vegetation by examining their location along a river although they are a part of the highly dynamic ecosystem of river corridors.

The GIS-based decision support system, proposed here, emphasised the biological aspect of restoration by focus on finding the areas most suitable for re-vegetation with native plant communities that would form the natural vegetation of riparian areas in the pre-disturbance state.

Overall framework

There are many possible ways to define the suitability for restoration of ecosystems. In general, all the approaches vary between two extreme ways to determine suitability for restoration. First, the more disturbed or degraded an ecosystem, or a part of an ecosystem, the higher the need for restoration, and the more suitable it is for restoration. Second, the closer an ecosystem or part of an ecosystem to the pre-disturbance area is, the higher the suitability for restoration.

The GIS-based DSS used the latter approach and determined the level of degradation by using five criteria. The RMC, as framework and main criterion provided a ranking in terms of "closeness to a pre-disturbance state". This ranking is based on the RMC's assessment of biophysical functions of 100 meter river sections in Canterbury, New Zealand. The higher the rating for the biophysical functions the closer the state of a section to a pre-disturbance state. The other four criteria, land cover, land use (type of farming), proximity to previously restored areas, and proximity to freshwater ecosystems of national significance modified the RMC-based ranking by integrating factors describing surrounding and off-channel influences. The classification system contained four classes and defined the level of degradation and hence the suitability for restoration (Table 3). The four classes ranged from highly degraded (high grade of disturbance, lowest average RMC potential rating, and high proximity to previously restored areas and freshwater ecosystems of national significance), over moderate degraded, low grade of degradation, to no degradation (close to pre-disturbance state to no disturbance and human impact, highest average RMC potential rating, and very close to previously restored areas, and freshwater ecosystems of national significance).

Classes	Description	Rating
Highly degraded	high grade of disturbance in terms of land use and land cover, lowest average RMC potential rating, and high proximity to previously restored areas and freshwater ecosystems of national significance	0 - 25
Moderate degraded	moderate grade of disturbance in terms of land use and land cover, low average RMC potential rating, smaller proximity to restoration sites and freshwater ecosystems of national significance	26 - 50
Low grade of degradation	Low grade of disturbance or human impact in terms of land use and land cover, medium average RMC potential rating, close to restoration sites and freshwater ecosystems of national significance	51 - 75
No degradation	Close to pre-disturbance state to pre-disturbance state, highest average RMC potential rating, and very close to previously restored areas, and freshwater ecosystems of national significance	76 - 100

Table 3 illustrates the classification system for stage one of the model

Stage two of the GIS-based decision support system, used the same classification but other criteria because of the change in scale. The chosen criteria for stage one of the decision support system were appropriate for the broad-scaled analysis but were not appropriate for the onsite scale of stage two of the GIS-based decision support system.

3.3.2 Model development

Stage one of GIS-based DSS was based on five main criteria to locate the most suitable riparian areas for restoration. Table 4 illustrates the criteria used in stage one of the model and the data based on.

The five criteria used are, land cover/land use, the average RMC potential rating for improving biophysical functions for Canterbury, the type of farming in those areas or at the adjacent land, the proximity to previously restored areas, and the proximity to freshwater ecosystems of natural significance (Table 4). Based on the module character, every criterion formed a sub- model in the final stage one model, allowing further changes in the model criteria itself and replacing them with other criteria to examine diverse outcomes. Its module character allows an adaptation on various catchments and changing the values for the criteria

This model focused on locating those areas with the highest potential of improvement regarding to their biophysical and ecological functions. Other aspects such as economical, social and land owner ship criteria could be taken into account at a later point of time, after identifying the locations of suitable areas were from a biophysical and ecological point of view. Some parts of the social aspects were indirectly included via the average RMC potential ratings for the aesthetical and recreational potential.

3.3.2.1 Assumptions

The underlying assumption of the whole approach was that the closer to the natural state, the more suitable a site will be for restoration. However, because of the model format, the values for classes can be changed; for example the most disturbed areas such as built up urban areas illustrated in the Land Cover Data Base 2, can be highlighted to start with local restoration. The ranking and values for each class are illustrated in the tables for each criterion.

3.3.2.2 Criteria description

The following five sub sections describe the criteria that have been chosen to locate the most suitable riparian areas for ecological restoration regarding their biophysical and ecological potential.

Table 4 illustrates the used input data and the five criteria based on them to classify riparian areas regarding their level of degradation at stage one of the model. It also highlights the importance for, and the influence the criteria have on the model.

Stage one of the GIS model used the RMC as a framework. Stage one can be used as basis for the second stage of the model in terms of using the resulting map for the on site surveys. The onsite surveys were essential for the collecting the data for stage two of the model. Doing the stage one analysis is a top down approach because it just uses already existing data and there are no restoration groups, farmers or interested people involved who could incorporate work or data.

Criteria/Parameter	Data source	Importance for/influence on the model
average RMC potential rating of the biophysical functions riparian areas provide in this section (under best management practices: fencing and planting)	RMC	Framework: provides the 100 meter sections as basis units for stage one of the model; criterion: ranking of grade of degradation of those sections based on the assessment of the biophysical functions
Land Cover	Land Cover data base 2	important for incorporation of surrounding and broader scaled off-channel activities
Type of farming	NRFA	important for incorporation of surrounding and broader scaled off-channel activities
Proximity to previously restored areas	NZERN data base	important for incorporation of the ecological function of connectivity
Proximity to freshwater ecosystems of national significance	DOC data	important for incorporation of the ecological function of connectivity

Table 4 illustrates the criteria used in stage one of the model and the data based on

The RMC (Riparian Management Classification)

The data RMC potential ratings were obtained from NIWA mainly in the form of excel spreadsheets but also partly in GIS format (vector data – polylines, based on the REC). This data was first published in 2003.

In New Zealand Quinn et al. (1999, 2001a, 2003) together with NIWA, Environment Waikato, Environment Canterbury and the Ministry for the Environment have developed the Riparian Management Classification (RMC) for assessing and classifying riparian areas regarding their biophysical functions. The study aimed to develop ways of classifying riparian areas according to their functional roles in improving stream habitat, controlling contaminant inputs, enhancing aesthetics, biodiversity and recreation.

The classification is based on an assessment of 10 biophysical functions riparian areas can provide to enhance stream habitat and water quality. This approach also takes into account the fact that those biophysical functions change as the rivers change from headwaters to lowland floodplain rivers. Therefore protocols were used to survey and rate those ten functions from zero (absent) to five (very high activity) on 313 sites over 100 m long reaches in Canterbury:

- Streambank stabilisation
- Filtering contaminants in overland flow
- Nutrient uptake from shallow groundwater
- Denitrification of shallow groundwater
- Shade for instream temperature and nuisance plant control
- Input of wood and leaf litter to the streams
- Fish habitat enhancement
- Control of downstream flooding
- Human recreation
- Stream aesthetics.

Besides the assessment data, the RMC is additionally based on REC (River Environment Classification) and Land Environment New Zealand (LENZ) data to incorporate broader scaled factors, such as climate, soil, geology and topology. Using these three types of input data the RMC assessed the current activity of biophysical functions (RMC-C) for 100 meter sections. Additionally, by applying statistical methods such as cluster analysis and the use of discriminant function models, the RMC calculated a potential classification (RMC-P) for 100 meter sections. The potential for enhancement of the biophysical functions at the 100 meter sections is reliant upon the application of best practicable riparian management practices, such as fencing and planting.

Ultimately, the RMC is a tool to classify riparian sections, first on the current activity of biophysical functions of those sections (RMC-C), and second, to predict the potential of those functions at the sections (RMC-P), when best practicable riparian management practices were applied.

The statistical clustering and modelling procedures calculated three main RMC potential groups (RMC-P) and twelve subgroups called *cells* (Appendix A - Glossary). Map 01 demonstrates the average RMC potential rating for riparian areas in the Temuka catchment.

Land Cover Database 2

The New Zealand Land Cover Database (LCDB) is a Crown database that translates satellite images of New Zealand into information on the different types of land cover that exist on the ground. The whole area of New Zealand has been identified and classified into eight 1st Order Classes and seventeen LCDB 1 classes (LCDB 1). This was further refined into eight 1st Order Classes and seventy LCDB2 Classes (LCDB 2). LCDB 2 is the second version of LCDB 1 (satellite imagery in 1996/97). According to the Ministry of Environment the overall map accuracy is estimated at 93.9% (Ministry for the Environment, 2006). Table 5 illustrates the classification of the Land Cover Databases. The land cover database 2 data were obtained from NZERN in GIS format as vector data (polygons). The land cover database 2 was completed in 2001/02. Map 02 demonstrates the land cover classes in the Temuka catchment.

1st Order Class	LCDB1 Class	LCDB2 Class
Artificial surfaces	1. Urban Area	1. Built-up Area
	2. Urban Open Space	2. Urban Parkland/Open Space
	3. Mines and Dumps	3. Surface Mine
		4. Dump
		5. Transport Infrastructure
Bare or Lightly Vegetated Surfaces	4. Coastal Sand	10. Coastal Sand and Gravel
	5. Bare Ground	11. River and Lakeshore Gravel and Rock
		12. Landslide
		13. Alpine Gravel and Rock
		14. Permanent Snow and ice
		15. Alpine Grass-/Herbfield
Water Bodies	6. Inland Water	20. Lake and Pond
		21. River
		22. Estuarine Open Water
Cropland	9. Primarily Horticulture	30. Short-rotation Cropland
		31. Vineyard
		32. Orchard and Other Perennial Crops
Grassland	10. Primarily Pastoral	40. High Producing Exotic Grassland
		41. Low Producing Grassland
	11. Tussock Grassland	42. Tall Tussock Grassland
		43. Depleted Tussock Grassland
Sedgeland Saltmarsh	7. Inland Wetland	45. Freshwater Sedgeland / Rushland
	8. Coastal Wetland	46. Saltmarsh
		47. Flaxland
Scrub and/or Shrubland	12. Scrub	50. Bracken Fern
		51. Gorse and Broom
		52. Manuka and or Kanuka
		53. Matagouri
		54. Broadleaved Indigenous Hardwoods
		55. Sub Alpine Shrubland
		56. Mixed Exotic Shrubland
		57. Grey Scrub
Forest	13. Mangroves	60. Minor Shelterbelts
	14. Major Shelterbelts	61. Major Shelterbelts
	15. Planted Forest	62. Afforestation (not imaged)
		63. Afforestation (imaged, post LCDB 1)
		64. Forest - Harvested
		65. Pine Forest - Open Canopy
		66. Pine Forest - Closed Canopy
		67. Other Exotic Forest
	16. Willows and Poplars	68. Deciduous Hardwoods
	17. Indigenous Forest	69. Indigenous Forest
		70. Mangrove

Table 5 Land Cover classification of LCDB 1 and LCDB 2 (Ministry for the Environment, 2006)

Type of farming (land use) data

The data for type of farming is based on major livestock-based pastoral farm type classifications stored in AgriBase, a national spatial farm database, current up to December 2000. It was prepared in December 2000 for the Ministry for the Environment by Robert Sanson, AgriQuality, New Zealand. The primary purpose of AgriBase is to provide information that underpins national and regional policies and programmes that benefit rural New Zealand and primary sector industries. Such policies and programmes include civil defence and emergency management, new or emerging disease investigations, pest and disease eradication efforts, food safety quality assurance programmes, including traceability, State of Environment reporting, provision of agricultural statistics and land use decision support (Sanson, 2000).

The data represents the dominant farm type indicated by the farmer at the time of the last update (in the majority of cases this would have been within the previous 3 years). Each farm is given a unique farm identifier (the farm _id) and the types of information stored include the name and address (contact details) of the key personnel on the farm, the homestead and gate locations as map co-ordinates, the total farm size, the animal numbers by livestock class, planted areas of crops/orchards/vineyards (including exotic and native forests), land parcels that make up the farm, based on Land Information New Zealand's Digital Cadastral Database (DCDB) and the dominant farm type (Sanson, 2000).

The data were obtained by NZERN in GIS format as vector data (polygons). The data was published in 2000. Map 03 demonstrates the various farming types in the Temuka catchment.

Previously restored areas

There are over 2000 restoration sites registered with *NZERN* (Appendix A - Glossary). The physical locations of about half of the locations are known exactly and the locations of the other half are roughly known at this stage. From the locations that are known exactly, about 60% are already in a useable GIS standard format, and available as shapefiles while 40% are still only archived on paper. The transformation into GIS standard is an ongoing process and NZERN works to bring them all to the GIS standard. Map 04 demonstrates the location of the restoration sites in the Temuka catchment.

In the Waihi catchment, the area for my case study, NZERN has three registered restoration sites. The site names are Talbot Forest, Waihi River Project managed by the Waihi River Group, and Kakahu bush.

Areas with ecosystems of national significance

As part of the Sustainable Development Programme of Action for Freshwater, established by the Government, the Department of Conservation (DOC) was given the task to identify a candidate list of nationally-important aquatic systems for freshwater natural heritage.

The objective of the whole Programme of Action is to reconcile competing demands such as irrigation and energy generation for freshwater ecosystems to manage the intensified pressure put on by these demands on New Zealand freshwater ecosystems in a better way. In addition, the changes in land use and the related increase of nutrient loading and its management to stop the declining water quality, will be reviewed by the Programme (Chadderton et al., 2004).

To date, DOC has found eighteen areas or freshwater ecosystems of national importance or significance for biodiversity (WONI) in the Waihi catchment. The GIS data about this freshwater ecosystems used for the dissertation was in vector data form, and obtained from DOC.

By using the following input data the natural heritage value scores have been calculated (Index of natural heritage value - NHV). These scores help in listing catchments and stream reaches with respect to their state of naturalness. The input data were

- A classification of river reaches to indicate what each catchment contributes to the range of environments represented (i.e. the river reach classification within the River Environment Classification).

- The quantity of biodiversity likely to be present (catchment area, number of river reach types present, catchment distinctiveness).

- The degradation pressure on the catchment as a surrogate for naturalness (land clearance; land use intensity; discharges; dams; exotic fish).

- The vulnerable natural features present (threatened species; natural floodplain forest; national or internationally significant features).

Map 05 demonstrates the location of the areas with freshwater ecosystems of national significance. The data were derived from NZERN in GIS format as vector data (polygons).

3.3.2.3 The GIS-based DSS

The GIS-based DSS is a *vector* based model (Appendix A - Glossary). It only uses vector data (points, polylines and polygons) for the suitability analysis. The advantage of vector based data compared to raster based data is the higher accuracy which is essential for a suitability analysis. Figure 10 illustrates the conceptual flow chart of stage one of the GIS-based DSS whereas the symbols for input data and results are coloured light blue and numbered from one to five and GIS-related geoprocessing steps are coloured green and structured by letters from A to D.

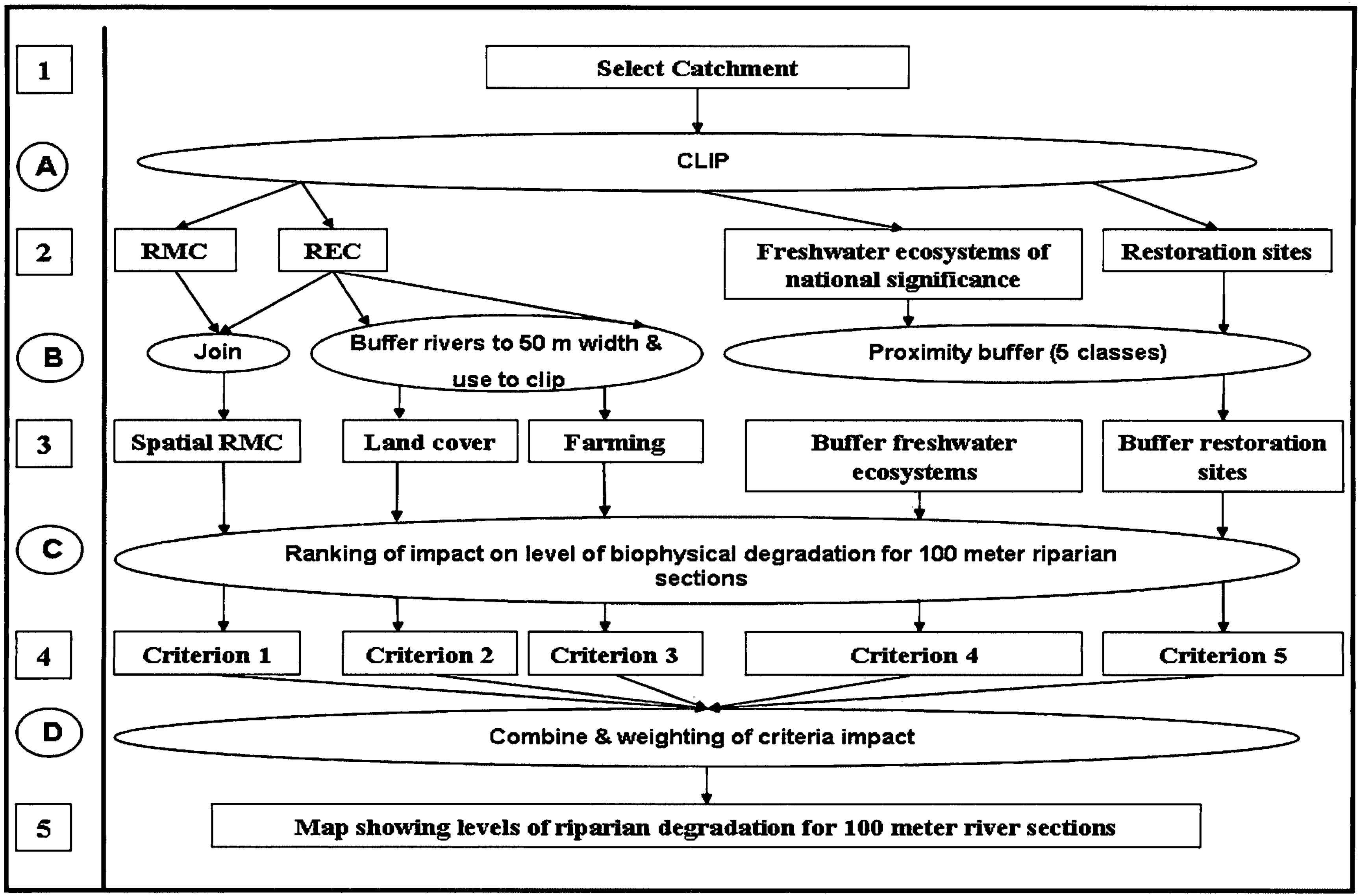

Figure 10 illustrates the conceptual flow chart of stage one of the GIS-based DSS

Stage one of the GIS-based decision support system allows a selection of the catchment by the name of the main river in the catchment (1). Based on this selection all input data is being clipped to the catchment boundaries (A).The REC and the RMC (2) are joined (B) to get spatial extended RMC data in form of polygons.

Land Environment New Zealand (LENZ) data was important input data for the RMC (2) and based on the results of testing the accuracy of the RMC with or without LENZ data the decision was made to only classify areas where all data was available (Quinn, 2003). According to Quinn (2003) the prediction accuracy dropped significantly without LENZ data. However, for the use of the sub model RMC of the model (2), excluding these sections would have meant that these areas also have to be excluded for every following other sub model (criterion) since LENZ data for those sections for the RMC, the only one criterion, were not available. Only 3.93 % (38.1 km out of 968. 4 km) of the streams and rivers in the Temuka catchment had no data available. For some sections of the Waihi River, the Hae Hae Te Moana and the Kakahu River had no data available. Map 01 illustrates the locations where no LENZ data were available. In further analyses, this value of 0 for those areas can be updated when first it becomes available, and second, it becomes necessary for restoration completion.

Stage one calculates a 50 meter buffer (25 m on each side of every stream and river) as potential riparian areas by buffering the REC river polylines (B). This geoprocessing calculation is part of the RMC sub model which is the first sub model illustrated in the flow chart for the whole stage one of the model (Appendix B). The model uses this buffer to clip (B) the land cover and type of farming data (3) to save calculation time. The buffer size can be changed very easily and the model can be run with a different buffer width. The 50 m buffer was assumed to be an average value for riparian areas width. Additionally, the model allows the user to change all criteria values within every sub model to allow for the comparison among various scenarios.

Stage one of the model calculates a multiple buffer for the data on freshwater ecosystems of national significance and previously restored areas (2). Five buffer rings with a width of 50 m each are calculated (B). The classes of the five input data are ranked in terms of their impact on the level of biophysical and ecological degradation for 100 meter sections (C).

Criterion one (4 in Figure 10), sub model one of stage one of the GIS-based decision support model, uses the average potential rating of biophysical functions of riparian sections based on the RMC. For every cell, the rating of every single biophysical function is measured, summarised and divided through the number of assessed functions to get the average potential activity rating for each *cell* (Table 6). For example, c*ell* twelve, the cell with the highest average potential rating, is assigned the highest value while whilst *cell* nine, the cell with the lowest average potential rating, is given the lowest value in the sub model. The new calculated valuation and ranking of the cells for stage one the GIS-based decision support system is illustrated in Table 6 and can be found in the last two rows.

Potential riparian function activity ratings (RMC-P)												
Biophysical functions assessed	Group 1		Group 2		Group 3							
	Cell 1	Cell 2	Cell 3	Cell 4	Cell 7	Cell 8	Cell 11	Cell 12	Cell 5	Cell 6	Cell 9	Cell 10
Overland flow	2,9	2,4	2,7	3,8	3,1	3,4	2,8	3,9	2,2	2,2	2,4	2,8
Bank stability	3,2	3,6	3,8	4,2	3,9	4,0	3,9	4,1	3,1	3,6	2,9	3,6
Denitrification	0,7	1,4	2,3	2,3	1,2	2,3	0,9	1,8	0,5	1,4	0,3	0,6
Shade for plants	4,2	4,0	4,2	4,9	3,9	4,5	3,4	4,7	2,4	2,9	1,0	2,0
Wood input	2,4	3,3	3,6	4,1	3,7	4,0	3,4	4,2	2,3	2,4	2,0	2,5
Nutrient uptake	3,1	3,2	3,3	4,2	3,7	4,0	3,5	4,4	2,8	2,6	2,4	3,3
Shade for temperature	4,2	4,0	4,3	5,0	4,1	4,9	3,5	4,7	2,5	3,2	1,0	2,2
Litter input	2,2	3,2	3,4	4,0	3,0	3,8	3,2	4,1	2,0	2,7	2,3	2,6
Aesthetics	2,5	2,8	3,2	3,1	3,6	3,7	3,9	4,5	2,1	3,1	2,9	3,8
Fish habitat	0,5	1,9	2,7	3,6	3,1	3,3	2,7	3,9	0,9	2,5	0,9	2,2
Downstream flooding	2,2	2,1	2,9	3,7	2,7	3,3	3,3	3,2	2,2	2,7	2,2	3
Recreation	0,1	1,8	1,8	1,7	1,8	2,3	3,5	3,7	0,7	2,1	2,8	3,4
Sum	28,2	33,7	38,2	44,6	37,8	43,5	38,0	47,2	23,7	31,4	23,1	35,4
Average potential riparian functions activity ratings	2,35	2,8	3,2	3,7	3,15	3,6	3,2	3,9	2	2,6	1,9	3
Ranking	10	8	4	2	6	3	5	1	11	9	12	7
Value in the model	20	40	80	90	60	85	75	100	10	30	5	50

Table 6 illustrates the 12 biophysical functions and their calculated average potential riparian activity ratings, the ranking for that criterion and its value in the model

Based on the land cover database 2 data, criterion two (4 in Figure 10), sub model two of stage one of the GIS-based decision support system, ranks the 70 containing classes (listed in Table 5) regarding their potential as area for riparian ecological restoration (Table 7).

The model measures the potential as areas for riparian restoration with respect to the area's classification as either forest, scrub- and/or shrubland, sedge land – salt marsh, grassland, cropland, bare or lightly vegetated surfaces, artificial surfaces and the water bodies (1^{st} order classes in the LCDB 2). The highest rankings is given to the areas with herbaceous freshwater vegetation, indigenous forests or shrubs as land cover because they provide a high "naturalness" value and can be seen as the goal the restoration strives to achieve.

In general, the assumed ranking goes from highest for sedge land – salt marsh (herbaceous freshwater vegetation), and decreases in score gradually for forest (indigenous forest); scrub- and/or shrubland; grassland; bare or lightly vegetated surfaces; forest (exotic); cropland; artificial surfaces (apart from parklands and open areas); to finally include the water bodies (a water body itself is rated 0 because it cannot be an area for riparian restoration). Table 7 shows the assumed ranking results regarding the area's potential for riparian restoration and how the seventy classes were aggregated in the model.

1st Order Class	LCDB1 Class	LCDB2 Class	Aggregation of the LCDB2 classes for criterion landcover	Ranking	Value in the model
Artificial surfaces	1. Urban Area	1. Built-up Area		16	0
	2. Urban Open Space	2. Urban Parkland/Open Space	6	4	85
	3. Mines and Dumps	3. Surface Mine		16	0
		4. Dump		16	0
		5. Transport Infrastructure		16	0
Bare or Lightly Vegetated Surfaces	4. Coastal Sand	10. Coastal Sand and Gravel	not available for the Temuka catchment		
	5. Bare Ground	11. River and Lakeshore Gravel and Rock		5	80
		12. Landslide		12	40
		13. Alpine Gravel and Rock		11	50
		14. Permanent Snow and Ice	not available for the Temuka catchment		
		15. Alpine Grass-/Herbfield	4	13	35
Water Bodies	6. Inland Water	20. Lake and Pond	13	17	0
		21. River	-13	17	0
		22. Estuarine Open Water	-13	17	0
Cropland	9. Primarily Horticulture	30. Short-rotation Cropland	17	15	15
		31. Vineyard	-17	15	15
		32. Orchard and Other Perennial Crops	17	15	15
Grassland	10. Primarily Pastoral	40. High Producing Exotic Grassland	17	15	15
		41. Low Producing Grassland	7	6	75
	11. Tussock Grassland	42. Tall Tussock Grassland	7	6	75
		43. Depleted Tussock Grassland	7	6	75
Sedgeland Saltmarsh	7. Inland Wetland	45. Freshwater Sedgeland / Rushland (Herbaceous Freshwater Vegetation		1	100
	8. Coastal Wetland	46. Saltmarsh	not available for the Temuka catchment		
		47. Flaxland	not available for the Temuka catchment		

[1] The minus symbol means that this class was not existent in the Waihi catchment but if available it would be aggregated in the same coloured class.

Scrub and/or Shrubland	12. Scrub	50. Bracken Fern (Fernland)	[redacted]	9	60
		51. Gorse and Broom	[redacted]	10	55
		52. Manuka and or Kanuka	[redacted]	2	95
		53. Matagouri	not available for the Temuka catchment		
		54. Broadleaved Indigenous Hardwoods	[redacted]	2	95
		55. Sub Alpine Shrubland	[redacted]	8	65
		56. Mixed Exotic Shrubland	not available for the Temuka catchment		
		57. Grey Scrub	[redacted]	8	65
Forest	13. Mangroves	60. Minor Shelterbelts	not available for the Temuka catchment		
	14. Major Shelterbelts	61. Major Shelterbelts	15	3	90
	15. Planted Forest	62. Afforestation (not imaged)	[redacted]	7	70
		63. Afforestation (imaged, post LCDB 1)	[redacted]	7	70
		64. Forest - Harvested	[redacted]	7	70
		65. Pine Forest - Open Canopy	5	14	30
		66. Pine Forest - Closed Canopy	5	14	30
		67. Other Exotic Forest	5	14	30
	16. Willows and Poplars	68. Deciduous Hardwoods	5	14	30
	17. Indigenous Forest	69. Indigenous Forest	[redacted]	2	95
		70. Mangrove	not available for the Temuka catchment		

Table 7 illustrates the aggregation of the LCDB2 classes, their ranking and its value in the model regarding their potential for riparian restoration

Criterion three (4 in Figure 10), sub model three of stage one of the GIS-based decision support model, uses the attribute dominant farm type to locate the most potential or suitable sites for riparian restoration. Table 8 illustrates the various farm types and their assumed ranking regarding their contribution or possibility to riparian restoration at these areas.

The assumption here is that sheep or deer have less impact on riparian areas because of lower weight and therefore cause less erosion and destruction of riparian vegetation especially the grass and herb layer but also at the shrub layer and young trees. Another aspect considers the higher nitrogen input from cattle stock compared to sheep and their negative impact on riparian areas and the water quality of the river or stream. Areas without any type of those farm types are not taken into account in the model.

Type of farming	Ranking	Value in the model
Primarily beef farming	7	0
Dairy farming	6	15
Deer farming	4	35
Dairy dry stock	5	20
Grazing properties	1	100
Primarily sheep	2	75
Mixed sheep and beef	3	50

Table 8 illustrates the types of farming, its ranking and its value in stage one of the model

Criterion four (4 in Figure 10), sub model four of stage one of the GIS-based decision support model, the proximity to previously restored areas or areas where restoration work is in progress, uses the GIS-based NZERN data about this areas as input data.

The assumption of the model is that areas closer to patches such as previously restored areas or areas were restoration is in progress are more suitable and have a greater potential for success in order to fulfil the essential ecological functions such as connectivity and providing a corridor.

The model calculates five buffer rings (B in Figure 10) around the restoration sites, ranks (C) and values them according to their location. The first calculated buffer width is zero to fifty meter and get the highest value. However, areas within the fifth buffer ring, a proximity to the restoration sites greater than 200 meters, and further away located areas get the lowest value in the model. Table 9 shows the widths of the buffer rings, and their ranking in the GIS-based decision support model.

The current restoration sites themselves are not rated for two reasons. Firstly, they are either previously restored or part of the restoration process, or they are mainly part of the land cover database 2 and thereby are implemented as areas with indigenous vegetation (broadleaved indigenous hardwoods, indigenous forest, Manuka and or Kanuka). However, in some instances they do not only contain indigenous vegetation; that is the restoration sites may also includes gorse and broom vegetation, high producing exotic grassland, and pine forests

Buffer width (in m)	Ranking	Value in the model
0 - 50	1	100
50 - 100	2	50
100 - 150	3	15
150 - 200	4	5
> 200	5	0

Table 9 illustrates the intervals in proximity to the restored areas, their ranking and their values in stage one of the model

Criterion five (4 in Figure 10), sub model five of stage one of the GIS-based decision support model, the proximity to areas with freshwater ecosystems of national importance or significance, uses the Department of Conservation (DOC) data about freshwater ecosystems with national importance as input data.

Regarding the ecological aspects of connectivity and the corridor function riparian areas can provide, having a close the proximity to such areas is very important. Furthermore, the creation of a connection between such essential patches and areas with high biodiversity or at least a reduction of the gaps between those areas can support an improvement in transport, habitat diversity and exchange of species and their gene pools. Hence the assumption in this part of the model is that areas closer to connectivity corridors have a higher potential for restoration.

The model calculates five buffer rings (B in Figure 10) around the freshwater ecosystems of national significance, ranks and values (C) them according to their location. The first calculated buffer width is zero to fifty meter and get the highest value. However, areas within the fifth buffer ring, a proximity to the restoration sites greater than 200 meters, and further away located areas get the lowest value in the model. Table 10 shows the buffer widths and their ranking in the GIS-based decision support model.

Buffer width (in m)	Ranking	Value in the model
0 - 50	1	100
50 - 100	2	50
100 - 150	3	15
150 - 200	4	5
> 200	5	0

Table 10 illustrates the intervals in proximity to the areas of national significance, their ranking and their values in stage one of the model

After calculating all sub models the criteria are combined with the union geoprocessing tool, and weighted (D in Figure 10). This weighting also can be changed very easily before running the model. The resulting map (5 in Figure 10) shows the levels of riparian degradation in form of the classification system (Table 3) with its four classes of degradation.

The whole model is illustrated in form of a GIS work flowchart in Appendix B. The graphical illustration of flowcharts of the sub models are attached in Appendix C - Flowcharts of the sub models.

3.3.2.4 Four scenarios

Stage one of the GIS-based DSS was tested by running it with different weightings of the five criteria. Four scenarios were calculated. Scenario 1 used the equal weighting for the five criteria. Each criterion was assigned a weighting of 20%.

Scenario 2 used a different weighting for the five criteria. This scenario assumed a higher importance or influence of land cover on the potential for riparian restoration then the proximity to previously restored areas or areas with freshwater ecosystems of national significance. Thus the model calculated a weighting of 40% for the criterion land cover, 20% for the criteria RMC, land use (type of farming), and 10% for the proximity to previously restored areas and areas with freshwater ecosystems of national significance and importance.

Scenario 3 assumed a higher importance or influence of the average RMC potential rating on the potential for riparian restoration then the proximity to previously restored areas or areas with freshwater ecosystems of national significance. Hence, the model placed a weighting of 40% for the RMC ranking, 20% for the land cover criteria and use (type of farming), and 10% for the proximity to previously restored areas and areas with freshwater ecosystems of national significance and important.

The assumptions of Scenario 4 gave a higher importance or influence of location of the areas to their proximity to previously restored areas or areas with freshwater ecosystems of national significance. Land cover, the land use, and the average RMC potential rating were less important in this analysis. Thus, the weighting was 35% for the criteria proximity to previously restored areas and proximity to freshwater ecosystems of national significance, and 10% for the criteria land cover, land use (type of farming), and the average RMC potential rating.

3.3.2.5 Outputs

The result of running the first stage of the model was a map (5 in Figure 10) that displayed the riparian areas classified in regards of the level of biophysical degradation (Table 3). The resulting map used following classification:

- No degradation (Score: 100 to 76 points)
- Low grade of degradation (Score: 75 to 51 points)
- Moderate degraded (Score: 50 to 26 points)
- Highly degraded (Score: 25 to 0 points)

Besides the classification of the riparian areas regarding their grade of degradation, the map also included

- Additional data (topographical elements like bridges, streets and ownership boundaries) which are laid underneath to ease the orientation for the data collection by restoration groups, farmers or interested people for stage two of the model.
- The REC to locate all the rivers and streams in a catchment
- A grid (25 by 25 meters) to subdivide the longer sections from stage one of the model into 25 by 25 meter grids. Every grid was assigned a number and the map was printed out.

3.4 GIS decision support system – stage two

The stage two model objective is:

To find the riparian areas with the highest potential of improvement with regard to their biophysical and ecological functions (as support for proposed riparian restoration efforts) on an on site scale (10^2 m – 10^1 m).

3.4.1 Justification

The successful management and restoration of riparian areas without including the community and stakeholder is not possible. Broadly scaled planning, as described in 3.3 is an essential part of successful restoration but it also needs a refinement in form of a tool for the people who are willing to manage and restore riparian areas on their properties. Stage one of the GIS decision support system provides the opportunity to look for the most suitable riparian areas for restoration on a broader scale. Additionally, stage two of the GIS-based decision support system is a tool for communities, farmers, restoration groups or interested people that facilitates their restoration efforts by locating the most suitable areas for riparian restoration at the onsite scale, the scale where restoration ultimately occurs (Harris et al., 1997).

3.4.2 Model development

Stage two is based on a combination of the results of the first stage, and additional data collected from onsite criteria during fieldwork. This stage refines the results of the first stage analyses by using the on site data as criteria for classifying riparian areas on a finer scale (10^2 m – 10^1 m). Once inputted to the GIS, the final, most accurate results could be established.

As stage one of the GIS-based decision support system, stage two also emphasises the biological aspect of restoration by focus on finding the areas most suitable for re-vegetation with native plant communities that would form the natural vegetation of riparian areas in the pre-disturbance state.

3.4.2.1 Assumptions

As for stage one of the GIS-based decision support system, the underlying assumption for stage two was that the closer to the natural state or the lower the grade of degradation, the more suitable a site will be for restoration. Eleven onsite criteria were determined to assess the grade of natural state of the riparian areas. The onsite criteria were chosen out of a wide range of systems and approaches that are not only focused on ecological restoration of riparian areas. The selection of onsite criteria/parameters was based on their potential relevance for successful ecological restoration at riparian areas. Every criterion/parameter contains four options at onsite assessment regarding their ability or potential for success. Onsite scale refers to the 25 by 25 meter grids that were assessed.

3.4.2.2 Criteria description

The following eleven criteria were assessed for every 25 m x 25 m grid that was situated in the riparian zone of the Waihi River. The criteria can be divided into hydrological and geomorphic, a biotic and zonal (lateral profile of the survey site) criteria and parameter. The criteria/parameters (Table 11) were based on literature and already existing systems to manage, evaluate, and prioritize riparian areas regarding their biophysical functions, conditions, values and benefits.

The criteria/parameters were adopted from Petersen's RCE (1992), Federal Interagency Stream Restoration Working Group's Stream Corridor Restoration Report (1998), Fry et al.'s (1994) RESA (Riparian Evaluation and Site Assessment), Rosgen's Classification (1994), the USDA Forest's Service Integrated Riparian Evaluation Guide (1992) and Quinn et al.'s (1999, 2001a, 2003) RMC (Riparian Management Classification). They were slightly modified for the use at an on site scale. The ranking system of the classes was based on Petersen's RCE (1992) that provided four classes similar to the four classes at stage one of the model. The resulting map was like the resulting map at stage one of the model following a degradation classification but used an adapted version of Petersen's (1992) rating system for the classes (Table 11):

- No degradation (Score: 285 to 215 points)
- Low grade of degradation (Score: 214 to 144 points)
- Moderate degraded (Score: 143 to 72 points)
- Highly degraded (Score: 71 to 11 points)

Criteria/Parameter	Rating for classes	Description
Channel or stream form, Rosgen's Classification (1994); Interagency Stream Restoration Working Group, 1998)	25	Thread: single (steep: > 10 %, no sinuosity)
	15	Thread: single (less steep: 4 – 10 %, small sinuosity, sometimes little meandering)
	5	Thread multiple – braided (gentle: < 4 %, meandering)
	1	Thread multiple – anastomosed (gentle: < 4 %, meandering low to high)
Channel structure (channel width to depth ratio), Rosgen's Classification (1994)	25	< 12 W/D ratio
	15	12 to 25 W/D ratio
	5	26 to 40 W/D ratio
	1	> 40 W/D ratio
Local land use of the adjacent upland, Petersen (RCE, 1992); Fry et al. (RESA, 1994)	30	Undisturbed, consisting of forest, natural wetlands, bogs and/or mires
	20	Permanent pasture mixed with woodlots and swamps, few row of crops
	10	Mixed row of crops and pasture
	1	Mainly row crops
Width of the riparian zone from stream edge to field, Petersen (RCE, 1992)	30	Marshy or woody riparian zone > 30 m wide
	20	Marshy or woody riparian zone varying from 5 to 30 m
	5	Marshy or woody riparian zone 1 to 5 m
	1	Marshy or woody riparian zone absent

Completeness of riparian zone, Petersen (RCE, 1992)	30	Riparian zone intact with very small breaks in vegetation (Lateral and longitudinal)
	20	Breaks occurring at intervals of > half the length of the grid used for assessment
	5	Breaks frequent with some gullies and scars every half of the length of the grid used for assessment
	1	Deeply scarred with gullies or other types of breaks along its length
Vegetation of riparian zone within 10 m of channel, Petersen (RCE, 1992); Fry et al. (RESA, 1994)	25	> 90 % plant density on non-pioneer trees or shrubs, or native marsh plants
	15	Mixed pioneer species along channel and mature trees behind
	5	Vegetation of mixed grasses and sparse pioneer tree or shrub species
	1	Vegetation consisting of grasses, few trees and shrubs
Slope of the riverbank, Quinn et al.'s RMC (1999, 2001a, 2003); USDA Forest's Service Integrated Riparian Evaluation Guide (1992);	20	< 1°
	10	1° – 2°
	5	2° – 4°
	1	> 4°
Bank undercutting (Grade of erosion, Petersen (RCE, 1992; US Federal Interagency Stream Restoration Working Group, 1998); Fry et al. (RESA, 1994)	20	Little or none evident or restricted to areas with tree root support
	15	Cutting only on curves and at constrictions
	5	Cutting frequent, undercutting of banks and roots
	1	Severe cutting along channel, banks falling in
Stream bank structure, Petersen (RCE, 1992)	25	Banks stable, of rock and soil held firmly by grasses, shrubs and tree roots
	15	Banks firm but loosely held by grass and shrubs
	5	Banks loose soil held by a sparse layer of grass and shrubs
	1	Bank unstable, of loose soil or sand easily disturbed
Riffles and pools or	25	Distinct, occurring at intervals of 5-7x stream width

meanders (sinuosity), Petersen (RCE, 1992, US Federal Interagency Stream Restoration Working Group, 1998)	20	Irregularly spaced
	10	Long pools separating short riffles, meanders absent
	1	Meanders and riffles/pools absent or stream channelised
Fencing existent to prevent stock access to riparian area, Quinn et al. (1999, 2001a, 2003, RMC)	30	Fencing along the whole grid unit
	1	No fencing along the grid unit

Table 11 illustrates the criteria for the onsite assessment to locate the most suitable sites for riparian restoration

3.4.2.3 The GIS model

Stage two of the model is not directly linked to the results of stage one, but both can be used together. Using both together, the results of stage two of the model can refine the resulting map of stage of the model.

The 25 by 25 meter grids were created with DS Map Book for ArcGIS 9.1, free extension software for ArcGIS provided by ESRI. This new shapefile stored all the data assessed as an attribute for every single grid. By adding fields for every criterion in the attribute table of the gird shape, each grid stored its assessed data. Every grid was assigned a unique index. After collecting the data, they were incorporated back into the GIS model resulting in a finer-scaled map.

There were two options available for this data incorporation. The transfer of the data optionally could be performed via ArcPad and GPS devices. The advantage of this option is that these devices can be used for the on-site assessment. That means that the data for each criterion assessed would be stored electronically on the devices and the data can be plugged back into the GIS system very easily by plugging the devices into a computer with GIS software. The GPS would allow a more accurate and provable location of the 25 x 25 m grids. The disadvantage of this option is that the people who want to do the assessment need knowledge and experience how those devices work and how they have to use them properly.

Option two is to use a printed out resulting map from stage one of the model where people have to use paper forms to fill out every criterion. This means the users have to find the 25 x 25 m grids by using the map, have to collect the data manually, and also input the data collected into the attribute table of the grid shapefile manually. The advantage of this option is that is technically less complex and less extensive, but the technique has the disadvantage of a higher error likelihood because first people have to find the grids with the map, and secondly, they assess the criteria manually and the transfer of those data is also performed manually. The latter source of error can be reduced by setting up domain rules in the geodatabase where the shapefile with the grids is stored. Rules can be set for data entry; hence the likelihood of error can be reduced.

After developing stage one (objective one), and stage two (objective two) of the GIS-based decision support system, objective three of the dissertation was:

To collect onsite data to prove and test if the model is going to deliver reasonable and helpful results to support and improve such on site restoration efforts by running the model with the collected data.

A test survey was completed by collecting data at the Waihi River in the Temuka catchment, South Canterbury, New Zealand. This test was the tool to prove and verify if the model delivers sensible and useful information. To verify stage two, one identified section, based on the classification from stage on of the model, was chosen to do the assessment. The assessment was done for every 25 x 25 m grid along this section by filling out a prepared assessment form (Appendix D - Assessment form for the onsite assessment). The chosen section is situated north of Geraldine and is part of a restoration site; managed by the Waihi Working Group. Figure 11 in illustrates the restoration site and the area for the onsite assessment at this site. The results from this test survey can be found in chapter 4.2.

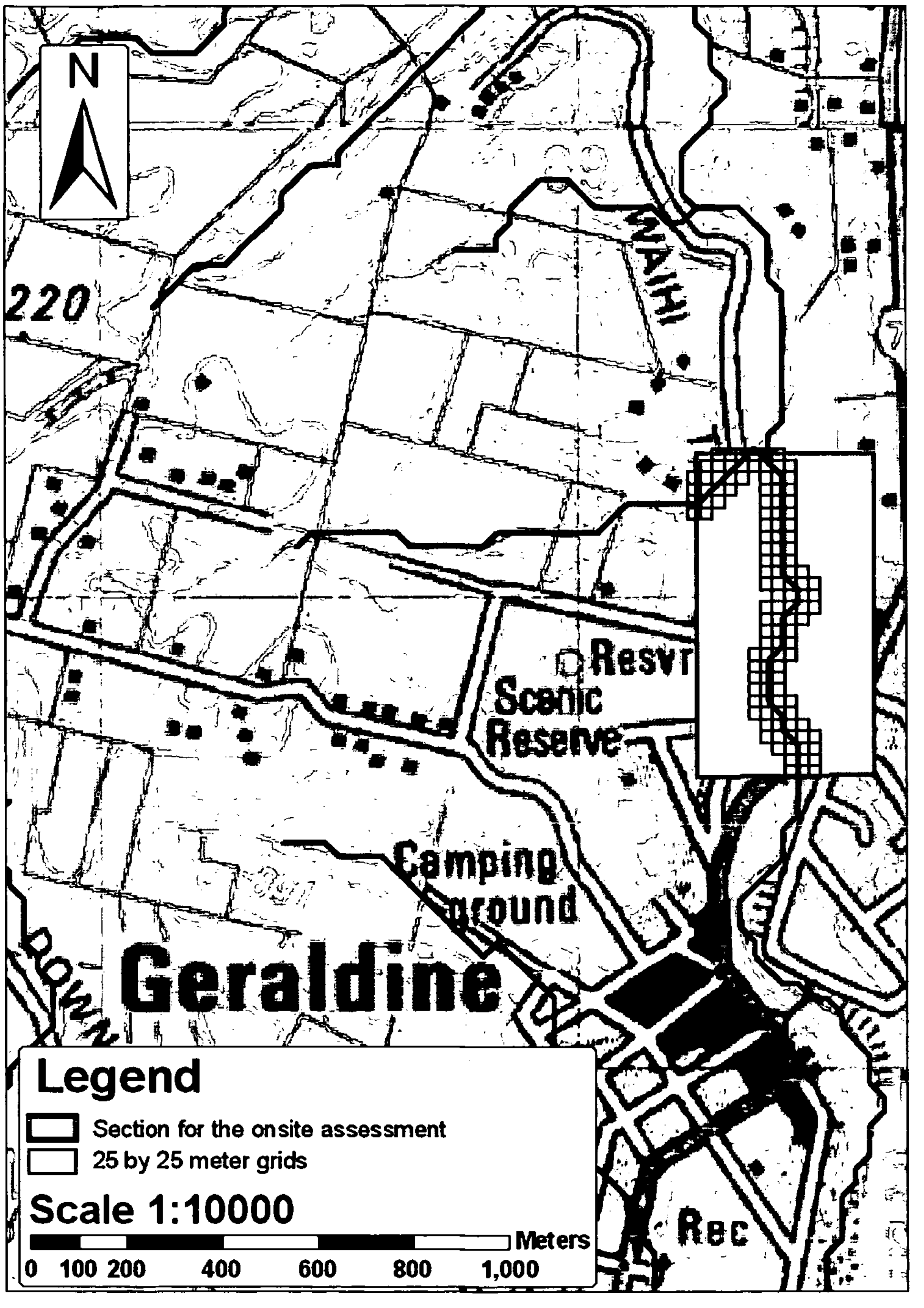

Figure 11 illustrates the area for the onsite assessment and the 25 by 25 m grids for stage two of the model.

3.4.2.4 Outputs

The resulting map of stage two of the model showed the riparian areas classified by their potential for ecological restoration efforts on a refined scale in 25 by 25 m grids. The areas for further assessment at stage two of the model are the areas with a rating of no degradation or low grade of degradation from stage one of the model. Besides the 25 x 25 m grid, the following layers were added to the resulting map of stage one to build the map for stage two:

- Topographical maps (from LINZ – Land Inventory New Zealand, scale 1:50000 were laid underneath to ease the orientation and location for the data collection (assessment of the criteria).
- The REC (River Environment Classification) to locate all the rivers and streams in a catchment.

4 Results

This chapter presents the key findings from using the GIS-based decision support system to analyse the Temuka Catchment, Canterbury, New Zealand. Section 4.1 describes the results of running stage one of the model with four different scenarios. Section 4.2 illustrates the results of using stage two of the model for a test survey at the Waihi River, in the Temuka Catchment, New Zealand. The onsite assessment is based on the results of Scenario 1, where all five criteria were given the same weighting.

4.1 Stage one of the model

Every scenario used the same ranking and values for each class of the five criteria as illustrated and explained in chapter 3.3.2.2. The following four subchapters describe the four different potential scenarios previously identified for the five given criteria. The total area of riparian zones in the Temuka Catchment calculated by the model, based on the assumed average 50 m buffer, is approximately 50.48 km^2 or 5048 hectares. Riparian zones thus compose 8.74% of the total area of the Temuka Catchment (577.35 km^2 or 57735 hectares).

4.1.1 Scenario 1

The model identified 45.96% (2319.71 hectares) of the total riparian areas as highly degraded (Table 12). Furthermore, 49% (2473.25 hectares) was identified as moderate degraded. Thus, in total for Scenario 1, 4.56%, (or 230.24 hectares) were classified with a low grade of degradation. The model calculated an area of 24.39 hectares as not degraded. As a percentage, no degradation area was only 0.48% of the whole Catchment region. Map 06 demonstrates the location of the areas classified within these four classes in the Temuka Catchment. In Scenario1 the areas rated as not degraded were located in the foothills, and only limited to two small sections, one in the south-eastern part of the Temuka Catchment, and the second one, located geographically right in the middle of the Catchment. In terms of the criteria, these areas featured a high average RMC potential ranking, freshwater ecosystems of national significance, and grazing as their major land use. Through Scenario 1, no riparian areas along the Waihi River were classified as not degraded.

OBJECTID	Level of degradation	Shape_Area (in hectares)	Percentage for Area
2	Highly degraded	2319,71	45,96
1	Moderate degraded	2473,25	49,00
3	Low grade of degradation	230,24	4,56
4	No degradation	24,39	0,48
	Sum	5047,58	**100**

Table 12 illustrates the results of scenario one with equal weighting for the five criteria

4.1.2 Scenario 2

The total area of riparian zones calculated by the model was about 5047.58 hectares (Table 13). The model rated more than a third of the area, or 34.56% (1744.22 hectares) as highly degraded. More than half of the whole area or 51.34% (2591.44 hectares) was classified as moderate degraded. 12.95% (653.46 hectares) was rated with a low grad of degradation. The model calculated 1.16% (58.46 hectares), as not degraded. Map 07 demonstrates the location of the areas classified within these four classes in the Temuka Catchment.

In Scenario 2, the areas rated as not degraded were located in the foothills only. Those areas identified as not degraded were mainly sections with lengths greater than 200 meters. Along the Waihi River, five areas were identified that rated as not degraded. Three sections were longer than 200 meters and two sections shorter than 200m. In terms of the criteria, the areas rated as not degraded featured a high average RMC potential ranking, contained freshwater ecosystems of national significance, and had major land use types varying from primarily sheep grazing, to mixed sheep and beef grazing.

OBJECTID	Level of degradation	Shape_Area (in hectares)	Percentage for Area
2	Highly degraded	1744,22	34,56
1	Moderate degraded	2591,44	51,34
3	Low grade of degradation	653,46	12,95
4	No degradation	58,46	1,16
	Sum	5047,58	**100**

Table 13 illustrates the results of scenario two with a higher weighting of land cover and a lower weighting for the two proximity criteria

4.1.3 Scenario 3

The total area of riparian zones calculated by this model was about 5047.58 hectares (Table 14). The model calculated an area of 6.72% (339.02 hectares) as highly degraded. Almost three quarters of the whole area or 71.62% (3614.88 hectares) were classified as moderate degraded. Another 20.61% (1040.12

hectares) was rated with a low grade of degradation, while 1.06% (53.56 hectares) was classified as not degraded. Map 08 demonstrates the location of the areas classified within these four classes in the Temuka Catchment.

In Scenario 3, the location of the areas rated as not degraded are distributed similarly to the distribution in Scenario 2. More than half of all ranked areas are longer than 200 meters. Along the Waihi River, five areas rated as not degraded were identified. Once again, three sections were longer than 200 meters and two sections were shorter than 200m. In terms of the criteria, the areas rated as not degraded featured a high average RMC potential ranking, and freshwater ecosystems of national significance containing restoration sites. Major land use types varied from grazing, primarily sheep, to mixed sheep and beef.

OBJECTID	Level of degradation	Shape_Area (in hectares)	Percentage for Area
2	Highly degraded	339,02	6,72
1	Moderate degraded	3614,88	71,62
3	Low grade of degradation	1040,12	20,61
4	No degradation	53,56	1,06
	Sum	5047,58	**100**

Table 14 illustrates the results of scenario three with a higher weighting of land cover and a lower weighting for the two proximity criteria

4.1.4 Scenario 4

The total area of riparian zones calculated in Scenario 4 was about 5047.58 hectares (Table 15). The model rated an area of 89.93 % (4539.52 hectares) as highly degraded. A further 297.11 hectares (5.89 %) were classified as moderate degraded. Only 3.53% (178.15 hectares) was ranked with a low grade of degradation. The model calculated an area of 32.80 hectares as not degraded. This represents 0.65 % of the whole riparian area. Map 09 demonstrates the location of the areas classified in Scenario 4 within these four classes in the Temuka Catchment. In Scenario 4, the area rated as not degraded was located at the southern end of the foothills, and only at one small area in the south-eastern part of the Temuka Catchment. This area features both freshwater ecosystems of national significance and restoration sites. In Scenario 4, no riparian areas along the Waihi River were classified as not degraded.

OBJECTID	Level of degradation	Shape_Area (in hectares)	Percentage for Area
2	Highly degraded	4539,52	89,93
1	Moderate degraded	297,11	5,89
3	Low grade of degradation	178,15	3,53
4	No degradation	32,80	0,65
	Sum	5047,58	**100**

Table 15 illustrates the results of scenario four with a higher weighting of the two proximity criteria and a lower weighting for land cover and the average RMC potential rating

4.1.5 Summary and comparison of the Scenarios

This subsection illustrates the changes among the four scenarios and the related key findings (Table 16). The areas classified as highly degraded vary by 83.22% between Scenario 4 with the highest proportion of 89.93% and Scenario 3 with the lowest proportion of 6.72%. The areas ranked as moderate degraded vary by 65.73% between Scenario 3 with the highest proportion of 71.62% and Scenario 4 with the lowest proportion of 5.89%. In Scenarios 1 and 2 the classification of areas ranked as moderate degraded represented about half of the whole riparian area. There is only a marginal change between Scenario 1 with a proportion of 49% and scenario 2 with 51.34%. Between Scenario 3 and Scenario 4 is a significant switch among those two categories. At Scenario 3 the area categorized as highly degraded was 6.72%, which increased significantly to 89.93% in Scenario 4. The proportion of areas rated as moderate degraded was 71.62 % in Scenario 3, which dropped significantly to 5.89% in Scenario 4.

Areas ranked with a low grade of degeneration varied by 17.08% which is significantly lower than the range at the categories highly degraded and moderate degraded. Scenario 3 has the highest proportion of areas ranked with a low grade of degradation with 20.61%. Scenario 4 had the lowest proportion of areas ranked with a low grade of degradation with 3.53%. The areas classified as not degraded varied by 0.17%. The range of land area between the scenarios for the category not degraded is significantly lower than for the other three classes.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Max. change (in %)
Level of degradation	**Shape_Area (in hectares)**	**Percent**	**Shape_Area (in hectares)**	**Percent**	**Shape_Area (in hectares)**	**Percent**	**Shape_Area (in hectares)**	**Percent**	
Highly degraded	2319,71	45,96	1744,22	34,56	339,02	6,72	4539,52	89,93	**83,22**
Moderate degraded	2473,25	49,00	2591,44	51,34	3614,88	71,62	297,11	5,89	**65,73**
Low grade of degradation	230,24	4,56	653,46	12,95	1040,12	20,61	178,15	3,53	**17,08**
No degradation	24,39	0,48	58,46	1,16	53,56	1,06	32,80	0,65	**0,17**
Sum	5047,58	100	5047,58	100	5047,58	100	5047,58	100	

Table 16 illustrates the maximum changes of areas in the four degradation classes among the 4 Scenarios in percent.

4.2 Stage two of the model

This subsection presents the key findings of using stage two of the model for a test survey at the Waihi River, north of Geraldine in the Temuka Catchment, New Zealand. Hence, this subsection contains the results for objective two (stage two of the model) and objective three of the dissertation (applying the model and testing it). The assessment was based on the results of Scenario 1 of stage one of the model, where all five criteria were given the same weighting. The chosen section was calculated as highly degraded at stage one of the model.

The length of the chosen section was approximately 300 meters. The total assessed area was 2.875 hectares, which was divided into 46 grids. The grids were surveyed on August the 9th, 2006 between 10am and 3.30pm. To assess the 46 grids, 25 evaluation forms were used (Appendix D - Assessment form for the onsite assessment). Due to the specific locations of some of the grids one assessment form was used for more than one grid. Due to physical constraints in the area, some grid assessments were performed from the other side of the river, and are mentioned on the respective assessment forms. The average time for assessing a grid by using the eleven onsite criteria (Table 11) was 6.5 minutes. Map 10 demonstrates the assessed grids and their rankings.

Out of the assessed 46 grids (Table 17), five grids or 10.87% of the area were ranked as highly degraded (0.313 hectares). A further thirty-three grids or 71.74% of the area (2.063 hectares) were classified as *moderate degraded* by stage two of the model. Eight grids, or 17.39% of the area (0.5 hectares), were rated with a low grade of degradation. Map 05 illustrates the classified grids.

Level of degradation	Number of grids	Area (in hectares)	Percentage
Highly degraded	5	0.313	10.87
Moderate degraded	33	2.063	71.74
Low grade of degradation	8	0.500	17.39
No degradation	0	0.000	0.00
Sum	46	2.875	**100**

Table 17 illustrates the results of the onsite assessment

5 Discussion

This research successfully implemented an ecological restoration mapping challenge into a GIS system. The three objectives of this dissertation were:

1. To develop a GIS-based decision support system locating the riparian areas with the highest potential of improvement regarding to their biophysical and ecological functions on two scales;
2. To perform the calculations on the catchments down to a stream reach scale (stage one of the model) and on an onsite scale (stage two of the model);
3. To perform an onsite assessment and collect data to prove and test if the model delivers reasonable results to support and improve onsite restoration efforts by running stage two of the model with the collected data.

The developed GIS-based decision support model operated at two spatial scales and allowed the user to choose either to run it for a broader-scaled analysis to locate riparian areas most suitable for restoration on catchments down to stream-reach scale, or using the model for locating those areas on an onsite scale. The model format also allows for using the model for various catchments in Canterbury, based on the input data for doing this type of research. Furthermore, the criteria aspect weightings, built in as sub models, can easily be replaced in the model. The values for every class in every sub model can be manipulated to reflect the importance of certain criteria as more scientific support becomes available. This offers various possibilities how the classes in every criterion are valued, for example the value for the land cover classes can be changed very easily if, for example, if looking for highly disturbed areas such as urban areas, to begin with restoration efforts.

The most important findings by applying the GIS-based decision support system at the Temuka Catchment, New Zealand can be divided into two parts. First, the findings from applying the first stage of the model reflect how different weightings for criteria influence the degradation assessments. Secondly, comparing onsite assessment in stage two of the model gives varying results to those found by GIS assessment alone at the Waihi River in the Temuka catchment.

Applying stage one of the model and using four different scenarios revealed a significant switch between the results of Scenarios 3 and 4 among for the categories of highly degraded and moderate degraded. In fact, in Scenario 3, (with more weighting on RMC and land cover) 92.23% of the area was rated as moderate degraded or low grade of degradation, whereas in Scenario 4 (with an increased weighting for already restored areas, or proximity to freshwater ecosystems with national significance) only 9.42% of the area was rated in those two median classes. Thus, for Scenario 4, 90.58% of the area was ranked in the two extreme classes either highly degraded or not degraded. Hence, increasing the weight of the average RMC potential rating influenced the ranking in a more attenuated way, whereas increasing the proximity criteria influenced the ratings in a more extreme way; that is, almost 90% of the area was rated as highly degraded and only 0.65% was rated as not degraded.

The locations of areas ranked as not degraded for riparian restoration in Scenario 2 and 3 are very similar although the extent varies between 53.56 hectares in Scenario 3 and 58.46 hectares in Scenario 2. In Scenario 2 and 3 areas ranked as not degraded occurred in the foothills only. However, in Scenarios 1 and 4, riparian areas classified as not degraded are only half of the extent than in Scenario 2 and 3, and are limited to areas close to already established restoration sites and freshwater ecosystems of national significance. It is very likely that, in Scenario 4, the relatively high rating for both proximity criteria (35% each) influenced this trend positively. A comparison of the resulting map (Map 09) with the locations of freshwater ecosystems of national significance (Map 04) and the restored areas (Map 05) supported this opinion. Hence, it is very likely that the chosen option of rating the criteria does not deliver accurate results and should not be used as basis for any restoration decision.

The area used for the application of stage two of the model, located along the Waihi River north of Geraldine in the Temuka Catchment, earned a ranking as highly to moderate degraded in stage one of the model. However, using the collected data from the onsite assessment provided a different classification at the onsite scale. The ranking varied from highly degraded for five grids, to having a moderate degradation for thirty-three grids, to having a low grade of degradation at eight grids. The reason for this is that every stage used different criteria aligned to the scale at which it operates. Such a discrepancy does not mean the model delivers inconsistent results. It is based on the use of different criteria for each of the two stages.

The pattern, illustrated in Map 10, of the two grids horizontally adjacent to each other with the same rating is based on the fact that when using the onsite assessment form, one form was often used for two grids if one grid was inaccessible or both grids together formed the riparian area for that 25 meter section of the river.

Not less important but not included in this model are economical, social and land ownership aspects. This model focuses on locating those areas with the highest biophysical and ecological potential for a restoration project. The other aspects such as economical factors or land ownership are not less important and should be taken into account at a later point of time; such as, after figuring out where the most potential areas from a biophysical and ecological point of view are located. Also, the question of accessibility is very important and should be taken into account at a later point of time. Once identified by modelling, restoration sites need to be visited onsite to determine any accessibility issues prior to a project being initiated.

Stage two of the model adopted a slightly modified version of Petersen's classifications (1992) to rank riparian areas. The slight modifications were that not all Petersen's criteria were taken into consideration, and class four in Petersen's classification which he described as areas to protect and monitor, were changed into areas not degraded for riparian restoration. The criteria for stage two of the model after Petersen's classification were also mixed with criteria from various other approaches, focusing on ecological restoration of riparian areas. Although initially developed for streams in lowland, agricultural areas and first applied in an agricultural province of Scania in southern Sweden, Petersen noted in 1994, that the Riparian, Channel and Environmental Inventory (RCE) classification also was successfully applied in an alpine area of Italy, and a mountainous area in the United States. Based on these findings and the successfully application in various landscapes, the decision was made to use this classification system and apply it for a catchment in New Zealand with similar landscapes. Nevertheless, the mixture of onsite criteria out of various approaches could be a possible source of error. Further research into onsite criteria selection would help to find the criteria that provide the most accurate results in the New Zealand context.

Criterion one, the average RMC potential rating, was an average value of all twelve assessed biophysical functions a one-hundred meter section of riparian areas can fulfil. Since the aim of this research was to locate the most potential sites for ecological restoration and not all twelve assessed functions are as important as others in regards of locating the sites with the most potential for ecological restoration, the application of an average rate for all twelve assessed values could be a possible source of error and decrease the appropriateness of the calculated classification. To overcome this error, one could focus on the biophysical functions which are most important for ecological restoration, and use an average value of those functions only.

This GIS-based decision support system can be a helpful tool to locate the most potential riparian areas for restoration at two spatial scales. However, the system has some limitations which differ depending on which stage of the model is being examined.

The assumption of an average 50m buffer for locating the riparian areas is an appropriate average value for doing this analysis on a catchment scale, but is too imprecisely as a basis for an onsite scale that stage two of the model uses. To overcome this limitation the width of the riparian area could also be assessed at the onsite scale. In do so, the crude assumption of a 50m width can be corrected to reflect the real extent of the riparian area at the assessed grids.

Another limitation is that the locations of areas with freshwater ecosystems of national significance and established restoration sites in the adjacent catchments are not considered in the model. Thus, the catchments' boundary becomes the boundary for any calculation. This limitation could be overcome by adding a buffer calculation of the catchment boundary into the model, which could also include the proximity of freshwater ecosystems and restoration sites located in adjacent catchments. Doing so would result in a more realistic analysis since catchments boundaries are not rigid boundaries for fauna and flora.

The positive influence riparian zones have on rivers are correlated to the width of the river. The wider the river, the less the impacts of riparian areas are. To implement this fact into stage one of the model, clipping out all rivers with a certain stream order (after Strahler's influence) could improve the usefulness of the model and reduce the calculating time of the model. Forsyth et al. (2005) recommended in their report for the Greater Wellington Regional Council to clip all rivers larger than 4th order, because they would be too wide to benefit from riparian restoration.

Stage two of the model has a methodologically limitation. Applying the DS Map Book software, which is free additional software for ArcGIS can help to increase detail at the onsite level. However, the software could not be included in the model builder for ArcGIS due to technological restraints. Generating the grids for the onsite assessment had to be done manually.

Accomplishing the onsite assessment revealed some limitations or possible sources of error. Finding the location of the grids based on the print-out map was sometimes difficult. A recommendation to overcome this limitation is to use a Global Positioning System (GPS) device to locate the grids digitally on the device and when in the field. This device also could help to minimise the source of human error by making the data entry (using digital forms for the assessment) and data transfer back into the GIS-based decision support system automatic. Furthermore the GPS device could store the maps digitally increasing the user-friendliness.

After the data entry of the onsite assessed criteria another limitation became obvious. The shapefile which stores the 25 by 25m grids and data for each criterion as attributes could be enhanced. Adding the data from the header of each assessment form as additional attributes can help to make stage two of the model more accurate. Otherwise it is very likely that this useful labelling information gets lost because it is not stored digitally.

Another limitation of stage two of the GIS-based decision support model was that some onsite criteria were not useful for an assessment of 25 by 25m grids as they were developed for an assessment of 100 meter sections or longer. One example was criterion seven, slope of the riverbank. The onsite assessment revealed that 100 % of all observed grids had a slope of the riverbank greater than 4 °. It is likely that this criterion distorted the accuracy of the results.

6 Conclusion

This research successfully implemented an ecological restoration problem into a GIS system. The developed GIS-based decision support system operated at two spatial scales and its model character provided the option to use it for various catchments in Canterbury, New Zealand. The research proved useful in terms of applying a GIS-based, multi-scaled model concept, in the Temuka Catchment to locate the most suitable riparian areas for restoration.

This research has the following implications. First, the research successfully demonstrated the use of GIS-based decision support system at two spatial scales. The multi-scaled approach provided the option to choose either using this GIS-based system to locate the most potential areas for riparian restoration on a catchments scale, down to a regional scale, while applying broad-scaled criteria to take into account the influential aspects of riparian areas. Applying the model at varying scales can be interesting for Regional Councils, District Councils, and other institutions or organisations which have to plan and make decisions on such differing ranges. Stage one of the model also allows users to apply the system to various catchments. The advantage of using this GIS-based decision support system is that different councils and regional groups accessing the support system gain results based on their regional criteria.

In contrast, the GIS-based system can be used to locate the most potential sites for riparian restoration at the onsite scale to facilitate local restoration efforts. This stage can be a useful decision support tool for farmers, restoration groups or interested people who want to restore riparian zones on their private property. Hence, the approach of a GIS-based decision support system for multiple scales, and the model character itself makes it a very useful tool.

However, as pointed out earlier it has limitations and sources of errors. Further research need to be done to make the model more sophisticated. The following paragraphs highlight suggestions for future research to improve the model and the accuracy of its results.

The modelling calibration and validation are the most important issues. Calibration and validation are essential in terms of testing the rules and parameters of the model, the accuracy of the results and finding out what are the most influential criteria either on a smaller scale, or on an onsite scale, to choose for getting the most accurate results.

The extent of the whole process of calibrating and validating models for such a complex ecosystem would have gone beyond the scope of a dissertation. The criteria selection at this stage of the model is based on literature and various classification and restoration approaches. Hence, further research in the fields of calibration, validation and criteria selection could improve the accuracy of the model. Such research must include field work to assess the characteristics and conditions of riparian areas in the catchment and compare it to the results of the model. The nomination of test sites, where the conditions in regards to the assessed criteria are known, could be the measurement for the level of accuracy of the model.

In terms of finding out what are the most influential onsite criteria, further research could reveal the accuracy of the chosen approach to use a modified version of Petersen's classification (1992). Does the chosen approach provide the most accurate results, or are there other more influential criteria that have not been identified? In general, more research in criteria selection at both scales could improve and enhance the usefulness of the model.

Another suggestion for an ongoing research question would be if the implementation of a criterion regarding the upstream conditions could improve the model and make its results more accurate. If so, how could the impact of upstream conditions be implemented into the model? From a catchments perspective, the upstream factors are essential to the health of the ecosystem. Any activity or change in geomorphic, hydrological, or biological (fauna and flora) processes can have large impacts on ecosystems further downstream. Hence, by recognising the upstream factor a more holistic model could result.

Finally this GIS-based decision support model can help to improve restoration efforts by locating the most suitable areas for riparian restoration at two scales but at its best, it is just a tool to facilitate restoration efforts and enhance the decision making process. But restoration in general and riparian restoration specifically, needs the support of the community and the local people as the most important part (I. Stäger, personal communication, June 30, 2006). Restoration processes take a lot of time and are ongoing projects that must include monitoring to establish a steady improvement in ecological health. With increased effort by community members, restoration efforts can secure high quality ecological results.

7 List of references

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8.1 Appendix A - Glossary

Cells: Cells in the RMC are an expression of how riparian sections were grouped regarding their assessed (current state) or calculated (potential) biophysical functions. Using cluster analysis and modelling procedures, the potential riparian functions were calculated which resulted in and twelve different cells. Sections were (based on their rating of biophysical functions) grouped into 12 cells which form three main groups. Each single cell contained assessed (current RMC rating) or calculated (potential RMC rating) sections of riparian areas based on their similar biophysical ratings.

Connectivity: A measure of how spatially continuous a corridor or matrix is. This function is influenced by breaks or gaps along a stream corridor which include the stream and its riparian areas, and between the corridor and the adjacent upland land uses (Forman and Godron, 1986; cited in (US Federal Interagency Stream Restoration Working Group, 1998a).

Denitrification: Most nitrates in riparian groundwater are returned to the atmosphere by the microbial process called "denitrification" (Environment Canterbury, 2005) Denitrification is a chemical process by which bacteria reduce nitrate to nitrous oxide and N_2 gases that are lost to the atmosphere, providing permanent N removal from the water (Hill, 1996; Willems et al. 1997; cited in (Quinn, 2003).

Ecotones: Ecotones are landscape boundaries connecting different ecosystems. An ecotonal community commonly contains many of the organisms of each of the overlapping communities. The tendency of having an augmented variety and density at community junctions is known as the "edge effect" (Odum, 1971; cited in (Holland et al., 1991) , p. 1).

Geographic Information Systems (GIS): GIS are computer based information systems. They are useful tools helping to store, manage, and display digital geographic (spatial) data and information, as well as non-spatial data and information in the form of attributes. GIS allows for the performance of operations, such as spatial analysis, on geographic data to reveal new and underlying information that is otherwise invisible. Based on this functionality, GIS models can be used as a spatial decision support system and therefore help to solve geographic or spatial real-world problems (Longley et al., 2005). This wide functionality makes GIS highly complex, though its components are well-defined. A GIS consists of six essential parts; people, hardware, software, data (databases), procedures and the internet acting as a connecting network that links the five previous components (Figure 12).

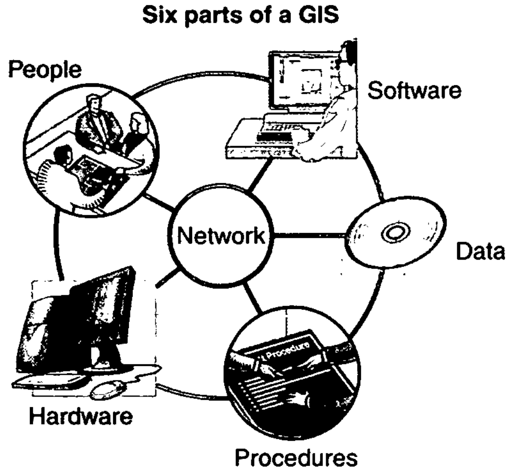


Figure 12 illustrates the six component parts of a GIS (Longley et al., 2005)

Habitat: By its definition habitat describes an area where fauna (including people) or flora normally live, grow, feed, reproduce, and otherwise exist for any portion of their life cycle. Habitats provide the necessary elements of life, such as space, food, water and shelter.

Macrophytes: In general, macrophytes are aquatic plants growing in or near lakes, ponds, and rivers. The common classifications for the wide range of such plants include: emergent (rooted in the bottom and extending out of water), submerged (rooted in the bottom but not extending out of the water), floating (rooted in the bottom with leaves floating on the surface of the water), and free-floating (not rooted in the bottom and leaves floating on the surface). Macrophytes provide cover for fish, and substrates for aquatic invertebrates (United States Environmental Protection Agency, 2006)

Macropores: Using the size or diameter of soil pores is a very simple but common classification approach. This approach classifies soil pores into micropores (less than a micrometer in width), capillary pores (from several micrometers to a few millimetres) and macropores (several millimetres to centimetres). Macropores are a result of biological activity such as burrowing animals like earthworms, and the presence of decayed roots in all types of soils. Macropores also occur from cracks or fissures in clayey soils drying out, thus having a decisive impact on various flow phenomena, such as infiltration, drainage, and the transport of solutes in saturated or near-saturated conditions (Hillel, 1998).

NZERN: New Zealand Ecological Restoration Network (NZERN) is a non-profit, community-driven organisation dedicated to sharing knowledge and experiences about native habitat protection, management and ecological restoration in Aotearoa (Land of the long white cloud) – New Zealand. Amongst other services NZERN has also started to provide Geographic Information Systems (GIS) to community restoration groups.

Riparian: The word riparian originates from the Latin word *riparius* and has the meaning "of or belonging to the bank of a river" (Naiman et al., 2005).

Shapefiles: A shapefile is a dataset that contains both spatial/geographic data, *vector data*, in the form of points, lines, and polygons, and non-spatial data in form of attribute tables. This file format is used in ArcGIS software developed by ESRI (McCoy, 2004).

Stream Order (after Strahler, 1957): This is a classification method for rivers in a catchment regarding their hierarchy. Headwater channels with no upstream tributaries are designated as 1st order streams until they join another stream further downstream. A 2nd order stream is the result of the confluence of two 1st order streams. Third order streams are the result of the confluence of two 2nd order streams. A confluence of a channel with a stream of lower order does not raise the order of the stream below their intersection. Knowing the order of a stream gives some information about the river section, such as which longitudinal zone it resides in, and the relative channel size and depth (US Federal Interagency Stream Restoration Working Group, 1998a).

KaiTiaki: Kaitiaki can be one person, or collectively guarded by a tribe, with different roles for individuals in guarding a particular natural resource.

Vector based model: A vector based model uses points, lines, and polygons to spatially represent the world. It is more useful in GIS models for storing data that has discrete boundaries, such as country borders, land parcels, and streets (McCoy, 2004).

8.2 Appendix B – Flowchart of stage one of the model

Please, find the flowchart of stage one of the model as poster attached at the inside of the hardcopy cover of the dissertation (Diplomarbeit).

8.3 Appendix C - Flowcharts of the sub models

Please, find the flowchart of the five sub models as poster attached at the inside of the hardcopy cover of the dissertation (Diplomarbeit).

8.4 Appendix D - Assessment form for the onsite assessment

Please, find the onsite assessment form attached at the inside of the hardcopy cover of the dissertation (Diplomarbeit).

Assessment Number: ____________ **GRID Number:** ________________________

Date: ________________________ **Assessed by:** ___________________________

Name of the catchment: ____________________________

Name of the river: _________________________________

Location: ____

____

Feedback for improvements, limitations, problems: ____

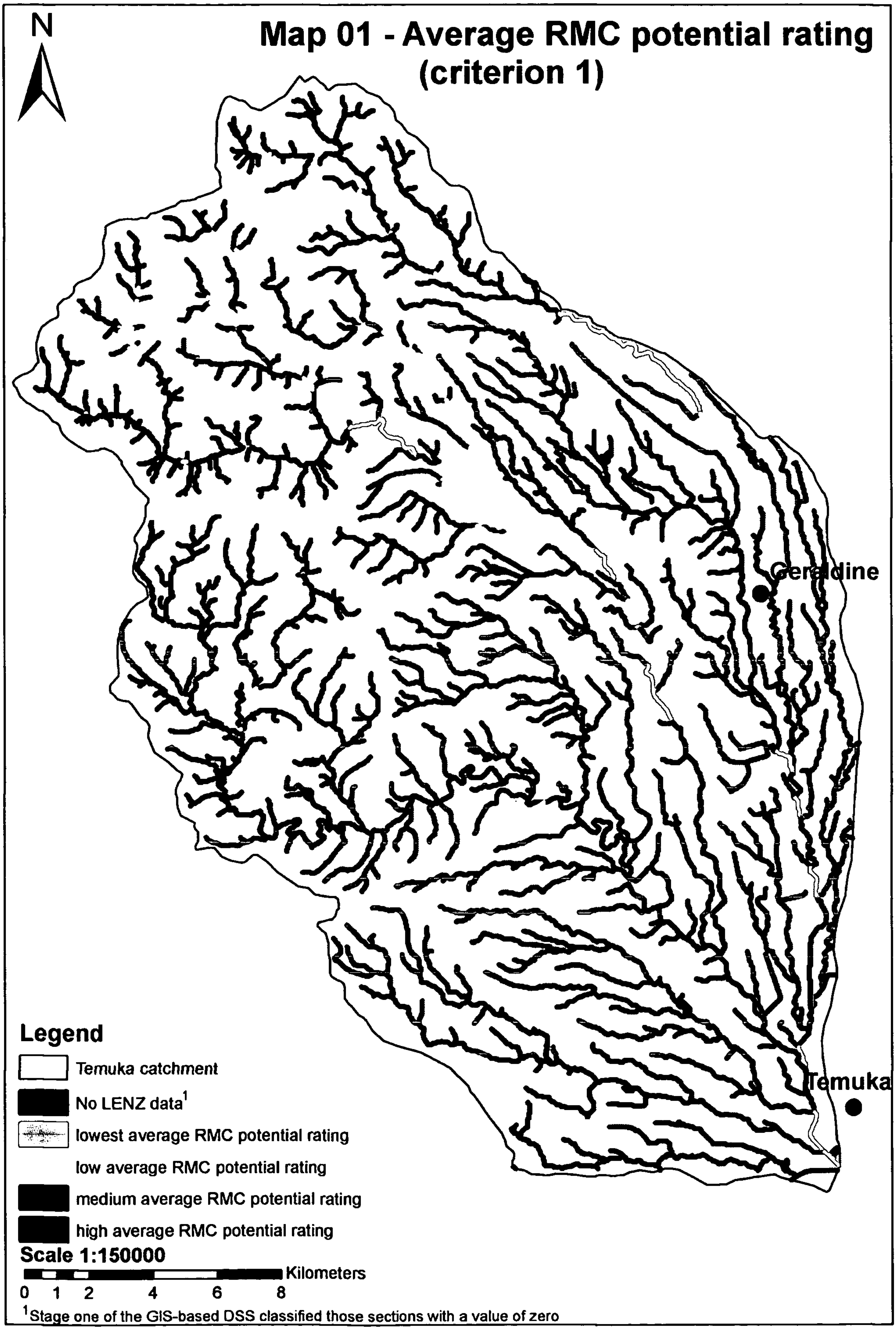
____

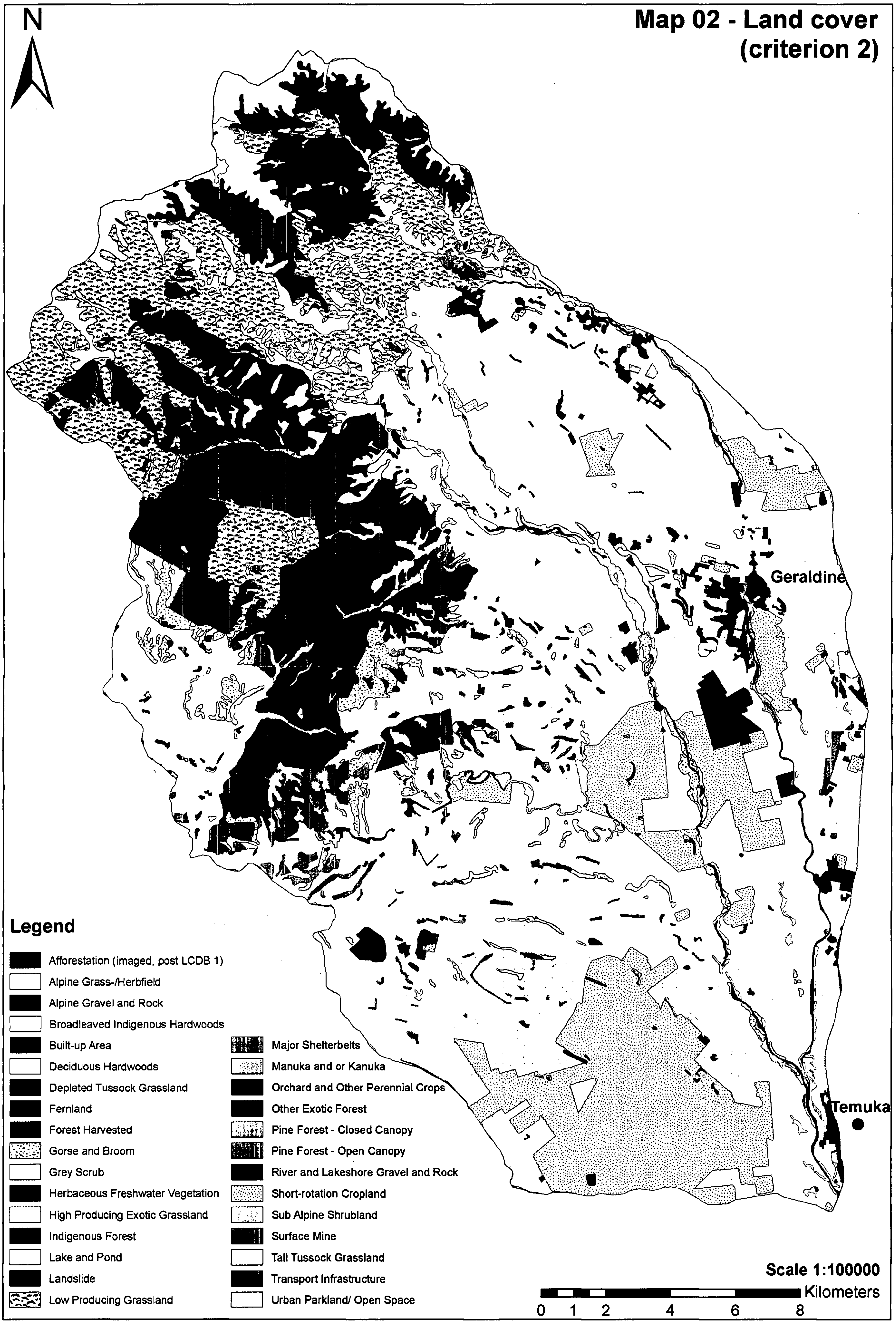
____

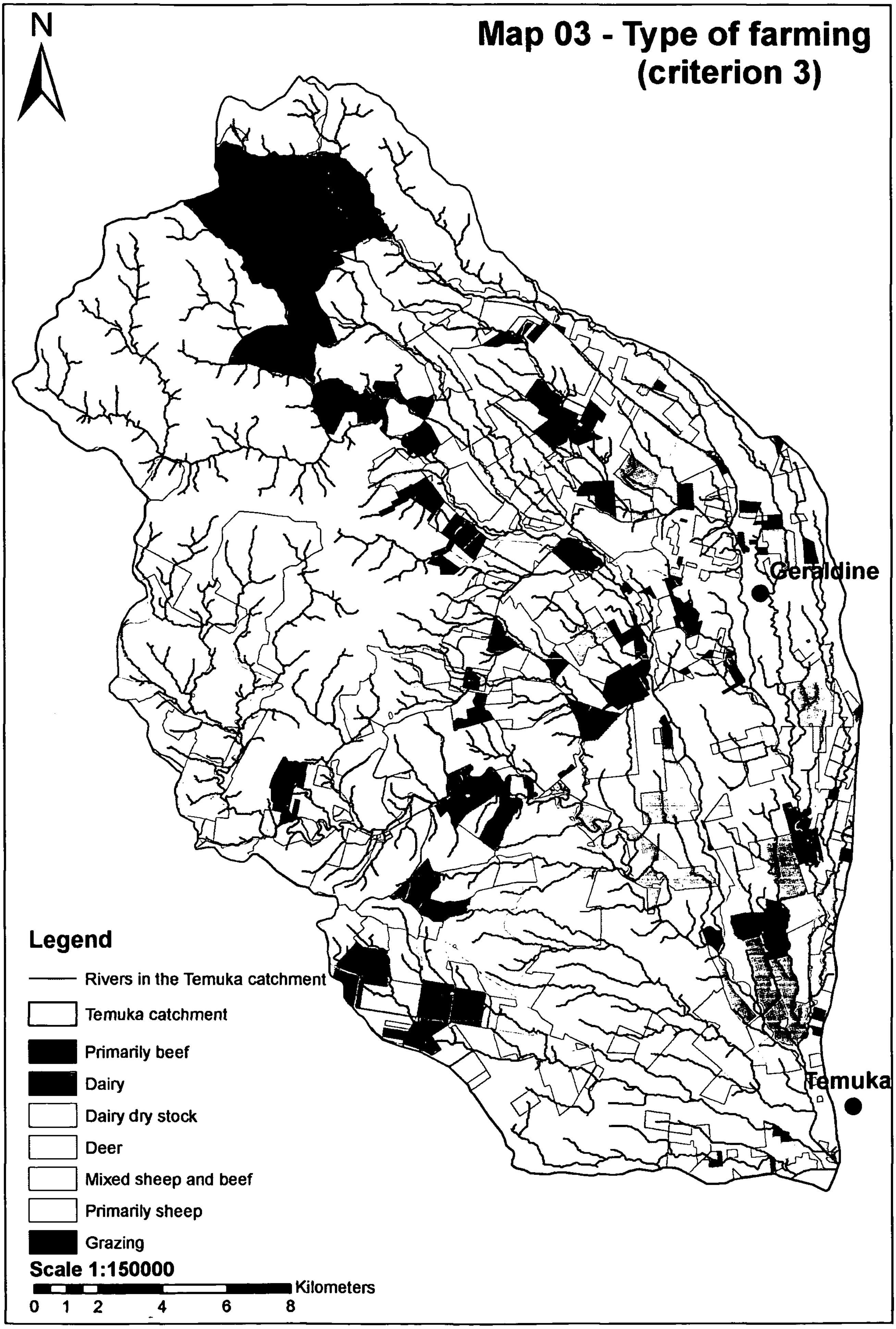
Number	Criteria/Parameter	Description	Rating for classes	Assessed rating
1	Channel or stream form	Thread: single (steep: > 10 %, no sinuosity)	25	
		Thread: single (less steep: 4 – 10 %, small sinuosity, sometimes little meandering)	15	
		Thread multiple – braided (gentle: < 4 %, meandering)	5	
		Thread multiple – anastomosed (gentle: < 4 %, meandering low to high)	1	
2	Channel structure (channel width to depth ratio)	< 12 W/D ratio	25	
		12 to 25 W/D ratio	15	
		26 to 40 W/D ratio	5	
		> 40 W/D ratio	1	

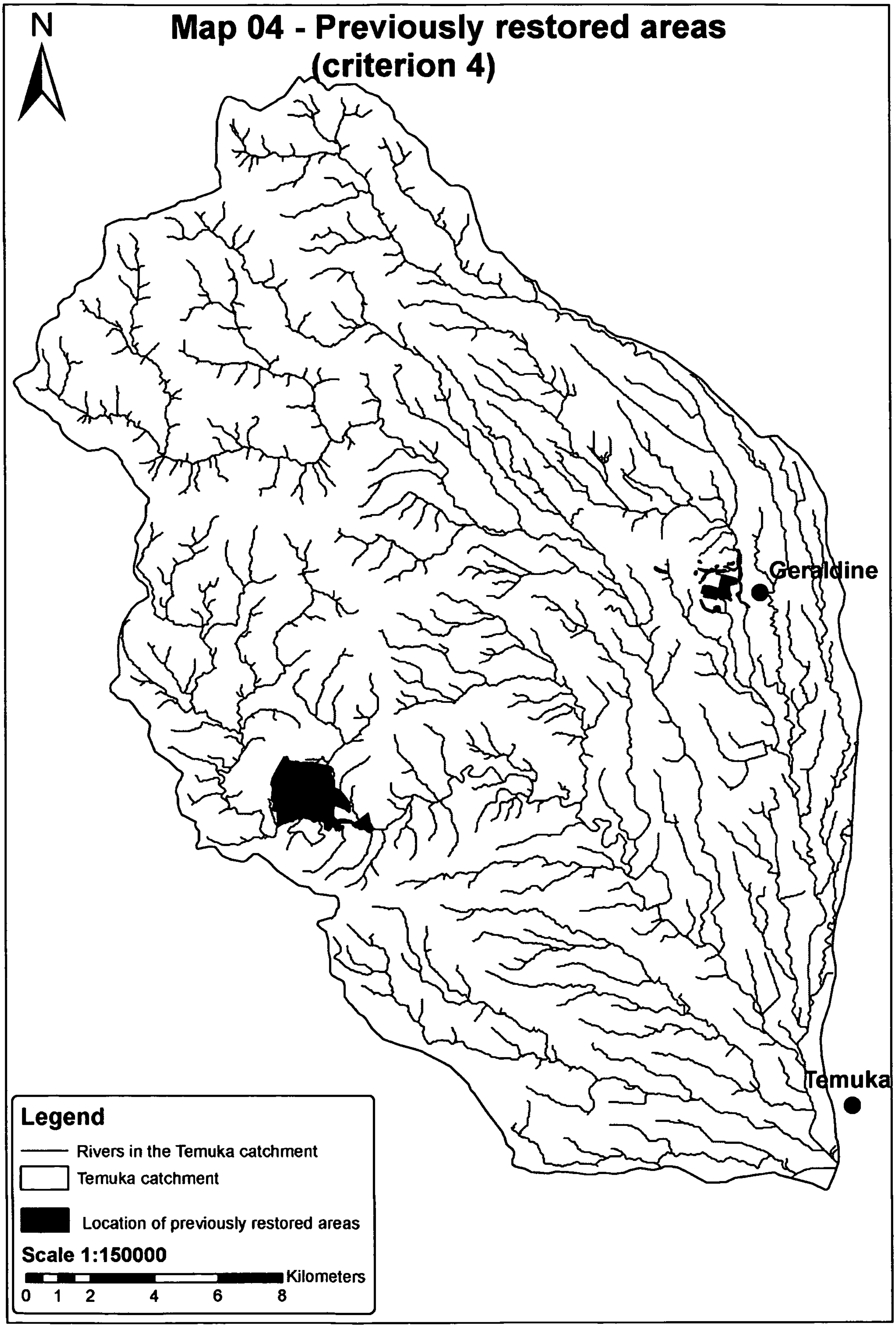
3	Local land use of the adjacent upland	Undisturbed, consisting of forest, natural wetlands, bogs and/or mires	30	
		Permanent pasture mixed with woodlots and swamps, few row of crops	20	
		Mixed row of crops and pasture	10	
		Mainly row crops	1	
4	Width of the riparian zone from stream edge to field	Marshy or woody riparian zone > 30 m wide	30	
		Marshy or woody riparian zone varying from 5 to 30 m	20	
		Marshy or woody riparian zone 1 to 5 m	5	
		Marshy or woody riparian zone absent	1	
5	Completeness of riparian zone	Riparian zone intact with very small breaks in vegetation (Lateral and longitudinal)	30	
		Breaks occurring at intervals of > half the length of the grid used for assessment	20	
		Breaks frequent with some gullies and scars every half of the length of the grid used for assessment	5	
		Deeply scarred with gullies or other types of breaks along its length	1	
6	Vegetation of riparian zone within 10 m of channel	> 90 % plant density on non-pioneer trees or shrubs, or native marsh plants	25	
		Mixed pioneer species along channel and mature trees behind	15	
		Vegetation of mixed grasses and sparse pioneer tree or shrub species	5	
		Vegetation consisting of grasses, few trees and shrubs	1	

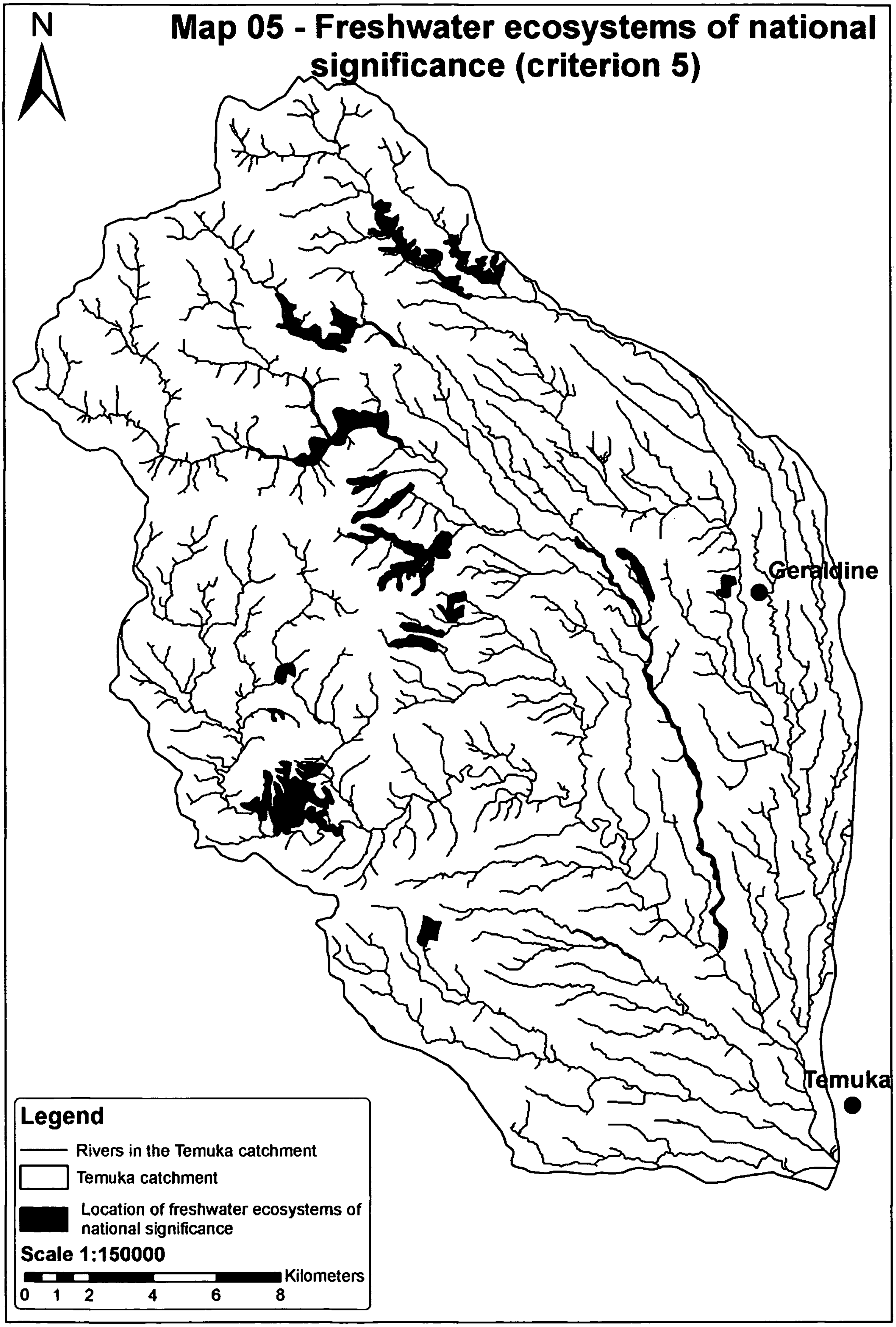
7	Slope of the riverbank	< 1°	20	
		1° – 2°	10	
		2° – 4°	5	
		> 4°	1	
8	Bank undercutting (Grade of erosion)	Little or none evident or restricted to areas with tree root support	20	
		Cutting only on curves and at constrictions	15	
		Cutting frequent, undercutting of banks and roots	5	
		Severe cutting along channel, banks falling in	1	
9	Stream bank structure	Banks stable, of rock and soil held firmly by grasses, shrubs and tree roots	25	
		Banks firm but loosely held by grass and shrubs	15	
		Banks loose soil held by a sparse layer of grass and shrubs	5	
		Bank unstable, of loose soil or sand easily disturbed	1	
10	Riffles and pools or meanders (sinuosity)	Distinct, occurring at intervals of 5-7x stream width	25	
		Irregularly spaced	20	
		Long pools separating short riffles, meanders absent	10	
		Meanders and riffles/pools absent or stream channelised	1	
11	Fencing existent to prevent stock access to riparian area	Fencing along the whole grid unit	30	
		No fencing along the grid unit	1	
			TOTAL	

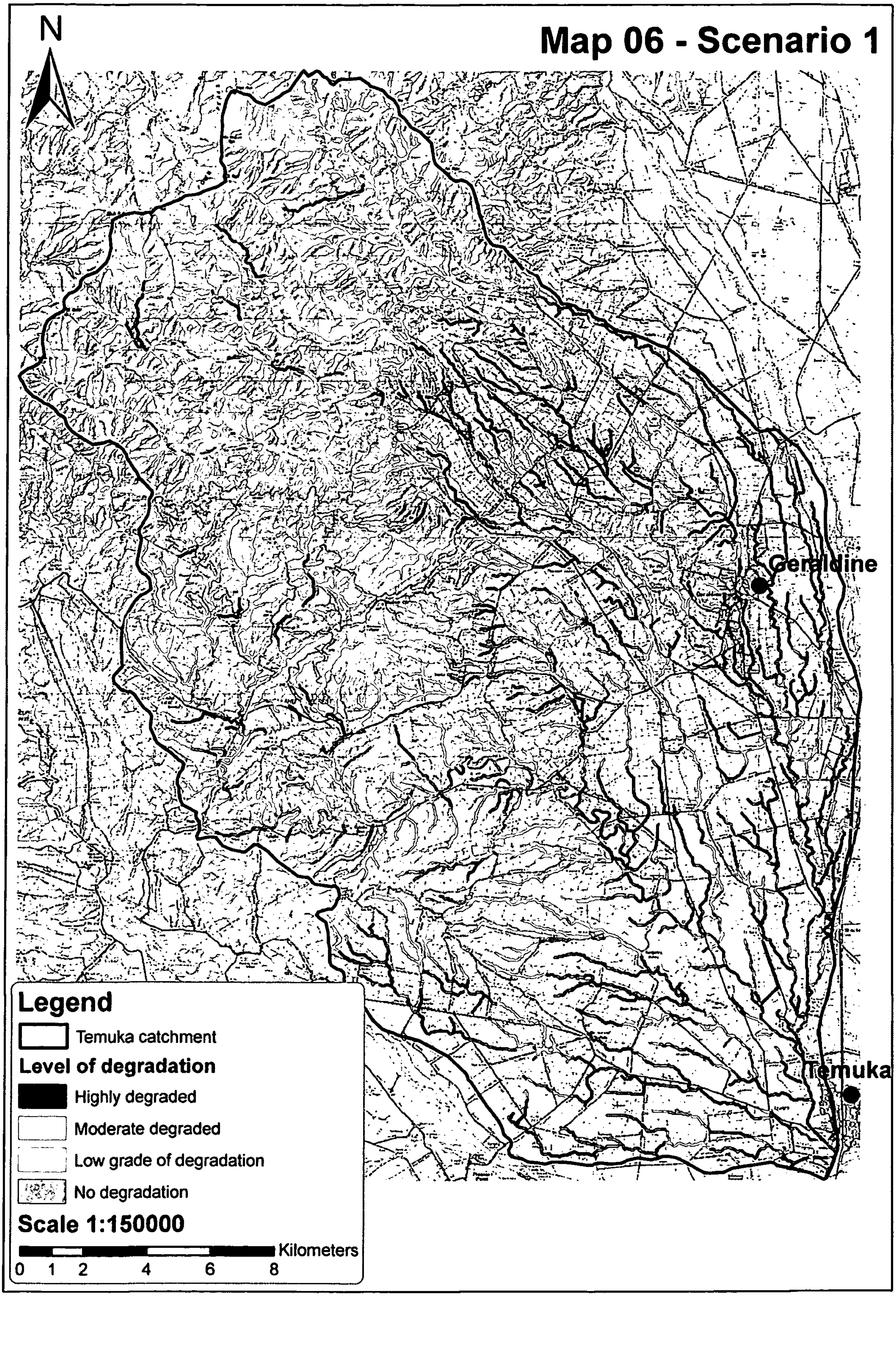

N
Map 01 - Average RMC potential rating (criterion 1)
Geraldine
Temuka
Legend
Temuka catchment
No LENZ data[1]
lowest average RMC potential rating
low average RMC potential rating
medium average RMC potential rating
high average RMC potential rating
Scale 1:150000
0 1 2 4 6 8 Kilometers
[1]Stage one of the GIS-based DSS classified those sections with a value of zero


N
Map 02 - Land cover
(criterion 2)
Geraldine
Temuka
Legend
Afforestation (imaged, post LCDB 1)
Alpine Grass-/Herbfield
Alpine Gravel and Rock
Broadleaved Indigenous Hardwoods
Built-up Area
Deciduous Hardwoods
Depleted Tussock Grassland
Fernland
Forest Harvested
Gorse and Broom
Grey Scrub
Herbaceous Freshwater Vegetation
High Producing Exotic Grassland
Indigenous Forest
Lake and Pond
Landslide
Low Producing Grassland
Major Shelterbelts
Manuka and or Kanuka
Orchard and Other Perennial Crops
Other Exotic Forest
Pine Forest - Closed Canopy
Pine Forest - Open Canopy
River and Lakeshore Gravel and Rock
Short-rotation Cropland
Sub Alpine Shrubland
Surface Mine
Tall Tussock Grassland
Transport Infrastructure
Urban Parkland/ Open Space
Scale 1:100000
Kilometers
0 1 2 4 6 8

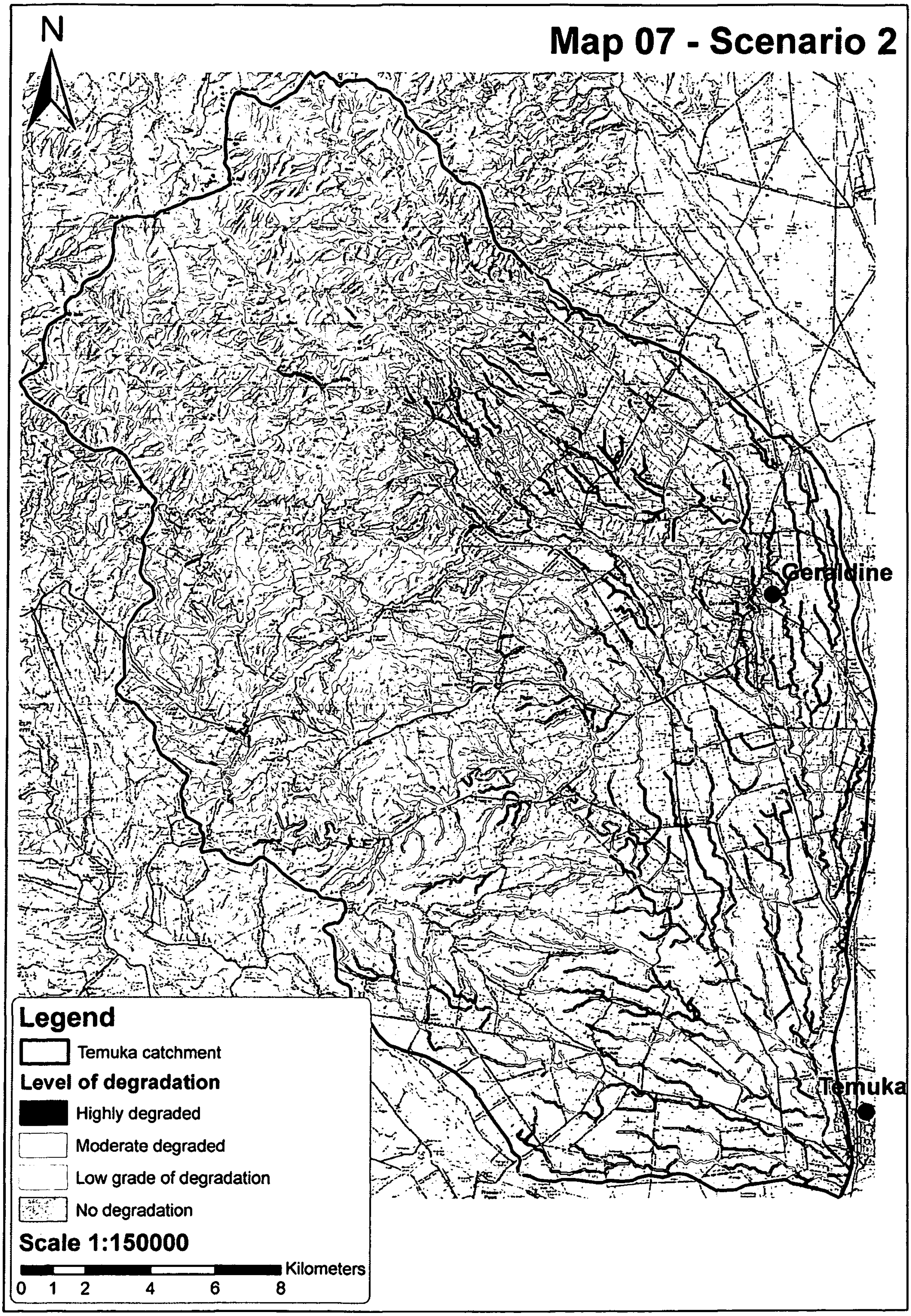

Map 03 - Type of farming (criterion 3)
N
Geraldine
Temuka
Legend
Rivers in the Temuka catchment
Temuka catchment
Primarily beef
Dairy
Dairy dry stock
Deer
Mixed sheep and beef
Primarily sheep
Grazing
Scale 1:150000
Kilometers
0 1 2 4 6 8


N
Map 04 - Previously restored areas
(criterion 4)
Geraldine
Temuka
Legend
Rivers in the Temuka catchment
Temuka catchment
Location of previously restored areas
Scale 1:150000
Kilometers
0 1 2 4 6 8

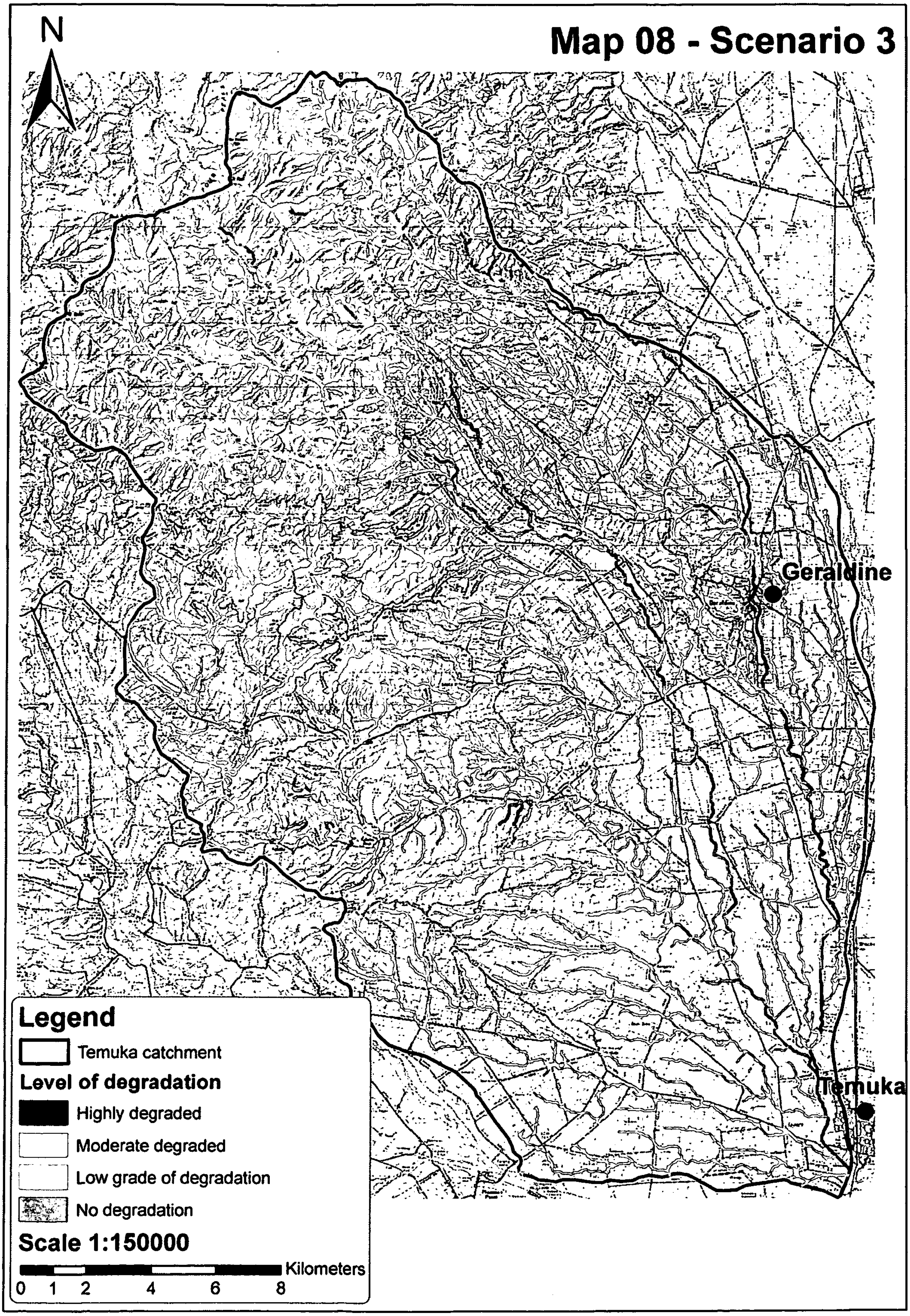

N
Map 05 - Freshwater ecosystems of national significance (criterion 5)
Geraldine
Temuka
Legend
Rivers in the Temuka catchment
Temuka catchment
Location of freshwater ecosystems of national significance
Scale 1:150000
Kilometers
0 1 2 4 6 8

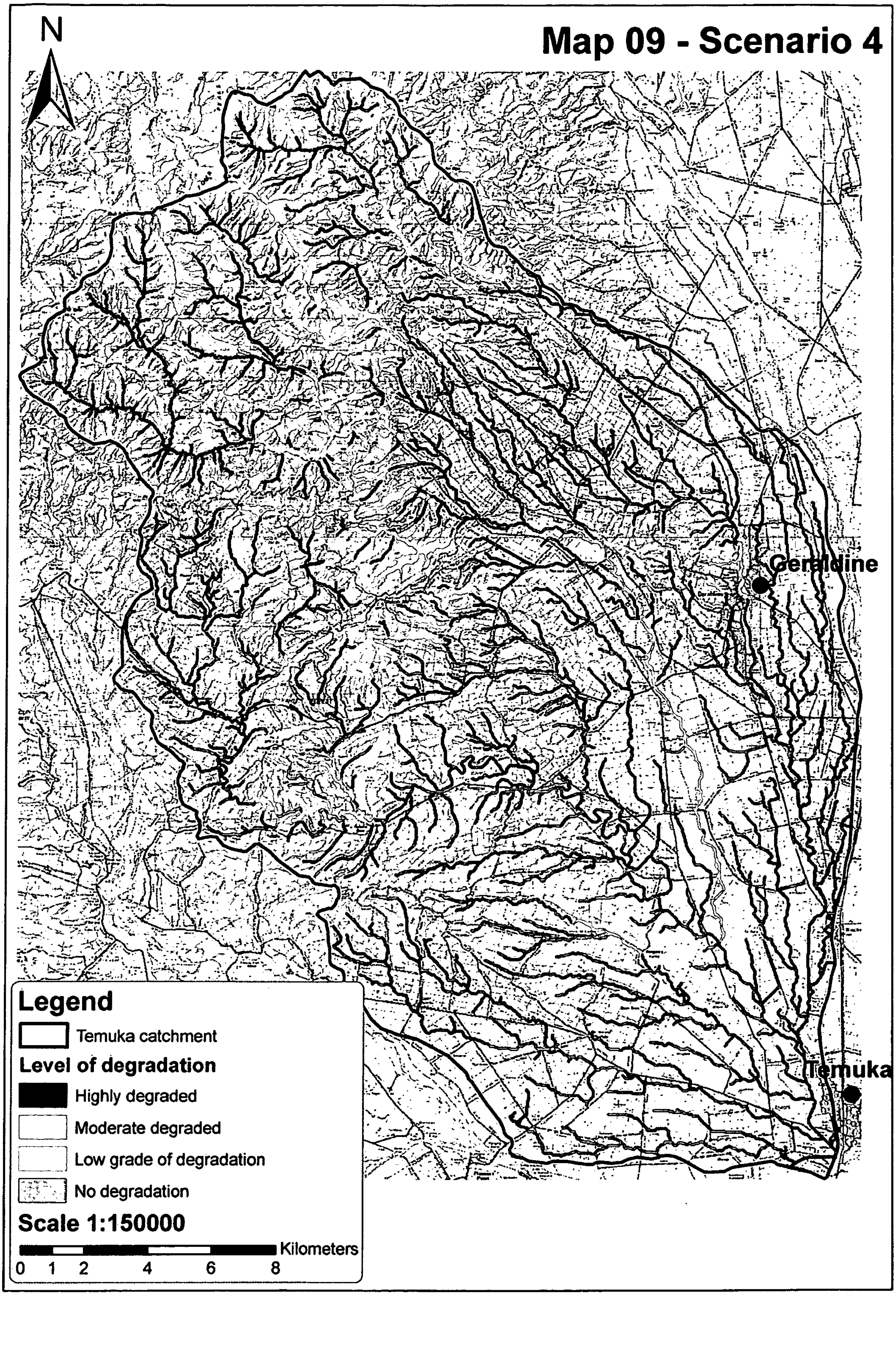


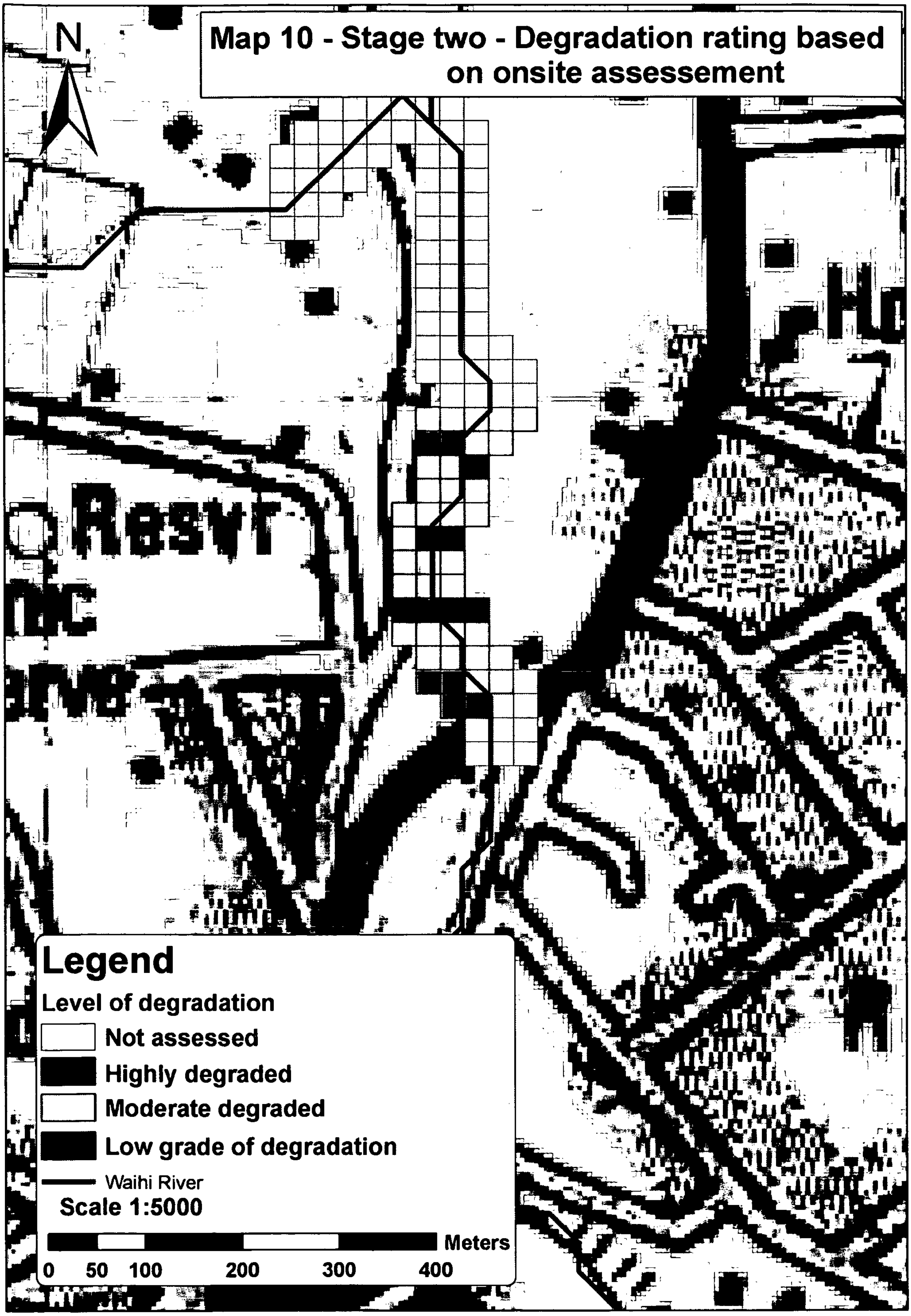
N
Map 06 - Scenario 1
Geraldine
Temuka
Legend
Temuka catchment
Level of degradation
Highly degraded
Moderate degraded
Low grade of degradation
No degradation
Scale 1:150000
Kilometers
0 1 2 4 6 8



N
Map 07 - Scenario 2
Geraldine
Temuka
Legend
Temuka catchment
Level of degradation
Highly degraded
Moderate degraded
Low grade of degradation
No degradation
Scale 1:150000
Kilometers
0 1 2 4 6 8

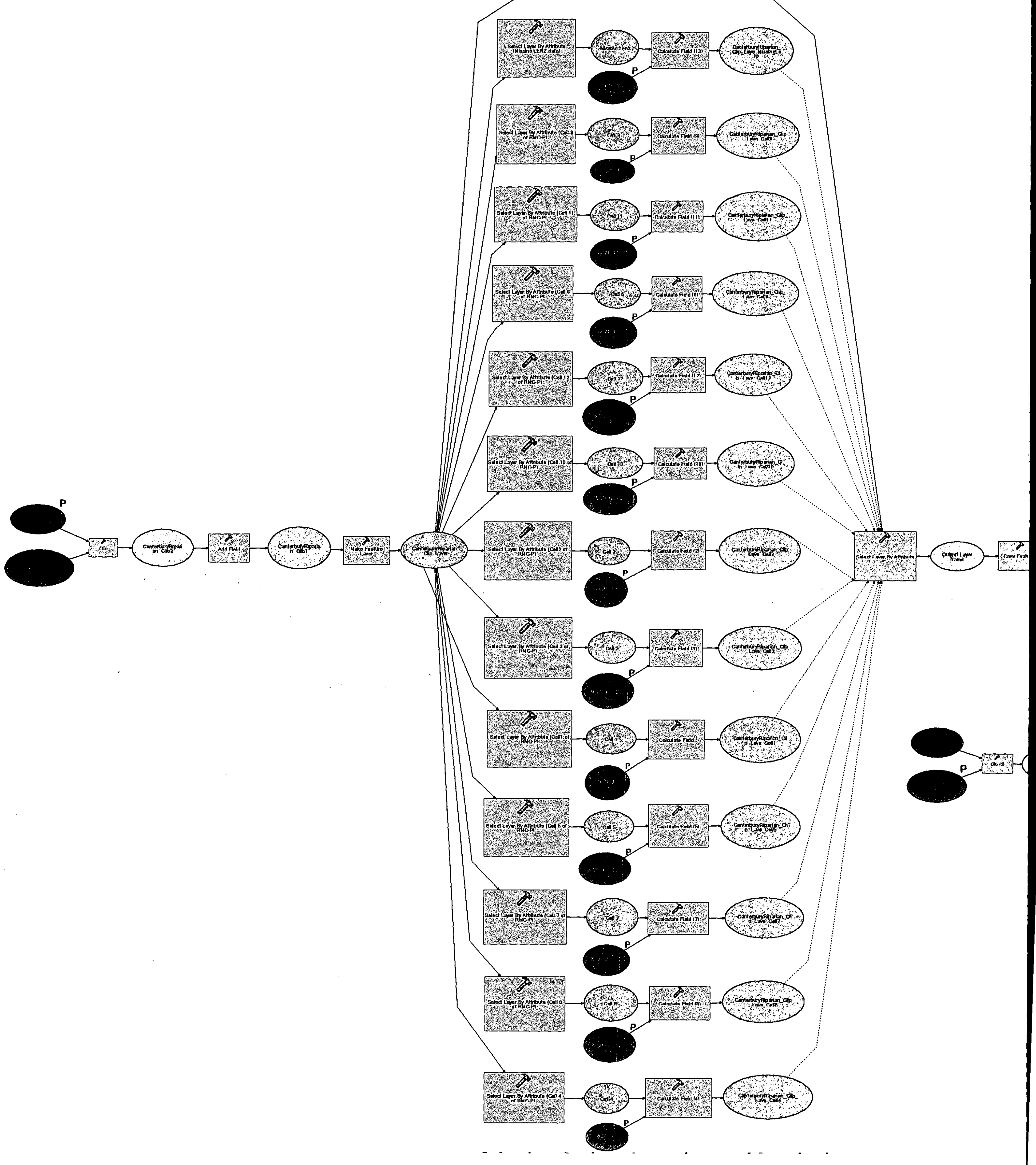

N
Map 08 - Scenario 3
Geraldine
Temuka
Legend
Temuka catchment
Level of degradation
Highly degraded
Moderate degraded
Low grade of degradation
No degradation
Scale 1:150000
Kilometers
0 1 2 4 6 8


N
Map 09 - Scenario 4
Geraldine
Temuka
Legend
Temuka catchment
Level of degradation
Highly degraded
Moderate degraded
Low grade of degradation
No degradation
Scale 1:150000
Kilometers
0 1 2 4 6 8

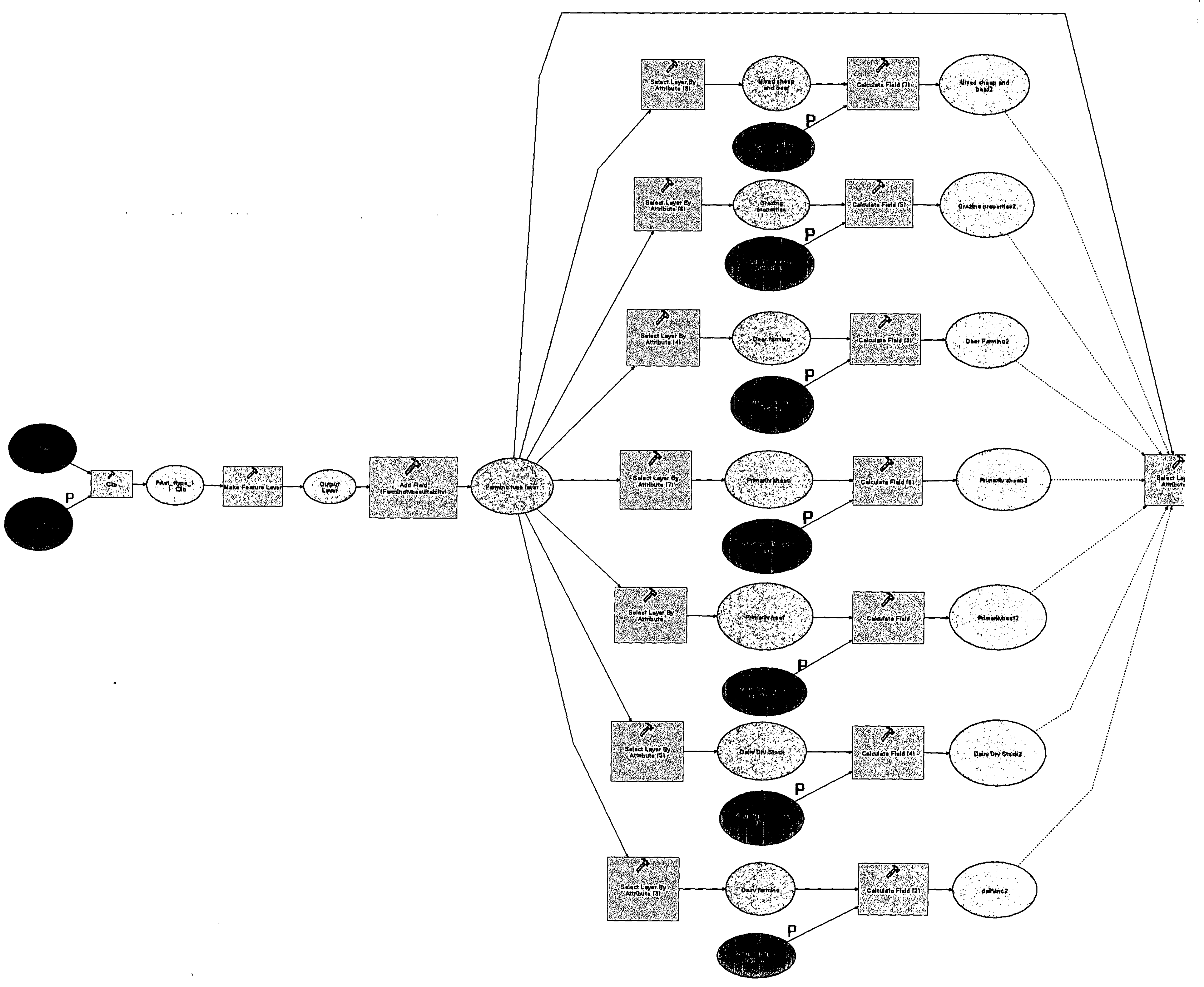

N
Map 10 - Stage two - Degradation rating based on onsite assessement
Resvr
Legend
Level of degradation
Not assessed
Highly degraded
Moderate degraded
Low grade of degradation
Waihi River
Scale 1:5000
Meters
0 50 100 200 300 400

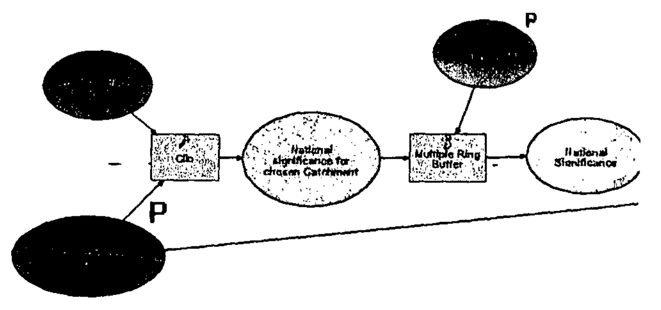
Stage one of the GIS-based decision support model

Sub model for Criterion 1 – The average RMC potential rating

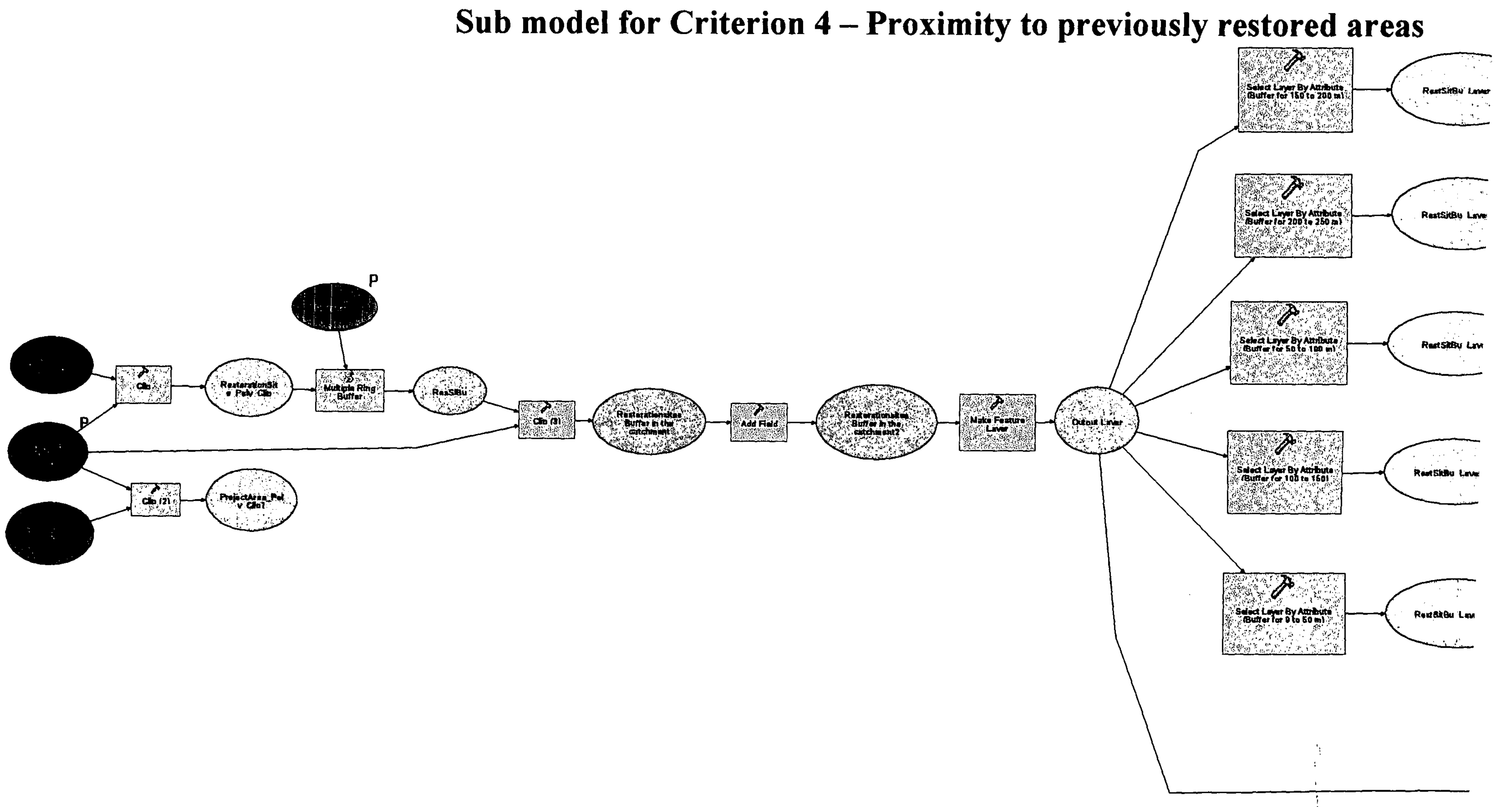


Sub model for Criterion 3 – Land use (type of farming)

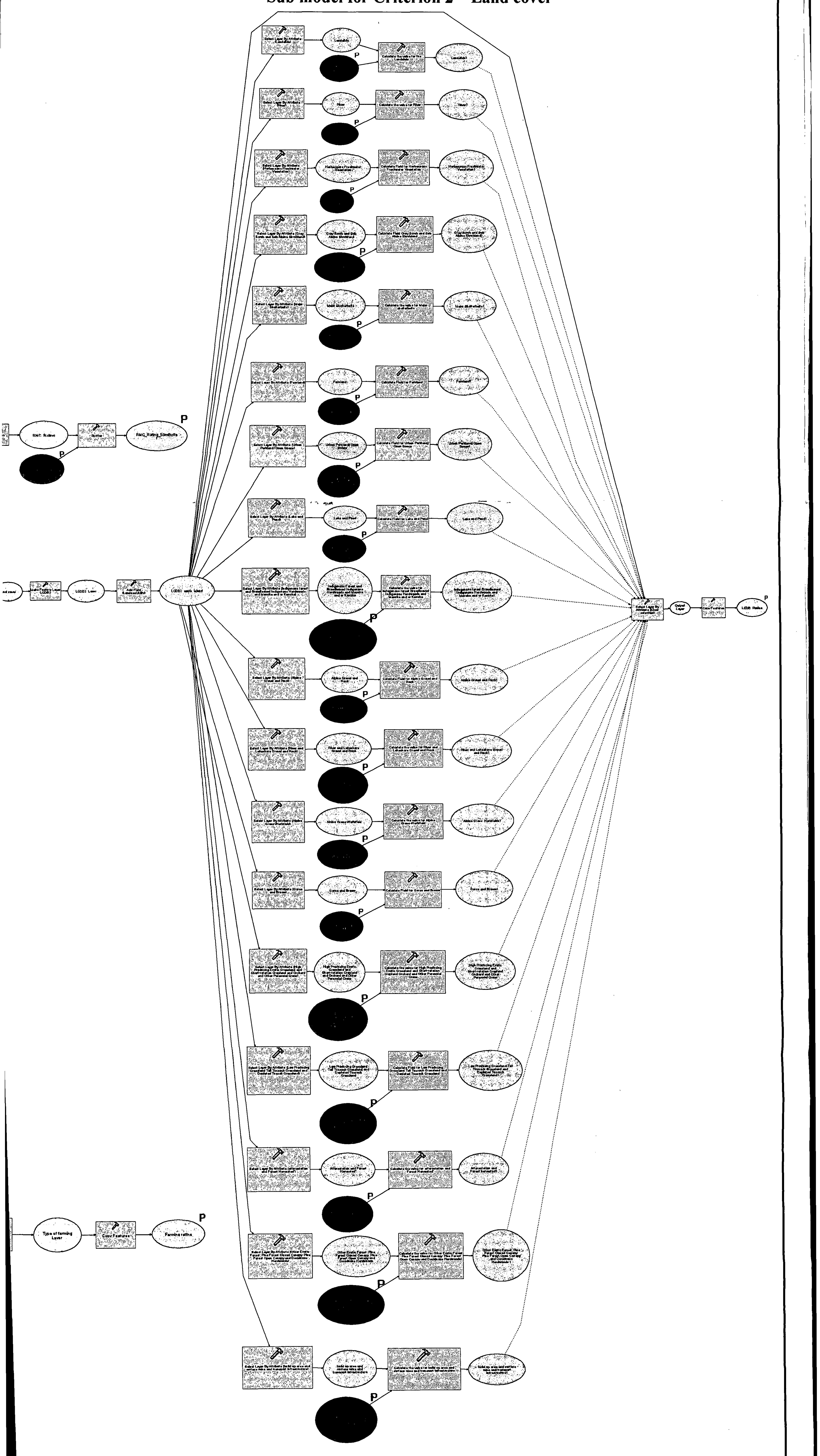




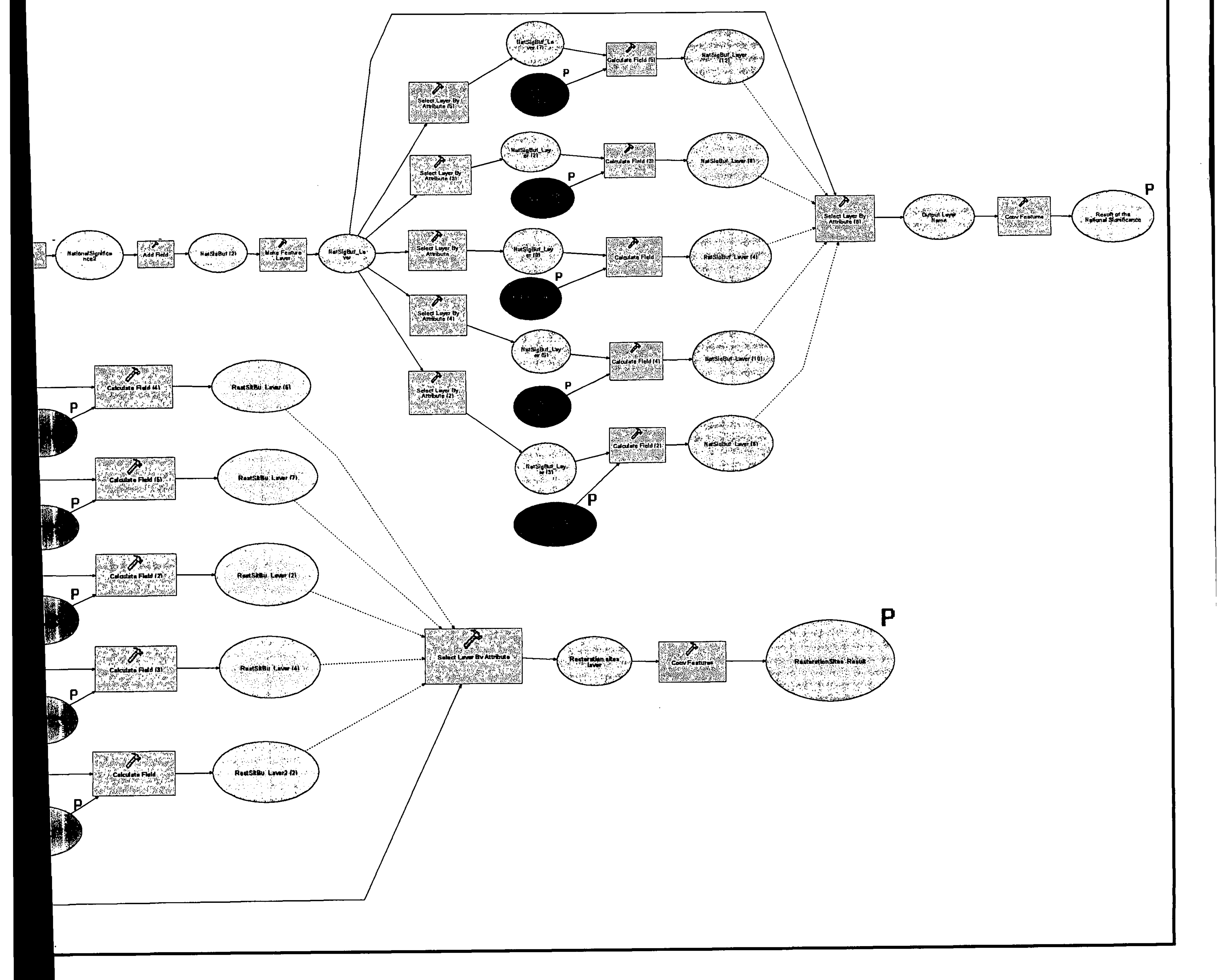
Sub model for Criterion 4 – Proximity to previously restored areas



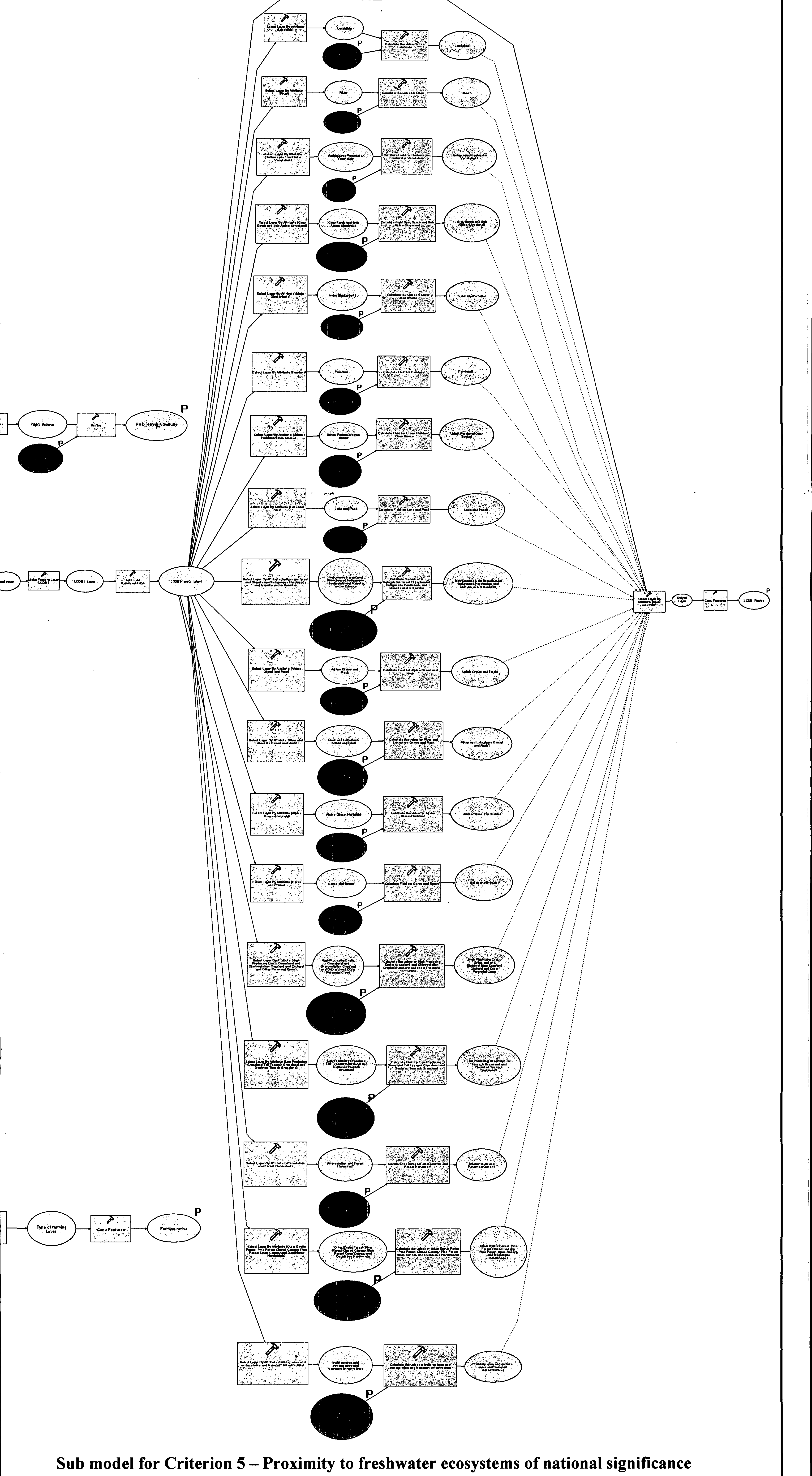
Sub model for Criterion 2 – Land cover



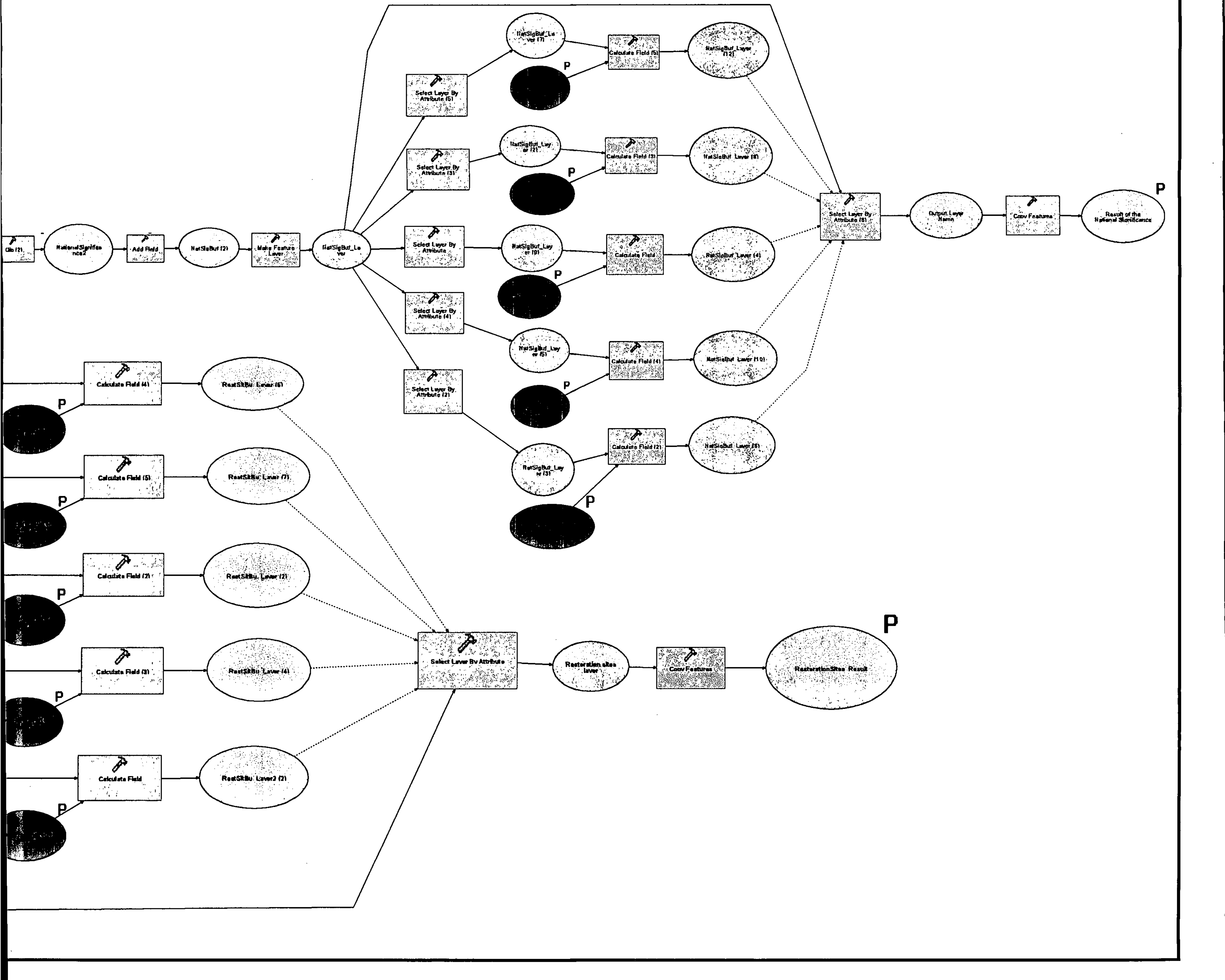
Sub model for Criterion 5 – Proximity to freshwater ecosystems of national significance



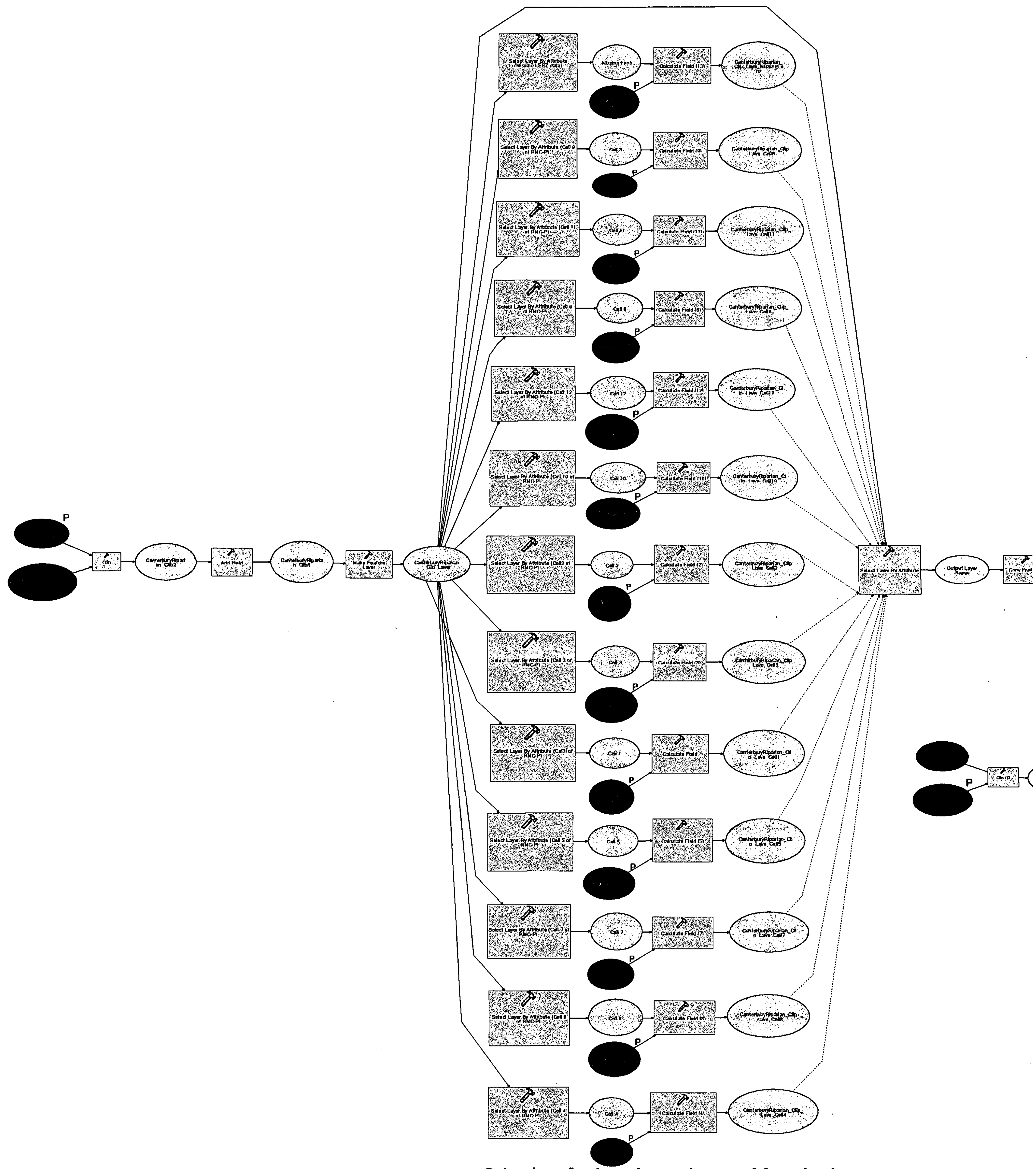
Sub model for Criterion 2 – Land cover



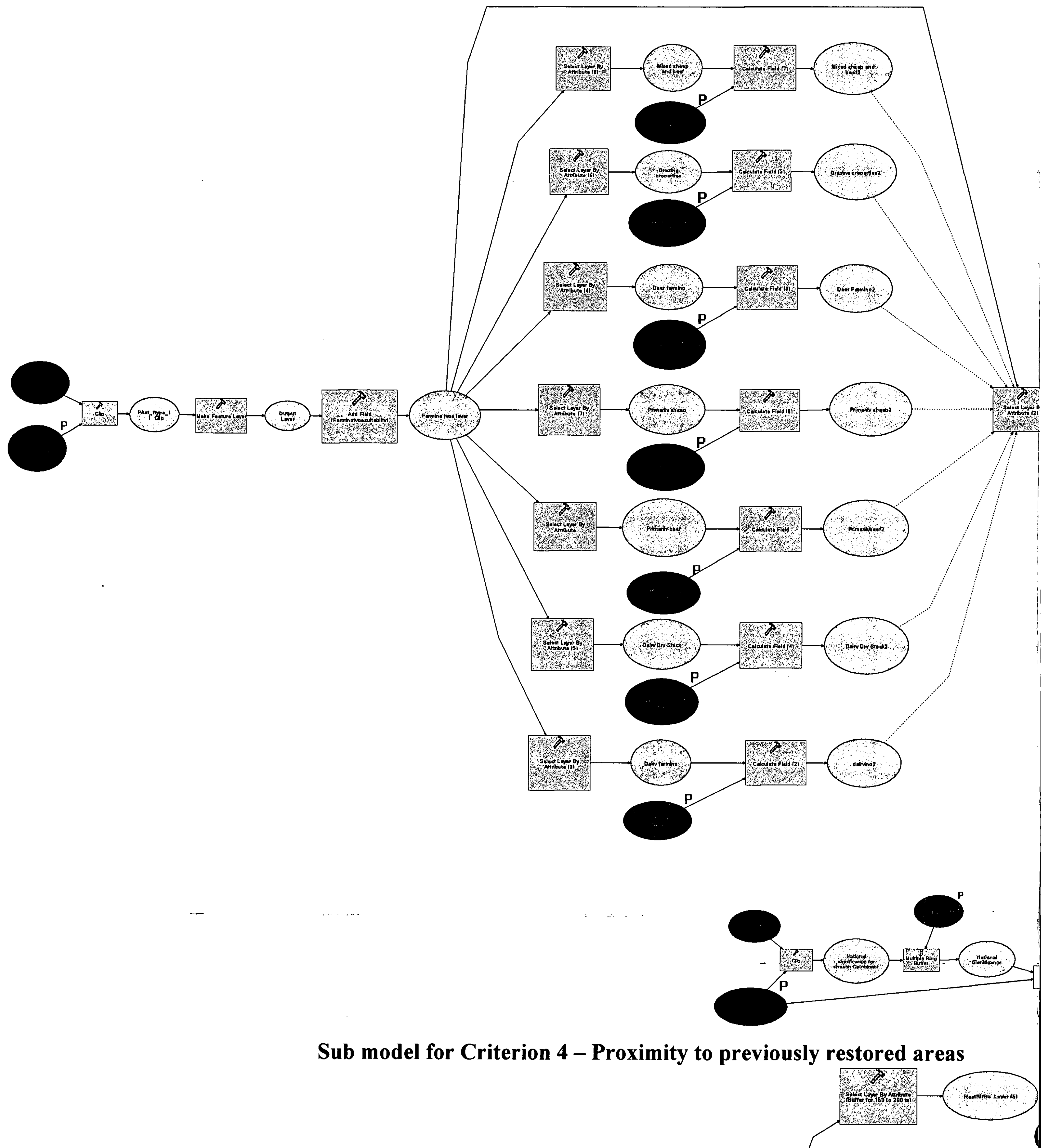
Sub model for Criterion 5 – Proximity to freshwater ecosystems of national significance

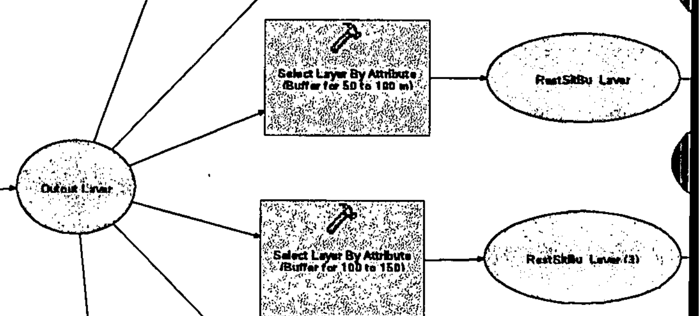


Sub model for Criterion 1 – The average RMC potential rating



Sub model for Criterion 3 – Land use (type of farming)





Sub model for Criterion 4 – Proximity to previously restored areas