# Hill country erosion: a review of knowledge on erosion processes, mitigation options, social learning and their long-term effectiveness in the management of hill country erosion

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## Summary Final Report – Operation Research 2007/2008

**Project Code:** 6822010028

**Business/Institution:** Landcare Research

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**Programme Title:** Commercial Catchment

**Goal:** To review existing knowledge on the prevention, treatment and management of hill country erosion.

**Context of the project:**
Landcare Research, in collaboration with AgResearch, HortResearch and the University of Auckland, was contracted by MAFPolicy to review existing knowledge on the prevention, treatment and management of hill country erosion. The scope of the review included: sources and flows of sediment; management practices, and their long-term management, used in the treatment of erosion; social learning and adaptation to treating and managing hill country erosion. The project also sought to identify gaps in existing knowledge and future research requirements.

**Approach:**
An inventory and synthesis of existing knowledge and current work on erosion processes, mitigation options, and social learning in the management of hill country erosion was compiled. Regional councils, key industry groups (farming and forestry), central government agencies, universities and Crown Research Institutes were surveyed to access information on unpublished literature, current research and research capability, sources used to provide management information, experience with social learning and adaptive management, and individual views on information gaps and research needs.

**Recommendations:**
**Future research needs:** A survey of regional councils, industry, central government agencies and science providers identified a wide variety of research needs to assist improved management of hill country erosion. Gaps identified by the greatest number of stakeholders included:

- ability to measure regional/catchment rates of erosion and determine what is tolerable, including measuring the contribution from different land uses and land management practices, being able to distinguish natural and induced erosion, and the contribution of different processes
- integrated research on sediment dynamics (connectivity and lags) within catchments and downstream effects, including slope–channel linkages
- development of erosion prediction tools/models incorporating land use/management effects and able to distinguish different erosion processes

- effectiveness of space-planted trees (including willows, poplars and natives) for erosion control and their management requirements, and other erosion control measures, over a range of event magnitudes
- cost–benefit analysis of different mitigation techniques including co-benefits of erosion control on carbon storage, role of erosion in the carbon budget
- effective community engagement processes for erosion and catchment management, and improved technology transfer.

**Summary:**

**Hill country description:** Hill country was defined as including
*'all lowland and montane hill and steeplands (slope >15°), classified as land use capability (LUC) class 5, 6, or 7, and being described in the unit descriptions in the New Zealand Land Resource Inventory as hill country'.*
This land is widely accepted as capable of sustainable pastoral and commercial forestry production, provided appropriate soil conservation measures and practices are used. It covers 10 million hextares, the majority (63%) of which occurs in the North Island; is physically diverse; and, as a consequence, the productive potential and its response to land-use and environmental pressure vary significantly. Twenty-one different types of hill country terrain are defined, 13 in the North Island and 8 in the South Island, based on rock type, topography, erosion processes and severity. A broad classification of erosion susceptibility was used to group the terrains into low, medium, and high susceptibility. Three terrains were rated high (on soft rock and crushed soft rock), five were low (on hard rocks or easier slopes) and the remainder medium.

In the North Island, the majority of hill country is developed on soft rock and crushed soft rock terrain in the south-east and west of the island, with smaller areas of volcanic ash and loess-mantled terrain (largely on the periphery of the Central Volcanic Zone), hard rock hill country on the margins of the axial ranges, and deeply weathered sedimentary and igneous rocks (in Northland and on the Coromandel Peninsula). While erosion is widespread, only 200,000 ha has a mapped erosion severity of severe, very severe or extreme, mostly located on the East Coast, with smaller areas in inland Taranaki, Coromandel and Northland. The North Island hill country is dominated by mass movement erosion (soil slip[1], earthflow and gully erosion).

In the South Island most hill country is developed on hard rock terrain, with minor areas on soft rocks and weathered hard rocks. Loess mantles many hill country areas in the east of the South Island. The South Island is dominated by surface erosion, with mass movement erosion far less extensive than in the North Island. Less than 103,000 ha have an erosion severity ranking of severe, very severe or extreme.

**Erosion processes:** There is a substantial body of literature describing both natural and induced erosion in hill country, although much of it is descriptive (particularly the pre-1970s literature) and it is patchy in its geographical coverage and understanding of the

[1] Soil slip is the term used in the New Zealand Land Resource Inventory to refer to shallow, translational landslides.

mechanics and significance of different processes. Landslides, and their impacts, are the best studied erosion process. Gully and earthflow erosion are far less well studied. Research into hill country erosion is patchy geographically. Recent (post-1970) research has focused on the most highly erodible areas, often in response to the impacts of storms. The Wellington and Wairarapa areas, Hawke's Bay and Gisborne areas (particularly Lake Tutira and the Waipaoa catchment), the Taranaki region and the Manawatu–Wanganui area have been major foci for research. Far less is known of hill country erosion processes in areas such as Northland, Coromandel, Waikato–King Country, the Central North Island Volcanic Plateau and the South Island.

Geology (rock type, induration, regolith composition, drainage and permeability), uplift rates, and climate (rainfall amounts and intensities, frequency of large storms) largely determine the landscape's inherent susceptibility to erosion, including the response to vegetation change. Susceptibility to erosion is readily identifiable at a regional scale and increasingly tools and methods are becoming available that can be used at hillslope and farm scale. Large storms, or long wet periods, drive mass movement (landslide, earthflow) on hillslopes. These are high-magnitude events that occur at low frequency. For fluvial erosion (gullying, bank and channel erosion) the smaller more frequent storms are more important (i.e. low-magnitude, high-frequency events). Earthquakes are a significant driver for deep-seated mass movements and are much lower frequency events.

Shallow landslides affect the greatest proportion of hill country terrain; earthflow, slumps, and gully erosion are far less extensive and frequent. The relative impact of sheetwash erosion and its contribution to the sediment budget in pastoral hill country areas is poorly known. Sheetwash is the least important of the sediment-generating processes on forest cutover, with shallow landsliding, roads and landings generating the most sediment. Shallow landslides and gully erosion result in the greatest, long-term, on-site (loss of soil depth and productive capacity) and off-site (sedimentation and flooding) environmental degradation. Productivity on landslide scars after 20 years is 80% of that for stable sites unaffected by landsliding. Gully erosion needs to be identified and treated early. Untreated gullies increase in size and activity over time, lessening the chance of treatment being successful.

Closed-canopy woody vegetation reduces rates of hillslope erosion by an order of magnitude on the most susceptible terrain; on other terrain hillslope erosion is reduced but the degree of reduction is not as well quantified. Vegetative erosion control through reforestation, reversion and pole planting has proven successful for controlling much erosion. However, the use of pole planting for the treatment of large and active mass movement features (earthflow and slump) and gully erosion, in the most highly erodible terrains, has had only limited success. Space-planted poles can provide protection against the initiation of shallow landslides if planted in sufficient numbers and in the appropriate position on slopes.

The impacts of pre- or post-European deforestation have persisted for more than a century especially in those landscapes with thick regoliths and/or soft rocks. Harvesting of forests increases erosion rates in the short term, but over the length of a forest rotation pasture produces more sediment than forestry. Climate change is likely to exacerbate erosion problems in the worst affected areas since it is predicted to cause heavier and/or more frequent extreme rainfalls.

**Erosion control information sources:** There is a wide range of information sources on management options for preventing and controlling erosion in New Zealand hill country. The *Plant Materials Handbook for Soil Conservation* (3 volumes) summarised the state of knowledge up to the 1980s on vegetation options for managing soil erosion. *Control of Soil Erosion on Farmland* (Hicks 1995) was published by MAF in 1995 and summarised a large amount of information on agricultural techniques for managing soil erosion throughout New Zealand. The *Soil Conservation Technical Handbook*, published in 2001, describes a range of plant and engineering techniques for treating all hill country erosion types. Most regional councils use these sources and have developed locally relevant and practical resources that they use to provide advice to farmers (fact sheets, newsletters, website information, etc.). Much of the information contained in the *Plant Materials Handbook for Soil Conservation*, along with more recent research and user knowledge on site characterisation, plant selection, tree–pasture interactions, erosion risks and financial planning has been packaged into a freely available decision support system called the ‘Green Toolbox’. There have been several iterations of a Code of Practice for plantation forestry, the most recent of which was published in 2007, providing practical advice for managing the environmental impacts of forestry.

**Erosion control techniques:** On hill slopes without a woody component, maintaining a persistent, complete pasture cover reduces surface erosion processes of wind, sheet wash, and rilling. The most effective vegetation for controlling mass movement on the most severely eroding land is mature/closed canopy, indigenous or exotic forest (i.e. a change in land use).

Two-tier systems using a woody component (usually *Populus*, *Salix, Eucalyptus*, *Pinus*, or *Acacia* spp.) have commonly been used to reduce the likelihood of mass movement while maintaining pastoral land use. These are either placed at strategic positions on a slope (e.g. those with maximum potential for erosion), or in a systematic planting grid across the slope. Trees for slope stabilisation should be planted at 5 × 5 m to 15 × 15 m spacing depending on the severity of landsliding, and it is recommended that planting be extended beyond the slipped land on to relatively stable ground. Lateral roots of broadleaved trees interlock for distances of up to 12 m from the trunk, and form very dense networks within 5 or 6 m of the trunk. Trees can be planted on slipped sites but it is recommended that they be planted on sites with potential to slip, rather than for remediation.

Control of gully erosion aims to reduce further deepening and undercutting. The severity of the gully dictates the type of treatment. For shallow (< 2 m deep) and moderate (2–5 m deep) gullies, spaced planting of *Populus* or *Salix* spp. in combination with engineering structures (e.g. debris dams), while the trees establish, is recommended. The most successful system is ‘pair planting’ up the gully at 2–10 m spacing between pairs. Each pair comprises a tree on opposite sides of the gully, frequently between 1 and 2 m apart, or alternate planting in a 'zigzag' fashion along opposite sides of the gully. Severely eroding gullies should be retired from grazing and closed-planted with trees.

Earthflows and slumps can be stabilised by space-planted trees and afforestation, along with the use of subsurface drains and diversion banks. Tree spacings recommended vary depending on attributes such as the extent of the earthflow, its movement and stage of development, and depth to the failure plane. On intermittently moving or creeping earthflows, tree spacing of < 12 m may enable adequate erosion control and satisfactory pasture production, whereas for more active, continuously moving earthflows, spacings < 5 m are recommended to encourage development of a denser root network. Deep earthflows (e.g. several metres deep) are much more difficult to control with vegetation and dewatering with fast-growing evergreen species and subsurface drains are recommended.

*Populus* and *Salix* species are often preferred where erosion is mediated by surplus soil water and it is feasible to graze livestock (sheep) during tree establishment. *Acacia* spp. and *Eucalyptus* spp. are recommended for use on seasonally drought-prone sites such as those on upper slopes with northerly aspect, where *Populus* spp. and *Salix* spp. can fail to establish or survive. Two-tier systems involving *Pinus radiata* originated as a component of forestry management in the late 1960s – early 1970s and aimed to derive dual benefits of timber production at maturity and meat/wool income in at least the early and intermediate years of the tree rotation. The system was also deemed to be useful for erosion control, though there are no specific detailed studies of the erosion benefits of agroforestry systems.

**Effectiveness of controlling erosion with vegetation:** The effectiveness of mature, closed-canopy indigenous or exotic forest for controlling various types of mass movement is well documented in a range of hill country terrains (including soft rock, crushed soft rock, deeply weathered rocks, and steep hard rock), and event sizes, including extreme storm events such as Cyclone Bola. In two-tier systems where trees are spaced to enable satisfactory erosion control and the maintenance of an understorey pasture for livestock grazing, measures of effectiveness for erosion control are not as well documented scientifically as for mature forests. It is estimated mature trees of *Populus* spp. and *Salix* spp. and other broadleaved species at spacings of 12 m or less can reduce landsliding in pasture by 50–80%, whereas partial planting of erosion-prone slopes with trees can reduce landsliding by 10–20%, and similarly for areas where older tree stands have not been maintained. The effectiveness of *Populus* and *Salix* for controlling gully and earthflow erosion in soft rock terrain in the Gisborne–East Coast region was determined in 1989–91 following Cyclone Bola. For gullies < 2 m deep, tree spacing of 2–4 m was successful in 9 of 10 sites, whereas a spacing of 4–8 m was successful in 11 of 32 sites. Erosion control on earthflow sites with shallow untreated toe gullying was successful where spacing was 3–5 m (4 of 4 sites), but lower proportions of sites were successful where spacing was 8–10 m (7 of 20 sites) or greater than 10 m (2 of 10 sites). These results suggest that the interaction between roots of neighbouring trees at closer spacings was a major factor in treatment success. Recent work on the effectiveness of spaced trees (mostly *Populus* spp. and *Eucalyptus* spp.) has measured attributes of individual trees and tree spacings, so that better information is becoming available on the condition and arrangement of trees and their root systems to allow better recommendations on appropriate tree spacings to minimise erosion.

**Social learning for managing erosion:** The recognition that soil erosion in large tracts of New Zealand hill country is in large part a result of land use practices, and the need to address social or behavioural factors as 'drivers' of accelerated soil erosion, has been acknowledged since the 1940s. However, research specifically addressing social aspects of the impact of land management on soil erosion in New Zealand is limited. While our understanding of soil erosion as a physical process is well advanced, there is little published research that specifically addresses land management from a social or behavioural perspective. Given the broad acceptance that erosion remains New Zealand's fundamental environmental threat, particularly in agriculture, the extent and depth of research available on the social and behavioural causes of the problem (and its solution) remains surprisingly small.

While large storms continue to have a severe impact on many hill country areas, there is little evidence that this has generated any sizeable body of social science research to expose either the drivers of pre-existing management practices or attitudes to the need for future change. Some commentators suggest erosion may well have worsened in the aftermath of the agricultural and local government reforms of the 1980s as a consequence of a decline in farmers' ability to afford trees, although it is suggested that as economic conditions improve this could be expected to reverse. The inherent assumption behind the 1980s' reforms was that the market would result in a more efficient pattern of land use (implicitly this was expected to involve more trees replacing pasture in erosion-prone hill country), but this has not occurred.

Recent research has more explicitly examined behavioural factors associated with individual landholders' views on erosion management and control. New Zealand's commitment to a free market model to promote land use change has increasingly focused social research on 'sustainable land use', and a primary acceptance that voluntary actions by farmers are the key to achieve desired outcomes. Some literature suggests this is largely seen within the context of economic viability, while other studies suggest it more often reflects the underlying environmental values of those farmers concerned. The contradictory evidence suggests a lack of understanding of the characteristics and values which determine land management practices. It is also acknowledged that overseas voluntary approaches to erosion control and improved land management have not always been successful. Recent initiatives (such as the East Coast Forestry Project and Horizon's Sustainable Land Use Initiative) reflect a revival in interest by central and local government in soil erosion and sustainable land-use issues.

There is little evidence that there has been either an effective effort by behavioural scientists or the necessary full integration of behavioural factors into management policies. Nor has there been much effort placed on institutional behaviour and the need for institutional support if voluntary strategies are to remain New Zealand's key strategy for managing hill country erosion. The failure to move to a more integrated, multidisciplinary approach incorporating a number of different physical and social science disciplines in hill country research is a result of a number of factors including funding constraints, low priority given to erosion research by funders and research providers, lack of interest among social scientists, and the difficulty of managing multidisciplinary team approaches. Many social scientists are working on behavioural factors within the context of sustainable land management, and commonly recognise that erosion control is a key component in this work.

**Research capability and research programmes:** A large number of scientists have capability for hill country erosion research, but a far smaller number are currently actively engaged in relevant research, and many of those that are only have a small proportion of their time devoted to hill country erosion issues. It is not possible to accurately estimate the number of full-time-equivalent staff working on hill country erosion. At least $1.8 million per annum is being spent on aspects of hill country research, but it is scattered across a wide variety of programmes and projects, and research providers, and as a consequence is poorly coordinated. There are only two central government (FRST) funded major research programmes that focus almost entirely on hill country erosion (GNS's 'Margins Source-to-Sink' programme, Landcare Research's 'Landscape Resilience' programme under FRST transition funding). Other FRST-funded programmes run by Ensis, GNS, NIWA, Landcare Research, and SLURI have minor components of hill country erosion research within them. Direct regional council funding and Envirolink are significant sources of funding.

**Future research needs:** A survey of regional councils, industry, central government agencies and science providers identified a wide variety of research needs to assist improved management of hill country erosion. Gaps identified by the greatest number of stakeholders included:

- ability to measure regional/catchment rates of erosion and determine what is tolerable, including measuring the contribution from different land uses and land management practices, being able to distinguish natural and induced erosion, and the contribution of different processes
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# Contents

# 1 Introduction

Ministry of Agriculture and Forestry (MAF) recently established the Sustainable Land Management (SLM) hill country erosion programme to provide targeted government support to communities that need to protect erosion-prone hill country while also retaining the maximum practical production from their land. SLM aims to build resilience into land-based industries and communities, reduce the risks they face from adverse climatic events, and promote long-term economic growth within environmental limits.

As part of the process of developing the SLM hill country erosion programme MAF has sought to identify the information needed to underpin long-term solutions to hill country erosion. In July 2007 MAF released a request for proposals (RFP) to undertake a stocktake of current knowledge and identify future priority knowledge gaps relating to the prevention, treatment and management of hill country erosion in New Zealand, including physical, social, environmental and economic dimensions. The RFP requested two components:

- a review of existing knowledge (both published and unpublished) on the prevention, treatment, and management of hill country erosion
- identification of gaps in existing research, future knowledge needs, and the requirements to transfer the information to land managers and associated stakeholders.

MAF stated that the scope of the review should cover: sources and flows of sediment; the specific managements, technologies and practices used in the treatment of erosion and the long-term management of those treatments; and social learning and adaptation to treating and managing hill country erosion. Some issues were specifically excluded from the review: nutrient management and water quality, river protection and flood control, and factors influencing land use change. MAF wishes to use the information gap and future needs analysis in its own policy and operational activities, and in its interactions with the Ministry of Research, Science and Technology and the Foundation for Research, Science and Technology.

Landcare Research, in association with AgResearch, HortResearch and the University of Auckland (School of Geography, Geology and Environmental Science), responded to the RFP with a collaborative proposal which was successful in gaining funding.

# 2 Background

Erosion is a significant environmental issue facing agricultural and forestry land uses in large parts of the hill country of New Zealand. It causes both on-site (loss of soil productive capacity and water holding capacity) and off-site (declining water quality, river aggradation, increased vulnerability of infrastructure to severe climatic events) effects. As well as the environmental costs there are major financial risks to individuals, communities, local and central government and social consequences of repeated erosion and flooding events.

Despite a heavy investment in soil conservation and catchment initiatives over the past 70 years (through catchment boards and regional councils) the problem of hill country erosion continues to persist and is limiting the growth of farming communities in heavily affected areas. There is a long history, extending back to the 1940s, of basic and applied research into both erosion processes and the treatment and prevention of hill country erosion (see McCaskill 1973; Roche 1994). Despite this rich past there remain large tracts of New Zealand hill country where erosion has a significant impact and where the long-term sustainability of farming and/or forestry is uncertain. Periodic large storm events (e.g. Cyclone Alison, Marlborough 1975; Cyclone Bola, East Coast North Island 1988; Cyclone Hilda, Taranaki–Wanganui 1990; Manawatu–Wanganui, February 2004; Northland, July–August 2007) continue to cause widespread erosion and impose massive on-site and off-site repair costs on farmers, local, regional and central government. While plantation forestry land use can have a beneficial effect in reducing erosion in the long term (e.g. Phillips et al. 1990; Eyles & Fahey 2006), there are significant risks during the harvesting phase (e.g. Pearce & Hodgkiss 1987; NZ Forest Owners Association 2007) that have caused many regional councils to heavily regulate forestry activities in hill country.

Many commentators agree there is a need for rationalisation of land use in the erodible hill country to reduce the impact of erosion through a process of identification of highly erodible land and the design and implementation of more sustainable land-use options in hill country. This will become even more imperative in the future with the likelihood that climate change will increase climate variability and the incidence of large storm events that cause much of the erosion (e.g. Basher 1990).

This report reviews:

- information on hill country erosion processes and their management
- experiences with social learning and adaptive management approaches to hill country erosion management
- research capability and current research and investigations into hill country erosion and management, and includes
- an information gap and research needs analysis gained from surveying regional councils, key industry representatives (farming and forestry), central government agencies, universities and Crown Research Institutes.

# 3 Objectives

The specific objectives of the work were to:

- compile an inventory and synthesis of existing knowledge and current work on erosion processes, mitigation options and their long-term effectiveness in the management of hill country erosion
- make this inventory available to all stakeholders with an interest in managing hill country erosion and promoting sustainable land use
- seek agreement on future information needs and approaches to underpin long-term solutions to hill country erosion through an inclusive process involving all stakeholders, including key industries (farming and forestry), scientists, policy and regulatory agencies.

The project was split into two objectives: Objective 1 was a review of hill country erosion processes and management; Objective 2 was a workshop on future research needs.
This report describes the work completed in Objective 1. It also includes information gathered from individual stakeholders on future research needs, that will form the basis of the workshop for objective 2.

# 4 Methods

A bibliography of information on hill country erosion processes and sediment sources and an assessment of their relative contribution to hill country erosion problems was compiled (Appendix 1). It built on previous reviews undertaken by Landcare Research as part of research to compile data to underpin the development of erosion models (Elliott et al. 2006), work on the analysis of the contribution of erosion to the carbon budget of New Zealand (Basher 2001), and prior contract work for a range of clients (e.g. Hunter et al. 1996; Basher 1997; Lynn 1999a, b; Phillips & Marden 2001) with updating to ensure recent publications were included. It also drew on comprehensive bibliographies and analyses of landslide erosion compiled by Victoria University of Wellington (Glade 1997, 1998, 2003; Glade & Crozier 1997, 1999) and GNS Science (Page 2008).

The bibliography includes both published and unpublished literature, derived from electronic literature searches (of university and Crown Research Institute (CRI) libraries, scientific journals and websites) and surveys of key agencies that may have held unpublished sources of information (regional councils, universities and CRIs). Key databases such as the New Zealand Land Resource Inventory (NZLRI; NWASCO 1979), the derived erosion terrain classification, and the recently developed suspended sediment yield calculator (Hicks et al. 2003) were used to provide an analysis of the spatial extent and severity of hill country erosion processes and to assess the transferability of erosion process and management information.

Information sources identifying both the appropriate management practices to treat hill country erosion problems and the long-term management needs to ensure those practices remain effective were also compiled (Appendix 1) through literature searches and by contacting regional councils and key industries (pastoral farming, forestry) to identify what sources of information they used when providing advice on hill country erosion management. Appendix 2 lists the organisations and individuals contacted and Appendix 3 summarises the responses received. An inventory of decision support tools available to manage hill country erosion was also compiled. The review also includes an analysis of the effectiveness of erosion control measures where this is available (e.g. Luckman & Thompson 1991a, b; Thompson & Luckman 1991a, b, 1992, 1993; Phillips et al. 2000; Marden 2001, 2004).

Literature on New Zealand social research into erosion management in hill country was compiled (Appendix 1) and summarised, then followed up by telephone interviews with key informants. Key informants were individuals who have experience in and a good understanding of erosion management in hill country areas. Starting with key individuals we knew, a snowballing technique was used to identify other appropriate participants and information was sought from them about their experiences with managing erosion in hill country. Their experiences are summarised in section 5.3.2.

An inventory of present research activities by CRIs, universities and regional councils was compiled (Appendices 3 and 4) that includes erosion process research, recent advances in development of modelling and prediction tools, advances in understanding management options, and social learning research. This information was sought directly from a wide variety of research providers and management agencies. It is summarised (section 5.4.2) in terms of the balance between strategic and applied research, and technology development. An analysis of the available research capability to deal with hill country erosion problems covers the full spectrum from fundamental biophysical process research through to social learning and adaptive management.

As part of the survey of research providers and management agencies we also sought comment on key information gaps and research. A preliminary assessment of information gaps and research needs has been summarised incorporating this feedback. The individual feedback is listed (Appendices 3 and 4) and it has been summarised by grouping it into classes of like research needs (section 5.5).

# 5 Results

## 5.1 Erosion processes

### 5.1.1 Extent and types of hill country and their erosion processes

New Zealand is a predominantly hilly and mountainous country. An area of 18 million hectares (69%) has slopes greater than 12°, and is commonly called 'hill country'. This is further divided into 'hill-land' (12–28°) and 'steepland' (if slope exceeds 28°) (DSIR 1980). The range of slope and elevation, coupled with a wide latitudinal range, a mid-oceanic setting encompassing subtropical to cool temperate climates, and complex geologic and tectonic regimes means that New Zealand's 'hill country' is physically diverse. As a consequence of this diversity, the productive potential of New Zealand's' hill country, and its response to climatic events, land use pressure and environmental change varies significantly across the country.

To provide the initial spatial context for this study a generalised working definition of 'hill country' was developed, and this terrain extracted from the New Zealand Land Resource Inventory (NZLRI) database (NWASCO 1979). Hill country is defined as: *all lowland and montane hill and steeplands (slope >15°), classified as land use capability (LUC) class 5, 6, or 7, and being described in the unit descriptions as 'hill country'*[2] The land use capability classes are those defined and used in the New Zealand Land Resource Inventory regional studies (Ministry of Works (MOW) 1974; NWASCO 1979, 1983; Blaschke 1985; Noble 1985; Fletcher 1987; Page 1976, 1988, 1995; Harmsworth 1996; Lynn 1996; Jessen et al. 1999).

The hill country terrain extracted under this definition is widely accepted as capable of sustainable pastoral and commercial forestry production, provided appropriate soil conservation measures are in place (NWASCO 1979). Figure 1 shows the national distribution of hill country as defined above. The majority 63% occurs in the North Island and only 37% in the South Island.

Based on an analysis of the NZLRI physical data (focusing on erosion type and severity) and using a previous 'Erosion Carbon' terrain analysis (Landcare Research unpubl.), 21 specific types of hill country can be recognised (Table 1; Fig. 2). A summary description of the erosion processes, topography, rock types, and suspended sediment yields for the 21 types of hill country is given in Tables 1 and 2. Present erosion type and severity are those defined and assessed in the New Zealand Land Resource Inventory first edition whose data were largely compiled in the 1970s and 1980s (MOW 1974; Eyles 1985) or the second edition (1985–95) where available. Results of the first-edition mapping were

[2] LUC class as defined in MOW (1974): 'lowland' and 'montane' follow the altitude/temperature-related bioclimatic zones of Wardle (1991).

previously summarised at national scale by Eyles (1983). A broad classification of erosion susceptibility (low, medium, high) for each of the 21 hill country types is given in Table 1. It is derived from analysis of the present (Table 2) and potential erosion (considering inherent soil, slope and climate characteristics) in the NZLRI.

Of the 6.3 million hectares in the North Island, the majority is developed on soft rock and crushed soft rock terrain in the south-east and west of the island (2 825 000 ha, 45% – see Fig. 2a). Volcanic ash and loess-mantled terrain comprises another 23% (1 456 000 ha), largely on the periphery of the Central Volcanic Zone. Hard rock hill country, exclusive of the igneous hard rock hill country, is largely concentrated on the margins of the axial ranges (919 000 ha, 14.5%), whereas the hill country developed on deeply weathered sedimentary and igneous rocks (863 000 ha, 13.6%) is located predominantly in Northland and on the Coromandel Peninsula. In the North Island approximately 200 000 ha has a mapped erosion severity of severe, very severe or extreme (Fig. 3), mostly located on the East Coast, with smaller areas in inland Taranaki, Coromandel and Northland. The North Island hill country is dominated by mass movement erosion (Fig. 4). Soil slip and sheet erosion are the most widely distributed followed by earthflow and gully erosion (Figs 5–8). Sediment yield is highest in the northern east coast, and high throughout much of the rest of the east coast, inland Taranaki and parts of Northland (Fig. 9). Mean sediment yields are highest in the crushed soft rock hill country and hilly steeplands, and steep soft rock hill country.

In contrast to the North Island, 56% of the South Island's 3.7 million hectares of hill country is developed on hard rock terrain (Table 1). Only 569 000 ha is developed on soft rocks, largely in coastal Marlborough, fringing the North and South Canterbury downlands, north and coastal Otago, western Southland, and restricted areas of lowland Nelson and the West Coast (Fig. 2b). Steep weathered hill country on both schist and greywacke, and weathered igneous rock, is limited to the Marlborough Sounds and lowland Nelson. Loess mantles significant areas especially in the east, whereas morainic hill country is restricted to the inland basins and headwaters of the major river systems. In the South Island less than 103 000 ha has an erosion severity ranking of severe, very severe or extreme (Fig. 10). Unlike the North Island, the South Island is dominated by surface erosion types (Fig. 11). Mass movement is the dominant form of erosion on the West Coast, and is common in Nelson, Marlborough, North Canterbury, Banks Peninsula the Otago Peninsula, parts of Otago and western Southland. Tunnel gullying is also far more common in the South Island. Sheet and soil slip erosion are the most common forms of erosion in the South Island hill country (Figs 12, 13), while gully and earthflow erosion are far less common (Figs 14, 15). Sediment yields tend to be far lower in the South Island (Fig. 16) and are highest on the West Coast because of the higher rainfall. They are also high in parts of North Canterbury, coastal Otago and Southland. Mean sediment yields are highest in the steep soft rock hill country.


**Fig. 1** Extent of hill country in New Zealand.

**Table 1** Brief description of hill country terrains.

| | Type of hill country and brief description | Area (ha) | Dominant erosion types | Erosion susceptibility* | SSY‡ (t/km²/yr) |
|---|---|---|---|---|---|
| **North Island** | **Hill country (16–25 degrees), with strongly rolling to moderately steep slopes** | | | | |
| 1. Loess hill country | Low elevation hill country developed on deep (>1 m) loess, overlying both soft† rock and hard† rock terrain. | 113 000 | Sheet, Soil slip, Tunnel gully | Medium | 46 (low) |
| 2. Tephric (ash) hill country | Mantled with young tephra, and/or older tephra (late Pleistocene/early Holocene), or tephric loess to depths of 0.3 – >1.0 m. | 1 343 000 | Soil slip, Sheet, Gully | Medium | 171 (med) |
| 3. Hard igneous rock hill country | Developed on hard young basalt domes and cones. | 16 000 | Sheet, Soil slip | Low | 54 (low) |
| 4. Crushed soft rock hill country with moderate to severe erosion | Developed on soft crushed Tertiary-aged mudstone, sandstone; argillite, or ancient volcanic rock (frequently, with tephra cover), with moderate to severe earthflow-dominated erosion, and soft crushed argillite, sandstone, or greywacke, with severe gully-dominated erosion. | 580 000 | Earthflow, Gully, Sheet | High | 12 013 (very high) |
| 5. Soft rock hill country | Developed on soft sandstone, mudstone or soft to very strong calcareous sedimentary rocks. | 1 011 000 | Soil slip, Earthflow, Sheet | Medium | 563 (med) |
| 6. Hard rock hill country | Developed on hard unweathered to moderately weathered greywacke and argillite. | 300 000 | Soil Slip, Sheet, Scree | Low | 312 (med |
| 7. Deeply weathered hill country | Developed on residual weathered to highly (often deeply) weathered rocks. | 578 000 | Soil slip, Sheet, Earthflow | Medium | 123 (med) |
| | **Hilly steeplands (> 25 degrees), with moderately steep to steep slopes** | | | | |
| 8. Steep tephric (ash) hill country | Covered with young tephra, and/or older tephra (late Pleistocene/early Holocene) or tephric loess to depths of 0.3 – >1.0m. | 321 000 | Soil slip, Sheet, Debris avalanche | Medium | 351 (med) |
| 9. Steep hard igneous rock hill country | Developed on fresh to slightly weathered hard welded rhyolitic rock, or bouldery andesitic lahar deposits. | 51 000 | Soil slip, Sheet, Debris avalanche | Medium | 56 (low) |
| 10. Steep crushed rock hill country | Developed on crushed argillite with gully-dominated erosion. | 56 000 | Gully, Earthflow, Sheet | High | 67 000 (very high) |
| 11. Steep soft rock hill country | Developed on soft sandstone, mudstone, and sandy gravels. | 1 170 000 | Soil slip, Sheet, | High | 1290 (high) |

| | Type of hill country and brief description | Area (ha) | Dominant erosion types | Erosion susceptibility* | SSY‡ (t/km$^2$/yr) |
|---|---|---|---|---|---|
| 12. Steep hard rock hill country | Developed on unweathered to moderately weathered hard greywacke and argillite. | 620 000 | Earthflow Debris avalanche, Soil slip, Sheet | Low | 511 (med) |
| 13. Steep deeply weathered hill country | Developed on residual weathered to highly (often deeply) weathered rocks (including igneous rocks, greywacke and argillite). | 185 000 | Soil slip, Sheet, Debris avalanche | Medium | 135 (med) |
| **South Island** | **Hill country (16–25 degrees), with strongly rolling to moderately steep slopes** | | | | |
| 14. Morainic hill country | Low elevation valley or basin floor hill country, developed on moraine and dissected outwash alluvium. | 170000 | Sheet, Soil slip, Gully | Low | 906 (high) |
| 15. Loess hill country | Low elevation hill country developed, on deep (>1 m) loess, overlying both soft rock and hard rock terrain. | 245000 | Sheet, Soil slip, Tunnel gully | Medium | 214 (med) |
| 16. Soft rock hill country | Developed on soft mudstone, sandstone or conglomerate, soft to very strong calcareous rocks. | 532000 | Soil slip, Sheet, Gully | Medium | 368 (med) |
| 17. Hard rock hill country | Developed on hard sedimentary and schist rocks, hard coarse-grained igneous and metamorphic rocks, fine-grained igneous rocks. | 1 161 000 | Sheet, Soil slip, Wind | Low | 52 (low) |
| | **Hilly steeplands (>25 degrees), with moderately steep to steep slopes** | | | | |
| 18. Steep soft rock hill country | Developed on soft sedimentary mudstone, sandstone and conglomerate. | 367 000 | Soil Slip, Sheet, Debris avalanche | Medium | 1163 (high) |
| 19. Steep hard rock hill country | Developed on hard sedimentary and schist rocks, coarse-grained igneous and metamorphic rocks, fine-grained igneous rocks, and carbonate rocks. | 859 000 | Sheet, Soil slip, Scree | Medium | 88 (low) |
| 20. Steep weathered hill country | Developed on weathered hard schist and greywacke rocks in the Marlborough Sounds, especially on the lower slopes (<200 m). | 241 000 | Sheet, Soil slip, Scree | Medium | 89 (low) |
| 21. Steep weathered igneous rock hill country | Developed on weathered hard coarse-grained igneous rocks (e.g. Separation Point Granite in the Motueka catchment). | 18 000 | Soil slip, Sheet, Debris avalanche | Medium | 351 (med) |

† The division between soft and hard conforms to the separation between soft and moderately hard of Lynn & Crippen (1991, p.11), ‡ Average suspended sediment yield for terrain derived from data described in Hicks et al. (2003)

**Table 2** Dominant erosion types and severities as mapped in the NZLRI for each hill country terrain type.

| | **Area (ha)** | Type of hill country and brief description | Dominant erosion | Erosion severity (% area in mapped class) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| **North Island** | **Hill country (16–25 degrees), with strongly rolling to moderately steep slopes** | | | | | | | |
| 1. Loess hill country | 113 000 | Low elevation hill country developed on deep (>1 m) loess, overlying both soft rock and hard rock terrain. | Ss | 34 | 7 | | | |
| | | | Sh | 11 | <1 | | | |
| | | | T | 5 | 2 | | | |
| 2. Tephric (ash) hill country | 1 343 000 | Mantled with young tephra, and/or older tephra (late Pleistocene/early Holocene), or tephric loess to depths of 0.3–>1.0 m. | Ss | 25 | 1 | <1 | | |
| | | | Sh | 16 | 1 | <1 | | |
| | | | G | 5 | 1 | | | |
| 3. Hard igneous rock hill country | 16 000 | Developed on hard young basalt domes and cones. | Sh | 57 | 3 | | | |
| | | | Ss | 14 | 2 | | | |
| | | | G | 3 | | | | |
| 4. Crushed soft rock hill country with moderate to severe erosion | 580 000 | Developed on soft crushed Tertiary-aged mudstone, sandstone; argillite, or ancient volcanic rock (often with tephra cover), moderate to severe earthflow dominated erosion, and soft crushed argillite, sandstone, or greywacke with severe gully erosion. | Ef | 21 | 22 | 9 | 2 | <1 |
| | | | G | 9 | 5 | 1 | 1 | |
| | | | Sh | 13 | 1 | | | |
| | | | Ss | 6 | 3 | 1 | <1 | |
| 5. Soft rock hill country | 1 011 000 | Developed on soft sandstone, mudstone or soft to very strong calcareous sedimentary rocks. | Ss | 37 | 11 | <1 | | |
| | | | Ef | 14 | 7 | <1 | | |
| | | | Sh | 10 | 1 | <1 | | |
| | | | T | 3 | 1 | | | |
| 6. Hard rock hill country | 300 000 | Developed on hard unweathered to moderately weathered greywacke and argillite. | Ss | 37 | 1 | | | |
| | | | Sh | 19 | 2 | | | |
| | | | Sc | 4 | <1 | | | |
| 7. Deeply weathered hill country | 578 000 | Developed on residual weathered to highly (often deeply) weathered rocks. | Sh, | 31 | 3 | | | |
| | | | Ss | 25 | 2 | <1 | | |
| | | | Ef | <1 | | | | |
| | | | T | 4 | 1 | | | |
| | **Hilly steeplands (>25 degrees), with moderately steep to steep slopes** | | | | | | | |
| 8. Steep tephric (ash) hill country | 321 000 | Covered with young tephra, and older tephra (late Pleistocene/early Holocene) or tephric loess to depths of 0.3 – >1.0 m. | Ss | 25 | 4 | | | |
| | | | Sh | 10 | 5 | <1 | | |
| | | | Da | 14 | 2 | <1 | | |
| 9. Steep hard igneous rock | 51 000 | Developed on fresh to slightly weathered hard welded rhyolitic rock, or bouldery andesitic lahar deposits. | Ss | 23 | 23 | 2 | | |
| | | | Sh | 9 | <1 | | | |

| | Area (ha) | Type of hill country and brief description | Dominant erosion | Erosion severity (% area in mapped class) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| hill country | | | G | 10 | <1 | 2 | | |
| 10. Steep crushed rock hill country | 56 000 | Developed on crushed argillite with gully-dominated erosion. | G | 12 | 30 | 21 | 8 | 1 |
| | | | Sh | 2 | 3 | | | |
| | | | Ss | 11 | 4 | 1 | | |
| 11. Steep soft rock hill country | 1 170 000 | Developed on soft sandstone, mudstone, and sandy gravels. | Ss | 33 | 21 | 4 | 1 | |
| | | | Sh | 4 | 1 | <1 | <1 | |
| | | | Ef | 1 | 3 | 1 | | |
| | | | Da | 15 | 4 | <1 | <1 | |
| | | | G | 1 | <1 | <1 | <1 | |
| 12. Steep hard rock hill country | 620 000 | Developed on unweathered to moderately weathered hard greywacke and argillite. | Da | 37 | 6 | 1 | | |
| | | | Ss | 20 | 5 | <1 | | |
| | | | Sh | 5 | 2 | | | |
| | | | Sc | 4 | 1 | | | |
| 13. Steep deeply weathered hill country | 185 000 | Developed on residual weathered to highly (often deeply) weathered rocks (including igneous rocks, greywacke and argillite). | Ss | 27 | 6 | <1 | | |
| | | | Sh | 10 | 7 | | | |
| | | | Da | 13 | 3.4 | <1 | | |
| **South Island** | **Hill country (16–25 degrees), with strongly rolling to moderately steep slopes** | | | | | | | |
| 14. Morainic hill country | 170 000 | Low elevation valley or basin floor hill country, developed on moraine and dissected outwash alluvium. | Sh | 48 | 6.5 | 1 | <1 | |
| | | | Ss | 18 | 4 | <1 | <1 | |
| | | | G | <1 | <1 | <1 | | |
| 15. Loess hill country | 245 000 | Low elevation hill country developed, on deep (>1 m) loess, overlying both soft rock and hard rock terrain. | Sh | 49 | 12 | <1 | | |
| | | | Ss | 13 | 6 | <1 | | |
| | | | T | 5 | 4 | <1 | <1 | |
| 16. Soft rock hill country | 532 000 | Developed on soft mudstone, sandstone or conglomerate, soft to very strong calcareous rocks | Sh | 44 | 8 | <1 | <1 | <1 |
| | | | Ss | 26 | 4 | <1 | <1 | |
| | | | G | 4 | 1 | <1 | <1 | <1 |
| 17. Hard rock hill country (ha) | 1 161 000 | Developed on hard sedimentary and schist rocks, hard coarse-grained igneous and metamorphic rocks, fine-grained igneous rocks. | Sh | 71 | 9 | 1 | | |
| | | | Ss | 8 | 1 | | | |
| | | | W | 2 | 4 | | | |
| | **Hilly steeplands (>25 degrees), with moderately steep to steep slopes** | | | | | | | |
| 18. Steep soft rock hill country | 367 000 | Developed on soft sedimentary mudstone, sandstone and conglomerate. | Ss | 45 | 23 | 4 | <1 | 3 |
| | | | Sh | 16 | <1 | <1 | | |
| | | | Da | <1 | <1 | <1 | | |

| | **Area (ha)** | Type of hill country and brief description | Dominant erosion | Erosion severity (% area in mapped class) 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| 19. Steep hard rock hill country | 859 000 | Moderately steep to steep hill country developed on hard sedimentary and schist rocks, coarse-grained igneous and metamorphic rocks, fine-grained igneous rocks, carbonate rocks. | Sh | 51 | 18 | 2 | <1 | |
| | | | Ss | 15 | 5 | <1 | <1 | |
| | | | Sc | 2 | 3 | 1 | | |
| 20. Steep weathered hill country | 241 000 | Moderately steep to steep hill country developed on weathered hard schist and greywacke rocks in the Marlborough Sound, especially on the lower slopes (<200 m). | Sh | 32 | 17 | <1 | | |
| | | | Ss | 30 | 5 | <1 | | |
| | | | Sc | | | | | |
| 21. Steep weathered igneous rock hill country | 18 000 | Moderately steep to steep hill country developed on weathered hard coarse-grained igneous rocks (e.g. Separation Point Granite in the Motueka catchment). | Sh | 43 | 14 | | | |
| | | | Ss | 27 | 16 | | | |

Types of erosion (Eyles 1985)
Da – debris avalanche Ef – earthflow G – gully Ss – soil slip Sh – sheet Sc – scree T – tunnel gully

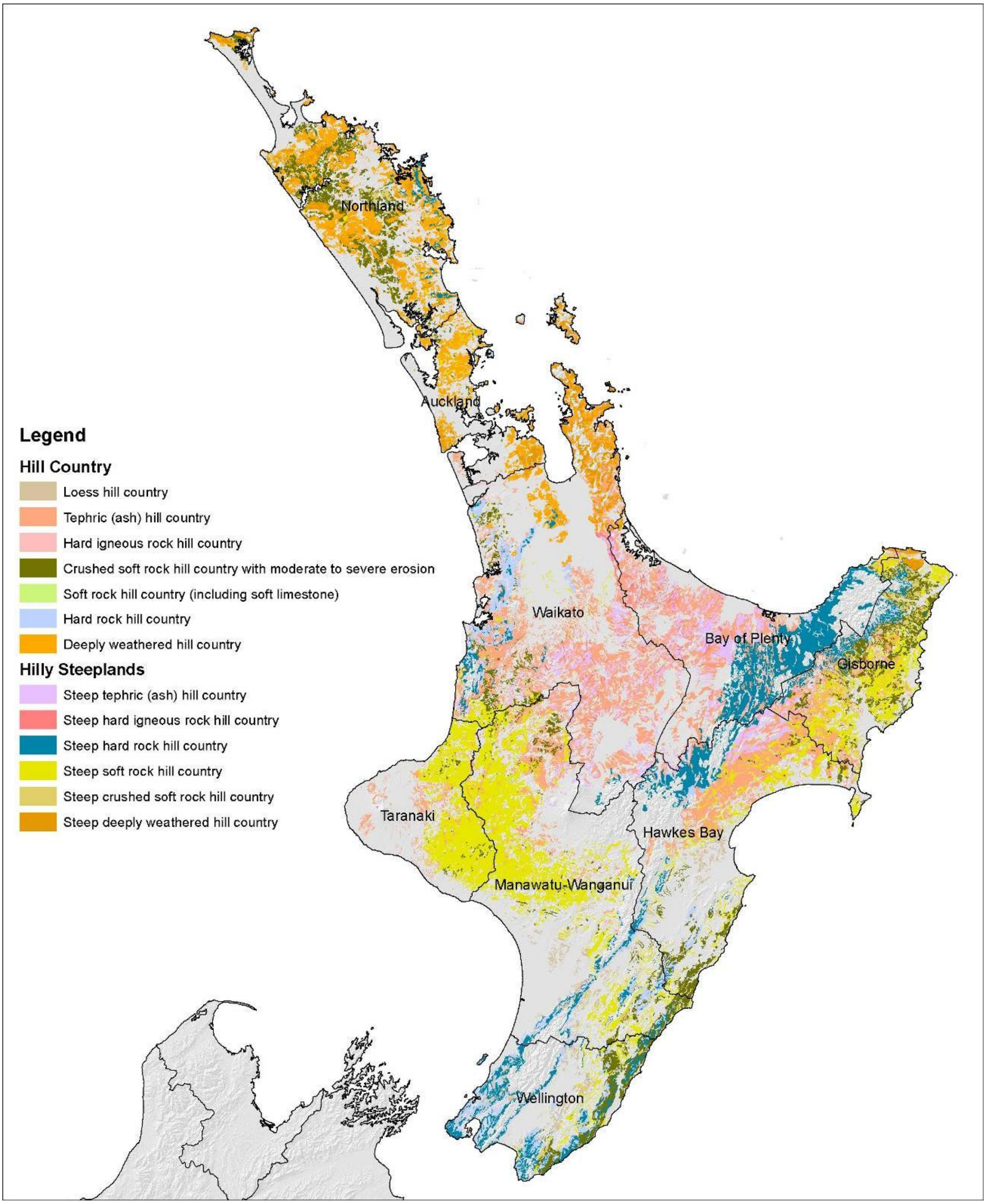


**Fig. 2a** Distribution of hill country types in the North Island, New Zealand.

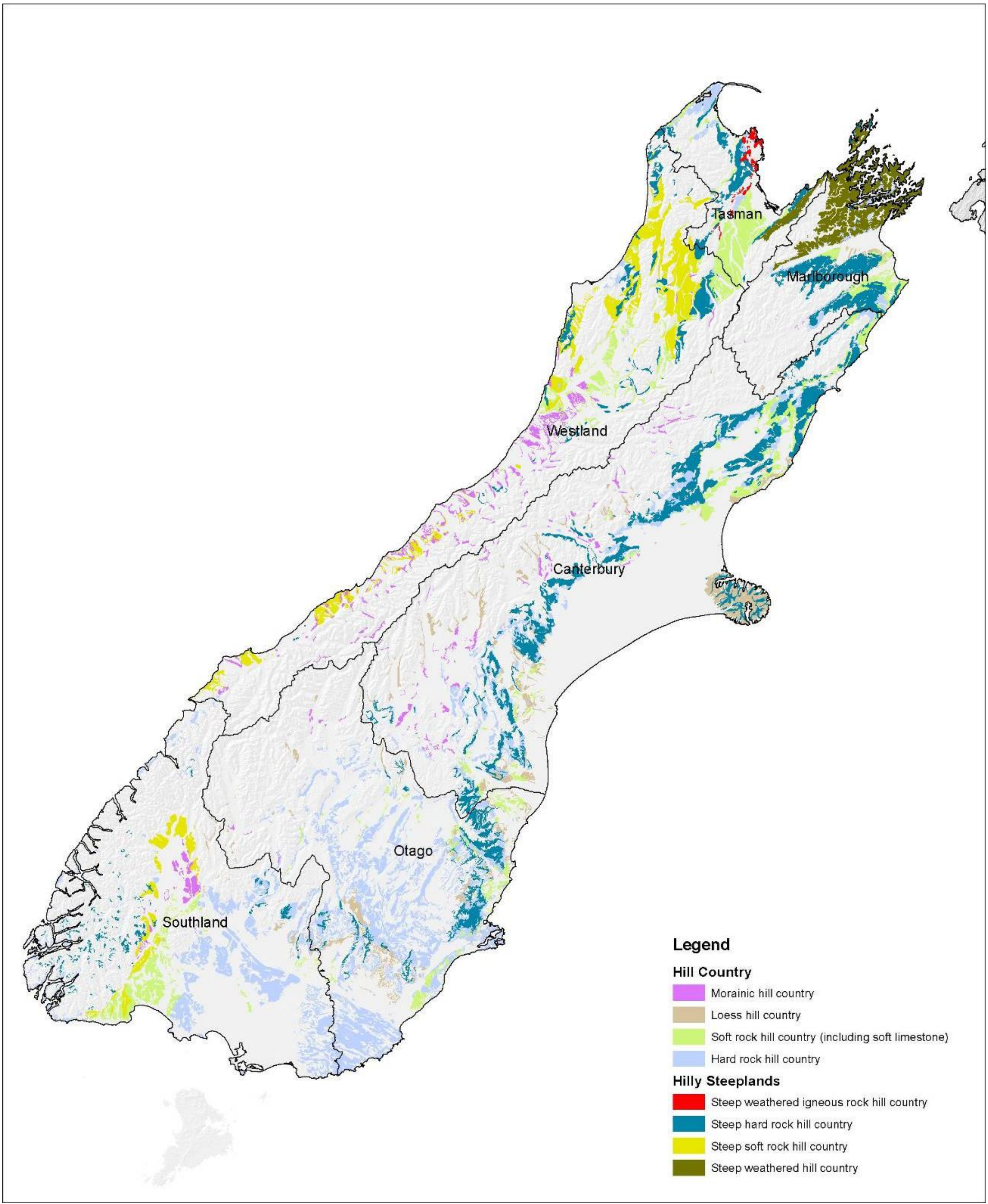


**Fig. 2b** Distribution of hill country types in the South Island, New Zealand.

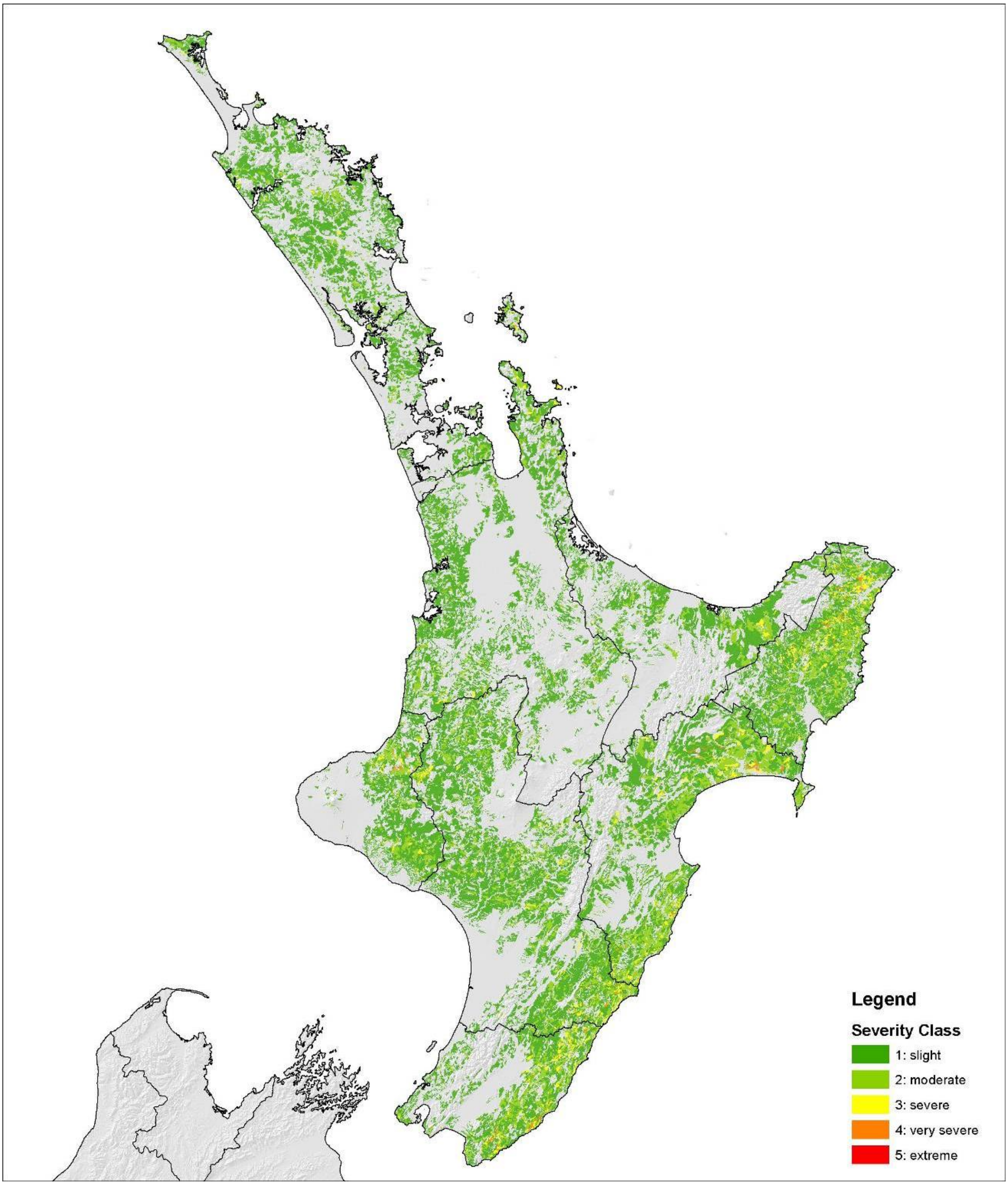


**Fig. 3** Erosion severity on North Island hill country.

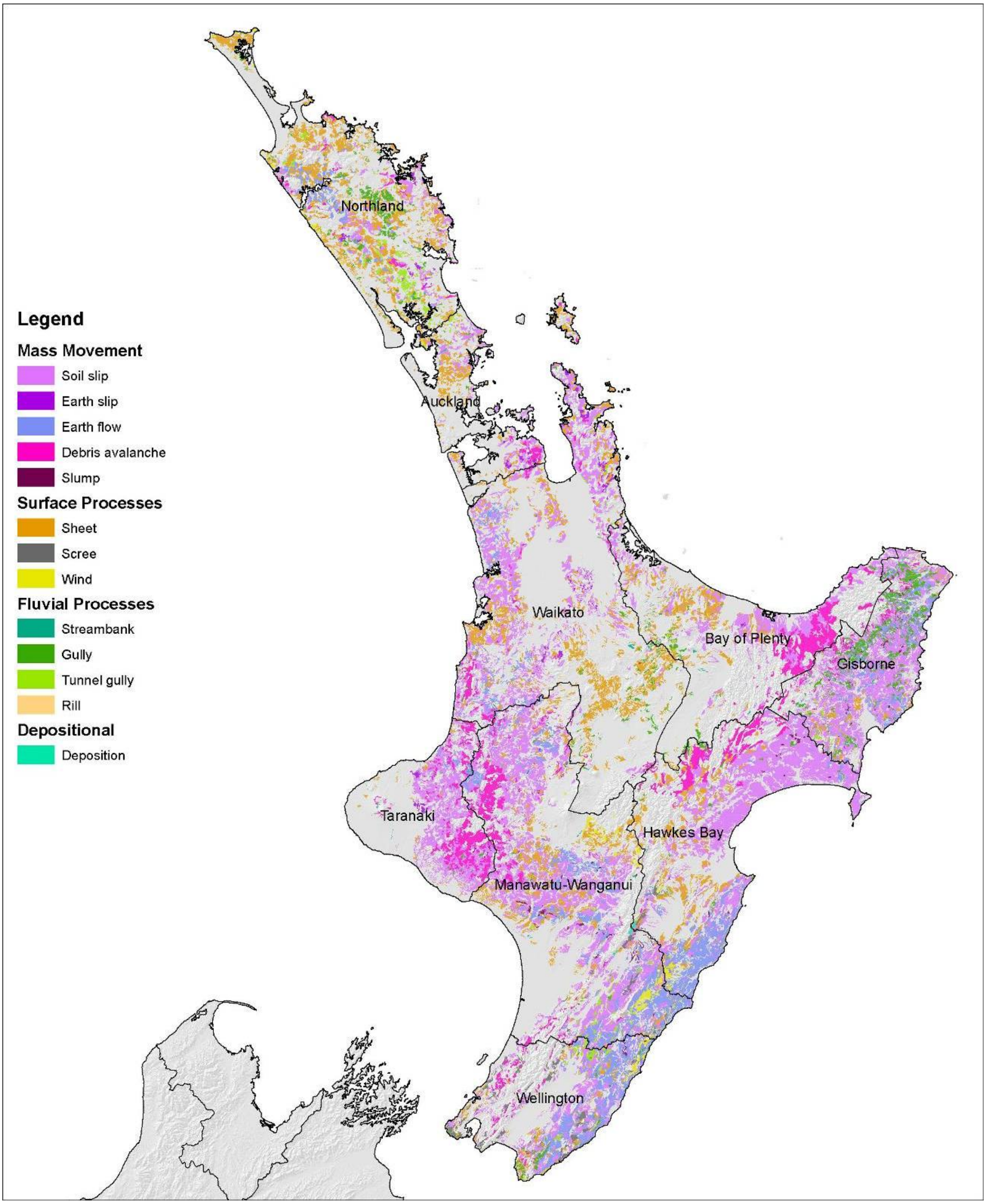


**Fig. 4** Dominant erosion types on North Island hill country.

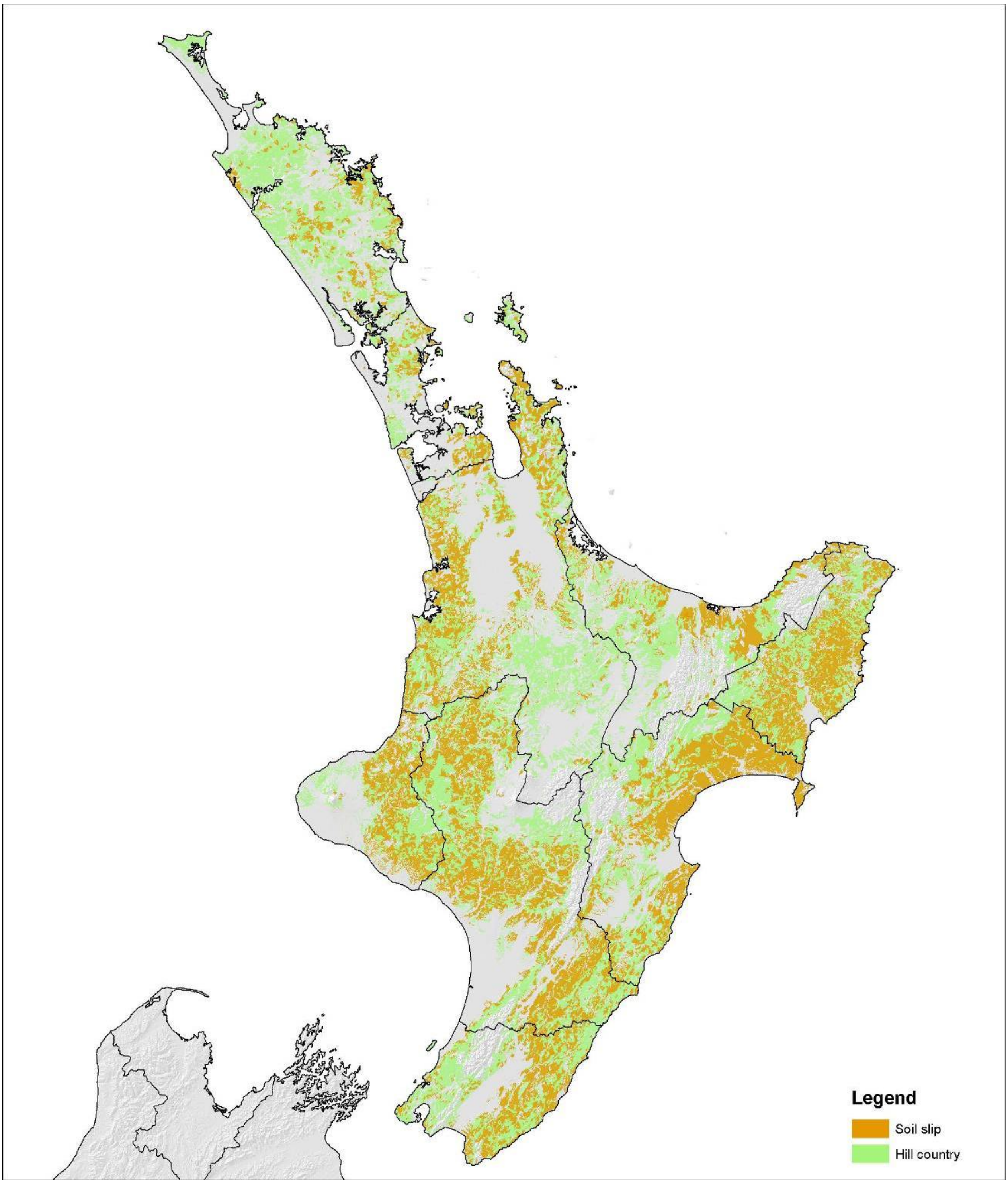


**Fig. 5** Distribution of soil slip erosion on North Island hill country[3].

[3] Note that the maps (Figs 5-8 and 12-15 show the distribution of NZLRI polygons affected by each erosion type, not the actual area directly affected by each erosion type.

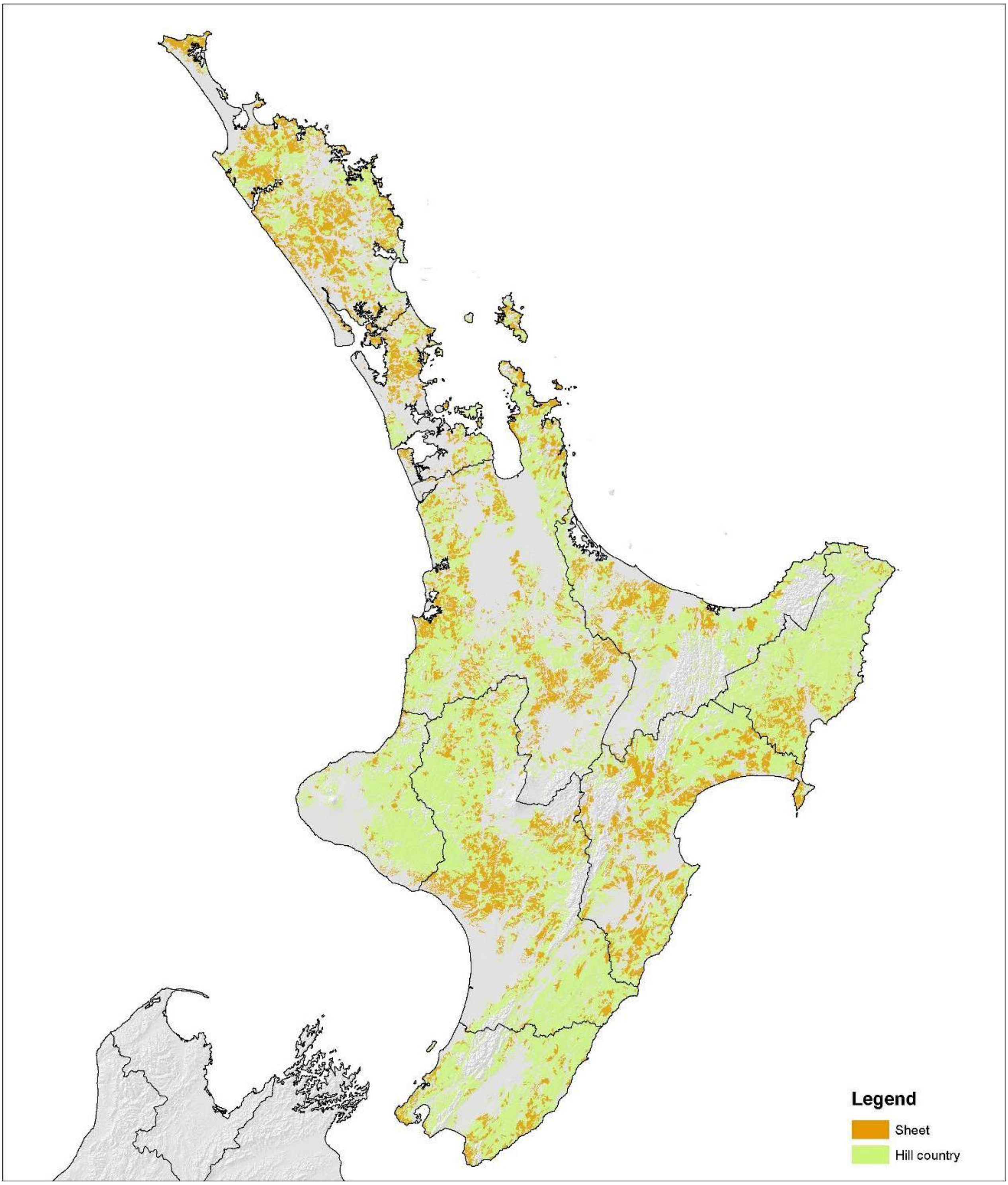


**Fig. 6** Distribution of sheet erosion on North Island hill country.

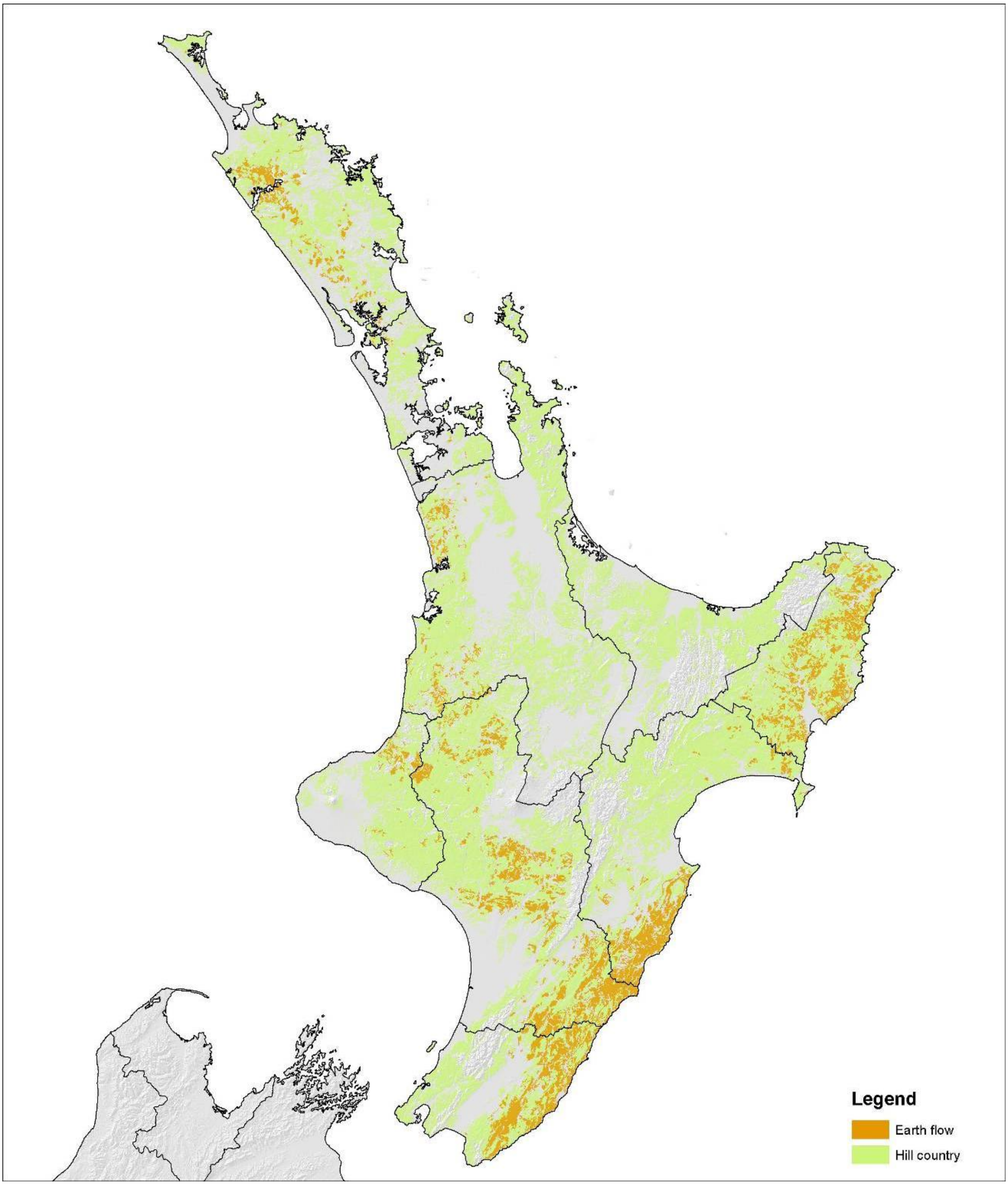


**Fig. 7** Distribution of earthflow erosion on North Island hill country.

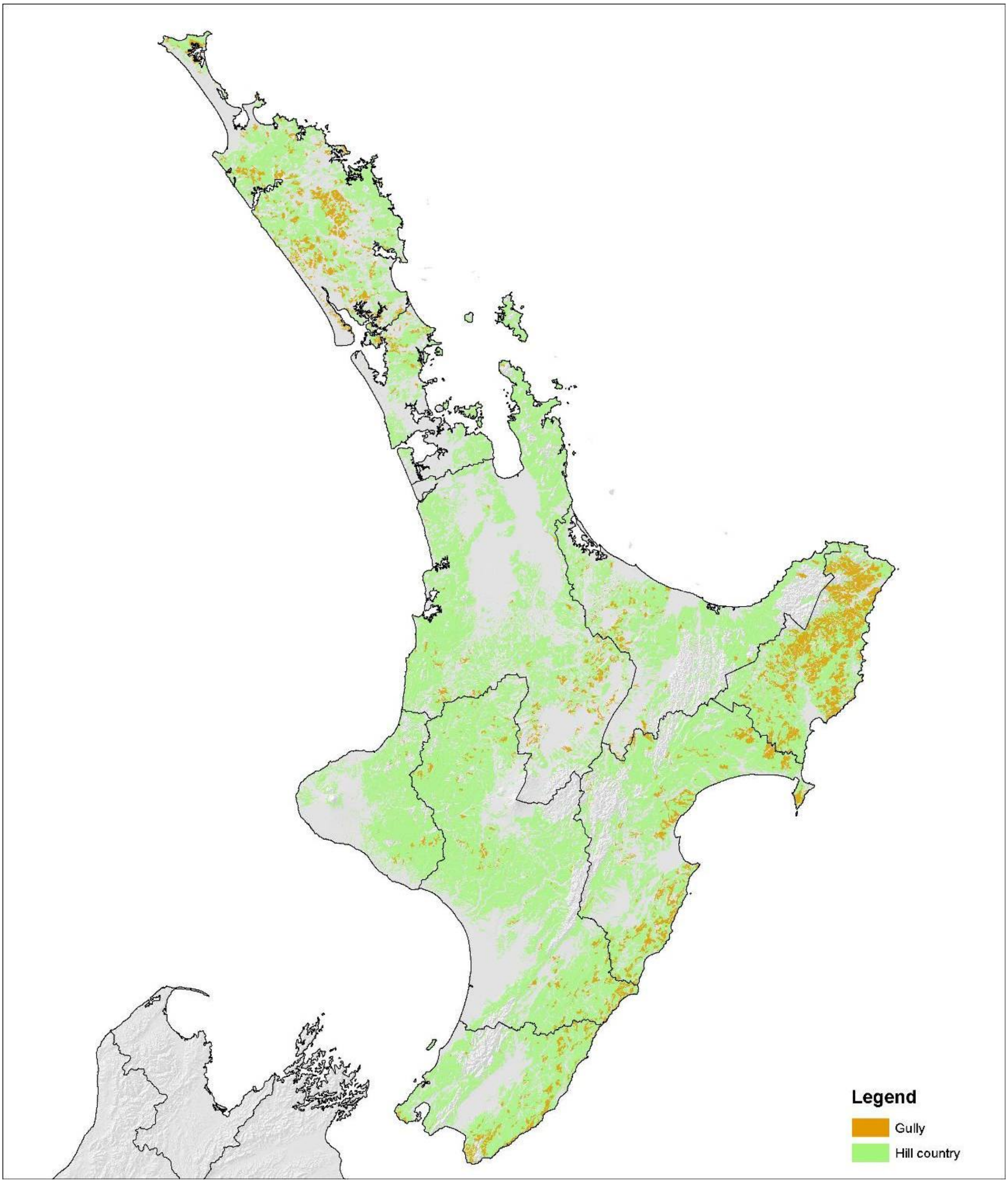


**Fig. 8** Distribution of gully erosion on North Island hill country.

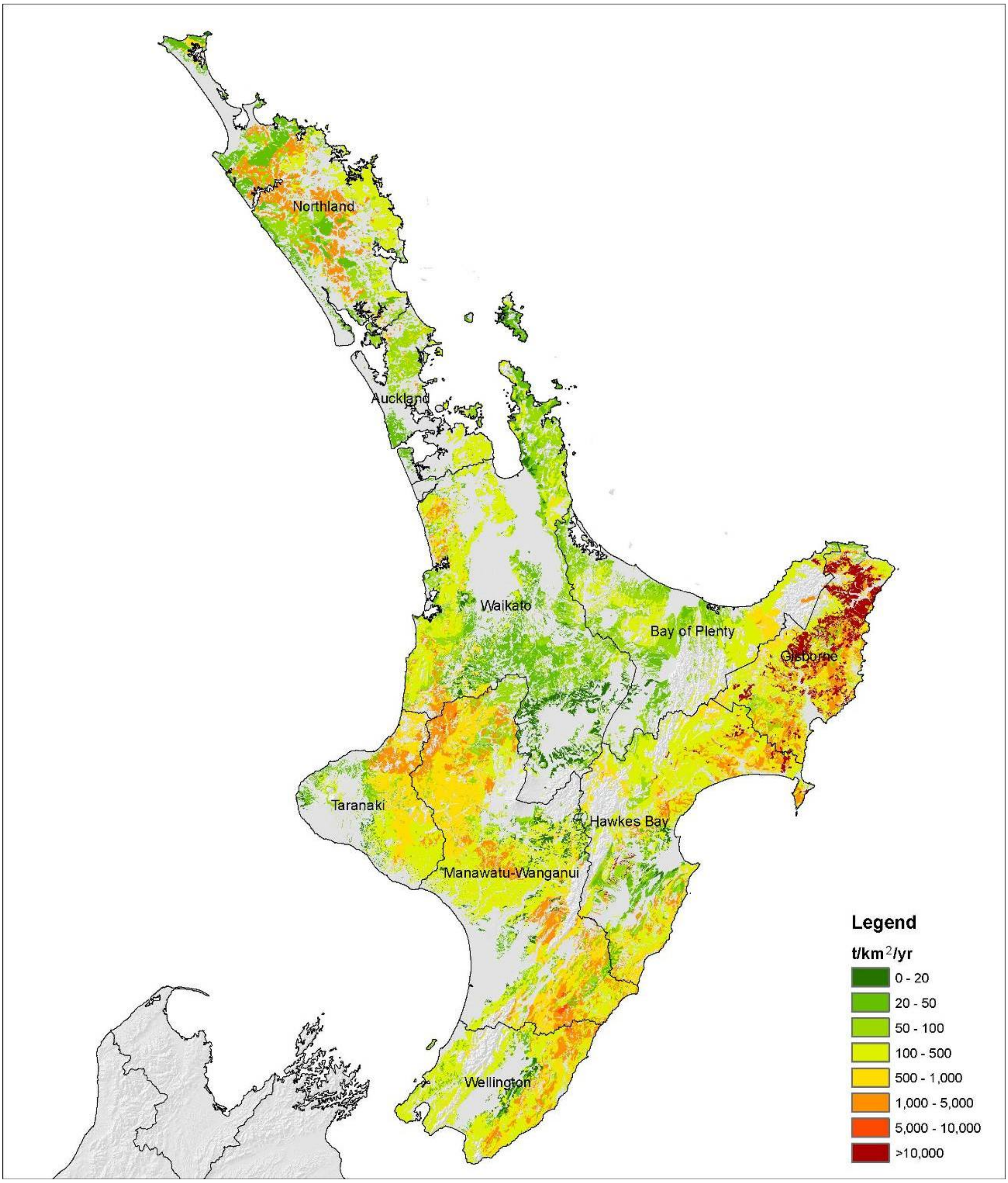


**Fig. 9** Sediment yield on North Island hill country (from Hicks and Shankar 2002).

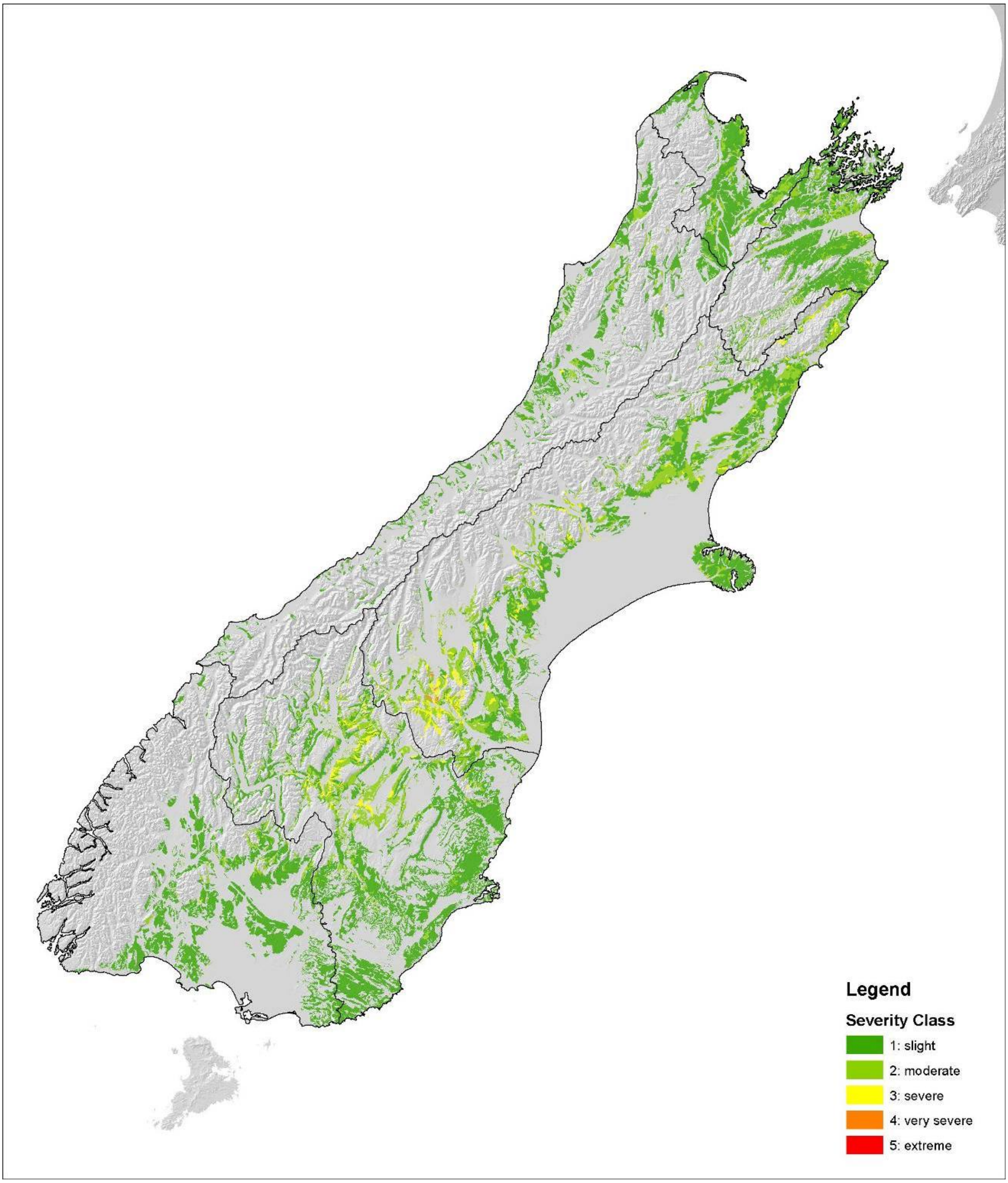


**Fig. 10** Erosion severity on South Island hill country.

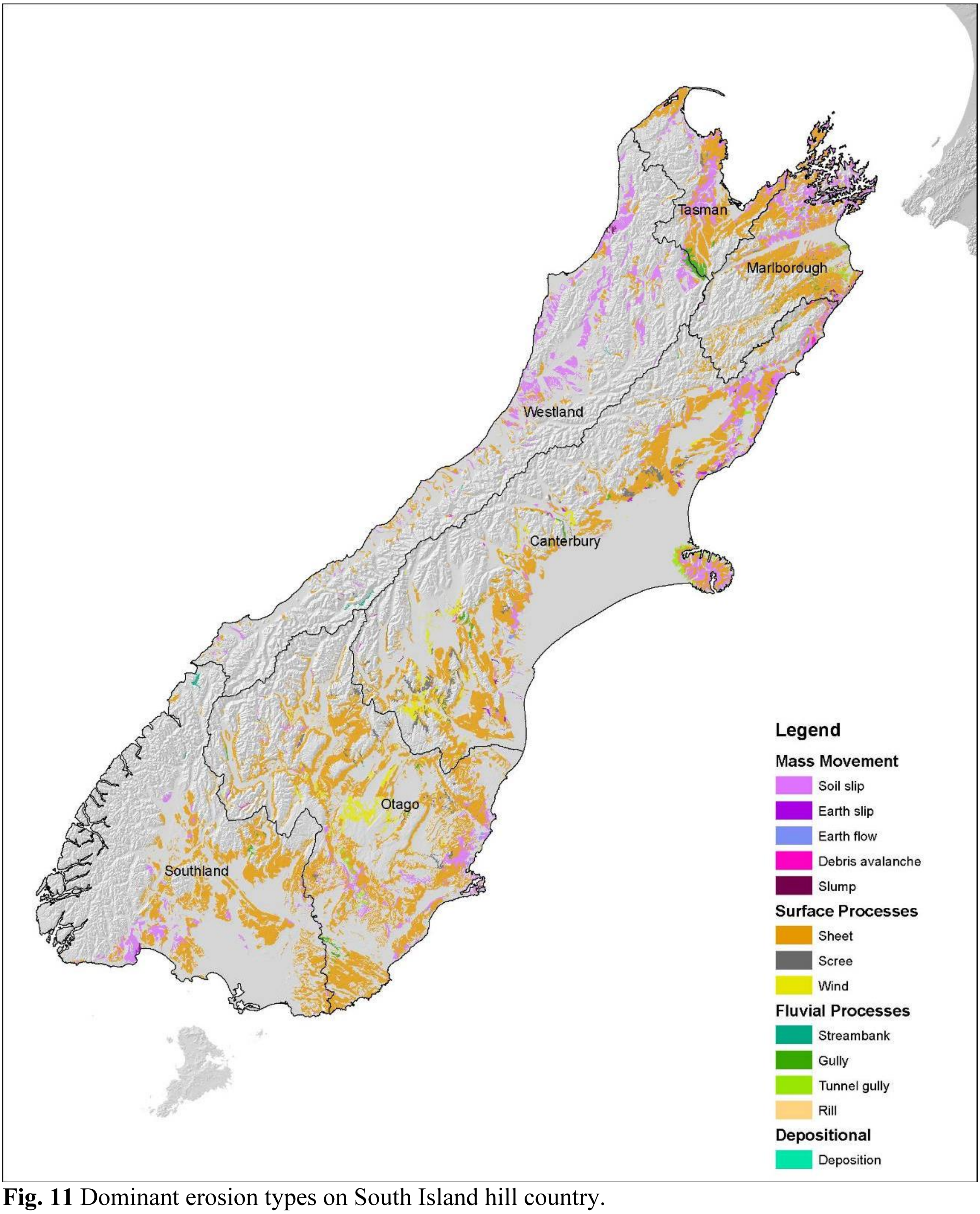


**Fig. 11** Dominant erosion types on South Island hill country.

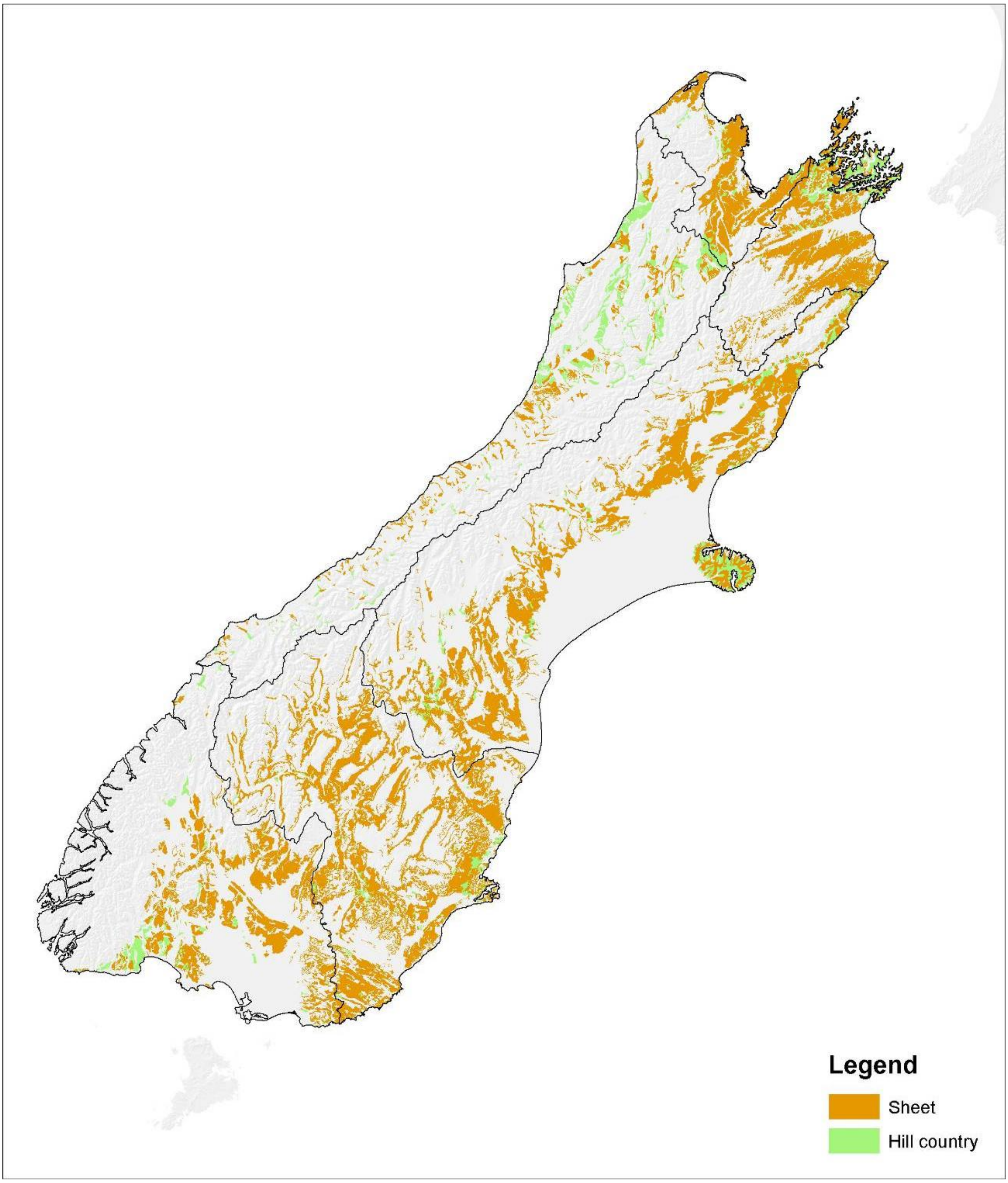


**Fig. 12** Distribution of sheet erosion on South Island hill country.

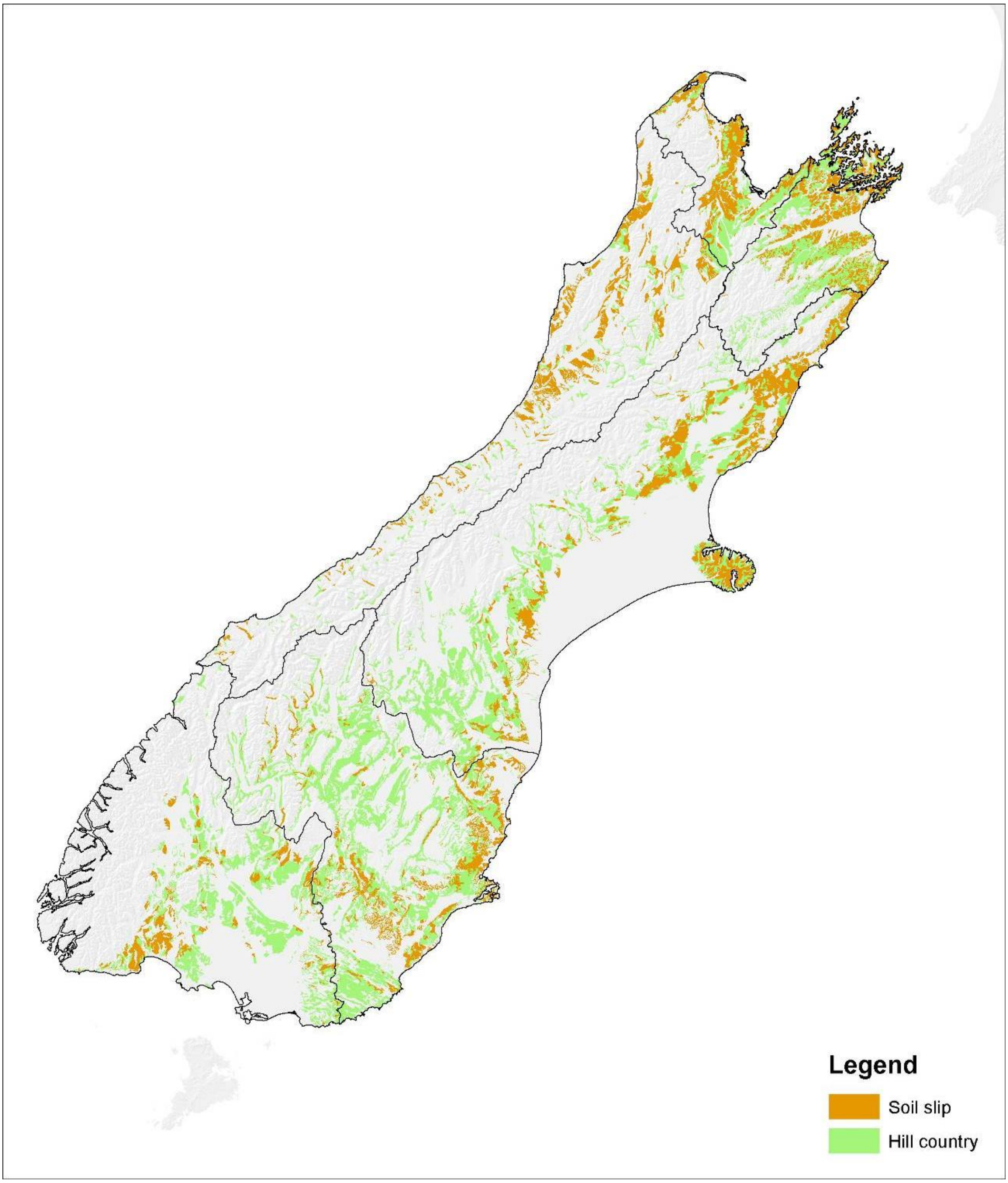


**Fig. 13** Distribution of soil slip erosion on South Island hill country.

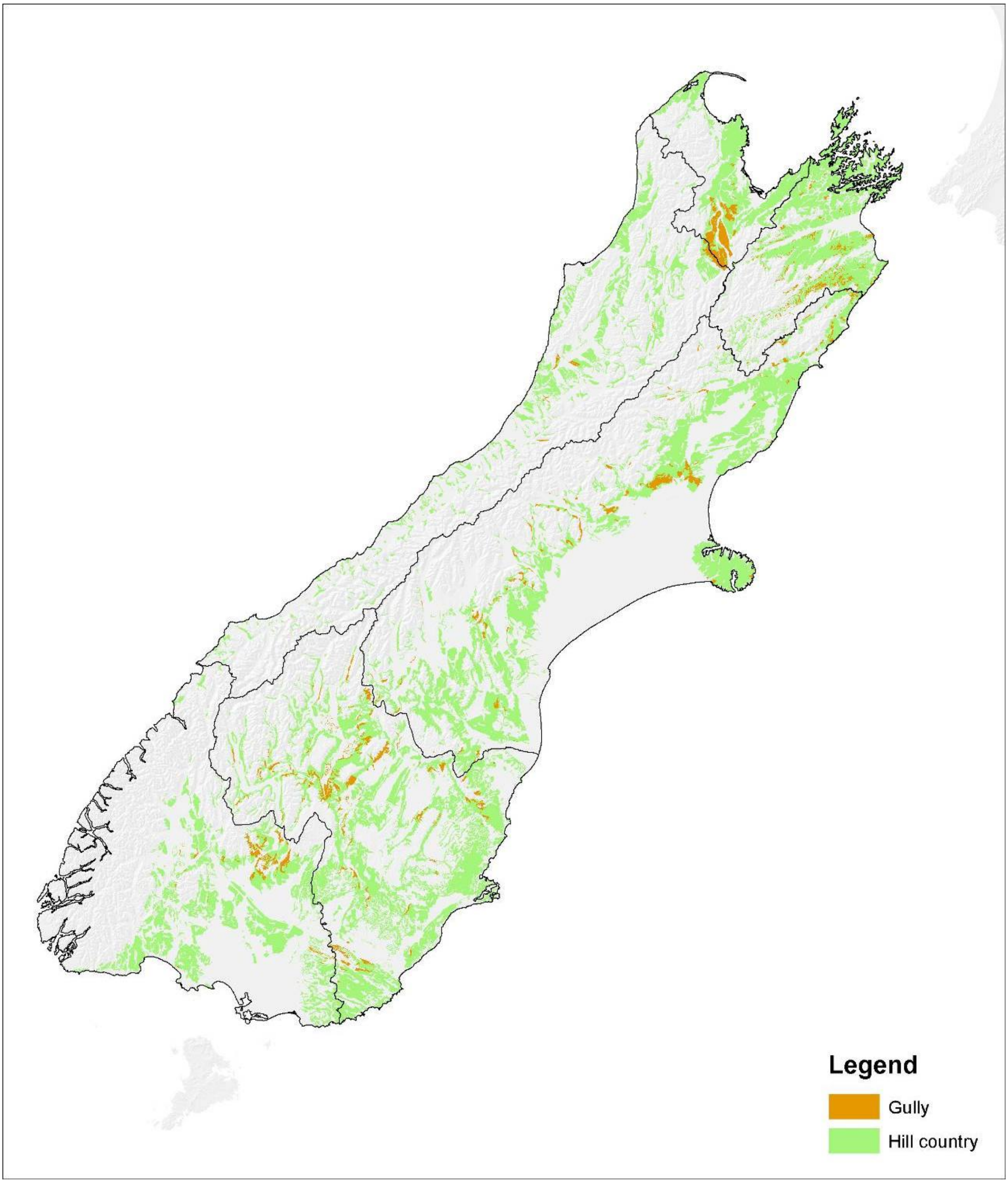


**Fig. 14** Distribution of gully erosion on South Island hill country.

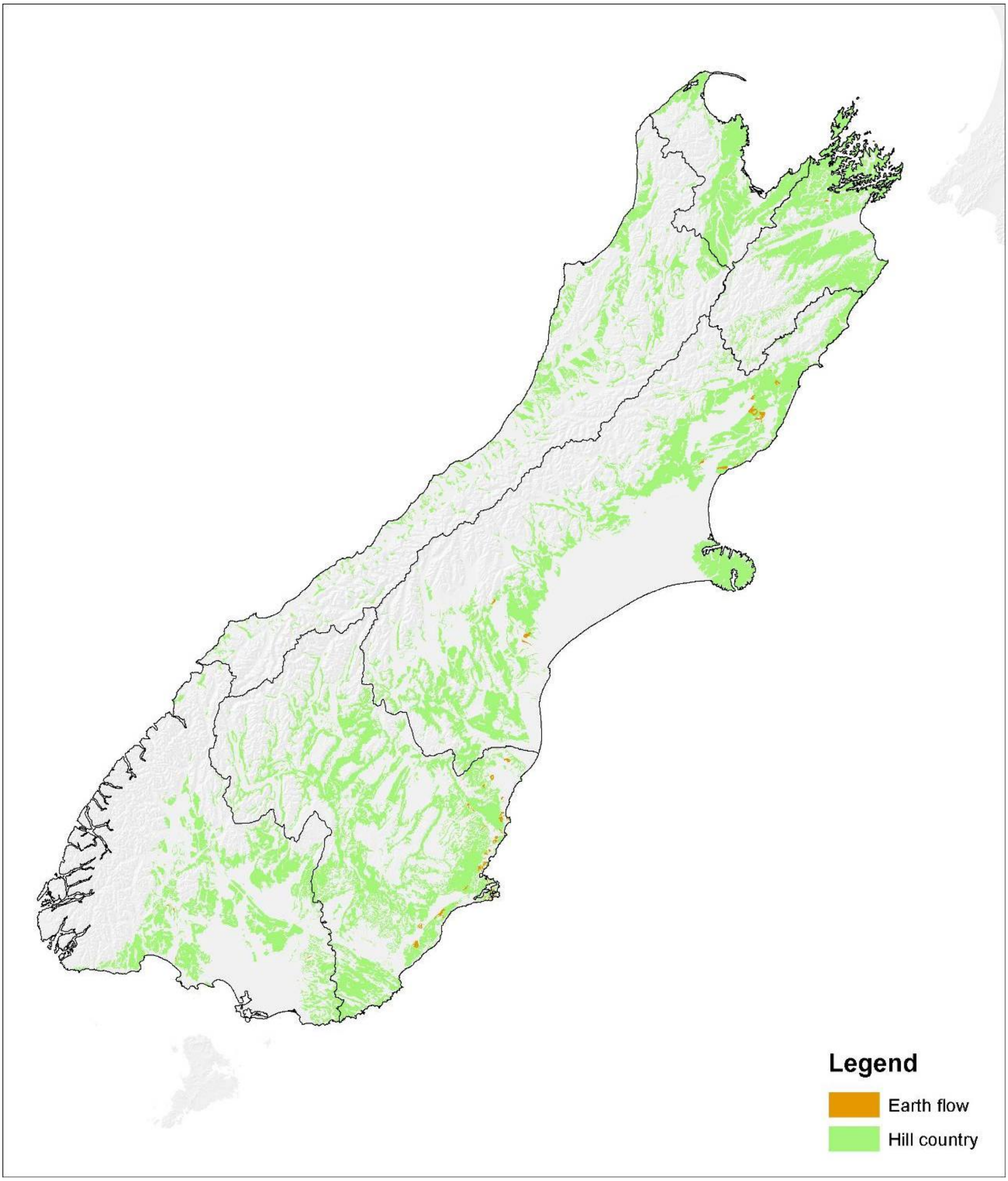


**Fig. 15** Distribution of earthflow erosion on South Island hill country.

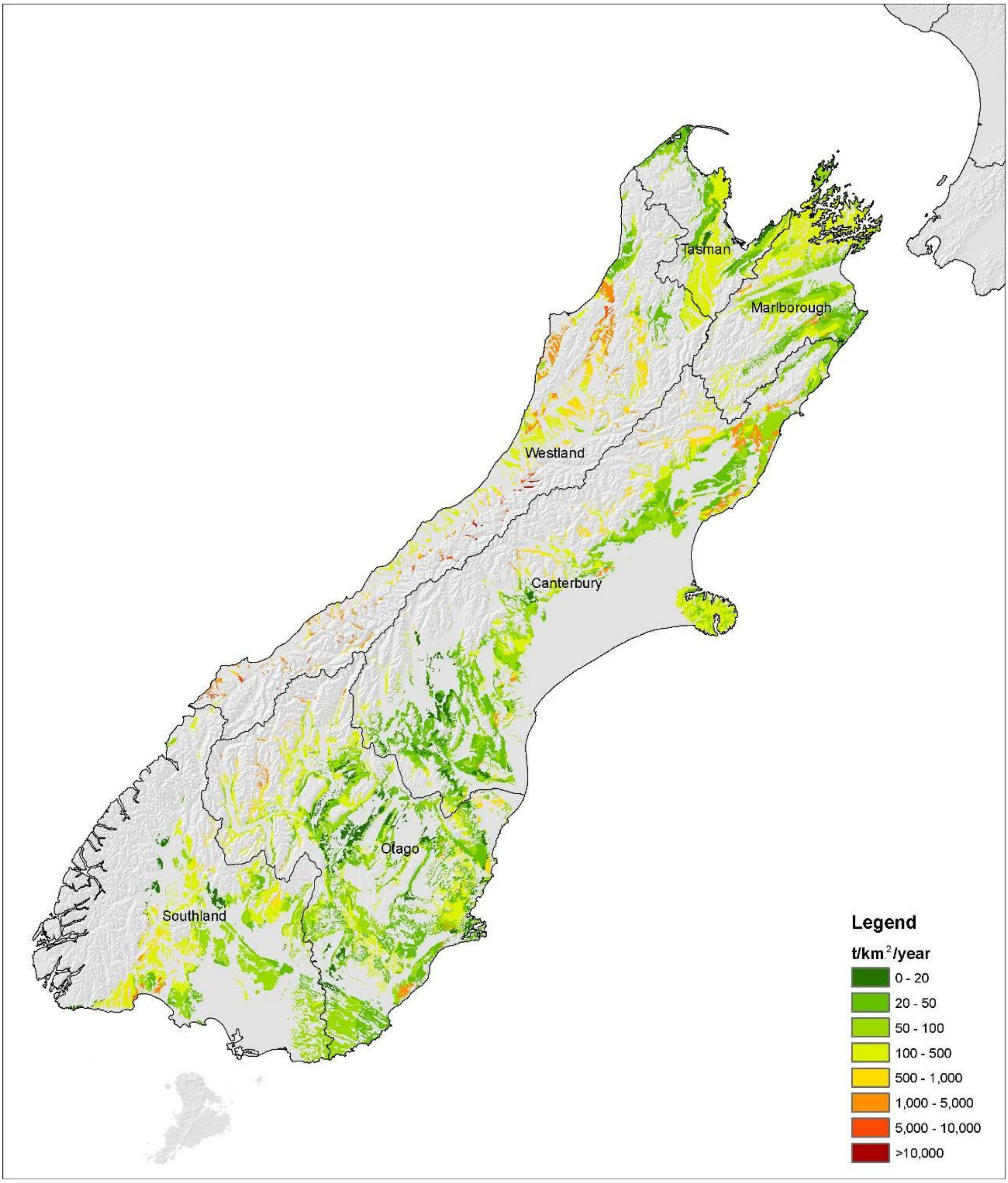


**Fig. 16** Sediment yield on South Island hill country (from Hicks and Shankar 2002).

### 5.1.2 Information on erosion processes on hill country

New Zealand is widely recognised as having high rates of both natural and man-induced erosion. The extent and type of natural erosion is determined by the complex interplay between geology (rock type, weathering, structure, and regional plate tectonics), climate (particularly rainfall amounts and intensities, frequency of large storms) and vegetation, producing regional variation in the susceptibility of the land to erosion. For example, severe earthflow and gully erosion are closely related to the extensive areas of mudstone and crushed rock terrain in the North Island. In the South Island gully erosion is largely associated with hill country developed on easily eroded soft mudstone, sandstone, and weakly consolidated conglomerate, and regional fault and crush zones. Regional studies by Griffiths (1981, 1982) and Hicks et al. (1996) show that annual rainfall is the dominant factor influencing rates of erosion, as measured by suspended sediment yields, and numerous studies point to the importance of large storms as triggers for widespread landsliding.

Imposed on these natural drivers of erosion is the effect of historical deforestation and land use which has increased erosion to a greater or lesser degree depending on the lands' inherent susceptibility to erosion. Numerous studies demonstrate the linkage between increased sedimentation rates, European settlement and deforestation (e.g. Trustrum & Page 1992; Page et al. 1994a, b). Page et al. (2000) also demonstrate the dramatic enhancement of the susceptibility to shallow regolith landsliding with the removal of the indigenous forest cover in the east coast of the North Island. Deforestation can lead to at least a 10-fold increase in erosion both in the long term and during large storms, while short-term sediment yield increases of up to 100 times after forest harvesting have been recorded (e.g. Fahey et al. 1993). Glade (2003) reviews evidence on the relationship between land-use (vegetation) change and landsliding. Using sedimentation rates as a surrogate for erosion rates he shows sedimentation rates from a series of North Island sites increased by 7–18 times following deforestation. Much of the increase occurs when the tree roots lose their strength, about 2–5 years after forest removal. However, the impact of deforestation persists in many deforested areas with thick regolith or soft rocks which continue to erode faster than similar forested areas for at least a century (Page et al. 2000).

There is a substantial body of literature describing both natural and induced erosion in hill country (see Appendix 1), although much of it is descriptive (particularly the pre-1970s literature) and it is patchy in its geographical coverage and understanding of the mechanics and significance of different processes. Landslides are the best studied erosion process, are very widespread, and a major contributor to hillslope erosion and sediment yield. Glade and Crozier (1999) and Page (2008) provide extensive bibliographies and some analysis of the extensive landslide literature. Glade (1998) analyses landslide events in New Zealand to establish the frequency and magnitude of landslide-triggering storm events suggesting that daily rainfalls as small as 20 mm can trigger landslides (given high antecedent moisture conditions), and that daily rainfalls in excess of 120 mm trigger extensive landsliding in many areas. Crozier (2005) concludes that most common landslide events are triggered by storm rainfall with critical intensities governed by the prevailing antecedent moisture conditions, rainfall duration and amount. Since the onset of European deforestation, increased sediment production over much of New Zealand has largely been determined by landslide events (Glade 2003). On unstable slopes, thousands of landslides can be triggered by high-magnitude/low-frequency climatic events during storms with estimated return periods in excess of 50 years (e.g. Glade 1997, 1998, 2003). Earthquakes are also capable of triggering multiple-occurrence regional landslide events, but at a far lower frequency than their rainfall-triggered counterparts (Hancox et al. 1997).

In contrast, gully (e.g. Betts et al. 2003; Gomez et al. 2003; Marden et al. 2005; Parkner et al. 2006, 2007) and earthflow erosion (e.g. Wasson & Hall 1976; McConchie 1986; Zhang et al. 1991a, b, 1993; Trotter 1993) are far less well studied. However, in at least some east coast areas gullies cover much less area than landslides but make a far larger contribution to sediment yield as low-magnitude/high frequency rainfall events activate gully erosion (Page et al. 2000).

Research into hill country erosion is patchy geographically. Recent (post-1970) research has focused on the most highly erodible areas, often in response to the impacts of storms. The Wellington and Wairarapa areas received considerable attention after a wet period during the 1970s (e.g. Owen 1979; Crozier et al. 1980, 1982; Crozier 1983, 1990). The east coast of the North Island, particularly Lake Tutira and the Waipaoa catchment, has been a major research focus since Cyclone Bola in 1988 (summarised in Page et al. 2000) and the Taranaki region was well studied following Cyclone Hilda in 1980 (e.g. Trustrum & DeRose 1988; DeRose et al. 1991, 1993; Trustrum et al. 1993; DeRose 1996). More recently the Manawatu–Wanganui area has been a focus following the 2004 storms (e.g. Fuller & Heerdegen 2005; Hancox & Wright 2005a, b; Dymond et al. 2006; Hancox et al. 2007). Far less is known of hill country erosion processes in areas such as Northland, Coromandel, Waikato–King Country, the Central North Island Volcanic Plateau, and the South Island.

An analysis of information available for the range of erosion terrains described in section 5.1.1 is given below. The terrains are grouped according to their susceptibility to erosion. The focus is on quantitative rather than descriptive information on erosion processes and rates.

### 5.1.2.1 Land with a low erosion susceptibility

In the North Island this includes the hard rock hill country on igneous rocks (terrain 3), and the hill country and hilly steeplands from weakly weathered greywacke and argillite (terrains 6 and 12). Very little information is available for terrains 3 and 6. Process-based data for this terrain largely consists of one-off site investigations of material properties and engineering geology insights into the mechanisms and influences leading to the failure of large-scale mass movements, predominantly rotational slumping (Selby 1966; Riddolls 1977; McManus 1981; Beetham 1983; Davies 1996).

For the hilly steeplands (terrain 12) there are descriptions of the state of vegetation cover and erosion in steep hill country much of which has National Park status or is in the process of reverting to mānuka/kānuka and/or shrubby hardwood (Cunningham 1974; Cunningham & Stribling 1978). Research includes description of predominantly shallow landslides, their causes and relationships with vegetation cover (Jackson 1966; Marden 1984; Heine 1988). Storms (Selby 1967), weathering (Davies 1996) and earthquakes (Dellow 1988; Hancox et al. 1997) have been identified as the principal triggering mechanisms. Animal browsing has also been cited as a contributing factor (Marden 1984). The distribution and properties of soils in this terrain have been used to reconstruct the history of erosional events (Hubbard 1978; Hubbard & Neall 1980). Incidences of geological controls on the formation of large landslides (Read et al. 1992) and gullies (Parkner et al. 2006, 2007) have also been documented.

Very little research appears to have been undertaken on pastoral hill country in this terrain (Selby 1967). Most of the issues associated with this terrain focus on the downstream river management of sediment and flooding (Blakely 1977; Mosley 1978) and the recognition of landslides as a hazard in urban areas such as Wellington (Dellow 1988; Hancox et al. 1994).

In the South Island this includes the hill country from moraine (terrain 14) and hard rock (terrain 17). These terrains are susceptible to mass movement erosion especially soil slip and debris avalanches when subjected to long-duration high-intensity rainfall events (e.g. Bell 1976; Bowring et al. 1978). Published information specific to this type of hill country is largely descriptive, and rarely contains quantitative estimates of rates of sediment generation. The dominant erosion processes have been identified in both central government agency and regional council reports (e.g. NWASCO 1975–79; Cuff 1981). The key sediment-generating processes active in these landscapes include localised point sources (e.g. fault-controlled gullies, crush zones and associated slumps), riparian erosion, shallow landslides and sheetwash. The main erosion-triggering mechanisms are considered to be storm events or earthquakes, following pre- or post-European deforestation, exclusive of localised point sources such as fault-controlled gullies, crush zones and associated slumps.

### 5.1.2.2 Land with a medium erosion susceptibility

In the North Island this includes the loess hill country (terrain 1), the tephric hill country and hilly steeplands (terrains 2, 8), the soft rock hill country (terrain 5), the deeply weathered hill country and hilly steeplands (terrains 7, 13), and the hilly steeplands on hard igneous rock (terrain 9).

In the loess hill country a large body of information on soil slip erosion (shallow landslides) has been collected over the years and includes quantitative data on factors that predispose slopes in this terrain to soil slip (Crozier et al. 1990). Data capture was aided by the introduction of remote sensing and used experimentally as a quick means of surveying erosion and catchment condition (Stephens et al. 1983). Storm-damage assessments have generated a wealth of data on erosion extent, aspect and slope position, runout distance etc. This has in turn been related to (a) existing land use and (b) storm rainfall intensity and durations, giving a better understanding of the frequency–magnitude relations for soil slip erosion in this terrain. There are several detailed studies characterising earthflow movement patterns and rates, the thresholds at initiation and cessation of movements, the role of antecedent moisture conditions, rainfall and pore water pressure and composition and strength of earthflow material (Owen 1979; McConchie 1986). The most valuable data on erosion processes (soil slip and earthflows) are contained in student theses and have been collected during the course of long-term studies at established field sites located in the Wairarapa (e.g. Owen 1979; Crozier 1990). There has been limited research on tunnel gully erosion in this terrain (Kerrison 1981).

Soil conservation efforts have been well documented, though many are pictorial and/or descriptive (King 1963). Most deal with the revegetation of soil slips, the influence of soil conservation planting on pastoral productivity, topsoil and pasture biomass recovery, and long-term impacts of soil slip erosion as a constraint to sustainability (e.g. Trustrum et al. 1984; Lambert et al. 1993; Sparling et al. 2003).

In the tephric hill country and hilly steeplands (terrain 2) process studies deal with the measurement of sediment generation and delivery to waterways (Phillips & Nelson 1981) from gully erosion (Healy 1967), sheetwash (Marden et al. 2007), landing failure (Pearce & Hodgkiss 1987) and tracking (Smith & Fenton 1993) predominantly within exotic forests. Collection of much of the raw data has been commissioned by the forestry industry and is contained in client contract reports. Reports have a strong management focus dealing largely with the impacts of forest harvesting on sedimentation rates and on catchment hydrology (Coker et al. 1990; Rowe 1995; Rowe & Marden 1996, 1998; Rowe et al. 1996, 2001). There are limited data on landslides with one paper on debris flows (Costello 2007) and another on creep (Selby 1974). Similarly, few papers deal with erosion–land-use relationships on pastoral hill country in this terrain (Healy 1967; Selby 1972; Dons 1987).

No references were found specific to the hilly steepland tephric terrain (8).

In the soft rock hill country (terrain 5) process-based research is predominantly concerned with soil slips and earthflows in a pastoral hill country setting. Soil slip research is largely focused on their distribution (Crozier et al. 1980), nature of the failed materials (Brooks et al. 2002), controlling factors (Crozier 1990; Brooks et al. 2002), triggers (Crozier 1990), and run-out behaviour (Crozier 1996). Findings led to the development and application of a two-dimensional coupled soil hydrology–slope stability model for soil slips in Hawke's Bay (Brooks et al. 2002, 2004). Earthflow studies included real-time monitoring of soil moisture conditions leading to a better understanding of the role of soil moisture in the control of earthflow initiation, propagation and cessation of movement (McConchie 1986; McConchie et al. 2000). Several publications give an engineering perspective on the mechanisms involved in large-scale, deep-seated landslide failures. They provide valuable insights into the susceptibility of this terrain to potential large-scale landsliding (Pettinga 1987a, ; Stockbridge 1991). One publication raises management issues arising from landslide and related activity (Crozier 1993).

Published information for hill country derived from deeply weathered rocks (terrain 7) has a strong engineering geology focus on site investigations of rock properties, defects (Williams 1989) and weathering (Davies 1996) leading to large-scale mass movement failure in the Auckland, Waikato, Coromandel and Northland areas of this terrain (Ward 1966a; Waldvogel 1979; McManus 1981; Whyte 1982; Ashby 1985; Simpson 1987; Tilsley 1993; Chapman 1998; Hill 2000). There are limited data on soil piping and tunnel gullying predominantly stemming from student investigations in Northland (Ward 1966b; Vissers 1969; Goldsmith & Smith 1985). Studies on shallow landslides document their distribution, classification, causes and mode of failure (Rodgers 1978; Rodgers & Selby 1980). The initiation of landslides is mostly attributed to high-intensity rainfall events (Selby 1967, 1976). Data include comparisons of landslide occurrence across different land uses and their increased incidence as a consequence of forest removal (Parker 1978). Many publications recount different episodes of landsliding during the 1960–70s which impacted areas of indigenous forest (Selby 1967, 1976; Pain 1968a, b, 1969, 1971; Rodgers 1978; Rodgers & Selby 1980). Limited information is available on gully erosion and soil conservation techniques used to control it (Schouten 1976; Schouten & Hambuechen 1978).

In the hilly steeplands derived from deeply weathered rocks (terrain 13) storm damage assessments document the distribution of shallow landsliding in relation to slope and site factors, and age and type of vegetation cover, including pasture (Salter et al. 1983; Marden & Rowan 1995a, b). One study quantified the volume of sediment delivered to streams by landslides initiated on forest cutover during storms (Marden et al. 2006). Another assessed the risk of storm-initiated landslides to exotic forest in the Coromandel (Phillips et al. 1999). Slopewash and sediment yield research is related to forest management practices in an exotic forest estate. Slopewash research documents the rate of sediment generation over a 2-year period following forest clearfelling (Marden et al. 2006). Sediment yield data are also available from the same site (Phillips et al. 2005). There is limited research on geological controls on landsliding in this terrain (Lowe 1910; Ashby 1985).

For the hilly steeplands on hard igneous rock (9) there are no relevant studies.

The South Island hill country with a medium erosion susceptibility includes the loess hill country (terrain 15), the soft rock hill country (terrain 16), and all the hilly steeplands (terrains 18, 19, 20, 21).

For the loess hill country (terrain 15) published information is largely descriptive, and there are no long-term studies or quantitative data on erosion rates from loess hill country. Some localised semi-quantitative event-based studies of mobilised sediment volumes and delivery ratio to streams are available (e.g. Harvey 1976). The distribution and mechanism of formation of tunnel gullies have been the focus of several studies (Gibbs 1945; Laffan & Cutler 1977a, b; Trangmar 1983; Lynn & Eyles 1984).

More information is available for the soft rock hill country and hilly steeplands (terrains 16, 18), particularly for small forested catchments and their response to harvesting, primarily on weakly consolidated conglomerate, sandstones and mudstones. Medium-term suspended sediment yield data for undisturbed forested catchments range from 4 t/km$^2$/yr on the Moutere Gravels under an annual rainfall of 1060 mm/yr (DM Hicks 1990), to 77 t/km$^2$/yr on the Old Man Gravels at higher rainfalls of 2600 mm/yr (O'Loughlin et al. 1978). Sediment yield increases up to 100 times at harvesting, dependent on harvesting method, have been recorded (O'Loughlin et al. 1976, 1980). Sediment yields of up to 15100 t/km$^2$ in individual storms (>20-yr return period) have also been measured (O'Loughlin et al. 1982). Low-frequency large storms are considered primarily responsible for most of the sediment yield in both undisturbed and disturbed forested catchments (O'Loughlin et al. 1982). In undisturbed catchments the storm-induced increased sediment yields are not necessarily accompanied by an increased incidence of landslides, indicating the significance of other forms of erosion (e.g. riparian erosion) to sediment yield.

This terrain is susceptible to both mass movement and fluvial erosion especially soil slip (shallow landslide), gully, debris avalanche, and slump in long-duration high-intensity rainfall events (e.g. Bell 1976; O'Loughlin & Pearce 1976; Bowring et al. 1978; O'Loughlin et al. 1980). Post-storm measurements of deposits and/or dimensions of eroded areas give background denudation rates of approximately 140 t/km$^2$/yr on the largely steep, dissected, massive sandstone and siltstone terrain of the Notown area of the West Coast (annual rainfall 2300 mm/yr). In the same area, sediment yields of 1540–5600 t/km$^2$/yr followed clearfelling (O'Loughlin & Pearce 1976). There are a few large steep-walled active gully systems but they are restricted in distribution to the mudstone, sandstone or conglomerate lithologies (e.g. along the Clarence coast; Bell 1976).

In contrast to a forest cover, suspended sediment yields on the Moutere Gravels from pasture range from 21 to 79 t/km$^2$/yr. Sediment yield data from small catchments were 4 t/km$^2$/yr under pine forest and 79 t/km$^2$/yr under pasture (DM Hicks 1990). The storm events which were most effective in transporting sediment were those that reoccurred every few months. Smith (1989, 1992) also lists measured sediment yields for this terrain as 21 t/km$^2$/yr under pasture, and 32 and 67 t/km$^2$/yr from two catchments under pasture with riparian pine. She suggested increased erosion in the pasture catchments with riparian pine was associated with poor ground cover in riparian forest causing overland flow and streambank erosion.

The steep hard rock and steep weathered hill country terrains (19, 20) are susceptible to mass movement erosion, especially soil slip and debris avalanches when subjected to long-duration high-intensity rainfall events (e.g. Bell 1976; Bowring et al. 1978). Medium-return-period storms trigger mass movement failures regardless of land use on the more strongly weathered slopes <200 m in the more humid climates of the Marlborough Sounds (Phillips et al. 1996). Published information specific to this type of hill country is largely descriptive, and rarely contains quantitative estimates of rates of sediment generation (e.g. Coker 1994). The dominant erosion processes have been identified in both central government agency, and regional council reports (e.g. NWASCO 1975–79; Marlborough Catchment Board, Marlborough Sounds Land Resource Survey 1980s, unpubl.). The key sediment-generating processes active in these landscapes include localised point sources (e.g. fault-controlled gullies, crush zones and associated slumps), riparian erosion, shallow landslides, and sheetwash. The main erosion-triggering mechanisms are considered to be storm events or earthquakes, following pre- or post-European deforestation, exclusive of localised point sources such as fault-controlled gullies, crush zones and associated slumps. Limited quantitative data on annual sediment delivery rates from specific sources are available (e.g. from a forestry road network, determined using runoff plots by Fahey & Coker (1992)).

On the more areally restricted, deeply weathered igneous rock terrain (terrain 21) quantitative data are limited to post-storm measurements of deposits and/or dimensions of eroded areas, primarily those associated with forestry road networks. Sediment yields from surface erosion from forestry roads has been measured at 37 t/km$^2$, and that for mass movement erosion associated with forestry activities at 280 t/km$^2$/yr (Fahey & Coker 1989; Coker & Fahey 1993), while denudation rates for natural erosion are estimated to be 500 t/km$^2$/yr (Adams 1980; Fahey & Coker 1989). This terrain is susceptible to mass movement erosion, debris slide and debris avalanches, and slumps when subjected to long-duration high-intensity rainfall events, which trigger failures regardless of land use (Coker & Fahey 1993).

#### 5.1.2.3 Land with a high erosion susceptibility

In the North Island this includes the crushed rock terrains (terrains 4, 10) and the hilly steeplands on soft rock (terrain 11). No South Island terrains are ranked as having high erosion susceptibility although locally, and during large storms, parts of some of the terrains (particularly the steep soft rock hill country) are highly susceptible to erosion.

Most literature dealing with erosion and land-use issues in hill country is from studies in soft rock terrain. Many of the references cited for ‘crushed soft rock terrain’ also have relevance to soft rock terrains (5, 11) and vice versa.

Process-focused research includes studies of earthflow materials (Trotter 1993) and movement rates from long-term study sites located in pastoral hill country (Wasson 1976; Wasson & Hall 1976, 1981). There is a large amount of literature quantifying magnitude–frequency relationships for storm-initiated landslides (e.g. Reid & Page 2003) and the volume of sediment generated by them (e.g. Page et al. 1999). Similarly there is a large body of literature on assessments of the erosion control effectiveness of past soil conservation efforts both in the longer term (Hamilton & Kelman 1952; Todd 1963, 1965; Sutherland et al. 1974; Seddon 1981; Pearce 1983; Haylock & Trotter 1985; Miller 1986; Hicks 1988; Kelliher et al. 1992; Oshaka et al. 1994; Phillips et al. 2000) and as a consequence of damage sustained during Cyclone Bola (Hicks 1989b, c, 1991a). Mostly they are descriptive; however, there are several key attempts to quantify the performance of biological erosion control measures (Hicks 1989b; Luckman & Thompson 1991a, b; Thompson & Luckman 1991a, b, 1992, 1993). Much of this literature has previously been summarised and reviewed by Phillips et al. (2000).

The research has almost solely been undertaken in East Coast region with very little from similar terrain in Northland.

For the steep crushed rock hilly steeplands (terrain 10) the literature is dominated by research on the initiation, development and remediation of gully erosion and earthflows. For gully erosion, there are substantial databases on their spatial distribution and location in relation to geology and vegetation cover (Marden unpublished). Gully development has been captured using sequential aerial photography and DEMs of gullies used to calculate sediment generation rates (De Rose et al. 1998; Betts et al. 2003; Marden et al. 2005). Sediment delivery ratios during and after a major cyclonic event have been calculated for major gully systems (De Rose et al. 1998; Gomez et al. 2003; Kasai et al. 2005). The role of weathering and structural–tectonic influences on gully development has been investigated at a cursory level (Pearce et al. 1981; D'Ath 2002).

Much of the research on earthflow and interrelated processes in this terrain has been done at Mangatu Forest over the past two decades (Marden et al. 1992). Data include earthflow displacement rates (including comparison between forested and unforested earthflows), internal deformation patterns, characterisation of earthflow material properties, measurement of pore water fluctuations and soil moisture content, and the hydrological effects of reforestation and deforestation on earthflows and other erosion processes (Pearce 1982; Pearce et al. 1987; Zhang et al. 1991a, b, 1993). The rheological parameters of debris flow material from a mass movement – gully complex have also been investigated (Phillips 1988) and sheetwash erosion rates have been measured for a 2-year period following forest harvesting (Marden & Rowan 1997).

The findings of the process-related literature have implications for the management of gully (Marden et al. 2005), earthflow (O'Loughlin & Zhang 1986) and sheetwash erosion (Marden & Rowan 1997) in this hill country terrain. Demonstration of the influence of forestry in restoring stability to earthflow topography, reducing landsliding and in closing down gullies is particularly significant to the management of this terrain (Marden 2004).

In the hilly steepland soft rock terrain (11) research is predominantly on shallow landslide erosion with fewer accounts documenting the existence and ongoing behaviour of deeper-seated mass movements (Belz 1967; Ker 1970; Stout 1977). Most accounts attribute the incidence of shallow landsliding to be a consequence of forest clearing (Trustrum & De Rose 1988; Thorn 1994) and triggered by heavy-rainfall events (Marden et al. 1991; Marden & Rowan 1993; De Rose 1994; Page et al. 1994a, b; Fransen & Brownlie 1996; Ekanayake & Phillips 1999a). Earthquake activity is the preferred mechanism leading to the failure of large landslides (Edwards 1990; Crozier et al. 1995). Aspects of shallow landslide research include post-deforestation soil loss (De Rose et al. 1993; Thorn 1994), measurement and modelling of soil moisture and pore-water pressure before and during failure (Ekanayake & Phillips 1999a, 2002), rainfall intensity – landslide distribution relationships (De Rose 1994), the influence of different vegetation types and age on landslide initiation during storm events (Marden et al. 1995) and rates of soil recovery on landslide scars (Trustrum & De Rose 1988). Models of slip erosion risk (Fransen 1996, 1998), and to determine thresholds for the initiation of landslides under near-saturated conditions (Ekanayake & Phillips 1999a, 2002) on steep soft rock hill country have been derived from these studies.

In one landmark study sediment yields from a pasture and a pine forest catchment were compared over a 12-year period (Fahey & Marden 2000; Fahey et al. 2003), during which the forested catchment was harvested, and showed:

a) For the pre-harvest period, sediment yields from the forested catchment were less that from the pastured catchment
b) During the logging phase of the harvest period sediment generation from the forest catchment exceeded that from the pastured catchment by 2–3 times but returned to pre-harvest levels within 2–3 years of completion of harvesting
c) The main sources of sediment were from banks, sidecast failures, shallow landslides and sediment stored in the channel bed
d) Slopewash on cutover was not an important sediment-generating process
e) Over the duration of the study the suspended sediment yield of the pastured catchment exceeded that of the forested catchment by 3–4 times
f) In the absence of a Bola-type event at or shortly after harvesting, total suspended sediment yields over a full forest rotation (c. 27 years) in this terrain will be substantially less than those from catchments in pasture

All aspects of this study have been published in Eyles & Fahey (2006).

Much of the literature on soil conservation practices (including reforestation, pole planting and reversion) and measures of their performance stem from research undertaken in this terrain. Assessments of soil conservation performance include: post-storm landslide damage assessments (Phillips et al. 1990; Marden et al. 1991, 1995; Bergin et al. 1995), tree root excavations (Watson & O'Loughlin 1990; Watson et al. 1995, 1997, 1999, 2000), and water balance comparisons for the different vegetation types (Rowe et al. 1999) and associated planting strategies/densities (Phillips et al. 1990; Hicks 1991c). While the effectiveness and performance of forestry and reversion is readily quantifiable and is supported by measured data, it has proven more difficult to measure the performance of pole plantings other than by semi-quantitative or descriptive means. Limited research on the oversowing of slips (Quilter et al. 1993) and vegetation and soil recovery on shallow landslides (Smale et al. 1997) has been undertaken in this terrain. In recognition of the severity of erosion and its impacts on pastoral productivity in this terrain several publications have attempted to raise the issue of sustainability and the need to protect remaining soil resources (e.g. Brown & Black 1989; Blaschke et al. 1992; Taranaki Regional Council 1992; Hicks et al. 1993). One study provides an economic analysis of the impact of a single storm event on hill country farms (Korte 1988).

### 5.1.3 Identification of highly erodible land

While the NZLRI data provide a broad national and regional picture of susceptibility to erosion (as described in section 5.1.1), they are inadequate for use at detailed scales (particularly farm scale). Recently work on defining highly erodible land (HEL) has been undertaken in the Manawatu (Page et al. 2005; Dymond & Shepherd 2006) using some of the research results described in the previous section. Highly erodible land was defined as 'land with a potential for severe erosion, or moderate erosion where sediment directly enters a watercourse, if it does not have protective woody vegetation'. It was identified from land use capability unit (primarily determined by rock type), a slope threshold for each LUC unit (ranging from 24 to 28º), and the presence of moderate or severe earthflow erosion. Subsequently this approach was developed into a model of landslide susceptibility (Dymond et al. 2006), including an analysis of whether sediment will be delivered into a stream system. The approach has now has been extended to the whole of the North Island by Dymond et al. (2008).

The model of landslide susceptibility was tested after the 2004 Manawatu storm by comparing the distribution of land classified as highly erodible with the map of actual erosion scars (Dymond et al. 2006). The landslide susceptibility model predicted land susceptible to landsliding with moderate accuracy: 58% of erosion scars in the February 2004 storm occurred on hillsides considered susceptible to landsliding. The moderate accuracy arose because the model incorporated a concept of slope thresholds (above which the probability of landsliding is high and below which the probability is low). This concept was inadequate; the 2004 storm showed that on land below the slope thresholds the relationship between slope and the probability of landsliding was approximately linear, and that there was significant landsliding on slopes below the thresholds used.

### 5.1.4 Modelling hill country erosion

Recently several approaches to modelling hill country erosion have been developed that are starting to provide (a) tools for assessing the impact of land management scenarios and (b) a means of synthesising the results of the multitude of process-based studies.

The New Zealand Empirical Erosion Model (NZEEM®), developed by Landcare Research (Dymond & Betts in press), uses empirical relationships between measured sediment yield and rainfall to respread sediment yield across the landscape and determine spatially distributed average annual erosion rates. It builds on the earlier work of Hicks et al. (1996, 2003) relating sediment yield to rainfall, rock type and erosion terrain by incorporating the impact of vegetation cover on sediment yield. The cover factor assumes a factor-of-10 difference between woody and herbaceous vegetation cover and allows the analysis of land-use scenarios involving vegetation cover change from pasture to woody vegetation. In respreading stream sediment yield across the landscape to determine average annual erosion rates, NZEEM® assumes a sediment delivery ratio of 1 (i.e. it assumes all sediment in the stream system has been immediately delivered with no storage of sediment on hillslopes to buffer sediment delivery). NZEEM has also been incorporated into a hybrid empirical-process-based model, developed in Australia (SedNet; Wilkinson et al. 2004), to evaluate the impact of various soil conservation options for reducing erosion rates in the Manawatu (Schierlitz et al. 2006).

CLUES (Catchment Land Use for Environmental Sustainability system) is another empirical model, under development by NIWA, that estimates nitrogen and phosphorus loads in streams in specific locations under different land-use scenarios. It uses the regional regression-based model prediction approach of SPARROW (SPatially Referenced

Regressions On Watershed Attributes) to estimate loads. It is currently being developed to provide estimates of sediment load (S. Elliott pers. comm. 2008).

These modelling approaches provide simple tools for evaluating the impact of changing land cover on hillslope erosion rates and predicting the outcome from different soil conservation scenarios (e.g. Schierlitz et al. 2006) and are appealing because of the limited data requirements. However, they are empirical in approach, are limited by the assumptions underlying model formulation, generally provide little detail on erosion processes, and largely remain to be rigorously tested.

The alternative approach has been to develop process-based models simulating single or multiple processes. Examples of this approach include the coupled slope-stability–hydrology–vegetation models used to model shallow landslide processes by Crozier (1999), Brooks et al. (2002, 2004) and Ekanayake and Phillips (1999a, b, 2002). More comprehensive models simulating multiple processes are currently in development with a major focus on SHETRAN (Elliott et al. 2002; Adams & Elliott 2006, Ekanayake & Basher 2006; Basher et al. 2007). This type of model can simulate multiple processes but their application is limited by the large data requirements to calibrate and verify them. Current efforts are aiming to develop hybrid models coupling some process representation with realistic data requirements (e.g. SedNet; Schierlitz et al. 2006).

### 5.1.5 Impact of climate change on hill country erosion

The main features of the New Zealand climate projections for the 2030s and 2080s (MfE 2004a, updated in NIWA 2007) are:

- Mean temperature is projected to increase (mid-scenario) 0.6–0.7°C by 2030s and 1.6–2.0°C by 2080s, with the strongest warming in winter, and a tendency for slightly more warming in the east and north.
- Daily temperature extremes will increase with fewer cold temperatures and frosts and more high temperature episodes projected.
- Mean rainfall impacts will vary around the country, with a tendency for annual rainfall to decrease in the north and east and increase in the south and west, associated with a stronger west-east rainfall gradient. Changes of the order of −5 to +5% by the 2030s and −10 to +15% by the 2080s are expected.
- Heavier and/or more frequent extreme rainfalls are expected, especially where mean rainfall increases are predicted, since a warmer atmosphere can hold more moisture (about 8% more for every 1ºC increase in temperature). There may be up to a four-fold reduction in storm return period by the 2080s, although there is little quantitative information available[4]. The frequency of extra tropical cyclones (which bring large storm events to the north and east of New Zealand) is predicted to decrease but their intensity is expected to increase.
- An increase in both mean annual westerly windflow and severe winds that cause wind erosion.

[4] Gray et al. (2005) and MFE (2004b) provide guidance on how to assess likely changes in extreme rainfall

The impact of climate change on soils and landscape processes has been reviewed by Basher (1990) using earlier estimates of likely climate change scenarios [5]. The direct effect of climate change on erosion is likely to be reflected in changes to the rates of erosion processes rather than the types of erosion occurring. The greatest effects are likely to occur through changes to precipitation processes and regimes, which will affect rates of erosion processes and recovery of vegetation following erosion. The pattern of erosion would be similar to the present, but the rates of individual erosion processes would be determined by changes in the frequency and magnitude of rain and wind storms. Annual rainfall is the dominant control on rates of erosion, as measured by suspended sediment yields (Griffiths 1981, 1982; Hicks et al. 1996), and if rainfall increases as predicted for many parts of the country, then erosion rates can be expected to increase substantially. Since most erosion occurs in large storm events, and these are predicted to increase even in areas where annual rainfall decreases, further information on likely changes in their patterns, frequency and intensity is needed to quantitatively assess the likely impact of climate change on hill country erosion. Climate scenarios suggest that for many areas there would be an increase in high-intensity storms (i.e. more rain on fewer days) and an increase in intensity of cyclonic storms of tropical origin especially in the North Island and north-east of the South Island. Tropical cyclonic storms tend to cause mass movement erosion and flooding over wide areas as experienced during Cyclones Alison (Bell 1976) and Bola (Trotter 1988). Likely changes in their frequency and magnitude are currently poorly known.

Temperature changes will modify water balance. With the projected increases in erosion rates, water storage and retention capability of hillslopes will be severely reduced because the storage capacity provided by the porous regolith will be depleted with removal leading to increased droughtiness especially in eastern regions. As a consequence more land will be exposed to sheet and wind erosion with drought effecting vegetation cover and re-establishment.

The newly exposed slip surfaces will also rapidly shed runoff water. Downstream channels will be affected by the increased frequency and magnitude of storm flows and consequently may become destabilised. Where there is a high degree of coupling between erosion processes and the drainage system, sediment supply will be enhanced. Low-gradient watercourses will consequently aggrade, reducing channel capacity and promoting overbank flooding.

The regional impacts of climate change on soils and landscape processes on the hill country can be summarised as follows (after Basher 1990):

**Northern North Island:** Northland, Auckland and eastern Bay of Plenty are predicted to become drier, while Waikato and western Bay of Plenty are likely to be wetter. A decrease in the frequency of high magnitude tropical cyclonic storms,  is predicted, but an increase in their intensity leading to larger storms, more flooding and bank erosion, and an increase in mass movement and surface erosion. Areas most susceptible to increased mass movement are the deeply weathered sedimentary and igneous rocks, especially where they are deeply dissected, steeply sloping and cleared of forest, and the highly erodible volcanic materials of the King Country and pumice lands of the Rotorua–Taupo districts.

**Taranaki–Manawatu–Wellington:** Most of this area is likely to become wetter, apart from eastern areas of the Wairarapa.An increased incidence of landslide erosion on the steep

[5] The 2007 IPCC estimates of climate change alter the magnitude of likely temperature rise but provide little more detail on impacts on rainfall amounts, intensities or frequency of large storms.

Tertiary soft rock hill country is likely, especially on deforested slopes, with predicted higher annual rainfall and higher-intensity rainfalls.
**Gisborne–Hawke's Bay–Wairarapa:** This area is likely to become drier overall. However, there is likely to be a significant increase in landslide erosion on the steep Tertiary soft rock hill country, especially on deforested slopes, with predicted higher-intensity rainfalls and intensity of extra-tropical cyclones (i.e. more 'Bola'-like storms with major effects on the hill country).
**Nelson–Marlborough:** Most of this area is likely to become wetter, apart from coastal Marlborough which could be drier. An increased incidence of northerly storms, with an increase in erosion rates and reduced return period of high-magnitude floods. Greater erosion, especially in the Marlborough Sounds.
**Canterbury**: Eastern Canterbury could be drier, while rainfall may increase in the Southern Alps. Increased soil water deficits and temperatures, with decreased rainfalls and higher temperatures could result in more prolonged droughts leading to increased potential for surface erosion.
**Westland–Fiordland:** The increase in erosion and flooding due to increased rainfall would be slight since there would be fewer high-intensity storms.
**Otago–Southland:** Increasing aridity in central and coastal areas, leading to increased potential for surface erosion. A predicted increase in mass movement erosion in coastal regions with an increased intensity of extra-tropical cyclonic storms. Likely to be considerably wetter in the west and in Southland, causing an increase in erosion and flooding.

### 5.1.6 Implications from process studies

Several key findings have come out of the extensive literature on erosion processes:

- Geology (rock type, induration, regolith composition, drainage and permeability), uplift rates, and climate (rainfall amounts, intensities) largely determine the landscape's inherent susceptibility to erosion. Susceptibility to erosion is readily identifiable at a regional scale and increasingly at hillslope and farm scale.
- Shallow landslides affect the greatest proportion of hill country terrain; earthflow, slumps, and gully erosion are far less extensive and frequent. The relative impact of sheetwash erosion and its contribution to the sediment budget in pastoral hillcountry areas (farm scale/catchments/erosion terrains/regions/nationally) is poorly known. Sheetwash is the least important of the sediment-generating processes on forest cutover, with shallow landsliding, roads and landings generating the most sediment. Shallow landslides and gully erosion result in the greatest long-term, on-site (soil loss) and off-site (sedimentation and flooding) environmental degradation.
- Large storms, or long wet periods, drive mass movement (landslide, earthflow, slump) on hillslopes. These are high-magnitude events that occur at low frequency. In catchments where these features dominate the landscape, sediment production from mass movements dominates catchment sediment budgets during, and for a short time after, storm events.
- For fluvial erosion (gullying, bank and channel erosion) the smaller more frequent storms are more important (i.e. low-magnitude, high-frequency events) because they are directly connected to the stream network. A substantial proportion of the sediment generated between large climatic events can be generated by these processes, and in at least some landscapes they can dominate overall sediment generation. Recovery of river networks from the impacts of gully-derived sedimentation is slower (decades to

millenium) than for rivers periodically impacted by other sediment-producing processes (annual to decade).

- In all terrains, but particularly in terrains identified as highly erodible, gully erosion needs to be identified and treated early. Untreated gullies increase in size and activity over time, lessening the chance of treatment being successful.
- Earthquakes are a significant driver for deep-seated mass movements but are far less frequent.
- Closed-canopy woody vegetation (evergreen species) reduces rates of hillslope erosion by an order of magnitude on the most susceptible terrain. On other less susceptible terrains hillslope erosion is reduced but the degree of reduction is not as well quantified, especially for space-planted poles.
- The impacts of pre- or post-European deforestation have persisted for more than a century especially in those landscapes with thick regoliths and/or soft rocks.
- Harvesting of forests in highly erodible terrain increases erosion rates in the short term, but over the length of a forest rotation (c. 27–30 years) pasture produces four times more sediment than forestry.
- Across all terrains, vegetative erosion control through reforestation, reversion and pole planting has proven successful for controlling much of the erosion. However, the use of pole planting for the treatment of large and active mass movement features (earthflow and slump) and gully erosion, in the most highly erodible terrains, has had only limited success. Space-planted poles can provide protection against the initiation of shallow landslides if planted in sufficient numbers and in the appropriate position on slopes. Failure to recognise this has resulted in a poor outcome for many past soil conservation efforts.
- Storm-initiated landslides deplete the soil resource on hill country. Soil loss as a consequence of recurrent storm events is cumulative. Soil recovery on landslide scars is slow. Productivity after 20 years is 80% of that for stable sites unaffected by landsliding.
- Climate change is likely to exacerbate erosion problems in the worst-affected areas since it is predicted to cause heavier and/or more frequent extreme rainfalls. This will result in a higher incidence of landsliding, and gullying in some areas where rainfall increases, and further depletion of the soil resource. Continued soil loss combined with slow soil recovery will ultimately impact the economic viability of hill country farms, particularly small farms in the more highly erodible terrains.

## *5.2 Erosion management*

### 5.2.1 Information sources

There is a wide range of information sources on management options for preventing and controlling erosion in New Zealand hill country. A number of reports, bulletins, articles and journal papers were produced in the 1940s–1970s (see Appendix 1) including those by Campbell (1945a, b, c, 1950), Campbell & Anaru (1964), Todd (1965), Wilkie (1965), Jones & Howie (1970), and Crimp (1975), which describe both vegetative and structural measures for controlling erosion. McCaskill's (1973) book *Hold this Land: a History of Soil and Water Cnservation in New Zealand* provides an extensive account of the history and approaches in soil conservation during earlier times. Various publications on guidelines for forestry operations were produced by catchment boards, forestry industry bodies and the National Water and Soil Conservation Organisation during the 1970s and 1980s, as summarised in the *Forestry Code of Practice* (Vaughan et al. 1993) and updated more recently in New Zealand Forest Owners Association (2007). A highly significant publication in the 1980s was the *Plant Materials Handbook for Soil Conservation*, comprising three volumes: Volume 1 – *Principles and Practices* (van Kraayenoord & Hathaway 1986a), Volume 2 – *Introduced Plants* (van Kraayenoord & Hathaway 1986b), and Volume 3 – *Native Plants* (Pollock 1986). This publication was the culmination of scientific research conducted during the previous 20+ years by the former National Plant Materials Centre of the Water and Soil Division of the Ministry of Works and Development, and the vast experience of soil conservators of the former catchment boards. It was an important reference source for anyone with an interest in soil conservation and was a common sight on bookshelves for a number of years after its release. Many parts of the publication are still relevant today, although new copies are unavailable.

An important sequel to the *Plant Materials Handbook for Soil Conservation* was the report prepared for MAF Policy titled *Control of Soil Erosion on Farmland* (Hicks 1995). This summarised the large amount of information on agricultural techniques for managing soil erosion throughout New Zealand and was aimed at encouraging landholders to control erosion on their properties. Six years later, the *Soil Conservation Technical Handbook* (Hicks & Anthony 2001) prepared by the Ministry for the Environment (MfE) and other parties was released. This comprehensive handbook describes a range of plant and engineering techniques for treating various erosion types encountered in hill country such as soil and earth slip, earthflow, gully and slump erosion. Contributors to the publication were experienced researchers and/or land managers in catchment boards or regional councils, and the publication is an important reference. It is illustrated with photographs and drawings and contains key relevant literature for further detailed description and understanding. The handbook titled *Managing Waterways on Farms* (Anthony 2001) focuses on waterways on flat to gently sloping land, but includes some examples of experiences with vegetation in catchment control schemes aimed at addressing significant erosion problems.

The above key publications are complemented by an extensive list of papers published in New Zealand and international scientific journals (see Appendix 1), articles featured in industry magazines such as *New Zealand Tree Grower* (e.g. Cairns 2004; Freeman 2004; Bergin 2005; Hocking 2006; Knowles 2006) and Gisborne District Council's 'Conservation Quorum' (e.g. Anon. 2004a, 2006a, b; Hambling 2004; Hughes 2004; Douglas et al. 2005; McIvor & Douglas 2007), and items in farming newspapers such as *CountryWide* (e.g. Anon. 2004b,c, 2005, 2006c,d). Computer developments have resulted in many organisations having extensive websites (e.g. all regional councils/unitary authorities, all Crown Research Institutes and universities) and a number of these have listings or links to extensive relevant databases pertaining to hill country erosion control and/or newsletters/fact sheets highlighting or describing relevant practical solutions to address particular erosion problems.

Examples from regional council websites with soil conservation information are: (www.ew.govt.nz/publications/technicalreports/tr0516.htm), tree planting information (www.ew.govt.nz/enviroinfo/land/treesonfarms.htm), control of earthflow and slump erosion (www.trc.govt.nz/environment/land/pdfs/46_control_earthflow_erosion.pdf),
pole planting (www.trc.govt.nz/environment/land/pdfs/32_poleplanting_benefits.pdf),
protecting farms from storm damage
(www.hbrc.govt.nz/LinkClick.aspx?fileticket=68%2bLckQxqMQ%3d&tabid=244&mid=123

3), repairing slip damage (www.hbrc.govt.nz/LinkClick.aspx?fileticket=DyudvDRJk7w%3d&tabid=244&mid=1233), catchment control schemes (www.gw.govt.nz/section864.cfm), and Sustainable Land Use Initiative (www.horizons.govt.nz/Images/Publications/SLUI/SLUI%20v4.pdf).

Much of the information contained in the *Plant Materials Handbook for Soil Conservation* (Pollock 1986; van Kraayenoord & Hathaway 1986a,b), along with more recent research and user knowledge on site characterisation, plant selection, tree–pasture interactions, erosion risks and financial planning, has been packaged into a decision support system (Luckman et al. 1999) called the 'Green Toolbox' released in 2001 by Landcare Research and freely available on the Internet (http://www.landcareresearch.co.nz/services/greentoolbox/). An initial evaluation of the tree–pasture component of the model was conducted on farms in the southern North Island (Dodd et al. 2004).

### 5.2.2 Key erosion management technologies using plants on hill country

The major vegetation types on hill country are pasture with and without spaced trees, indigenous scrub-forest, and exotic forest. It is well established that some pastoral hill land without woody vegetation is most vulnerable to erosion with, for example, the incidence of shallow mass movement such as shallow landslides (< 1 m soil depth) being at least 10-fold higher on steep slopes in pastoral use than on those covered by mature indigenous or exotic forest (Phillips et al. 1990; Marden & Rowan 1993; Bergin et al. 1995; Hicks 1995: Dymond et al. 2006), although not always (Blaschke et al. 1992). An overview of the different types of vegetation cover, including examples of species follows, before describing mostly vegetation options for addressing specific erosion types.

**Herbaceous species**: On hill slopes without a woody component, maintaining a persistent, complete pasture sward reduces the prevalence and severity of surface erosion processes of wind, sheet wash, and rilling (Hicks 1995). This can be achieved through strategic grazing management of the resident sward in spring to maintain a short, leafy pasture, reducing grazing pressure during drought, cold, or wet conditions to avoid loss of plant number, use of fertiliser to maintain sward vigour and growth, and establishing improved pastures using seed mixes comprising new cultivars of grass and legume species such as perennial ryegrass (*Lolium perenne*), cocksfoot (*Dactylis glomerata*), tall fescue (*Festuca arundinacea*), white clover (*Trifolium repens*), and subterranean clover (*Trifolium subterraneum*) (Charlton & Stewart 2006). New cultivars are better adapted to the harsh conditions in hill country than earlier available material (Kemp et al. 1999). In a review of previous work, Hicks (1995) concluded that improved pastures reduce surface erosion by 50–80% compared with levels occurring on land covered with unimproved pasture, and improved pastures in combination with more subdivision and better grazing enabled a 2–4 fold increase in stock carrying capacity. Failure to adequately control surface erosion can lead to more severe erosion types, for example rilling progressing to channel and gully formation and associated erosion.

**Tree–pasture systems**: A woody component (shrub or tree) can be introduced at various spacings into the pasture, either at strategic positions on a slope (e.g. those with maximum potential for erosion), or in a systematic planting grid across the slope to reduce the likelihood of mass movement (landsliding, slumping) and gully erosion impacting negatively on livestock production. These two-tier systems (known as tree–pasture systems, agroforestry systems, and silvopastoral systems) have been used widely in many pastoral hill country areas of New Zealand (Gillingham 1984; Percival & Hawke 1985; Hawke 1991; Knowles 1991; Mead 1995; Miller et al. 1996; Wall et al. 1997; Power et al. 1999, 2001; Guevara-Escobar et al. 2000; Douglas et al. 2006). Species used in these systems include those of the genera *Acacia*, *Eucalyptus*, *Pinus*, *Populus*, and *Salix*. *Populus* and *Salix* species are often preferred where erosion is mediated by surplus soil water and grazing livestock (sheep) during tree establishment is feasible (Wilkinson 1999). Some *Acacia* spp. and *Eucalyptus* spp. are recommended for use on seasonally drought-prone sites (Hathaway & King 1986; Hathaway & Sheppard 1986; Sheppard & Bulloch 1986; Bulloch 1991) such as those on upper slopes with northerly aspect, where *Populus* spp. and *Salix* spp. can fail to establish or survive.

Two-tier systems involving *Pinus radiata* originated as a component of forestry management in the late 1960s – early 1970s and aimed to derive dual benefits of timber production at maturity and meat/wool income in at least the early and intermediate years of the tree rotation. The system was also deemed to be useful for erosion control, though there are no specific detailed studies of the erosion benefits of agroforestry systems. A recent South Otago harvest of *P. radiata* at 155 stems per hectare (sph) concluded that there was a lack of volume of logs from such a system compared with trees grown in plantation at 320 sph and that 'you cannot, it seems, have it both ways' (Jones & Cullen 2008). There are probably few examples of on-farm two-tier systems involving *P. radiata*. It is predicted that this will remain in the foreseeable future because of low returns for the timber; the tree's evergreen, dense, canopy dramatically reduces the yield and changes the quality of the pasture understorey; and the species, like many alternatives, needs to be planted as seedlings and grazing stock excluded during the early stages of tree establishment.

An emerging problem with two-tier systems is the growth of large trees and their potential to topple as they age or during severe storms. Large trees can be a liability to livestock, farm infrastructure (buildings, fences, tracks), and even farmers, and it is now recommended that trees be managed over their lifetime to avoid potential problems. Aspects of tree management were investigated in a recently completed project (MAF SFF Grant 04/089) including strategic use of appropriate herbicides and concentrations to kill large trees, and methods to reduce canopy size such as pollarding part or all of the canopy every 4 or 5 years. Practical guidelines on these and other aspects of growing and managing *Populus* spp. and *Salix* spp. on farms have been produced (National Poplar and Willow Users Group 2007).

Root growth and strength of *Pinus radiata* have been determined in several studies to estimate the species' likely contribution to hill slope stability (Watson & O'Loughlin 1990; Ekanayake et al. 1997; Watson et al. 1999), and comparisons have been conducted with other species, including *Populus* spp., because of their suitability for similar erosion control functions (Knowles 2006). The maximum tensile strength of live roots of *P. radiata* (mean diameter 5.3 mm, range 1.3–13.9 mm) averaged 17.6 MPa (Watson et al. 1999) and 19 MPa has been used as a general estimate (Knowles 2006). In contrast, roots of *Populus* spp. (4–8 mm diameter) have a tensile strength of 23.3–48.6 MPa (estimated from data in Hathaway & Penny 1975) and recent estimates of average maximum tensile strength of 'Veronese' poplar growing on erodible slopes in the southern North Island are 36 MPa for roots of 4–6 mm diameter and 22.8 Mpa for roots of 7–10 mm diameter (McIvor et al. unpubl.). It can be concluded that roots of *Populus* spp. have higher tensile strength than *P. radiata*, although this attribute is probably less important to slope intactness than root distribution and the interactions between the roots of neighbouring trees across a slope.

*Populus* spp. have capacity for extensive lateral spread with roots > 2 mm diameter extending more than 14 m from the trunk of a tree aged 9.5 years (McIvor et al. 2008), and roots of older trees can extend beyond 20 m. Comparable distribution data for wide-spaced trees of *Pinus radiata* are lacking, with almost all work having been conducted with trees growing in more densely planted plantation forests (e.g. Phillips et al. 1990; Watson et al. 1999). The biomass of the root system of *P. radiata* exceeds that for *Populus* spp. at a given trunk diameter at breast height (dbh) and the difference increases with age (Knowles 2006). For example, a graph presented by Knowles (2006) showed that at a dbh of 30 cm, the root biomass of *P. radiata* was 150 kg compared with 60 kg for *Populus* spp. In an effort to estimate the likely soil binding ability of each species, Knowles (2006) multiplied root tensile strength by root biomass, which gave similar values for each species at dbh up to 50 cm. This contributes to the knowledge on the value of each species for slope stabilisation, but it does not allow for differences between the species in root distribution, particularly lateral spread. Research to determine such attributes of each species under the same environmental conditions, including wide spacing, is required to provide objective information to resolve the long-running debate about the value of each species for slope stabilisation.

**Forestry**: Hill slopes with mature cover of native or exotic forestry have the lowest incidence of erosion and this appears largely independent of species (Phillips et al. 1990; Brown 1991; Hicks 1991a, 1995; Marden & Rowan 1993; Hicks & Crippen 2004). By far the major exotic species for afforestation for protection planting and/or timber is *Pinus radiata*, with in excess of 1.6 million hectares in the national estate. Other exotic tree species used for multiple purposes including erosion control include *Pseudotsuga menziesii* and *Cupressus* spp. The major considerations for erosion management in tree plantations focus on establishment and harvesting activities, where vegetation removal and mechanical earthworks temporarily increase soil movement and the risk of significant soil loss. The forestry industry and government agencies have thus developed extensive guidelines (NWASCO 1978; Vaughan 1984; Spiers 1987) and a code of practice (Vaughan et al. 1993; New Zealand Forest Owners Association 2007) to guide operational planning and maintain soil and water values through mitigation of erosion and sedimentation. These focus heavily on the practices that have been shown to contribute most to sediment generation, particularly management of roads, landings and stream crossings.

Canopy development, age/size and density of vegetation are important determinants of effectiveness for controlling erosion. For example, on the East Cape after Cyclone Bola struck in March 1998, land with indigenous forest (>80 years, closed canopy, emergent broadleaved species including *Weinmannia racemosa* and *Knightia excelsa*) and exotic *Pinus radiata* forest aged greater than 8 years (closed canopy) had an average of less than 0.1 landslides/ha (Marden & Rowan 1993). This was less than for land supporting pasture and exotic forest less than 6 years old (negligible canopy cover), which had 0.5 landslides/ha or greater. Land with regenerating scrub comprising *Leptospermum scoparium* and/or *Kunzea ericoides* (closed canopy, 0.12 landslides/ha) and exotic *P. radiata* forest (6–8 years, 0.16 landslides/ha) had intermediate landslide densities (Marden & Rowan 1993).

Another study in the East Cape showed a highly significant relationship between the age of mixed stands of *Leptospermum scoparium* and *Kunzea ericioides* and the incidence of landslides (Bergin et al. 1995). Relative to pasture, stands aged 10 years had 65% less landslides/ha, 90% less at 20 years, and a near 100% reduction in landslide density in older stands. Over time, there was an increase in the proportion of the stands comprising *K. ericoides* and it was suggested that this species has a more effective root system for soil stabilisation than that of younger stands with a dominance of *L. scoparium* (Bergin et al. 1995).

**Surface erosion:** Maintenance of a complete, healthy ground cover is essential for effective prevention or control (Hicks 1995; Hicks & Anthony 2001). This can be achieved through pasture improvement using cultivars of grasses and legumes that are persistent and adapted to drought, wet, and cold, and variable intensities of grazing pressure. Associated with this are management options such as subdivision of large blocks (e.g. sunny vs shady aspects) and improved stock grazing practices (e.g. destocking paddocks at particular times of the year, more rotational grazing), and maintenance of soil fertility through strategic topdressing and animal transfer. Cover of unimproved pasture swards can also be maintained using some of these management options, but pasture growth responses are not generally as large as when applied to swards comprising improved pasture cultivars.

**Landslide erosion:** Areas prone to landslides can be identified from the remains of previous slip scars and from knowledge of the soil type, slope, existing vegetation cover, and total rainfall and its distribution. Landsliding can be reduced or prevented by:

- Ensuring a dense, healthy pasture sward coupled with establishment of wide-spaced trees, e.g. *Populus* spp., to provide deeper root-reinforcement of the substrate, and transpiration to reduce soil pore water pressure
- Changing land use to regenerating scrub – indigenous forest, or
- Establishing exotic forest for commercial timber production

(see Hathaway 1986a; Lambrechtsen 1986; Pollock 1986; Brown 1991; Hicks 1995; Hicks & Anthony 2001; Quinn et al. 2007).

Revegetation of slip scars occurs naturally through seed dispersal from vegetation on neighbouring uneroded ground and stock defecation, and can take 20+ years for full coverage. The process can be hastened by oversowing with appropriate grasses, legumes and herbs and seed mixtures are often tailored to site conditions to accommodate variation in such attributes as aspect (sunny vs shady), soil pH, and soil type (Lambrechtsen 1986; Lambert et al. 1993; Quilter et al. 1993). Opinion varies on the best time to oversow slips, ranging from as soon as possible after landsliding, while the sites are still moist, to autumn or spring in line with the timing of normal oversowing practice. Total sowing rates of 60–100 kg/ha or even higher have been used, but for general practice, they are uneconomic. Litherland et al. (2005a, b) describe experiences with regrassing slips and silt-covered areas following the 2004 Manawatu storm and suggest recommendations for best practice. Vegetation (both pasture and primary succession to natives) and soil recovery rates are described in Lambert et al. (1993), DeRose et al. (1995), Smale et al. (1997), and Sparling et al. (2003). These studies indicate landslide erosion causes a permanent reduction in mean herbage production and soil depth on hillslopes.

Trees for slope stabilisation should be planted at 5 × 5 m to 15 × 15 m (Hathaway 1986a) depending on the severity of landsliding, and it is recommended that planting be extended beyond the slipped land onto relatively stable ground. Lateral roots of broadleaved trees interlock for distances of up to 12 m from the trunk, and form very dense networks within 5–6 m of the trunk (Hicks 1995). Trees can be planted on slipped sites but it is recommended that they be planted on sites with potential to slip (Hicks & Anthony 2001), rather than for remediation.

**Gully erosion:** Most control of this erosion type aims to reduce further deepening and undercutting in the gully and its consequent effects on surrounding slope stability and reducing sediment discharge (Hathaway 1986b). The severity of the gully often dictates the type of treatment. For shallow (<2 m deep) gullies, spaced planting of *Populus* spp. or *Salix* spp., in combination with engineering structures (e.g. debris dams) while the trees establish, is recommended. For moderate (2–5 m deep) gullies the outcome of this type of treatment is less certain.

Tree planting patterns and spacings vary depending on the severity of erosion, with the most successful system being 'pair planting' up the watercourse at spacings of 2–10 m between pairs. Each pair comprises a tree on opposite sides of the watercourse, frequently between 1 and 2 m apart, or alternate planting in a 'zigzag' fashion along opposite sides of the watercourse (Hathaway 1986b; Hicks 1995; Hicks & Anthony 2001). The main treatment options for controlling gully erosion were presented in a hierarchical structure by Thompson and Luckman (1993), and although somewhat arbitrary, the classification is useful in the context of land management. They summarised the techniques commonly used to control gullying in soft rock terrain in the East Cape region as debris retention dams, channel (or pair) planting, gully wall planting, and afforestation.

Severely eroded gullies should be retired from grazing and closed-planted with trees (Hathaway 1986b; Hicks 1995; Hicks & Anthony 2001). Considerable experience has been gained with plantings of *Pinus radiata* but other species may also be used (e.g. *Populus* spp.). The land stabilisation role of the trees is paramount and therefore they should generally not be harvested for timber, although currently many gullies that have previously been afforested are being harvested (e.g. at Mangatu Forest). Succession to indigenous scrub and forest should be a long-term objective. There has been some success with retirement, planting *Salix* spp., and then selectively removing the trees to encourage establishment and growth of indigenous species. Depending on the severity and distribution of gully erosion in a catchment, treatment may range from individual gullies and their perimeters being planted, to afforestation of most or all of the catchment.

**Earthflow erosion:** There is a range of vegetation techniques to control earthflows including options such as space-planted trees and afforestation; non-biological options include subsurface drains and diversion banks (Thompson & Luckman 1993). Tree spacings recommended vary depending on attributes such as the extent of the earthflow, its movement and stage of development, and depth to the failure plane. On intermittently moving or creeping earthflows, tree spacing of >8 m may enable adequate erosion control and satisfactory pasture production. When using broadleaved tree species for control of mass movement such as earthflows, Hicks (1995) recommended that trees should be 12 m apart or closer to ensure some interlocking of roots from adjacent trees. For more active, continuously moving earthflows, spacings < 5 m (400+ sph) are recommended to encourage development of a denser root network.

Recommendations on appropriate control techniques vary with site geomorphology (Hicks & Anthony 2001). On crushed argillite, options are erosion control forestry, dewatering, and construction of debris dams, whereas on other sedimentary rocks, pole planting and dewatering are recommended. Successful control of shallow earthflows (< 3 m deep) has been achieved using various plantings of *Populus* spp. and *Salix* spp. Deep earthflows (e.g. several metres deep) are much more difficult to control with vegetation, and dewatering with fast-growing evergreen species is recommended (Hicks & Anthony 2001).

**Slump erosion:** Mitigation options are similar to those used to manage earthflow erosion. Spaced planting of trees in pasture is an effective preventative technique for potentially active sites or those with limited movement, and may offer some control on more active terrain. Depth of the failure plane is an important influence on how effective spaced-tree planting will be, and at depths greater than 5 m, additional control methods such as drainage will probably be necessary. Engineering methods have been used (Hicks 1995) to stabilise large, deep-seated slumps in bedrock where erosion threatens valuable infrastructure (e.g. roads, buildings) but their high cost precludes general applicability.

Severe slumping may require retirement from grazing and afforestation (close spacing) with species such as *Populus*, *Salix*, and *Pinus radiata* and other conifers (Hicks & Anthony 2001). The priority should be to retain the forest long-term. Harvesting for timber may be considered but care should be taken in deciding which trees are harvested. Replanting is recommended as soon as possible after harvesting to enable a new root system to develop before the previous one decays significantly. Encouraging the development of indigenous forest may offer better long-term stability.

### 5.2.3 Assessment of effectiveness

Surface erosion can be controlled effectively by maintaining a continuous, dense ground cover (Hicks 1995; Hicks & Anthony 2001). Work reviewed by Hicks (1995) found that improved pastures (new cultivars, fertiliser additions, good grazing management) reduced surface erosion by 50–80% compared with unimproved pasture. The benefits of providing complete, well-managed, herbaceous ground cover have been known for many years.

The most effective vegetation for controlling various types of mass movement is mature/closed canopy, indigenous or exotic forest (Van Kraayenoord & Hathaway 1986a, b; Hicks 1995; Hicks & Anthony 2001). For example, the incidence of shallow landslides (< 1 m depth) on steep slopes covered in closed-canopy forest is often at least 90% less than on slopes covered by pasture (Phillips et al. 1990; Marden & Rowan 1993; Bergin et al. 1995; Hicks 1995; Dymond et al. 2006). Aerial photography and assessment along transects or in plots across a range of landscapes/farms/vegetation covers following storm events have been conducted to determine the effectiveness of various vegetation covers (e.g. Phillips et al. 1990; Hicks 1991a, b, c; Marden & Rowan 1993; Thompson & Luckman 1993; Bergin et al. 1995; Hicks & Crippen 2004; Dymond et al. 2006).

In two-tier systems where trees are spaced to enable satisfactory erosion control and the maintenance of an understorey pasture for livestock grazing, measures of effectiveness for erosion control are not as well documented as those for mature forests. One of the most significant contributions with respect to spaced *Populus* spp. was estimation of the average (radial) range of influence of individual trees of *Populus ×euramericana* aged 14–17 years on the occurrence of landslides on erodible slopes near Gisborne (Hawley & Dymond 1988). It was estimated that the trees reduced pasture production losses by 13.8% and an average tree saved 8.4 $m^2$ of ground from failure. This work was extended by Hawley (1988) to determine the influence of root encroachment from neighbouring trees on slope stability. At a spacing of 11.5 m (75 sph), Hawley (1988) estimated that landsliding around one tree, including the contribution from a neighbouring tree, reduced from 8.2% to 1.4%.

Extensive surveys of vegetation, including spaced conservation trees, have been conducted on eroded landscapes following storms in the Wairarapa in autumn 1991 (Hicks 1991c), and Manawatu–Rangitikei in summer 2004 (Hicks & Crippen 2004). These and similar studies have provided valuable information on general effectiveness of spaced trees. Based on personal experiences (e.g. Hicks 1991b) and those of colleagues, Hicks (1995) concluded that mature trees of *Populus* spp. and *Salix* spp. and other broadleaved species at spacings of 12 m (70 sph) or less can reduce mass movement in pasture by 50–80%. Partial planting of erosion-prone slopes with trees can reduce mass movement by 10–20%, and similarly for areas where older tree stands have not been maintained (Hicks 1995). The effectiveness of vegetation for controlling various types of erosion is presented in Table 3.

**Table 3** Examples of vegetative methods for controlling different types of erosion. (Marden & Rowan 1993; Thompson & Luckman 1993; Bergin et al. 1995; Hicks 1995; Dymond et al. 2006).

| Erosion type | Method | Reduction in erosion (%) |
|---|---|---|
| Surface | Continuous, dense, improved pastures | 50–80[1] |
| Landslide | Forest (mature) | Mostly >90[2] |
| | Spaced tree plantings (< 12-m spacing), well maintained | 50–80[2] |
| | Partial tree planting and/or poorly maintained older plantings | 10–20[2] |
| Gully | Trees spaced 2–4 m | 90[3] |
| (< 2 m deep) | Trees spaced 4–8 m | 35[3] |
| Earthflow | Trees spaced 3–5 m | 100[3] |
| | Trees spaced 8–10 m | 35[3] |

[1] Compared with unimproved pasture; [2] Compared with area of slipped ground; [3] Percentage of sites where treatment effective.

The effectiveness of treatments for controlling gully and earthflow erosion in soft rock terrain in the Gisborne–East Coast region was determined in 1989–91 following Cyclone Bola in 1988 (Thompson & Luckman 1993). The treatments were based mainly on the planting of *Populus* and *Salix* trees (usually aged 10–30 years) and the study findings enabled minimum tree configurations (tree spacing and coverage of erosion landforms) to be specified. For example, for gullies less than 2 m deep, tree spacing of 2–4 m was successful in 9 of 10 sites, whereas a spacing of 4–8 m was successful in 11 of 32 sites. Earthflow sites with shallow, untreated toe gullying were successful where spacing was 3–5 m (4 of 4 sites), but lower proportions of sites were successful where spacing was 8–10 m (7 of 20 sites) or greater than 10 m (2 of 10 sites). These results suggest that the interaction between roots of neighbouring trees at closer spacings was a major factor in conferring treatment success.

Following a storm in Manawatu–Rangitikei in February 2004, the extent of erosion on eight landforms (e.g. ridges, upper slopes, foot slopes, gullies, downlands) under different vegetation covers was determined by Hicks & Crippen (2004). Within upper slopes, bare ground comprised 10% of areas covered in pasture, 6.4% of areas covered in pasture and scattered secondary vegetation, and 6.8% of areas covered in pasture with extensive secondary vegetation. Secondary vegetation in these categories was an amalgamation of scattered and extensive exotic trees and other vegetation, which precluded insights into, for example, the contribution of *Populus* spp. and *Salix* spp. in reducing landsliding – the main erosion type on this landform. Assuming that 6.6% (average of 6.4% and 6.8%) bare ground occurred solely under spaced *Populus* and *Salix* plantings, the presence of the trees reduced erosion by 34% compared with under open pasture (10% bare ground).

Recent work on the effectiveness of spaced trees (mostly *Populus* spp. and *Eucalyptus* spp.) has measured attributes of individual trees and tree spacings, so that better information is available on the condition and arrangement of trees on hillslopes that have remained intact or failed during recent storms. In Manawatu–Rangitikei (40 sites) and Wairarapa (25 sites), trees in groups of 5–10 trees per site have been measured for dbh, height, and canopy width, and the area of fresh slip scars within each treed area determined (Douglas & McIvor 2007 unpubl.). Landsliding on nearby control sites of pasture, with similar slope and aspect, has also been determined. Data analysis is being conducted and will quantify the reduction in landsliding due to the presence of spaced trees of known dimensions.

Spaced trees of *Populus* spp. and *Salix* spp. were assessed at 28 sites in the East Cape in January 2008 for effectiveness in controlling various erosion types, particularly earthflow and gully erosion (McIvor, Douglas, Marden, unpubl.). For example, a site with earthflow erosion was stabilised with trees of *Populus* spp. aged 20+ years which were probably planted as 3-m poles at 8 × 8 m. Some trees were on a lean up to 20 degrees (most were vertical), trunks and branches were slightly distorted, and several spacings were variable, which indicated continuing movement of the flow since planting. Diameter at breast height of 10 trees averaged 47.3 cm (SD = 7.9 cm). All findings will be included in a report to MAF by June 2008.

Root development has major implications for the effectiveness of tree plantings on slopes for reducing the incidence and severity of landsliding and other mass movement erosion types, and knowledge of it is very useful for recommending appropriate tree spacings to minimise erosion. On erodible hillslopes near Palmerston North, the distribution and architecture of roots > 2 mm in diameter of spaced trees of *Populus deltoides ×nigra* 'Veronese' aged 5, 7 and 9.5 years have been determined (McIvor et al. 2005, 2007, 2008) and results are presented in Table 4. The trees aged 7 and 9.5 years had considerably greater lateral root development than the trees aged 5 years, and the results indicate that the older trees are likely to have a much more significant role in slope stabilisation.

**Table 4** Dimensions of excavated 'Veronese' poplars and relationships between trunk dimensions and mass (excluding root crown) and length of roots > 2 mm in diameter, for trees of three ages growing on hill country near Palmerston North.

| Tree age (yr) | Height (m) | DBH (cm) | Trunk cross-sectional area ($cm^2$) | Root length (m) | Root mass (kg DM) | Root mass: trunk area | Root length: trunk area |
|---|---|---|---|---|---|---|---|
| 5 | 7.3 | 8.4 | 55.4 | 79.4 | 0.57 | 0.010 | 1.43 |
| 7 | 9.0 | 14.0 | 153.9 | 349.3 | 7.80 | 0.051 | 2.26 |
| 9.5 | 13.3 | 21.3 | 356.1 | 663.5 | 17.90 | 0.050 | 1.87 |

Strong, linear relationships between dbh and root mass, and dbh and root length, have been developed for these young trees (*n* = 6 from McIvor et al. (2008) and unpubl. data), as follows:

$$\text{Log}_{10} \text{ structural root mass} = 3.62 * \log_{10} \text{dbh} - 3.52 \ (R^2 = 0.95)$$

$$\text{Log}_{10} \text{ structural root length} = 2.26 * \log_{10} \text{dbh} - 0.18 \; (R^2 = 0.93).$$

These relationships show the benefit of measuring dbh of trees to estimate attributes of roots, and its measurement is quick and easy in the field. Relationships between dbh and root attributes remain to be determined for older trees.

There is increased interest in monitoring the effectiveness of planting programmes in whole-farm plans because it is critical for determining progress towards defined targets (e.g. sediment reduction) across each farm over time and achieving progress at the catchment scale. Catchment-scale studies clearly show lower levels of sediment export associated with higher levels of forest cover (e.g. Dons 1987; Quinn & Stroud 2002), and the reduction in sediment export resulting from afforestation (Quinn et al. 2007). A simple model that links vegetation type/land use at the farm scale with sediment export off-farm has been developed (Douglas et al. 2008). This provides a basis for quantitative assessment of the effectiveness of tree plantings and has input data of vegetation type (indigenous scrub/forest, exotic forest, spaced tree), age, area, canopy cover, dbh and tree extent (for spaced trees: proportion of trees that have been planted, have survived and that are well maintained). The model requires field validation on different farms and in different regions to appraise general applicability and identify where improvements/modifications are necessary, before being available for general release.

### 5.2.4 Transferability

It is important to identify the opportunities and barriers to transferability in relation to knowledge, techniques and end-user uptake of recognised technology. The gaps in current knowledge that provide opportunity for new research also provide barriers to uptake of current knowledge by end-users, particularly hill country pastoral farmers.

**Knowledge** of the root systems of the various species identified in Section 5.2.2 is based on localised data. Factors governing root growth such as availability of water, slope, depth of soil, soil bulk density, and tree spacing have not been measured in most cases. These variables are largely dealt with by using dbh, and not age, as the independent variable. The relationship between root mass and dbh is well established (Watson & O'Loughlin 1990). In the absence of more comprehensive data it is sensible to extrapolate these data to other locations, soil types and erosion features. However, further field data are needed to answer questions about appropriate spacings of woody vegetation with differing trunk sizes to ensure >90% slope stabilisation as provided by hill slopes afforested with *Pinus radiata* aged >10 years (Knowles 2006).

**Techniques** have been applied in most regions where hill country is erosion-prone. Information on how to deal with on-farm erosion is available from most regional council websites (e.g. www.trc.govt.nz/environment/land/pdfs/34_poleplanting_maintenance) and in published pamphlets. Techniques for managing gully erosion have proved successful in all regions, with local understanding of the processes modifying the mitigation measure (e.g. planting density, size of planting material). Most planting of erosion-prone slopes has focused on stabilising and remediating slip areas, with little attention given to stabilising areas before they slip. Spacing recommendations are not standard for all regions, and space-planting of trees across slopes for soil stabilisation is not widespread.

**End-user uptake**: From recent survey work (Douglas & McIvor 2007 unpubl.) carried out in Rangitikei, Manawatu and Wairarapa, it was apparent that many trees of *Populus* spp. and *Salix* spp. were planted from 1960 to 1985, but planting from 1985 to 2007 was reduced considerably. It was very difficult to locate sites with either *Populus* or *Salix* trees planted for less than 15 years for soil conservation on pastoral land. The most recent survey of *Populus* and *Salix* nursery cultivation was conducted in 1995 (Stace 1996). Current data on numbers of poles of each species being used are not available.

Establishing on-farm pole nurseries was common practice before 1985. In the Gisborne region, establishment of on-farm *Populus* nurseries for pole production has been resurrected and promoted since 2005 (MAF SFF Grant 05/144). This initiative has not yet been taken up in other regions, possibly because of variable pole quality and nursery management. Regional land managers are active in all regions promoting soil conservation, visiting with landowners and frequently managing the layout and planting of poles on pastoral slopes. However, there is still a large amount of erosion on unprotected hill country pastoral land following each rain storm event (e.g. Hicks 1991c; Hicks & Crippen 2004). The 'one argument that appears unassailable is the need to bombard landowners with technical and educational information on the role of tree cover in soil conservation and the range of possibilities available' (Hocking 2006). This statement seems difficult to dispute.

**End-user information sources**: Most of the regional council/unitary authority respondents to a survey (Appendix 3) cited the *Soil Conservation Technical Handbook* (Hicks & Anthony 2001) as an important reference source for staff, and some used it to assist with preparing notes/handouts for distribution to farmers and other parties. Other publications cited by one or more authorities included *Trees for the Land* (Mortimer 2008), 'Visual soil assessment, Vol. 4, Soil management guidelines for hill country land uses' (http://www.landcareresearch.co.nz/research/soil/vsa/fieldguide.asp#availability), *Control of Soil Erosion on Farmland* (Hicks 1995), and *Growing Poplar and Willow Trees on Farms* (National Poplar and Willow Users Group 2007). A number of authorities reported having a few to many in-house resources such as technical handouts and fact sheets on a range of erosion control topics such as planting material, establishment and management techniques, and retirement planting. Oral advice to landowners (e.g. visits, electronic means (email)), supplemented with handouts, was a significant feature stated or implied by respondents. The *New Zealand Forest Code of Practice* (Vaughan et al. 1993) is an important publication for managing plantation forests in an environmentally sustainable way. Federated Farmers informs its membership of relevant information.

## 5.3 Social learning experiences

### 5.3.1 Literature review

While the need to address social or behavioural factors as the 'drivers' of accelerated soil erosion in New Zealand was recognised as far back as the 19th century (see McCaskill 1973) this causal relationship was largely disregarded until the 1920s and '30s. Despite earlier acknowledgement of a link between deforestation, erosion and floods, public acceptance in New Zealand of the importance of land management in the promotion and management of erosion was a consequence of a USDA report (Bennett & Chapline 1928). This report highlighted the need for soil conservation in America and explicitly linked erosion to land management practices. This new awareness was evident in a subsequent DSIR report in 1939 that reinforced the importance of management practices in erosion control (Taylor et al. 1939). Two years previously Malabar (1937) had identified the need to get rid of deer, chamois, and even sheep if erosion was to be controlled. In the same year as the DSIR report, a special article 'Keeping our soil where it belongs' published in *The New Zealand Farmers Weekly* (1939) called on farmers to play their part as land managers in support of soil conservation. In that same year Connell (1939) highlighted the threat of erosion posed by the use of the hill country for sheep. Shortly afterwards (in 1941) the Soil Conservation and Rivers Control Act establishing catchment boards was passed to promote and support soil conservation by landholders. This legislation lasted into the 1980s.

Popular awareness that soil erosion as found in New Zealand was not 'normal' but in large part a result of land use practices was heightened by Cumberland (1943)[6]. His subsequent volume *Soil Erosion in New Zealand* (Cumberland 1944) further elaborated and extended this theme. Cumberland documented erosion across the country by area, type, and land use. He drew attention to the fact that two-fifths of the total land area and two-thirds of the occupied area suffered from accelerated erosion, in particular as a consequence of deforestation to clear land for agricultural use. He argued the need for interdisciplinary research that would address the interrelated components of land tenure, farming practices, water use and the like, pointing out that if the resource base continued to be neglected, food output would decline.

Subsequent and recent published research that specifically addresses social aspects of the impact of land management on soil erosion in New Zealand could only charitably be described as thin. While our understanding of soil erosion as a physical process may well be greater than for any aspect of environmental degradation, there is little published research that specifically addresses land management from a social or behavioural perspective.

Three volumes stand-out but these are now somewhat dated: McCaskill's *Hold This Land* (1973), Cumberland's *Landmarks* (1981) and Roche's *Land and Water* (1994). The first explores the history of soil conservation in New Zealand, tracing its initial popular recognition as a crisis in the late 1930s till the passing of the Water and Soil Conservation Act which came into operation in 1968. *Landmarks* is significant as the companion volume to a TV series of the same name, and although not devoted only to the issue of soil erosion, it undoubtedly heightened public interest in and awareness of people and land management practices in shaping the environment. Roche's (1994) volume traces the history of water and soil conservation and the role played by central government between 1941 and 1988, including an epilogue, on the emergence of the Resource Management Act 1991. It provides one of the most comprehensive bibliographies on erosion issues and the evolution of scientific research on erosion, and deals extensively with land management practices.

Roche (1994, p. 173) notes the relative lack of extensive debate on soil and water conservation in the passing of the Resource Management Act and the fact that many staff in the catchment boards moved into the new regional councils where they faced a number of competing claims that deflected from their former focus. Glasby (1991) echoes Roche's concern over soil conservation under the Resource Management Act and provides a useful review of research, which points to the importance of land management practices and of

[6] This view has been discredited in some parts of New Zealand (e.g. South Island high country) but largely remains true for hill country.

afforestation as a means of controlling erosion. Glasby also suggests that, even in 1991, while the importance of land management practices on erosion was well accepted by science, it was neither recognised nor fully accepted by the public at large. One might reasonably have expected this perspective to have shifted after Cyclone Bola, which hit Gisborne and the East Coast in March 1988. Certainly the impact of the cyclone generated research, technical and popular publications that highlighted the role of land clearance in the devastating erosion and flooding which resulted (e.g. Trotter 1988; Hicks 1989a, b, c; Singleton et al. 1989a, b). The dramatic summer floods of 2004 in the Manawatu offered a similar 'wake-up' call. However, there is little evidence that all this has generated any sizeable body of social science research to expose either the drivers of pre-existing management practices or attitudes to the need for future change. Indeed, an official publication, 'Aspects of New Zealand's experience in agricultural reform since 1984' (Walker & Bell 1994), acknowledged that erosion may well have worsened in the aftermath of the reforms as a consequence of a decline in farmers' ability to afford trees, although it argued too that as economic conditions improved this could be expected to be reversed. The recently released State of the Environment Report (MfE 2007) suggests, from an analysis of vegetation change from pasture to trees, that the area of hill country prone to erosion has reduced marginally (3%) between 1997 and 2002.

The inherent assumption behind the 1984 reforms that the market would result in a more efficient pattern of land use (implicit in the debate was that this would involve more trees replacing pasture in erosion-prone hill country) has not occurred. But the radical nature of the 1984 reforms and the innovative nature of the Resource Management Act may have lowered interest in erosion and deflected attention to other issues, deemed of higher priority. Anecdotally, this is certainly the view of many scientists. This may certainly go some way to explain more recent research carried out since 2000, which has more explicitly examined behavioural factors associated with individual landholders in erosion management and control. Much of this work has been done by scientists in the CRIs (e.g. Luckman et al. 2000; Allen et al. 2002; Philips & Marden 2003). In this, MAF funding has been fundamental. Recent work (including much of that listed above) has examined land management issues (including soil erosion) at a farm level and within the context of sustainable land use (e.g. Morris et al. 1995; Parminter 1995–96; Ryaniyar & Parker 1998; Allen et al. 2002; Buchan et al. 2006; Giera et al. 2007; Smith et al. 2007). Indeed the policy emphasis on sustainability and sustainable land use may hide some research with explicit applicability to issues of erosion management.

New Zealand's commitment, since 1984, to a free market model to promote land use change has, as described, increasingly focused social research on 'sustainable land use', and a primary acceptance that voluntary actions by farmers are the key to achieving the desired outcomes (e.g. Anthoni 2000). However, although this has changed the context of debate there is less evidence there has been an effective shift to the necessary 'systems thinking' required for effective land use for erosion control or sustainability in its fullest context. Thus while subsequent work by Luckman et al. (2000) outlines the development of a decision-support system to promote land management for soil conservation and recognises such variables as species choice, pasture production, land stability and user needs, it emphasises the information requirements of landusers rather than the characteristics or values that lead farmers to adopt more sustainable practices. Parminter's (1995–96) work has a similar focus. Ryaniyar & Parker (1998) also emphasise the characteristics that encourage individual farmer adoption or constrain land use change (in the Manawatu) and suggest that while those interviewed supported conservation and the concept of sustainability, and frequently were planting trees, few identified erosion as a major issue, and most viewed economic viability as their primary concern. A MAF Policy Technical Paper (Andrew et al. 1998), which focuses on the East Coast, again highlights the general acceptance of erosion control as primarily an issue of land use management and for individual landholders. Local governments ranked a poor second. At the same time, respondents were pretty evenly split on whether, since 1991, erosion on their property had improved or remained the same. Philips & Marden (2003), on the other hand, focus specifically on forest companies rather than farmers, but while cautiously optimistic, still find scope for improved land management practices for erosion control.

Rhodes et al. (2003) and Smith et al. (2007) provide evidence from the North Island hill country of a relatively high level of farmers' awareness of erosion issues and a sizeable commitment to land management practices to control erosion. This work also identifies the fact that farmer's behaviour and land use practices are largely unrelated to the economic status of the farmer. Rather, land management for erosion control (and sustainability) more often reflects the underlying environmental values of those farmers concerned. This plainly runs counter to the view that behaviour is solely determined by economic signals, but equally highlights the absence of appropriate understanding of the characteristics and values that determine land management practices. 'Bridging the gap' (Buchan et al. 2006; Giera et al. 2007), a three-year contract study managed through MAF and due to be completed this year (Buchan et al. 2008), picks up this issue and explores the relationship between science and environmental knowledge to generate appropriate land management practices. The report uses soil erosion as one of three case studies. It highlights a number of points, including the need for behaviour change (on the part of landowners), and points out that, overseas, voluntary approaches to erosion control and improved land management have not been successful. Berryman (1998) reports on work done within the Ministry for the Environment to develop indicators to establish the success of voluntary approaches in New Zealand. She suggested three steps were needed to evaluate voluntary approaches to sustainable land management: (1) ensure that environmental objectives are clearly specified and documented, (2) obtain good baseline data for measuring our progress and adapting programmes if needed, and (3) establish processes to track changes in the environment over time and identify the cause of those changes.

All this reflects a revival in interest by central and local government in soil erosion and sustainable land-use after what amounts to what many would argue has been an abdication of responsibility since the mid-1980s. Initiatives such as the East Coast Forestry Project and Horizon's Sustainable Land Use Initiative (SLUI) are designed to address and promote better land use practices, but largely remain focused at the level of individual landholders. As van Roon & Knight (2000) point out, there is a need for a much greater focus on catchment management, and recognition of catchments as the correct operational scale for successful conservation initiatives.

While there is a long history in New Zealand of research on soil erosion, and particularly on its physical expression, the emphasis on sustainable land management since the passing of the Resource Management Act in 1991 has done little to shift debate and generate a solid body of social science research on land management practices as either a cause of accelerated erosion or as a means of control.

At best, given the broad acceptance that erosion remains New Zealand's fundamental environmental threat, particularly in agriculture, the extent and depth of research available on the social and behavioural causes of the problem (and its solution) remain surprisingly disappointing. As suggested, most physical (soil and erosion) scientists recognise that land management is the key to erosion control and acknowledge this in their work, but there is little or no evidence that there has been either an effective effort by behavioural scientists or the necessary full integration of behavioural factors into management policies, nor has there as yet been much effort placed on institutional behaviour and the need for institutional support, if indeed individual voluntary strategies are to remain New Zealand's key strategy.

### 5.3.2 Interviews

A number of people with social learning experience were interviewed to assess their experiences with, and views on the relevance of, social learning to hill country land management (Appendix 2). In addition regional council staff were asked about their experiences with social learning and adaptive management.

Social learning is perhaps best viewed as a journey, not as a state or destination, and for many field staff the management of hill country erosion is an ongoing part of their day-to-day routine. Although one participant pointed out that the number of staff promoting soil conservation and sustainable management is far fewer than in 1992, those who are still directly involved in land management have learned much about the topic and continue to do so. However, as also noted, many of those formerly directly involved in land management for erosion control, even if still employed, whether in a regional council or other agency, are more often now in a different, 'hands-off' capacity.

None of those interviewed were aware of any current or recent social-science research focused specifically on erosion or soil conservation in hill country. What was noted by some was the value of a 'crisis' such as the East Coast floods of 1938, Cyclone Bola in 1988, and more recently the Manawatu floods of 2004 in stimulating political and scientific concern and interest.

Interviewees generally believe that human behaviour and land management practices as a direct contributory factor in soil erosion are now broadly accepted by researchers within both the physical and social sciences. This (and the current funding system), they believe, has encouraged many physical scientists to explicitly address land management and behavioural factors in their work. Many respondents acknowledged the need for a broad, inclusive approach to successfully encourage hill country management to control erosion and that erosion research should play an important role in this approach. However, most erosion research in New Zealand continues to be dominated by physical scientists whose primary expertise and interest is in physical processes rather than the human, economic, or political factors that drive land-use change. Consequently, while the importance of social factors is broadly accepted by research scientists it is rarely the explicit focus of work. In effect, respondents suggested that many physical scientists still assume that the scientific 'facts' from their research will automatically generate an appropriate response by landusers. At the same time the pivotal role of landusers and regional councils in securing the necessary changes on the ground was repeatedly highlighted.

This apparent failure to move to a more integrated, multidisciplinary approach incorporating a number of different physical and social science disciplines is variously explained. Funding constraints for environmental science in general have arguably discouraged a more cooperative approach. Some view the disbandment of catchment boards as having lowered the profile of erosion as a national concern. Some respondents view slower progress in the management of on-farm, hill-country soil erosion since 1989 as a consequence of this disbandment. Others note the lack of interest among social scientists to work with physical scientists, while recognising that for all scientists multidisciplinary team approaches tend to be costly and difficult to focus and manage. But equally, several respondents believed that policy, commitment and funding are the key to securing more, better, erosion control. As yet, 'buy-in' to the successful, costly and slow participatory approach developed and implemented for rabbit management and land conservation in Central Otago in the 1980s has not been backed by the funding such an approach requires.

However, it is also acknowledged that the situation is not all gloomy. Some respondents acknowledged the potential inherent in the new approach of the sustainable land management hill country erosion programme (announced in 2007) that includes subsidies for the retirement of and/or tree planting on land vulnerable to erosion. Respondents believe that both regional authorities and individual research scientists recognise the need for changes in land management practices. Equally, they broadly agreed that most farmers accept the need to address land management practices if they are to resolve their erosion issues. Thus while the volume of recent social science research to improvements in land management appears slight, the context has shifted. Today many social scientists are working on behavioural factors within the context of sustainable land management, and commonly recognise that erosion control is a key component in this work.

A specific example raised by a respondent perhaps illustrates the way forward: it involves the trial of a new approach to encourage hill country erosion management at a catchment scale and as part of a broader programme aimed to reduce runoff and sediment inputs (from all sources) into an adjacent harbour. The ongoing work involves an engagement with the local community to ensure the transfer of the project from being council-led to being community run. This project, now in year four of a five-year programme, is designed to run on beyond its current five-year funding horizon, but under direct community control. If successful, it is anticipated that the experience gained and resources secured will be transferred to address other priority catchments in the region. Other examples raised included further attempts to integrate or transfer research findings to landusers, as in *Sustainable Land Use in the Taranaki Hill Country* (Taranaki Regional Council 1992) and the Sustainable Land Use Initiative in the Manawatu.

## *5.4 Current research and investigation*

### 5.4.1 Capability

The major expertise for hill country erosion research lies within the universities and CRIs. This is described in detail in Appendix 4 and summarised in Table 5. Some regional councils have science staff (e.g. ARC, Environment Waikato, Hawke's Bay, Horizons) and carry out limited scientific investigations and State of the Environment monitoring (see Appendix 3). More commonly they contract out research to CRIs and universities.

Amongst the universities, Victoria University of Wellington has historically had the strongest interest in hill country erosion with a long record of work relating to landslides, and currently has two staff members active in hill country erosion research. University of Canterbury, University of Waikato and Massey University have staff with relevant expertise but with limited current activity. The universities tend to be working on fundamental process issues (e.g. landslide mechanics, hillslope-channel coupling).

The CRIs have a wide variety of staff with capability for hill country erosion research (Appendix 4) in the areas of:

- Erosion process measurement and understanding (Landcare Research, GNS)
- Soil mechanics and slope stability (GNS, Landcare Research)
- Hazard and risk assessment (GNS, Landcare Research)
- Modelling (Landcare Research, GNS, NIWA, Ensis)
- Remote sensing (Landcare Research, GNS, Ensis
- Erosion mitigation using vegetation, including vegetation management (AgResearch, HortResearch, Ensis, Landcare Research)
- Social science and natural resource economics (AgResearch, Landcare Research, Ensis).

Landcare Research and GNS have the most capability for erosion process and soil mechanics research while AgResearch, HortResearch and Ensis focus more on erosion mitigation. Landcare Research also has expertise in the contribution roots systems make to slope stability. Appendix 4 provides more detail on the capability and expertise of each organisation. The CRIs tend to focus more on applied research and technology development (e.g. the relationship between vegetation cover and erosion, development of new varieties of poplars and willows). While a large number of people have capability for hill country erosion research, a far smaller number are currently actively engaged in relevant research (Table 5) and many of those who are only have a small proportion of their time devoted to hill country erosion issues. For example, AgResearch and Landcare Research have a large number of social science research staff but none are actively involved in hill country research.

**Table 5** Summary of capability for hill country erosion research in CRIs and universities (* numbers currently working on some aspect of hill country erosion, note that none of these are working full time on hill country erosion; # staff with relevant expertise but not currently working on hill country erosion).

| | Currently active* | Capability# |
|---|---|---|
| University of Waikato | 1 (PhD student) | 5 |
| Massey University | 1 | |
| Victoria University of Wellington | 2 | . |
| University of Canterbury | | 2 |
| Ensis | 3 | 16 |
| GNS | 13 | |
| NIWA | 3 | |
| Landcare Research | 8 | 9 |
| AgResearch | 2 | 20 |
| HortResearch | 2 | 1 |

### 5.4.2 Current research programmes and projects

Details of current research are listed in Appendices 3 (regional councils) and 4 (universities and CRIs) and summarised below (Table 6). There are only two central government (FRST) funded major research programmes that focus almost entirely on hill country erosion, namely GNS 'Margins Source-to-Sink' programme and the Landcare Research ‘Landscape Resilience’ programme, which is funded by FRST transition funding and has an uncertain future. The other FRST-funded programmes (‘Protecting & Enhancing the Environment through Forestry’ – Ensis, ‘Immediate Surveillance and Damage Assessment following Natural Disasters’ – GNS, ‘Reducing the Impacts of Weather-related Hazards’, ‘Land Use Intensification: Sustainable Management of Water Quantity and Quality’ and ‘Effects-based Protection and Management of Aquatic Ecosystems’, ‘Restoration of Aquatic Ecosystems’ – NIWA, ‘Integrated Catchment Management’ – Landcare Research, SLURI with funding to Landcare Research, AgResearch, HortResearch) have minor components of hill country erosion research within them. Direct regional council funding and Envirolink are also significant sources of funding. At least $1.8 million is being spent on aspects of hill country research but it is scattered across a wide variety of programmes and projects, and research providers, and as a consequence is poorly coordinated. The level of funding, and the coordination of research on hill country erosion, has been severely reduced since the demise of the National Water and Soil Conservation Authority and its research arm, the Water and Soil Division of Ministry of Works and Development.

**Table 6** Summary of current research.

| Organisation | Programme/project | Estimated annual value of research | Funding source | Research type* |
|---|---|---|---|---|
| *Universities and CRIs* | | | | |
| University of Waikato | Effects of land use on erosion | PhD study | | S |
| Massey University | Slope-channel coupling at Tarndale slip | $18k | | S |
| | Slope-channel linkages following Feb. 2004 storm in the Manawatu | | | S |
| Victoria University of Wellington | Temporal changes in sediment delivery associated with landsliding | | | S |
| | Role of erosion in terrestrial carbon cycle | | | |
| University of Canterbury | Role of large landslides in sediment generation in the Waipaoa (subcontract in GNS 'Margins' programme) | | FRST | S |
| Ensis | Aquatic environmental quality objective in‘Protecting & Enhancing the Environment through Forestry’ (includes magnitude and duration of effects of harvesting and related forestry activities on sediment generation and movement) | | FRST | A |
| | Costs of erosion and benefits of mitigation | $60k | MAFPolicy | A |
| | Using finite element analysis and computational fluid dynamics modelling to determine erosion risk of different forest planting designs | | | A |
| GNS | Rapid response investigation of landslides following storms (GEONET ‘Geological Hazards and Society’ programme): focus on landslide hazard, but collects information on extent and characteristics of landslides; also establishing a | $150–250k | EQC (GEONET) and FRST | S |

| Organisation | Programme/project | Estimated annual value of research | Funding source | Research type* |
|---|---|---|---|---|
| | landslide database | | | |
| | ‘Immediate Surveillance and Damage Assessment following Natural Disasters’: developing pre- and post-event satellite imagery processing to accurately record the locations and size of landslides | | FRST | T |
| | ‘MARGINS Source-to-Sink’ developing a quantitative understanding of how landscapes respond to global environmental change and human interventions | $450 | FRST | S, A |
| | Developing a national landslide forecasting model. | $50k | FRST, subcontract with NIWA in ‘Reducing the Impacts of Weather-related Hazards’ programme | T |
| NIWA | Raglan Fine Sediment Study: modelling catchment sediment generation and delivery to the estuary (in ‘Land Use Intensification: Sustainable Management of Water Quantity and Quality’ and ‘Effects-based Protection and Management of Aquatic Ecosystems’ programmes) | $350k (includes the LCR $165k subcontract) | FRST | A, T |
| | Response of stream sediment yield/turbidity to land management changes at Whatawhata | $30k | FRST | A |

| Organisation | Programme/project | Estimated annual value of research | Funding source | Research type* |
|---|---|---|---|---|
| | ('Restoration of Aquatic Ecosystems' programme) | | | |
| | Compound-specific isotope tracer method for establishing sediment sources to estuaries (at Whangapoua, Mahurangi, Whangamata, Raglan) | | | T |
| | Landslide hazard assessment for New Plymouth District | | | A |
| Landcare Research | Raglan Fine Sediment Study: landslide modelling and associated work | $165k | Subcontract to NIWA'Land Use Intensification: Sustainable Management of Water Quantity and Quality' programme | A |
| | Identification of sources of sediment getting in to Raglan Harbour using sediment fingerprinting methods, utilising geochemistry, radionuclides and compound-specific isotopes (capability funded $80k this year, involves collaboration with NIWA for CSI work). | $85k | FRST capability fund | T |
| | Gully erosion in the East Coast | $100k | FRST transition funding, MAF | A |
| | Sediment impacts of forest roads and connectivity to streams; the effectiveness of | $90k | FRST-funded Ensis | A |

| Organisation | Programme/project | Estimated annual value of research | Funding source | Research type* |
|---|---|---|---|---|
| | riparian buffers in mitigating sediment. | | programmme | |
| | Below-ground characteristics of native plants (field trial) | $90k | FRST 'Integrated Catchment Management' programme | A |
| | Effect of landsliding on pasture productivity in hill country; development of erosion modelling capability with NZEEM® and SedNet. | $130k | FRST funding for SLURI | A, T |
| | Development of a decision support system for evaluating the effects of wide-spaced trees for soil conservation (collaborative with AgResearch, HortResearch). | $54k | MAF Policy | T |
| AgResearch | Effectiveness of spaced trees for erosion control and their root characteristics (collaborative with HortResearch): | | FRST funding for SLURI | A |
| | Monitoring and reporting of whole farm plans as a tool for affecting land use change | | FRST Envirolink, Horizons | T |
| | Development of a farm-scale risk optimisation model | | | T |
| HortResearch | Poplar and Willow Breeding Programme | $50k | Regional councils | A |
| | Effectiveness of spaced trees for erosion control and their root characteristics (collaborative with AgResearch) | | FRST funded SLURI | A |
| *Regional councils* | | | | |
| Auckland | Reviewing indicators used for hill country | | | A |

| Organisation | Programme/project | Estimated annual value of research | Funding source | Research type* |
|---|---|---|---|---|
| | erosion | | | |
| | Limited sediment monitoring as part of Mahurangi Action Plan | | | A |
| | Contribute to Willow and Poplar Research Collective | | | A |
| Waikato | Contributing to Raglan Fine Sediment Study | | | A |
| | Monitoring slip revegetation, density and distribution in a forested Coromandel catchment | | | A |
| Taranaki | Contribute to Willow and Poplar Research Collective | | | A |
| Horizons | Monitoring the implementation of the Whole Farm Plan (WFP) programme<br>LUC Handbook upgrade<br>Sednet modelling work<br>Best practice phosphorous project<br>Contribute to Willow and Poplar Research Collective | | FRST Envirolink and SFF | A, T |
| ECan | Review of earthworks and vegetation clearance activities in the Canterbury region | | | A |
| *Central government* | | | | |
| MfE | Revising 'Climate Change Effects and Impacts Assessment' to incorporate the most recent climate projections. | | | A |
| | Land Use and Carbon Analysis System will determine how to model and estimate carbon stocks (and stock change) in areas susceptible to erosion. | | | A |

* S – strategic, A – applied, T – technology development

## 5.5 Information gaps and research needs

Appendices 3 and 4 list the responses received from management agencies and research providers and give individual views about key research needs. These are summarised in Table 7 and grouped by the type of information gap and which agency regards it as a gap.

**Table 7** Research gaps identified by survey respondents.

| Gap | Agency |
|---|---|
| No process research needed | Taranaki RC |
| Ability to measure regional/catchment rates of erosion and determine what is tolerable, including measuring the contribution from different land uses and land management practices, being able to distinguish natural and induced erosion (long-term and event-based), and the contribution of different processes (sheet, landslides, bank erosion, earthflow) | Northland, ARC, EW, EBOP, Hawke's Bay, ECan, Fed Farmers, NZFOA, Waikato Uni, GNS, NIWA, LCR |
| Effective erosion indicators for SOE reporting | ARC, LCR |
| Integrated research on sediment dynamics (connectivity and lags) within catchments and downstream effects, including slope–channel linkages | EW, Hawke's Bay, Horizons, Gisborne DC, Waikato Uni, Massey Uni, VUW, GNS, NIWA, LCR |
| Field studies of landslide frequency/magnitude/impact, initiation thresholds | VUW, GNS, NIWA |
| Runoff generation processes | NIWA |
| Impacts of climate change on erosion | ARC, LCR |
| Long-term impacts of erosion (on soils and landscape response) | ECan, VUW |
| Erosion prediction tools/models incorporating land use/management effects and able to distinguish different erosion processes | EW, Taranaki, Hawke's Bay, GNS, LCR |
| Adequately funded willow and poplar breeding programme | Taranaki, Wellington RC |
| Biomechanics of erosion control , including alternative tree species | EBOP, LCR, AgResearch |
| Effectiveness of trees (including willows, poplars and natives) for erosion control and their management requirements, and other erosion control measures, over a range of event magnitude | ARC, Gisborne DC, ECan, GNS, LCR, AgResearch |
| Cost–benefit analysis of different mitigation techniques including co-benefits of erosion control on carbon storage, role of erosion in carbon budget | EBOP, Horizons, VUW, GNS, LCR, HortResearch, Ensis, NZFOA |
| Options for erosion management in native forests | EW |
| Design and implementation of optimal land use and land | Ensis, AgResearch |

| | |
|---|---|
| management patterns to maximise erosion mitigation while recognising production values | |
| Effective community engagement processes for erosion and catchment management | ARC, LCR, HortResearch |
| Improved technology transfer | EBOP, Hawke's Bay, Ensis |
| Biological and economic costs of erosion | NZFOA, Ensis |

# 6 Conclusions

Twenty-one different types of hill country terrain can be recognised based on variation in rock type, topography, erosion processes and severity. These terrains can be further grouped on inherent erosion susceptibility into low, medium, high susceptibility. Three terrains are rated high (on soft rock and crushed soft rock), five are low (on hard rocks or easier slopes) and the remainder medium.

In the North Island, the majority of hill country is developed on soft rock and crushed soft rock, with smaller areas of volcanic ash and loess-mantled terrain, hard rock hill country and deeply weathered sedimentary and igneous rocks. Erosion is widespread but only 200 000 ha has a mapped erosion severity of severe, very severe or extreme, mostly located on the East Coast, with smaller areas in inland Taranaki, Coromandel and Northland. The North Island hill country is dominated by mass movement erosion (soil slip, earthflow and gully erosion). In the South Island most hill country is developed on hard rock terrain, with minor areas on soft rocks, and weathered hard rocks. Loess mantles many hill country areas in the east of the South Island. The South Island is dominated by surface erosion, with far less extensive mass movement. Less than 103 000 ha have an erosion severity ranking of severe, very severe or extreme.

Landslides, and their impacts, are the best studied erosion process with gully and earthflow erosion far less well studied. Recent (post-1970) research has focused on the most highly erodible areas, often in response to the impacts of storms, including the Wellington and Wairarapa areas, Hawke's Bay and Gisborne, Taranaki region and the Manawatu–Wanganui area. Far less is known of hill country erosion processes in areas such as Northland, Coromandel, Waikato–King Country, the Central North Island Volcanic Plateau and the South Island.

Geology and climate largely determine the landscape's inherent susceptibility to erosion, including the response to vegetation change. Closed-canopy woody vegetation reduces rates of hillslope erosion by an order of magnitude on the most susceptible terrain; on other terrain hillslope erosion is reduced but the degree of reduction is not as well quantified. The impacts of pre- or post-European deforestation have persisted for more than a century especially in those landscapes with thick regoliths and/or soft rocks Susceptibility to erosion is readily identifiable at a regional scale and increasingly tools and methods are becoming available that can be used at hillslope and farm scale. Large storms, or long wet periods, drive mass movement (landslide, earthflow) on hillslopes (high-magnitude, low-frequency events). For fluvial erosion (gullying, bank and channel erosion) the smaller more frequent storms are more important (i.e. low-magnitude, high-frequency events). Harvesting of forests increases erosion rates in the short term, but over the length of a forest rotation pasture produces more sediment than forestry. Climate change is likely to exacerbate erosion problems in the worst-affected areas since it is predicted to cause heavier and/or more frequent extreme rainfalls.

There is a wide range of information sources on management options for preventing and controlling erosion in New Zealand hill country including the seminal publications the *Plant Materials Handbook for Soil Conservation* (Hathaway RL 1986a), *Control of Soil Erosion on Farmland* (Hicks 1995), the *Soil Conservation Technical Handbook* (Hicks & Anthony 2001) and the *New Zealand Environmental Code of Practice for Plantation Forestry* (New Zealand Forest Owners Association 2007). Most regional councils use these sources and have developed locally relevant and practical resources that they use to provide advice to farmers (fact sheets, newsletters, website information, etc.). Much of the information has been packaged into a freely available decision support system called the 'Green Toolbox'.

The most effective vegetation for controlling mass movement on the most severely eroding land is mature (closed canopy) indigenous or exotic forest (i.e. a change in land use). On hill slopes without a woody component, maintaining a persistent, complete pasture cover reduces surface erosion processes of wind, sheet wash, and rilling. Two-tier systems using a woody component (usually *Populus*, *Salix, Eucalyptus*, *Pinus*, or *Acacia* species) have commonly been used to reduce the likelihood of mass movement while maintaining pastoral land use. *Populus* and *Salix* species are preferred where erosion is mediated by surplus soil water and grazing livestock during tree establishment is feasible. *Acacia* and *Eucalyptus* species are recommended for use on seasonally drought-prone sites. Two-tier systems involving *Pinus radiata* can be used to derive dual benefits of timber production at maturity and meat/wool income in at least the early and intermediate years of the tree rotation.

Control of gully erosion uses spaced planting of *Populus* or *Salix* species in combination with engineering structures (e.g. debris dams) while the trees establish. The most successful system is 'pair planting' up the gully at spacings of 2–10 m between pairs. Severely eroding gullies should be retired from grazing and closed-planted with trees. Earthflows and slumps can be stabilised by space-planted trees and afforestation, along with the use of subsurface drains and diversion banks. Recommended tree spacings vary depending on attributes such as the extent of the earthflow, its movement and stage of development, and depth to the failure plane.

The effectiveness of mature (closed canopy) indigenous or exotic forest for controlling various types of mass movement is well documented in a range of hill country terrains (including soft rock, crushed soft rock, deeply weathered rocks,and steep hard rock), and event sizes, including extreme storm events such as Cyclone Bola. In two-tier systems where trees are spaced to enable erosion control and the maintenance of an understorey pasture for livestock grazing, measures of effectiveness for erosion control are not as well documented scientifically, but what studies are available suggest the interaction between roots of neighbouring trees at close spacings was a major factor in treatment success.

While understanding of soil erosion as a physical process is well advanced, there is little published research that specifically addresses land management from a social or behavioural perspective. Given the broad acceptance that erosion remains New Zealand's fundamental environmental threat, particularly in agriculture, the extent and depth of research available on the social and behavioural causes of the problem (and its solution) remain surprisingly small. While large storms continue to have a severe impact on many hill country areas, there is little evidence that this has generated any sizeable body of social science research to expose either the drivers of pre-existing management practices or attitudes to the need for future change.

New Zealand's commitment to a free market model to promote land use change has increasingly focused social research on 'sustainable land use', and a primary acceptance that voluntary actions by farmers are the key to achieve desired outcomes. Some literature suggests this is largely seen within the context of economic viability, while other studies suggest it more often reflects the underlying environmental values of those farmers concerned. The contradictory evidence suggests a lack of understanding of the characteristics and values that determine land management practices.

There is little evidence that there has been either an effective effort by behavioural scientists or the necessary full integration of behavioural factors into management policies. Nor has there been much effort placed on institutional behaviour and the need for institutional support if voluntary strategies are to remain New Zealand's key strategy for managing hill country erosion. The failure to move to a more integrated, multidisciplinary approach incorporating a number of different physical and social science disciplines in hill country research is a result of a number of factors including funding constraints, low priority given to erosion research by funders and research providers, lack of interest among social scientists, and the difficulty of managing multidisciplinary team approaches.

A large number of scientists have capability for hill country erosion research, but a far smaller number are currently actively engaged in relevant research, and many of those who are only have a small proportion of their time devoted to hill country erosion issues. At least $1.8 million per annum is being spent on aspects of hill country research, but it is scattered across a wide variety of programmes and projects, and research providers, and as a consequence is poorly coordinated. Only two central government (FRST) funded major research programmes focus almost entirely on hill country erosion (GNS 'Margins Source-to-Sink' programme, Landcare Research 'Landscape Resilience' programme). Other FRST-funded programmes run by Ensis, GNS, NIWA, Landcare Research, and SLURI have minor components of hill country erosion research within them. Direct regional council funding and Envirolink are significant sources of funding.

Research gaps identified by the greatest number of stakeholders included:

- Ability to measure regional/catchment rates of erosion and determine what is tolerable, including measuring the contribution from different land uses and land management practices, being able to distinguish natural and induced erosion, and the contribution of different processes
- Integrated research on sediment dynamics (connectivity and lags) within catchments and downstream effects, including slope–channel linkages
- Development of erosion prediction tools/models incorporating land use/management effects and able to distinguish different erosion processes
- Effectiveness of space-planted trees (including willows, poplars and natives) for erosion control and their management requirements, and other erosion control measures, over a range of event magnitudes
- Cost–benefit analysis of different mitigation techniques including co-benefits of erosion control on carbon storage, role of erosion in the carbon budget
- Effective community engagement processes for erosion and catchment management, and improved technology transfer

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# Appendix 2 – List of agencies and people contacted

| **Regional councils** | Person(s) responding |
|---|---|
| Northland | Bob Cathcart |
| Auckland | Paul Metcalf |
| Environment Waikato | Reece Hill |
| EBOP | Simon Stokes |
| Taranaki | Don Shearman |
| Gisborne DC | Trevor Freeman |
| Hawke's Bay | Garth Eyles, John Phillips |
| Horizons | Malcom Todd |
| GWRC | Dave Cameron |
| Marlborough | Nikki Eade |
| ECan | Cathie Brumley |
| Otago | Susie McKeague |
| Southland | Gary Morgan |
| | |
| **Industry** | |
| Meat and Wool | Mark Jeffries (no response) |
| Federated Farmers | Hilary Gubb |
| NZFOA | Dennis Hocking, Peter Weir |
| | |
| **Central government** | |
| MAF | John Greer (no response) |
| MfE | Vera Power |
| | |
| **Research providers** | |
| University of Auckland | Gary Brierley, Ian Boothroyd (no response) |
| University of Waikato | Megan Balks, Brendan Roddy |
| Massey University | Ian Fuller |
| Victoria University of Wellington | Mike Crozier, Nick Preston |
| University of Canterbury | Jarg Pettinga (no response) |
| University of Otago | Ewan Fordyce |
| Ensis | Hayden Jones |
| GNS | Mike Page |
| NIWA | Sandy Elliott |

Additional people interviewed about social learning:
Morgan Williams (former Parliamentary Commissioner for the Environment), Consultant
Ian Whitehouse (formerly Landcare Research), Consultant
Paul Blaschke, Consultant (Wellington)
Alec McKay (AgResearch, Palmerston North)
Gerald Rys, MAF (Wellington)
Paul Williams (University of Auckland)
Terry Parminter (AgResearch)

Doug Hicks (Consultant)
Murray Harris (Consultant)

**Copy of letter to regional councils, industry and central government**

Dear Sir

We have been contracted by the Ministry of Agriculture and Forestry to undertake a review of hill country erosion to identify the information needed to underpin long-term solutions to hill country erosion. The purpose of the review is 'to undertake a stocktake of current knowledge and identify priority knowledge gaps relating to the prevention, treatment and management of hill country erosion in New Zealand, including physical, social, environmental and economic dimensions'. Specifically we have been asked to review information on

- Sources and flows of sediment;
- The specific managements, technologies and practices used in the treatment of land and the long-term management of those treatments; and
- Social learning and adaptation to treating and managing hill country erosion.

Some of this information is published and some of it is held in unpublished form by regional councils, universities and Crown Research Institutes and we seek to identify all relevant information. We have also been asked to provide an assessment of current research and research capability related to the study and management of hill country erosion.

Further we have been asked to use this, in consultation with stakeholders, to identify future research needed to underpin long-term solutions to hill country erosion and how these needs might be met. The future information needs are to be agreed and prioritised by key land managers, scientists, and other stakeholders. We plan to consult widely with all relevant stakeholders, and to run a workshop with relevant stakeholders in early 2008 to specifically address the questions related to future information needs and how they might be met.

Our project team is led by Dr Les Basher (Research Leader Erosion and Sediment Processes, Landcare Research) and includes Mike Marden, Ian Lynn (Landcare Research), Grant Douglas, Mike Dodd, Neels Botha (AgResearch), Ian McIvor (Hort Research), and Willie Smith (School of Geography, Geology and Environmental Science, University of Auckland).

The purpose of this letter is to invite your input in to the review. We would value your answers to the following questions:

- Do you have in-house publications on hill country erosion processes or investigations that your organisation has carried out that we cannot access from bibliographic databases (such as NZ Science and library catalogues). Could you please provide a list?
- What resources do you use when providing management information to hill country farmers? Do you have in-house resources (and what are they) or do you

use published information such as the *Soil Conservation Technical Handbook*? Do you provide written or oral advice?
- Do you have experience with social learning and adaptive management approaches to managing hill country erosion problems? Are there any publications/reports that describe this experience, or can you summarise your experience for us?
- Are you currently carrying out any investigations or research into hill country erosion? If yes, please provide a brief description, a list of the persons involved, and the level of funding if possible.
- What capability do you have for research into hill country erosion processes and management?
- Do you have a view on research and information gaps that are needed to underpin long-term solutions to hill country erosion?

Your input will be acknowledged (unless you request otherwise) in our first report reviewing existing knowledge on erosion processes and erosion management, providing an inventory of current research, and including individual views on information gaps and research priorities. Having summarised the individual views we will seek to come to a consensus view on priorities through a workshop process to which a number of respondents to this survey will be invited.

We would prefer to receive your comments in electronic form if possible (email or other) to allow us to easily integrate your comments in to our report. We would be most grateful for your responses by 18 January 2008 to enable us to meet our project milestones.

Yours sincerely

Dr Les Basher
Landcare Research, Private Bag 6, Nelson
basherl@landcareresearch.co.nz

**Copy of letter to research providers**

Dear Sir

We have been contracted by the Ministry of Agriculture and Forestry to undertake a review of hill country erosion to identify the information needed to underpin long-term solutions to hill country erosion. The purpose of the review is ‘to undertake a stock take of current knowledge and identify priority knowledge gaps relating to the prevention, treatment and management of hill country erosion in New Zealand, including physical, social, environmental and economic dimensions’. Specifically we have been asked to review information on:
- Sources and flows of sediment;
- The specific managements, technologies and practices used in the treatment of land and the long-term management of those treatments, and

- Social learning and adaptation to treating and managing hill country erosion.

We have also been asked to provide an assessment of current research and research capability related to the study and management of hill country erosion.

Further we have been asked to use this, in consultation with stakeholders, to identify future research needed to underpin long-term solutions to hill country erosion and how these needs might be met, including funding options. The future information needs are to be agreed and prioritised by key land managers, scientists, and other stakeholders. We plan to consult widely with all relevant stakeholders, and to run a workshop with relevant stakeholders in early 2008 to specifically address the questions related to future information needs and how they might be met.

Our project team is led by Dr Les Basher (Research Leader Erosion and Sediment Processes, Landcare Research) and includes Mike Marden, Ian Lynn (Landcare Research), Grant Douglas, Mike Dodd, Neels Botha (AgResearch), Ian McIvor (Hort Research), and Willie Smith (School of Geography, Geology and Environmental Science, University of Auckland).

The purpose of this letter is to invite your input in to the review. We would value your answers to the following questions:

1. Are you currently carrying out any investigations or research into hill country erosion? If yes, please provide a brief description, a list of the persons involved, and funding level if possible.
2. What capability do you have for research into hill country erosion processes and management?
3. Do you have a view on research and information gaps that are needed to underpin long-term solutions to hill country erosion? We are interested in both the science perspective on research needs and the management perspective.

Your input will be acknowledged (unless you request otherwise) in our first report reviewing existing knowledge on erosion processes and erosion management, providing an inventory of current research, and including individual views on information gaps and research priorities. Having summarised the individual views we will seek to come to a consensus view on priorities through a workshop process to which a number of respondents to this survey will be invited.

We would prefer to receive your comments in electronic form if possible (email or other) to allow us to easily integrate your comments in to our report. We would be most grateful for your response by 18 January 2008 to enable us to meet our project milestones.

Yours sincerely

Dr Les Basher
Landcare Research, Private Bag 6, Nelson 7042
basherl@landcareresearch.co.nz

# Appendix 3 – Responses received from regional councils and industry

*Question* *What resources do you use when providing management information to hill country farmers? Do you have in-house resources (and what are they) or do you use published information such as the Soil Conservation Technical Handbook?*

*Regional councils*

**Northland**

Use *Soil Conservation Technical Handbook*. Also have some in-house resources (e.g. 'Soil Conservation Fact Sheet 1 – Controlling Stream Channel Erosion in Northland', 20-page NRC staff guide by Bob Cathcart, 1998; 'Soil Conservation Fact Sheet 2 – Gully Control in Northland', 20-page NRC staff guide by Bob Cathcart, 1998; *Trees for the Land* – 36-page NRC publication edited by Kathy Mortimer, 5th edn, December 2007).

**ARC**

- Primarily *Soil Conservation Technical Handbook*; 'Visual soil assessment. Volume 4. Soil management guidelines for hill country land uses'; 'Control of soil erosion on farmland', DL Hicks MAF report
- Have some in house fact sheets (e.g. A practical guide to pole planting)
- The Rural team provides advice to farmers/landowners on an as-required basis and is trialling the use of farm plans as a whole-farm management tool as part of the Mahurangi Action Plan.
- The Natural Heritage Team has some resources such as 'Riparian planting', 'Clay bank', 'Coastal Cliffs' and 'Wetland' ones. The fact sheets are supplied to farmers wanting to control erosion on their properties – not often hill country examples but more riparian erosion.

**EW**

*Soil Conservation Technical Handbook* (Hicks & Anthony 2001) and some in-house resources (e.g. 'Poplar and Willow Planting: a Guide to Planting Poplar and Willow on Your Property'; 'Trees on Farms: A guide with local experience of growing trees in the Waikato Region').

**EBOP**

*Soil Conservation Technical Handbook* (Hicks & Anthony 2001) and some in-house resources (e.g. 'Environmental Programmes', 'Riparian Protection', 'Farm Tracks: Planning, construction and maintenance', 'Management of retirement areas', 'Detention dams and drop structures', 'Plant selection for disturbed sites', 'Uses and management of willow species', 'Uses and management of poplar species', 'Care groups', 'How to establish revegetation plantings', 'Protecting our landscapes').

| | |
|---|---|
| Taranaki | Management information provided to farmers is through comprehensive farm planning. Land use capability mapping and its associated land resource information forms the base for the sustainable land management recommendations made plans. Plan includes present and potential pasture growth and utilisation information and an economic analysis on any projected increase in production. A variety of information sheets (available on TRC website) ranging from all aspects of poplar pole management to erosion processes and control techniques are also provided. The *Soil Conservation Technical Handbook* (Hicks & Anthony 2001) and NWSCA bulletins are used. Ongoing oral advice is provided through annual contact with plan holders. |
| GDC | Refer to a lot of published information, especially on plant materials, sediment control, geology, soils, forestry practices, soil erosion and soil conservation practices (e.g. MAF 'Soil Erosion Control on Farmland', Soil *Conservation Technical Handbook*). Produce a State of the Environment Report every two years and have a flagship educational resource in our quarterly publication 'Conservation Quorum'. Historical and recent oblique photography provides useful historical comparisons. We hold extensive aerial photography coverage of various ages; mostly B&W, some colour infrared and since 1988, colour. The GIS holds the 1999 NZLRI, soils, geology, DCDB, various planning layers and the detailed LUC grouping referred to above, as well as NZMS 260 and orthophoto backgrounds. Historical soil conservation works records are held on files. Most advice is oral. This is backed up in writing if required. Dissemination by email and website use is increasing. Most importantly, all our advice is tempered and modified by practical experience gained in local situations. Knowledge of what has worked and what has not worked in the past is an important resource. |
| HBRC | Mostly apply practical experience to farm plans; Environmental Topics provide information on the HBRC website (e.g. on 'Conservation Trees', 'Native Trees', 'Land Management'). Mostly oral advice often passed on by word-of-mouth to other farmers. |
| Horizons | Staff use the *Soil Conservation Technical Handbook*. The Sustainable Land Use Initiative (SLUI) Whole Farm Plan is the major resource kit provided to farmers. Technical handouts are in the process of being updated; they include the general pole planting and management type handouts. Various publications are used including 'Visual Soil Assessment (VSA)', 'Growing Poplar and Willow trees on farms', 'Visual Bush Assessment', etc. We rely heavily on the technical capability of our soil teams and invest in training as required. |
| GWRC | GWRC prepares two types of farm plan, a conservation plan and a sustainability plan. Both have as their core resource information a detailed (generally 1:10 000) land use capability map. Additional information in a sustainability plan includes information on pasture production and forestry site indices. Aerial photography is |

| | |
|---|---|
| | included, generally 2001-2002 coverage is available through GIS. Have a range of specific information sheets around poplars and willows. |
| Marlborough | Currently little work being done. |
| ECan | *Soil Conservation Technical Handbook* (Hicks & Anthony 2001) and ECan's in-house 'Erosion and Sediment Control Guidelines'. |
| Otago | Use the *Soil Conservation Technical Handbook* (Hicks & Anthony 2001) and have a few specifically developed fact sheets on erosion and poplar planting. Also refer clients to consultants in the district. |
| Southland | Have own handouts on pole planting etc. which are drawn from the Soil Conservation Plant Materials Handbook and the Soil Conservation Technical Manual. Visit land owners with hill country erosion issues and discuss options and solutions. ES Land Sustainability staff draw up planting programmes, dewatering works, etc. and supervise work programmes. |
| *Industry* | |
| Federated Farmers | Attempt to keep farmers aware of relevant information and have provided some specific information such as how to regrass slips and flood sediment following the 2004 Manawatu/Wanganui storm event (Litherland et al. 2005a, b). |
| NZ Forest Owners Association | Have developed the *Forest Code of Practice* (Vaughan et al. 1993) in association with the Logging Industry Research Organisation to increase awareness of the effects of forestry operations on both on- and off-site values. This is intended to ensure that environmental and commercial values are recognised in plantation forests. It lists forestry operations and their effects on the environment and the best environmental practices (BEP) methods of reducing those effects. The Code aims to be a key reference tool to a wide range of parties involved in managing forests by providing information on environmental values, how such values should be assimilated into operational planning, other references and resources as well as the BEPs. It can also serve as a useful framework for training purposes. |

*Do you have experience with social learning and adaptive management approaches to managing hill country erosion problems? Are there any publications/reports that describe this experience, or can you summarise your experiences for us?*

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| *Regional Councils* | |
| Northland | No, but it is inherent in the work that land management officers do in dealing with farmers. |
| ARC | ARC (with Rodney District Council) is currently trialling a catchment-based restoration programme |

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| | (Mahurangi Action Plan) in the Mahurangi Harbour. The aim is to reduce sediment inputs (from all sources) to improve the health of the harbour. A major component of the programme involves grants to landowners to reduce sediment inputs and this has been well received from landowners. Current work involves engagement with the local community to affect a transfer of the project from one of Council-led to community ownership. The project is in year four of five and it is anticipated that the community will lead the project beyond the five-year horizon. If the project is successful, it is anticipated that experiences and resources will be transferred to other priority catchments in the Auckland Region. |
| EW | One study (Ritchie HM 2005. Report on soil conservation and waterway protection in the middle Waikato. Environment Waikato Technical Report 2005/14). Farmers were interviewed to find out about the work they had done, their initial motivations and the farm benefits they had gained. They were also asked about any environmental benefits they observed as a result. Information was gathered about costs and the issues farmers had faced as well as lessons they had learned. A further aim of the study was to assess whether the current grants offered through Project Watershed and other schemes are justified, and set at a rate that reflects the balance of private and public benefit. |
| EBOP | Staff have practical experience in social learning and adaptive management. |
| Taranaki | Social learning and adaptive management approaches haven't been the focus for the region although the aim of ‘Sustainable Land Use in the Taranaki Hill Country – a case study’ was to apply the results of research on hill country pasture growth and soil erosion into an existing farming system (adaptive management?). Overall, the emphasis of the hill country programme has been on a ‘one on one’ approach aiming at changing behaviour. |
| GDC | No, but it is inherent in the work that land management staff do in dealing with farmers. We place a lot of emphasis in employing staff with the right personality and training to be able to easily relate to farmers. We give them the right tools and training to get messages across and bring about land use changes without undue angst. This relationship building on a one to one basis is fundamental to our work. Experience is critical. |
| HBRC | All Land Management Advisors have experience with social learning and adaptive management developed through practical experience. Some staff have been to facilitation courses. |
| Horizons | No formal studies done in this area, but have a wealth of practical experience. SLUI has been achieved through social buy-in via the community. This was driven by an initial community workshop that included a wide range of our regional groups (Fed. Farmers, CRIs, TLAs, forestry groups, NGOs, etc.). |

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| | Staff regularly work with groups to develop community responses and buy-in. The land group have been doing this recently through Whanganui Catchment Strategy (WRET) and SLUI. |
| GWRC | Have had little exposure to this. |
| Marlborough | The Starborough/Flaxbourne Landcare Group project involves a social learning component through workshops and field days. |
| ECan | ECan has a limited on-the-ground programme to encourage best practice and address erosion management. There is work going on with industry (Meat & Wool) on introducing the environment component into business plans for both their monitor farms and on a 3-tep land & environment plan programme that the industry is developing. |
| Otago | No |
| Southland | No |

*Industry*

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| Federated Farmers | No formal involvement but it is inherent in the way farmers operate, for example in exchanging information with other farmers, in attending field days and interacting with regional council staff and scientists. Learning by doing, and observing what other farmers are doing, is a very important component of farm management for many farmers. |
| NZ Forest Owners Association | No formal involvement but it is inherent in the way the forestry industry is organised (through the NZ Forest Owners Association), in the interactions between different forest companies and their staff, in attending field days, in the resource consent process, and interactions with regional council staff and scientists. |

*Are you currently carrying out any investigations or research into hill country erosion? If yes, please provide a brief description, a list of the persons involved and the level of funding if possible?*

*Regional Councils*

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| Northland | No |
| ARC | Reviewing indicators used for hill country erosion and likely that the survey conducted in 1999 will be repeated. Other methods may be investigated.<br>Limited sediment monitoring is being carried out in one sub-catchment in conjunction with the Mahurangi Action Plan. The aim is to detect the reduction in sediment in the stream, and improvement in stream health. |

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| | ARC contributes $4,000 annually to the willow and popular collective. |
| EW | Developed method for monitoring the changes related to soil conservation in priority catchments.<br>Monitoring slip revegetation, density and distribution in a forested catchment on the Coromandel as part of an assessment of biophysical benefits of animal pest control on the Coromandel Peninsula.<br>Contributing and involved with Fine Sediment Study in Raglan with NIWA, Landcare Research and others. |
| EBOP | None |
| Taranaki | No current investigations or research into hill country erosion.<br>TRC is a member ($7,500 per year) of the willow and poplar research collective, which does produce relevant research on poplars and erosion control. |
| GDC | Recently commissioned some small Envirolink projects and do get involved, usually on an in-kind contribution basis, mostly with Landcare research and AgResearch projects. |
| HBRC | No systematic monitoring of erosion in the region. Has been addressed through the Regional Land Monitoring Strategy compiled in 2006, in which erosion monitoring was to be initiated within the 2006–2011 period. Currently awaiting up-to-date satellite imagery from the whole-of-government tender which will be used to undertake a systematic assessment of the state of erosion throughout the region. For research, dependent largely on outputs of national research. |
| Horizons | Work within the Environmental Management Group (GEM) is based on monitoring the implementation of the Whole Farm Plan (WFP) programme. Trialling a system to map land use in relation to land use capability on-farm which is consistent with one proposed in an Envirolink report (by Grant Douglas). Builds on the detailed LUC map data for each farm using additional, slightly more quantified Land Resource Inventory (LRI) erosion inventory factors to back up field assessments of land priority and recommended land use.<br>Assessment of cover in relation to the priority land is also being trialled. The information required to do this assessment could by used to rank the amounts of sediment or nutrients leaving land unit. The system is to be used to map and report progress and also to feed into downstream sediment models that will feed on our State of the Environments (SOE) clarity and turbidity data. Currently available maps are not accurate at farm scale, but average calculations (accurate at regional scale) are already being presented at farm scale. This has high potential to create unrealistic expectations.<br><br>Other research and investigations:<br>- LUC Handbook upgrade |

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| | - Sednet modelling work<br>- Best Practice phosphorus project – the context of erosion contribution to supply of phosphorus in waterbodies and gains that can be made through treating erosion.<br>- Support for Sustainable Farming Fund (SFF) application for trees on farms<br>- Support for Hill Country Erosion Fund (HCEF) application for poplar and willow research<br>Mostly funded through application to Envirolink and Sustainable Farming Fund. |
| GWRC | Recently compiled a summary of the 2004 Soil Intactness report (by Doug Hicks). |
| Marlborough | Currently little work being done except for the dry lower hill country around Seddon/Ward where drought and pastoral farming practices have exacerbated erosion on loessial soils. The Starborough/Flaxbourne Landcare Group have looked at a range of factors affecting farming in this area, including climate, soils, vegetation, farm systems etc. Involves trial plots, focus farms, workshops and field days. |
| ECan | Vegetation monitoring by ground surveys and satellite image analysis.<br>Review of earthworks and vegetation clearance activities in the Canterbury Region and the susceptibility of soils to erosion from such activities. |
| Otago | Establishing a hazards database which will include sites which may be prone to erosion. |
| Southland | No |
| *Central government* | |
| MfE | In the process of revising report 'Climate Change Effects and Impacts Assessment' to incorporate the most recent climate projections. The LUCAS programme (Land Use and Carbon Analysis System) plans to investigate aspects of hill country erosion in areas of planted forest and pasture land use to determine best how to model and estimate carbon stocks (and stock change) in areas susceptible to erosion. |
| MAF | Three current projects:<br>- Costs of erosion and benefits of mitigation (contracted to Ensis)<br>- Release of NZeem® and landslide risk model to regional councils (contracted to Landcare Research)<br>- Development of a decision support system for evaluating the effects of wide-spaced trees for soil conservation (contracted to Landcare Research) |
| *Industry* | |
| Federated Farmers | No |
| NZ Forest Owners Association | Not as an organisation but individual companies periodically commission research as relevant to their own operations. |

*What capability do you have for research into hill country erosion processes and management?*

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| *Regional Councils* | |
| Northland | None |
| ARC | Limited capability |
| EW | Limited capability. Some investigations and State of Environment monitoring. |
| EBOP | Have qualified staff but also out-source work. |
| Taranaki | Limited |
| GDC | We have a strong science capability but no research capability. |
| HBRC | This Council (as do many regional councils) does not have the financial capability for the kind of research needed on this topic , primarily because it falls through the gap between the more expensive nationally applicable (and hence nationally funded) research, and the smaller-scale, more affordable regionally specific research. Envirolink has been an excellent mechanism for increasing funding of the latter through the small and medium advice grants. However, the multi-RC ‘Tools’ fund in Envirolink that provides bigger chunks of money is still in effect restricted by criteria relating to 'national applicability' (i.e. beyond one particular region where the research may be done). Research on erosion processes is expensive by nature, and this expense is compounded by the different processes at play in different catchment/land types – New Zealand's landscapes are far too diverse to expect any research to be 'nationally applicable'. Funding mechanisms are urgently needed in this country to address some of the more expensive regionally specific research. |
| Horizons | Science and land teams have skills and practical knowledge in erosion and erosion processes but are not actively involved in research. These teams are linked to academic research in terms of developing the information needed for better hill country management. |
| GWRC | Very limited capacity, but have a strong willingness to support research. |
| Marlborough | Little capability |
| ECan | Limited |
| Otago | Our funding capability for any research is very limited as hill country erosion is not a major issue. |
| Southland | No |

*Industry*

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| Fed Farmers | No |
| NZFOA | No |
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| Central government | |
| MAF | No |
| MfE | No |

*Do you have a view on research and information gaps that are needed to underpin long term solutions to hill country erosion?*

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| *Regional Councils* | |
| Northland | If we are to introduce rules for hill country land use, rules which may be perceived as reducing a landowner's land rights, we will need more hard science as to cause and effect of accelerated soil erosion and increased sediment transport. We will need to be able to quantify, in volumes and in dollars, just how much soil is being lost from land, where it is going and how much production/dollars are being lost compared with the total costs of reducing those losses. This will need to be scientifically robust to withstand scrutiny before the Environment Court. It will also need to be locally generated or at least calibrated as we will be challenged farm by farm rather than on matters of principle. |
| ARC | Regional based data and research is required.<br>Regional erosion rates – induced (farm tracks, over grazing etc.) vs natural (soil slip, riparian etc.) and an assessment of what are acceptable rates/thresholds – for example, if we wanted to have a target to reduce hill country erosion what do we compare it too (what is reasonable) and how do we account for natural event amounts?<br>How much natural erosion could we expect from hill country. Is there a soil/geology/slope/soil moisture/rainfall/land use risk and scenario tool that could be used in catchment planning?<br>Sediment source rates from land use types – intensive/extensive pastoral/forestry and during deforestation/native/scrub? Would be useful to help prioritise areas that require soil conservation management.<br>National review of what indicators are working for monitoring erosion on hill country, there was a lot of work in late '90s developing indicators and many regional councils said they were going to do. Did they work? |

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| | How effective were the indicators? Other methods in use since 1997? Cost-effectiveness? The usefulness to inform policy and planning?<br>At a regional level, the effects of climate change on rainfall intensity and implications for increased erosion and sedimentation of receiving waters.<br>A tool box (or forum) of techniques or examples of where communities have been engaged to respond to catchment-based initiatives. What worked, what didn't and why? Processes and techniques used. Results obtained?<br>The mix of planted native species that works best to most efficiently control erosion long term. Soil-binding ability, carbon sequestration rates, species mix for different topographies and growth rates. |
| EW | What options, other than pest control, do we have for erosion management in native forested areas?<br>The links and relative contributions of erosion types and sediment delivery from the land to the sea.<br>What is the cost of erosion at farm and regional scale? What is the value of soil conservation?<br>Especially with reference to forestry in the Coromandel, how does sediment move through the system (landscape), connectivity, the lags, transfer, storage and the relative contributions of different erosion types? Also, can we separate the land use acceleration of erosion from the event driven 'natural' erosion?<br>Can we predict or categorise the landscape according to what erosion may occur where? Using this, develop appropriate soil conservation/management options. The first bit for regional planning. A toolbox approach for the second point could help with our farm planning. |
| EBOP | Most information that is needed is available, but the process of transferring and training staff, farmers, agricultural professionals on what will practically achieve change is missing.<br>Also need information about the root dynamics of alternative tree species, the co-benefits of erosion control and carbon storage, the effect of cattle grazing density on sward density and sediment runoff, and the positive benefits of sustainable hill country land use. |
| Taranaki | We do not have any need for research into hill country erosion processes as this has been covered comprehensively in Taranaki.<br>The reinstatement of an adequately funded willow and poplar breeding programme and associated applied research (as outlined in the annual report to the Willow and Poplar Research Collective by Ian McIvor, 2007) is essential to underpin long-term solutions to hill country erosion.<br>Software models that compare pastoral farming and carbon farming under PFSI should be developed so that |

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| | alternative land-use changes can be made based on economics. |
| GDC | Need more research on types of trees that will arrest and prevent soil erosion, and their management requirements out to and including the long term.<br>We also need better information on induced sedimentation effects within the marine environment. |
| HBRC | Greatest need is to develop field-validated, catchment-specific (i.e. regionally specific) models to quantify spatial and temporal movement of sediment – not only from sources (such as slips) but also storage and timescales of movement in the landscape (e.g. toe of slips) and through river systems (e.g. banks, pools, floodplains) to the ocean, including particle size as an element of the models (as particle size relates to different kinds of downstream effects, such as water clarity, deposition, etc.). This is needed for the following reasons/outputs:<br>- identify relative contributions from different sources (at farm scale as well as catchment scale), so RC's can prioritise effort<br>- estimate timescales for mobilised sediment to work its way through the system (temporary landscape sinks, suspension/deposition within aquatic systems) so RC's can set realistic targets for improvement when directing effort at stabilising primary erosion sources<br>- scenario testing capability, so RC's can test the above & develop effective policy & target implementation to minimise erosion<br>- until recent years, the uptake of erosion control assistance (technical advice + financial) by landowners from HBRC was not fully utilised. Now that demand is starting to exceed Council's allocated resources for assistance, there is an emerging need to prioritise, so we need to develop the capability (information & tools) to be able to do so.<br><br>Research needs to be regionally applicable and property specific. |
| Horizons | A lot of good science has already been done and our current interest is in making land-use change happen. There is a need for better understanding and acceptance of the need for change by landowners.<br><br>Some specific areas for more research/information include:<br>- accurate carbon models for carbon accounting able to be used by our staff<br>- ability to further investigate the link between farm sediment sources and their impact on downstream (ecosystems and channel capacity). This has been started but needs a better whole-catchment approach |

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| | - improvements in productivity and LUC productivity tables. |
| GWRC | Poplar and willow breeding programme needs to be resurrected.<br>Need to take advantage of the climate change programmes and look for opportunities to integrate hill country planting programmes.<br>Search for other agroforestry options in hill country. |
| Marlborough | |
| ECan | Development of standards for land-use activities to minimise erosion risk.<br>Investigating the effectiveness of deep-rooted species for stabilising soils on soft-rock and loess-covered land.<br>Improving our understanding of the vulnerability of soils to erosion, the significance of long-term erosion losses (productivity, stability, soil quality factors), to what extent are current management practices affecting this vulnerability, wilding tree management. |
| Otago | No |
| Southland | Have some concerns about the increasing intensification of lower hill country for dairy runoff. This results in the cultivation of slopes up to 20º+ for winter feed crops (brassicas). The resultant 100% bare ground, which is usually severely pugged, is prone to severe sheet and rill erosion given the right climatic events.<br>Information on mitigation techniques – grassed waterways, contour ploughing, strip cropping etc. – could be useful. |
| *Industry* | |
| Federated Farmers | In submissions to regional plans have argued that policy and regulation development should be based on good science and that there remains difficulty in quantifying the causes of erosion and the effects of specific farm practices. |
| NZFOA | Forest Owners Association Environment Committee views:<br>- noted the considerable loss of capability and organisations (e.g. TGMLI, Water & Soil Division of MWD, and NWASCO) for erosion research over past decades and dispersal of information sources (e.g. reports and databases)<br>- would like to see more research into establishing the economic costs of erosion<br>- want mechanisms to enable due recognition of the beneficial role of forest plantations in erosion prevention and equitable treatment in the regulation of erosion under hill country forest management<br>- feel that the focus should be on the mitigation of erosion losses from pastoral land uses rather than on the re-examination of losses from plantation forests |

# Appendix 4 – Responses received from universities and CRIs

*Are you currently carrying out any investigations or research into hill country erosion?*

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| University of Waikato | One study looking at hill country erosion in Coromandel as part of a multiple comparison of pastoral, native and exotic forest land uses. Using sediment fingerprinting technique (being validated with radionuclide tracing and stream gauging) as well as some modelling of the catchment to determine the relative contributions of sediment from the three land-use types into Whangapoua Harbour. PhD student with funding, supervision and technical assistance from within the Earth Sciences Department. |
| Massey University | Tarndale Slip on going study of slope–channel coupling at Mangatu (detailed process study of sediment generation, storage and delivery from Tarndale slip), one year's funding for laser scanning ($18k). One staff member in collaboration with LCR and GNS.<br>Slope–channel linkages following Feb. 2004 storm in the Manawatu. MSc student defaulted. Trying to recover information. No funding |
| Victoria University of Wellington | Investigating temporal changes in offslope sediment delivery associated with landsliding. Decrease in sediment delivery ratio with increase in catchment size is a recognised phenomenon, with well-understood reasons (essentially, increased storage availability). It is also well understood that considerable variation in delivery at local scales is to be expected, contingent on a range of event-related factors, including frequency/magnitude, which influences the extent of slope–channel coupling. Coupling is also influenced by the location of individual landslides, and there is evidence to indicate that locations change through time in non-random ways, such that mean distances from channels can be hypothesised to increase, with a decrease over time in the degree of coupling. If this is true, then SDR might decrease through time in a similar fashion as it does in space. Working on this in the Waipaoa (with Katie Jones, MSc candidate) as part of GNS FRST-funded 'Margins' programme.<br><br>Role of erosion within terrestrial carbon cycle. Based at Tutira, where lake cores (lake is efficient sediment trap) and coring of valley floors provide an opportunity to refine the |

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| | historical sediment budget (i.e. since human disturbance). Most relevant is effect on short-term cycle: is colluvial/alluvial storage of sufficient magnitude to operate as short-term carbon sink, storing more C than the undisturbed soil organic C store? Effect on longer-term cycle is also a consideration: does erosion enhance the rate at which C is fixed from the atmosphere in bedrock weathering? |
| University of Canterbury | Some research in the Waipaoa as part of GNS FRST-funded 'Margins' programme on the role of large landslides in sediment generation. |
| Ensis | Costs of erosion and benefits of mitigation (MAF contract). Research aims to improve understanding of the costs of hill country erosion and the benefits of its mitigation in New Zealand, with a view to improved prioritisation and evaluation of future remedial actions. $60k this year.<br><br>FRST programme ‘Protecting & enhancing the environment through forestry’. The interactions between harvesting and other silvicultural impacts, riparian vegetation and aquatic health – both within and downstream of the forest – are investigated in an objective titled ‘Aquatic environmental quality’. This objective provides improved understanding of factors controlling the cumulative influences on aquatic environmental quality of managed planted forests. Key areas are: the magnitude and duration of effects of harvesting and related forestry activities on sediment generation and movement, woody debris, riparian vegetation, water quality, stream habitat and biota. This research will improve our understanding of how managed planted forests may affect aquatic environmental quality over time and particularly looks at forests in the context of a neighbour to other land uses.<br><br>Carbon stocks and change in New Zealand’s soils and forests (MAF contract). A component of the proposed work involves quantifying the net effect that rates of erosion, and soil recovery on erosion scars, have on national soil carbon stocks – including identification of likely anthropogenic and non-anthropogenic components, and mitigation opportunities.<br><br>Numerical modelling. Exploration of the potential for using finite element analysis and computational fluid dynamics modelling approaches for determining erosion risk and predicting |

the effects different forest planting designs.

GNS

As part of GEONET, GNS Science maintains a national rapid-response capability for landslides. The aim is to have team members mobilised within 24 hours of a major event to assess the hazard and provide advice to maximise public safety, and to collect landslide information. Although the focus is on the landslide hazard, information collected can be of value for management of hill country erosion.

GEONET funding is also used for compiling a landslide database for New Zealand. The database comprises:

i) an inventory of landslides and their attributes (location, type, cause, trigger, magnitude etc.)

ii) a catalogue of significant landslides since 1996 (date, location, size, damage etc.) This database is still being developed and continually added to.

GEONET funding for both the response/monitoring and database aspects is c.$200–250k/year.

Processes using pre- and post-event satellite imagery are being developed within the FRST-funded 'Immediate Surveillance and Damage Assessment following Natural Disasters' programme, to rapidly and accurately record the locations and size of landslides and other erosion after storms and earthquakes. This will become an operational tool to enhance GEONET rapid-response capability.

'Geological Hazards and Society' programme carries out research following unforeseen natural physical hazard events, including landslides (c.$350k/yr). It is anticipated that an annual average of c.$150k/yr of this money will continue to be used to fund research on erosion following storm events, although this may vary substantially on a yearly basis, based on the nature and frequency of hazard events (earthquakes, volcanic events, tsunamis, landslides). Studies of such storm events collect data necessary to help identify controls and quantify erosion impacts for the range of erodible New Zealand landscapes (e.g. Erosion Terrains). Social impacts of these events are also studied.

A further $450k/yr is allocated in the 'Geological Hazards and Society' programme for geological and geotechnical studies of the factors that initiate landslides, including rock mass characterisation. Particular focus has been on large deep-seated landslides, but debris flow events will in future be an important component of research. Aspects of social research will also be funded from this programme.

Subcontract with NIWA in their FRST-funded ‘Reducing the Impacts of Weather-related Hazards’ programme, to develop landslide–rainfall relationships and triggering thresholds for a national landslide forecasting model ($50k/yr). These data are being collected through GEONET and research funding.

GNS Science and Landcare Research have jointly funded a ‘Bibliography of Rainfall-Induced Landslide Studies in New Zealand’. This bibliography provides access to information necessary for the development of rainfall-induced landslide forecast models.

New FRST-funded programme ‘MARGINS Source-to-Sink’ ($450k/yr) will develop quantitative understanding of how landscapes respond to global environmental change and human interventions. As part of this programme, the role large, deep-seated landslides play in landscape evolution, their magnitude, frequency, controls and triggers, and contribution to sediment yields are being investigated. Programme will fund a PhD thesis on this topic and an MSc thesis will investigate hillslope–channel connectivity of shallow landslides under pasture and forest. Quantitative models will be developed to forecast landscape response to tectonic-, climatic- and human-induced change; four-year programme, with funding of landslide research likely to vary between c.$100–200k/year, but the programme as a whole contributes to hill country erosion issues.

In December 2007 the ‘Guidelines for assessing planning policy and consent requirements for landslide-prone land’ were produced (Saunders & Glassey 2007). While these guidelines are primarily for development in urban areas, they are also applicable for developments in rural areas.

Investigations for resource consent work for subdivisions (rural, rural lifestyle or urban).

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| | Erosion research carried out by GNS Science is focused on landslides as hazards and the risk they pose to infrastructure and communities, rather than the impact they have on sustainable land use and natural resources. Nevertheless this research has relevance to sustainable management. |
| NIWA | Landslide hazard assessment for New Plymouth District (NIWA 2007) including potential impacts of climate change. Modelling study to calculate return intervals of landslide-triggering rainfall event thresholds for different seasons. This included a field assessment of geotechnical soil strength in the study area. A prototype of a real-time landslide forecasting system has been developed based on a coarse assessment of geotechnical parameters for the North Island.<br><br>Modelling erosion processes and delivery to the estuary in the catchment of Raglan Harbour (in FRST programmes 'Land Use Intensification: Sustainable Management of Water Quantity and Quality' and 'Effects-based Protection and Management of Aquatic Ecosystems'). About $350k/yr of these programmes (combined) is related to catchment sediment generation and delivery to the estuary in the current year. This work is conducted in collaboration with Landcare Research, which has a $165k/yr subcontract. These programmes are aimed at protection of the aquatic environment, rather than protection of productive land. This work involves several strands:<br>- instrumentation of a steep hillslope to measure subsurface moisture response to rainfall, complemented with detailed SHETRAN modelling of water movement and landslide initiation.<br>- application of the detailed physically based model SHETRAN to prediction of sediment generation, including a landslide component. Comparison of results with measurements down the stream network in a moderate storm.<br>- development of management-oriented catchment model to predict sediment sources and delivery to estuaries. This model is at the early prototype stage.<br>- national-scale models of mean annual sediment load in streams, for inclusion into the CLUES framework, using the Sparrow regional regression model. This builds on previous methods by Hicks et al. (1996), and complements the NZEEM® model.<br>- compound-specific isotope tracer methods for identification of sediment sources. Complementary tracer work is being conducted by Landcare Research. |

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| | In the FRST 'Restoration of Aquatic Ecosystems Programme', measuring response of land management changes at Whatawhata in terms of stream sediment yield/turbidity (and other water quality parameters) and recording landslide erosion in response to major rain events. Approximately $30k/yr. |
| | Compound-specific isotope tracer methods for establishing erosion sources to estuaries – application at Whangapoua, Mahurangi and Whangamata and Raglan. |
| Landcare Research | Landcare Research component of the Raglan Fine Sediment Study aimed at developing the capability to predict the generation, transfer, dispersal and transformations of fine sediment throughout a catchment in a single event. Linking catchment model (SHETRAN) with stream transport model (RICOM) and estuary transport and dispersal model (DHI). Landcare Research has developed a landslide model component for SHETRAN and is providing field support for landslide and bank erosion studies. Subcontract to FRST-funded NIWA programme ($165k/yr). |
| | Identification of sources of sediment getting in to Raglan Harbour using sediment fingerprinting methods, utilising geochemistry, radionuclides and compound-specific isotopes (Capability Funded $80k this year, involves collaboration with NIWA for CSI work). |
| | Building knowledge base of below-ground characteristics of native plants through a field trial. Extends previous trial of colonisers and to include podocarps, and some non-woody species (flax, toitoi, *Carex*). Year four of a five-year trial ($90k/yr). |
| | Determining the amount of sediment coming from newly constructed forest roads and the connectivity to the drainage network; the effectiveness of riparian buffers in mitigating sediment. Subcontract to FRST-funded Ensis programme ($90k/yr). |
| | Investigation and modelling (of area–volume relationships) of gullies in the East Coast; development of understanding of gully erosion processes (mobilisation, storage and delivery of sediment); investigating the contribution of gully erosion and sediment storage to the long-term |

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| | sediment budget of the Waipaoa River; establishment of relationships between changes in gully size and vegetation change, and between gully distribution and geology (FRST-funded by transition funding).<br><br>Effect of landsliding on pasture productivity in hill country; development of erosion modelling capability with NZEEM® and SedNet (SLURI-funded $130k/yr).<br><br>Release of NZeem® and landslide risk model to regional councils (MAF Policy contract $65k)<br><br>Design of monitoring tools and methods for reporting on whole-farm plans as a tool for affecting land use change<br><br>Development of a decision support system for evaluating the effects of wide-spaced trees for soil conservation (MAF Policy contract $54k). Collaborative with AgResearch, and HortResearch. |
| AgResearch | FRST-funded Sustainable Land Use Research Initiative (SLURI) programme (collaborative with HortResearch):<br>- root growth and distribution of spaced poplar trees on erodible slopes at AgResearch's Ballantrae Hill Country Research Station.<br>- effect of management on poplar root growth and development, and implications for soil stability.<br>- effectiveness of spaced trees for reducing erosion in Manawatu/Rangitikei and Wairarapa following recent storms.<br><br>Monitoring and reporting of whole-farm plans as a tool for affecting land use change, using a simple model that links vegetation type/land use at the farm scale with sediment export off-farm. Funded by Envirolink (collaborative with Landcare Research and HortResearch) with in-kind contributions from Horizons (initiated project), Hawke's Bay, Greater Wellington, and Taranaki regional councils. |

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| | Development of a whole-farm-plan template and protocols for developing and implementing the plans for Horizons Regional Council as part of the Sustainable Land Use Initiative (SLUI).<br><br>Development of a farm-scale risk-optimisation model (FSRM) to evaluate farming options that a farmer can use to trade off financial and environmental risks at the whole-farm level. Enterprise options available to pastoral farmers include livestock production, cropping, plantation forestry, native bush, and riparian management activities. |
| HortResearch | Poplar and Willow Breeding Programme currently runs on c. $50k/yr provided by member regional councils through annual subscriptions to the Willow and Poplar Research Collective and supports a scientist at 0.2 FTE. Data are not being collected from field trials except for a nationwide *P. maximowiczii* × *P.nigra* trial established in 1999–2001 from material bred in 1993. Some experimental tree willow and poplar material bred between 1998 and 2003 is being trialled in nurseries in Masterton, Motueka and Clyde, and selections from this nursery trial material were planted out in a field trial on farmland by staff from HBRC in 2007.<br><br>As an outcome of the 1999–2001 trial four new *P. maximowiczii* × *P.nigra* poplar clones are being bulked up at selected regional council nurseries and should be available commercially in limited numbers in 2009–10. Results of the 1999–2001 *P. maximowiczii* × *P.nigra* trial were reported to WPRC members in October 2007 (McIvor 2007). Since funding is supplied by WPRC, P&W breeding is considered a commercial contract and WPRC members have first call on new material.<br><br>For older trials, records of the location, establishment date, reason for the trial, and the clones planted are still held at HortResearch, and probably at the appropriate regional council office. There were in excess of 100 trials established testing performance under different climate regimes, ease of establishment, relative performance of different clones, different densities of planting. Some trials were established in the expectation they would be useful for future research. Current research on root development at Ballantrae is benefiting from this foresight. Survival of trial material for most of the trials is unknown. |

The formation of the FRST-funded SLURI programme has provided an opportunity to proceed with new research on poplar root development on hill slopes at AgResearch's 'Ballantrae' research farm near Woodville. Veronese poplar trees at different ages and at different positions up a slope have been excavated to study root distribution and development. Theme 3 includes a project evaluating the effectiveness of conservation trees in preventing soil erosion on pastoral hill slopes in Manawatu and Wairarapa using field measurements. The methodology identified groups of space-planted trees in slip-prone locations from aerial photos taken following the 2004 floods (Manawatu) and the 2006 storm (Wairarapa), visiting the sites, measuring the topography (aspect, slope), assembling tree data (spacing between trees, dbh, height, and crown spread) and erosion (area of fresh slip scars on sites with trees, area of slips on pastoral land from aerial photos). Sixty-five sites were measured. DM productivity of slips of known age last measured in 1984 at Te Awhanga station in the Wairarapa is being remeasured to add to the data set collected around 1980, together with that of slips which occurred since 1981.

Erosion prevention is a significant work programme in the SLURI research programme being renegotiated with FRST from 2008 to 2017, being half of one of the three objectives being proposed. This research will aim to develop new understanding of the processes that confer structural intactness and resilience on New Zealand's soils, so that their porous functioning, health and resilience is enhanced, and they provide the water regulation and productive services we require of them. The research will be focused on tree–pasture systems using managed poplars, and in another objective will value the productivity gains generated through erosion prevention. Tree management will use pollarding as a tool since this has been proposed to farmers to control tree size, provide a fodder option, and minimise the impact of shading on pasture production.

*What capability do you have for research into hill country erosion processes and management?*

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| University of Auckland | |
| University of Waikato | One PhD student. Other expertise in engineering geology, hydrology, soil chemistry, and soil nutrients. The Earth and Ocean Sciences Department at Waikato has a long history of work in |

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| | hill country erosion and related issues of sedimentation in receiving environments. |
| Massey University | One staff member investigating slope–channel coupling processes and impact of large climatic events. |
| Victoria University of Wellington | Two staff with specific interests and background in hill country erosion, mostly related to landslides. |
| University of Canterbury | Two staff with expertise in landslide processes and hazard assessment. |
| Ensis | Scion currently has relevant capability in soil and landscape processes (6 staff), landscape modelling and remote sensing (7 staff), silvicultural management for erosion mitigation (2 staff), natural resource economics (2 staff), social sciences (2 staff). |
| GNS | GNS Science employs nine staff to undertake erosion research, principally for hazard assessment and management. The team comprises engineering geologists, geotechnical engineers, and geomorphologists. Main areas of expertise are magnitude, frequency and distribution of landslides, landslides types and behaviours, failure processes, stability of landslide-affected slopes and deposit material, sediment budgets, and hazards and risk assessment.<br><br>GIS and remote sensing specialists and landscape modellers also contribute to this research.<br><br>Planners and social scientists also contribute to erosion research through collaborative research with stakeholders into hazard management and response and recovery from hazard events, research into social, economic and environmental impacts of hazard events, and policy and planning research for hazards including landslide hazards. |
| NIWA | Have a large number of staff with interests in impacts of hill country erosion on receiving waters. Three staff with specific expertise in catchment processes and modelling. |
| Landcare Research | Six staff in an Erosion and Sediment Processes group, four staff with backgrounds in soil mechanics, plant performance and erosion processes, five staff with backgrounds in remote sensing and modelling. Expertise in erosion process understanding and measurement, landslide modelling, effect of tree roots on slope stability (field experimentation and modelling), and field experimentation. Supported by a number of significant databases (including NZ Land Resource Inventory, National Soils Database, LENZ, erosion terrains, a wide range of aerial photography |

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| | and satellite imagery). Three staff with experience in collaborative learning and adaptive management. |
| AgResearch | Two staff working on hill country erosion issues with expertise in tree–pasture interactions, root development, exotic and native plant establishment and management, revegetation of eroded sites with herbaceous, shrub and tree species, farm plan development and assessment, scenario visualisation and modelling nutrient movement on farms and in catchments.<br><br>An additional five staff with similar capability, and 15 staff working in a social research team with expertise in assessing environmental, social and economic impacts of land use change and change adoption. |
| HortResearch | One person working on plant performance and one additional person with expertise in tree performance on slopes. One person with expertise in field instrumentation. |

*Do you have a view on research and information gaps that are needed to underpin long-term solutions to hill country erosion?*

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| University of Waikato | Slope channel linkages, relationships between sediment generation processes, sediment storage and sediment delivery in events of different sizes.<br><br>Lack of long-term monitoring of erosion and sediment delivery. Needs a more integrated approach to generation, storage and delivery.<br><br>Encroachment of dairy farming, and dairy heifer grazing, onto the hill country and the higher level of surface soil damage that the heavier animals cause, compared to sheep. Also the effects of cattle compared to sheep grazing on erosion in hill country. |
| Massey University | Slope–channel coupling (i.e. unravelling the linkages between generation, storage and delivery of sediment across a range of scales and event magnitudes). |
| Victoria University of Wellington | Landsliding as a landforming phenomenon and a hazard. Determining the degree to which landscapes have evolved in terms of responding to the major deforestation disturbance, and |

hence their 'erosion status'.

Connectivity between hillslopes and channels, and the contribution of hill country erosion to fluvial sediment budgets (and what this implies about nutrient, contaminant and carbon fluxes), especially over longer time scales (i.e. attenuation of sediment transport).

Carbon budgets. Is it reasonable to assume that hill country erosion has a negative impact? Is storage of organic carbon in colluvial or alluvial sinks greater than in undisturbed hill country soils?

Impact and magnitude of Multiple Occurrence Regional landslide events. What is impact magnitude and what parameters should be used to assess impact magnitude, and how to get standard measurements of these for event comparison.

Considering the landscape (spatial) and centuries–millennia (temporal) scales. Sure, we understand physical mechanisms and much of what is necessary for on-site mitigation/remediation. We don't have such a good basis for directing mitigation/remediation. We understand at a qualitative level the role that hill country erosion plays in the broader landscape, but we don't have the quantification to go with it. Perhaps most importantly, we don't yet have a handle on response times or where our eroding landscapes are in an evolutionary trajectory. How advanced is the response to the major landscape transformation that deforestation and land use change represents? How widely distributed in space are those responses (how far have the sediment slugs moved)? How much longer will those responses continue? Are there parts of the landscape that are approaching internal thresholds (sensu Schumm) between aggradation and degradation? Has there been (or will there be) a shift from primary sources (hillslopes) of sediment in fluvial systems to secondary sources (reworking of sediment temporarily stored within the fluvial system)? What are those thresholds? How can we identify those sensitive locations? Can we develop geoindicators? Given these questions, are we able to reliably infer up- or down-system consequences of land use choices?

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| Ensis | Future research should build on the huge body of knowledge already in existence and be focused on achieving optimal land use patterns and the implementation of remedial actions. |
| | Technology transfer mechanisms (including retrieval mechanisms and capability to process and interpret the information) are required to allow improved end-user access to the body of existing knowledge. |
| | More work focused on quantifying the biological productivity impacts and economic costs of erosion and benefits of its prevention and mitigation in at-risk regions. |
| | Further research into the design and nature of future forests as a tool for erosion prevention and mitigation. Increased investment for developing capability in erosion prevention and land use optimisation research aligned with the forestry industry. |
| GNS | High quality data on landslide locations and age on a national basis, and development of a storm damage archive. Records of spatial and temporal distribution of erosion are vital to identify patterns and trends, and to provide quantitative data on damage to support research funding. |
| | Magnitude/frequency of events. Better magnitude/frequency records are needed to improve understanding of what constitute large-magnitude events, and to plan for them. There is a level of public confusion and cynicism surrounding regular use of the term ‘one in a hundred year event’, making planning and decision making difficult. |
| | Landslide initiation thresholds. Necessary to develop models for landslide forecasting. |
| | Sediment delivery/hillslope-channel connectivity. Historically New Zealand research has focused on sediment generation from hillslopes. With increasing intensification of floodplain land use and infrastructure development, it is important that the cumulative downstream impact of sediment and its sources are identified. |
| | Contribution of large landslides to sediment yields, and their role as hazards. Large, deep-seated |

landslides are a feature of many of our landscapes. The magnitude and frequency of occurrence is unknown and yet their contribution to long-term sediment yield, effect on landscape function and potential for damage may be large.

Effectiveness of soil conservation works for a range of storm magnitudes. More quantification is necessary to justify soil conservation expenditure and to calculate ‘area for benefit’.

Integrate land management with flood channel dynamics. The effect of land use and changing sediment supply on river morphology and behaviour is poorly understood, and yet necessary for river and floodplain management.

Ecological impacts of sediment on riverine and marine environments. What are the impacts of both elevated and sustained levels of sediment, and also large occasional inputs of sediment, on biological communities in rivers, lakes and the ocean? What is their ability to recover?

Effects of soil erosion on soil carbon and nutrient fluxes. As part of New Zealand’s commitment to the Kyoto Protocol and other international initiatives to reduce greenhouse gas emissions we need to continually improve our knowledge of the role erosion plays in the New Zealand carbon budget, both in terms of the physical transfer of soil carbon by erosion, and the biogeochemical transformations that soil carbon undergoes during transport and storage.

Impacts of lifestyle subdivisions in the rural environment – sediment generation and hazards. The increasing trend of lifestyle subdivisions introduces a new land use and new impacts on the rural environment – either increasing sediment generation (altered drainage, slope modification), or reducing sediment generation (planting trees and other woody vegetation). Lifestyle subdivisions in hill country environments can also be subject to an increased erosion risk.

Erosion models. Numerical models that integrate our knowledge of erosion to forecast landscape impacts and responses to natural and human-induced changes are necessary at the catchment, regional and national scale, for land management and policy formulation, and for emergency management. Models can also be used in the assessment of risk to communities and infrastructure.

Community perceptions of acceptable risk and damage versus acceptable costs to mitigate or avoid them. What size of event is it technically and economically practical to mitigate against? This information is required before society can debate how much it is prepared to pay to mitigate damage and what level of damage it is prepared to accept.

Barriers to land use change on highly erodible land. More studies are required to quantify costs associated with inappropriate land use:

Cost–benefit analysis for land use change based around estimations of:
– erosion damage and including short-, medium- and long-term analysis of various land use options
– cumulative costs to New Zealand's productive capacity through soil loss (longitudinal study), analysis of insurance claims trends for losses on highly erodible land

NIWA

Linking catchment erosion status, and its relationship to land management, with information on the sensitivity of downstream receiving waters (including consideration of flooding downstream, stream aggradation, and effects on biota in streams, estuaries and coastal areas) at regional and national scales. CLUES and NZEEM® modelling are starting to provide estimates of sediment loads, but these are not linked to effects in the downstream receiving water bodies.

Holistic, long-term understanding of erosion at key focal sites. New Zealand lacks an infrastructure of long-term integrated research sites where the combined skills of all relevant CRIs and universities can be drawn together to conduct studies that address the big issues at appropriate spatial and temporal scales.

Validated quantitative predictions of landslide hazard and runout in response to rainfall events of different magnitude, at a national level. Required for a better quantification of spatial variability of geotechnical soil parameters, as well as a better understanding of landslide processes in different environments in New Zealand. More field studies on landslide initiation and runout are needed to support these predictions.

Generation of surface erosion depends on the processes and spatial patterns of runoff generation and interactions of surface runoff and rainfall. These processes are only poorly understood in New Zealand. A limited number of field studies do not provide enough empirical evidence to draw conclusions about the spatial pattern of surface erosion in New Zealand. More field experiments in different and similar environments are required to understand the different erosion mechanisms in different environments and to quantify the uncertainty in erosion modelling.

Quantification of bank erosion processes in relation to hill erosion; understanding of the role of landscape sinks/stores such as wetlands and small terraces in meditating between hillslope erosion and effects on receiving water bodies.

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| Landcare Research | Replicable and low-cost methods of sediment tracing and sediment budgeting to enable: |

- quantitative assessment of the relative contribution of different erosion processes (mass movement, sheetwash, bank erosion), spatial patterns of sediment contribution, and of land use impacts on sediment generation
- quantitative assessment of the effectiveness of the range of erosion control treatments
- analysis of the dynamics of generation, storage and remobilisation of sediment within catchments, including improved understanding of the cumulative impacts of erosion/sediment transfer over time and space
- better understanding of the linkages between sediment and its biological impact at larger catchment scales; most information is limited to reach-scale

To allow us to better identify, rank and prioritise erosion processes for remedial treatment.

Upgrade the national and/or regional erosion inventories using modern technology (the LRI is 30 years old!).

The impact of climate change on potential hill country erosion rates – linkage with climate models. Understanding inherent resilience of landscapes to climate change and how we can better match land resources to land use to ‘future proof’ landscapes. Understanding the role of erosion in both the mobilisation and recovery of carbon – improving estimates for more accurate C reporting.

Understand and quantify the biomechanics of erosion and its control:

- improve knowledge of the usefulness of different vegetative and bioengineering mitigation options (e.g. root tensile strength and growth rates of indigenous species, seasonality of root tensile strength, etc.)
- how to configure the placement of vegetation in managed landscapes to optimise (or maximise) a range of benefits, or alternatively minimise a range of effects
- management effects on vegetation-based mitigation – what is the best management regime to get optimum stability?
- effectiveness of riparian buffers in hill country for reducing sediment input into streams (e.g. how much to plant, where to plant?, what to plant?, role for reversion? will it make a difference to stream sediment yield?)
- quantitative information on the effectiveness of various erosion control treatment options (excluding forestry) including riparian strips, reversion and space planting
- prediction and cost–benefit analysis of different mitigation techniques, including the externalities and integration of environmental benefits of land use change/management (erosion, biodiversity, greenhouse gases, nutrients)

Analysis of, and ways to remove, the barriers (psychological, sociological, economic or productivity based) to erosion mitigation. How to get greater acceptance of the beneficial role of planting trees on eroding pastoral hill country to prevent existing erosion getting worse and/or as a means of future-proofing against the likely impacts of climate change. Other benefits such as shade reducing stock stress, trees for fodder, timber and profit, improved landscape aesthetics translating into farm desirability needs to be backed by research and vigorously promoted.

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| | Incorporation of improved process and mitigation understanding into predictive models of sediment generation, storage and transport to allow scenario analysis. Includes both detailed process-based models and simple knowledge-based decision support systems (as people realise that the detailed scientific stuff can't be used for real management). |
| | Quantifiable, consistent, repeatable and robust indicators, and associated monitoring techniques of erosion for SOE reporting. |
| AgResearch | Information on what vegetation types have and haven't worked well to control erosion, and quantification of some of the attributes of the vegetation (e.g. size/diameter, stand density, age, canopy cover). A lot is known, but description of the state of vegetation at different times is lacking, particularly for spaced trees in two-tier systems. |
| | Root architecture of trees used in two-tier systems, and how this changes over time. What are the relationships between canopy form and root architecture, and variation with age and position on slope? Implications for recommendations on spacing, and tree management over lifetime? |
| | Big trees are a huge problem in some two-tier systems, and this problem will get worse (e.g. at more locations as younger plantings approach maturity). What are the best ways to manage trees over their lifetime, and how do these affect their soil stabilising role? |
| | Issue of when to retire land/plant in forest versus continue livestock farming on vulnerable land with adequate spaced trees (scrub or trees). What are the current guidelines, how have criteria changed in the last decade, and how far can we go in protecting erodible landscapes with regulation? How can avid livestock farmers (e.g. family farm for 1–3 generations) be coaxed to change land use? |
| | In two-tier systems, poplar and willow have very important roles, and these will undoubtedly remain so. However, are there additional woody species that can be used as spaced plants which are longer lived than poplar and willow (e.g. last 150+ years), have optimum canopy shape (dwarf, narrow, permeable, etc.), and offer multiple uses in addition to soil stabilisation? |

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| | The main focus for future research should be in two-tier systems. We know quite a lot about the extremes in vegetation cover (pasture vs forestry (indigenous and exotic)), but relatively little about trees in two-tier systems except for poplar and *P. radiata*. |
| | Improved information on the quantitative links between vegetation cover type/management within cover types, (e.g. grazing pressure, stem density) and sediment delivery to 1st, 2nd & 3rd-order streams, at the sub-catchment/farm scale where change in cover is managed by farmers. |
| HortResearch | We know little of the economic gains through erosion management: retention of soil organic matter on site, economic benefits of shelter and shade, economic benefits of tree fodder in drought<br><br>There is a need for better knowledge around the effect of a two-tiered system on soil properties: soil moisture availability, soil physical integrity (macroporosity, aggregate structure, soil strength).<br><br>There is a need for better knowledge around sediment loss from farm tracks, stock crossings, pugging locations in hill country.<br><br>Better understanding of farmer attitudes towards proactive erosion prevention also. |