Economic costs of hill country erosion and benefits of mitigation in New Zealand: Review and recommendation of approach

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Haydon Jones[1], Peter Clough[2], Barbara Höck[1], and Chris Phillips[3]

[1]Scion (Forest Research Institute Ltd)
[2]New Zealand Institute of Economic Research Ltd
[3]Landcare Research Ltd

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Executive summary

The available literature relating to the economic costs of hill country soil erosion and the benefits of its control in New Zealand and overseas was reviewed and described. Based on the findings of the review, an economic approach to the assessment of the economic costs of erosion is recommended and an analytical framework for the prioritisation of erosion control tree planting was developed and described.

Key results

The key findings of the study were:

1. The impacts of hill country soil erosion and sedimentation have both on- and off-site implications in terms of economic costs such as productivity declines and increased incidence of downstream flooding damage,
2. Some of the component costs associated with hill country erosion are inherently difficult to disaggregate, quantify, and assess,
3. Tree planting can be an effective means of erosion control, and in some areas, radiata pine woodlot planting may be a relatively profitable alternative to pastoral grazing,
4. A cost-benefit analysis approach, with support from non-market valuation techniques, to the assessment of erosion costs is generally recommended, and
5. In order to identify the locations where erosion control would be most effective, it is recommended that economic value at risk be defined in a spatial sense and that this information be used in association with information on the physical susceptibility to erosion and sedimentation (an analytic framework for this was developed)

Application of results and further work

Further work could be undertaken to trial the implementation of the approach recommended and frameworks developed for prioritising, in a combined spatial and economic context, soil conservation plantings in hill country at a regional level in association with a regional council.

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1 General introduction

The storm and flood events that badly affected the lower North Island in February and August of 2004 are a recent and pertinent example of the very costly implications of storm events in regions of New Zealand with significant areas of hill country susceptible to soil erosion and downstream sedimentation. The economic cost of this event, taking into account the costs of structure and infrastructure repair, stock and crop losses, and on-going productivity loss, has been estimated to be about $157 million (MAF, 2008).

The implementation of more sustainable land use management practices in New Zealand's hill country will be vital if the economic costs of soil erosion and sedimentation are to be limited in the future. 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 released a request for proposals (RFP) in 2007 covering three complementary areas:

- Undertake a review 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 (Basher et al., 2008)
- Determine the effectiveness of wide-spaced trees (Phillips et al., 2008)
- Determine the costs and benefits of erosion control (this project)

SCION, in association with Landcare Research and NZIER, responded to the third RFP with a successful collaborative proposal.

2 Literature review and meta-analysis

Introduction

Estimating the economic costs of hill country erosion and benefits of erosion control is crucial for the promotion and implementation of sustainable land management practices and policies. Getting a handle on the value at risk from erosion, how that changes with different mitigation measures, and the value of that change compared to the cost of mitigation provides a means of identifying what measures are worthwhile and where they will deliver the greatest net benefit. This literature review provides an overview of the magnitude and effects of soil erosion in New Zealand, economic methods and approaches commonly reported in the literature, and available information on national economic costs.

Overview of hill-country erosion in New Zealand

Nature and severity of hill country erosion

Hill country is defined as all Class V, VI, VII and VIII land from the NZ Land Resource Inventory (NZLRI) with grade D slopes and above (i.e. slopes >15˚) and located below an altitude of 1,000 m above sea level (Ministry for the Environment, 2008). Under this definition, 37% (10 million hectares) of New Zealand's total land area is classified as hill country, with the majority (6.3 million hectares) located in the North Island (Basher et al., 2008).

The susceptibility of hill country landscapes to erosion is largely controlled by the underlying geology, topography, rate of tectonic uplift and climatic conditions. Basher et al. (2008) have identified 21 types of hill country, based on analysis of NZLRI physical data including rock type, and erosion type and severity. In the North Island, approximately 200,000 hectares of hill country has a mapped potential erosion severity of severe, very severe, or extreme. The worst affected areas are mainly located in the East Coast region, with smaller areas in inland Taranaki, Coromandel, and Northland. The geology of the hill country landforms on the East Coast and inland Taranaki is predominantly soft rock and crushed soft rock, whereas the hill country in the Coromandel and Northland has developed predominantly on deeply weathered sedimentary and igneous rocks. Mass movement is the most common form of erosion, particularly soil slip and earthflow erosion. Sheet and gully erosion is also common.

In the South Island, less than 103,000 hectares of hill country has a potential erosion severity ranking of severe, very severe, or extreme. There, the hill country most susceptible to erosion is the hard rock terrain through Otago, Canterbury, and Marlborough. Surface erosion types are the most common form of erosion in the South Island, particularly sheet erosion. Soil slip and gully erosion are the next most common erosion types, with gully erosion predominantly occurring on the soft rock terrain in Tasman.

The methodology used by Basher et al. (2008) to determine the susceptibility of hill country is suitable for use at the national or regional scale. Further refinement is required for use at catchment or farm scales. Dymond (2007) has developed a GIS-based model to estimate erosion rates and the effect of land use change and soil conservation measures from hill country farms in catchments across New Zealand. The model incorporates rock type, slope and vegetation information to determine areas susceptible to erosion (Dymond et al., 2006).

It should be noted that erosion is often confused with sediment yield. However, soil erosion is the first step in the sedimentation process that consists of erosion, transportation, and deposition of sediment. Only a fraction of eroded soil passes through a channel system and contributes to sediment yield. Some of it stays close to where it was eroded and some of it gets deposited in stream channels (sedimentation). The ratio of erosion to sediment yield is known as the sediment delivery ratio (SDR).

Drivers of erosion

The inter-relationship and spatial variability of the natural drivers of erosion (i.e. geology, topography, active tectonics, and climate) determine the susceptibility of the landscape to erosion (Blaschke et al., 1992; Basher et al., 2008). Natural rates of erosion in New Zealand are high by world standards – New Zealand makes up ~0.1% of the global land mass yet discharges 1-2% of average annual sediment yields to the ocean (Hicks, 1996). Erosion is exacerbated by anthropogenic activities such as deforestation, unsuitable land use for the terrain, and soil management practices (Lal, 2001).

Historical deforestation in New Zealand reduced forest cover from approximately 50% of land area in 1840 to 18% by 1920 (Roche, 1994; Glade, 1998). Deforestation and agricultural development was considered to be responsible for increased flooding and soil erosion throughout the country during the 1930's (Roche, 1994). Various studies have shown the strong relationship between forest removal and increased soil erosion on a regional basis in New Zealand: Glade (1998) reported an increase in rainfall-triggered landslides one to two decades after deforestation and a decrease in landslide occurrence after afforestation. Derose et al. (1993) assessed post-deforestation soil loss on Taranaki hill country, and estimated an average soil depletion rate of 1.8 ± 0.5 mm yr^{-1} compared to undisturbed sites. Losses occur on hill slopes steeper than 28° and are greatest on slopes exceeding 32°.

Historical farming practices, such as the burning off of tussock to encourage palatable regrowth, expansion of marginal lands and overstocking to increase production, and introduction of exotic plants and animals (e.g. rabbits, deer) resulted in obvious signs of land depletion and erosion during the 1920's and 1930's (Roche, 1994; Dregne, 1995). Regional soil and land utilisation surveys undertaken by the Department of Scientific and Industrial Research (DSIR) in the late 1930's led DSIR's Norman Taylor to state that pastoral land use on steep hill country is not sustainable (Roche, 1994). This viewpoint has also been expressed in the findings of other research (i.e. Blaschke et al., 1992; McIntosh et al., 1996; Marden, 2004).

Studies have shown that there tends to be less erosion under forest cover than areas under scrub or pasture (Phillips et al., 1990; Blaschke et al., 1992; Marden and Rowan, 1993). Trees have a deeper, stronger root system, which helps to stabilise hill slopes and reduce mass erosion (Hawley and Dymond, 1988; Halliday and Knowles, 2003; Knowles, 2006). There is a well-established body of literature (both nationally and internationally) on the benefits of planting trees, including forests, for controlling or reducing erosion (e.g. Phillips et al., 1990; Marden and Rowan, 1993; Marden, 2004; Phillips and Marden, 2005; Marden, 2007). However, there are limited New Zealand studies on the effectiveness (quantitative or qualitative) of different erosion control techniques, i.e. complete cover vegetation (e.g. commercial forestry) (Phillips et al., 1990; Marden and Rowan 1993), scrub reversion (Marden and Rowan 1993; Bergin et al. 1995) and on-farm measures (Luckman and Thompson, 1993; Hicks et al., 1993; Thompson and Luckman, 1993; Hicks and Crippen, 2004). Vegetation also acts to protect the soil from direct raindrop impact, improve soil structure and promote infiltration, impede overland flow and sediment runoff and lower the watertable (Fransen, 2000; Phillips and Marden, 2006). Land use and soil management activities that remove vegetation and expose the soil to wind and water increase the susceptibility to erosion.

Impacts of soil erosion

Fertility and productivity

Soil erosion reduces soil fertility and productivity, causes damage to property, degrades air and water quality and ecological diversity, and has social implications. The impacts of soil erosion are generally described in terms of on-site and off-site effects, and further separated into direct and indirect damage costs and forgone output. The on-site (on-farm) effects of erosion might include the costs of labour and materials to repair damaged infrastructure and implement soil conservation measures, as well as a reduction in present and future income from soil productivity loss. However, the costs of soil productivity loss may not always be fully recognised and accounted for by the farmer due to information constraints. The wider community may be concerned with damage to transportation and utility networks, increased sedimentation and eutrophication of waterways, loss of wildlife habitat and disruption to aquatic ecosystems. Soil erosion also has a very visible impact on the landscape (i.e. slip scars) that, combined with unsustainable land use practices, has potential to affect New Zealand's 'clean green' image and future trade capacity (Pimental et al., 1995; Anthony and Hicks, 2001).

Erosion adversely affects soil fertility and productivity by reducing organic matter, nutrients, soil biota, infiltration rates, water holding capacity, and soil depth (Pimental et al., 1995; Gregorich et al., 1998). Each of these factors influences soil productivity individually but they also interact with other factors, making assessment of soil quality and changes in productivity from soil erosion difficult. Organic matter, for example, improves soil structure, facilitates cation exchange, enhances root growth, and stimulates the proliferation of soil biota. The removal of topsoil due to erosion can result in a significant decline in soil organic matter (Pimental et al., 1995; Vesely, 2006; Rice et al., 2007).

A number of field and modelling studies have attempted to assess the erosion-productivity relationship. Field-based studies generally compare pasture production in eroded areas to stable areas (e.g. Derose et al., 1995), while simulation models have been used to predict crop productivity and interdependence on site-specific inputs (Stocking and Lu, 2000; Lu and Stocking, 2000a; Sparling et al., 2006). Pasture recovery on landslip scars follows an exponential curve, with recovery greatest immediately after slipping followed by a more gradual increase. Topsoil properties and pasture recovery on eroded sites are not likely to fully recover within a human lifetime (i.e. > 80 years) (Derose et al., 1995; Sparling et al., 2003). Analysis of the relationship between erosion and productivity loss is complicated by the masking of erosion effects with increased productivity from fertilisers, pesticides, irrigation and improved cultivars (Pimental et al., 1995). The national agricultural production loss in New Zealand from erosion is estimated to be valued at around \$37 million (equivalent to NZ\$46.5 million in 2008) yr^{-1}, using productivity recovery curves, average gross margin, and stocking rate data (Krause et al., 2001).

Carbon sequestration

Recent research has focused on the impacts of erosion and land management practices on carbon sequestration (Healey et al., 2000; Coleman et al., 2004; Quinton et al., 2006; Mooney and Williams, 2007). Carbon is a major component of soil organic matter, and carbon sequestration (i.e. locking or storing C in the soil) has been suggested as a way to reduce greenhouse gas emissions to help offset global warming. This is of interest to producers and landowners due to the potential to generate tradeable soil C credits (Bernoux et al., 2006; Kimble et al., 2007; Ministry of Agriculture and Forestry, 2008). The economic value of such carbon sequestration depends on the relative ease of verifying measured carbon in soil compared with alternative forms of sequestration (e.g. growing trees). If there is uncertainty over carbon sequestered in soil, any carbon certificates issued will be viewed by the market as risky and devalued as a result. Two opposing hypotheses exist concerning the effect of erosion on soil C; (1) that erosion is a 'sink' for atmospheric CO_2, via replenishment of soil C stocks by photosynthesis and the burial of displaced soil C within sediments on land, in waterways and the marine environment; and (2) that accelerated erosion is a 'source' of atmospheric CO_2 due to mineralisation of soil organic matter in displaced soil (Lal, 2006; 2007). Accurate estimates of soil redistribution over the landscape are required to quantify net soil C gains or losses and determine which hypothesis best suits the landscape (Gregorich et al., 1998; Bernoux et al., 2006; Lal, 2005; Lal, 2007).

A number of recent studies have used ^{137}Cs analysis to assess soil C redistribution over the landscape (McCarty and Ritchie, 2002; Zhang et al., 2006; Quine and Van Oost, 2007). Direct measurements of soil organic carbon (SOC) have been used to assess changes in total soil organic C concentrations and form under different vegetation covers and after cultivation and runoff events (Coleman et al., 2004; Boye and Albrecht, 2006; Polyakov and Lal, 2008). These studies have found that upland eroded soils generally have lower levels of soil C compared to deposition areas (McCarty and Ritchie, 2002; Coleman et al., 2004; Zhang et al., 2006). The prolonged residence time of sediment on a slope and the break-up of soil aggregates by erosion and cultivation can significantly increase the amount of soil C mineralised (Polyakov and Lal, 2008). Polyakov and Lal (2008) estimated that 15% of SOC in sediment redistributed over a field is lost to the atmosphere. Quinton et al. (2006) estimated losses of 2-50% soil C after cultivation.

A mass balance approach was used to estimate soil C fluxes from landslide and sheet wash erosion in the Tutira catchment in Hawke's Bay, using information from previous erosion studies and 114-year lake sedimentation records. In this catchment, erosion was a net sink of soil C, accumulating approximately 0.94 ± 0.23 Mg C ha^{-1} yr^{-1} (Page et al., 2004). Van Rompaey et al. (2003) recommend the use of sedimentation records to produce soil risk erosion maps, validate erosion estimates and to assess the response of soil conservation measures at a regional scale.

Direct damage to property and infrastructure

In addition to soil productivity loss, another key impact from soil erosion is direct damage to private and public property. This damage may include repairs to farm infrastructure (tracks, bridges, and fences), residential and industrial buildings, and transportation, utility and recreation networks. Direct damage costs can be significant, for example, the estimated national cost of direct erosion damage in New Zealand is \$38.8 million (equivalent to NZ\$48.7 million in 2008) yr^{-1} (Krause et al., 2001).

Other impacts

Wind erosion can downgrade air quality and contribute to air pollution. Quantifying the effect of degraded air quality from wind erosion is extremely difficult. In Australia, emerging research is finding correlations between dust and asthma. If this correlation is verified then the implications for policy in Australia on wind erosion will be significant (Williams and Young, 1999). Wind erosion is less of a problem in New Zealand, but still a common feature in Central Otago hill country and the drier parts of Mackenzie basin and Marlborough (McGowan and Ledgard, 2005).

Other relatively minor or intangible impacts of soil erosion include social and ecological aspects, such as loss of farmer motivation and confidence due to repeated erosion, loss of visual amenity, or ecological costs from a reduction in indigenous vegetation. It is difficult to quantify the economic implications of these impacts.

Impacts of eroded sediment

Sediment impacts occur where eroded soil enters a waterway and settles or is redistributed further downstream. Specific impacts caused by increased sediment load may include increased flood severity, reduced water quality, biological degradation, stream-bed aggradation, and over-bank sedimentation.

Flooding

Increased flood severity resulting from a reduction in channel capacity and increase in suspended sediment increases the risk of breaching protection measures and greater flood damage (e.g. farm sedimentation, livestock losses, road blockage, bridge collapse, and house damage). Research in New Zealand has shown that annual water yield and flood peak declines when catchments are afforested or are allowed to revert (Blaschke et al., 2008), however it is unclear what proportion of flood magnitude and damages can be attributed to the quantity of sediment in New Zealand floodwaters (Krausse et al., 2001). Clark (1985) suggests sediment contributes to approximately 12% of total flood damages in the United States.

Water quality

Sedimentation affects water quality through changes in the chemical, physical, biological, and aesthetic values of the water. Chemical changes can be related to pollutant concentrations attached to soil particles (e.g. phosphorus or heavy metals). Physical changes can include increased water temperature in shallow channels and decreased water clarity, whereas biological impacts from sediment can result from changes to habitat and disruption of the food chain. Aesthetic degradation mainly impacts on recreational uses, such as fishing, boating, and swimming (Clark, 1985; Stonehouse, 1999; Krause et al., 2001). A reduction in water quality may result in higher filtration and water treatment costs for private and public water supplies, a potential loss of aquatic biodiversity, and less use of the resource for recreational activities.

Sedimentation

Sedimentation impacts can affect hydro-dams, water reservoirs, navigation, and water conveyance for irrigation. Sediment accumulation behind hydro-dams, water reservoirs, and in irrigation canals may require dredging or flushing to maintain optimal storage capacity and reduce wear and damage to machinery (e.g. turbines and pumps). This maintenance work is required to maximise economic returns, extend the life of the facility, and reduce potential for downstream flooding and water quality issues (Southgate and Macke, 1989; Brusven et al., 1995; Krause et al., 2001). In New Zealand, water storage capacity loss is not a major concern but the cost of turbine-wear can be significant. Remediation of the sedimentation impacts on navigation might involve the dredging of harbour access and docking ports which has costs associated with it (Krause et al., 2001).

Mitigation of erosion - common soil conservation practices

Soil conservation is the protection of soil from erosion and other types of deterioration, so as to maintain soil fertility and productivity and prevent property and ecosystem damage. The principal approach to soil conservation is to maintain a protective vegetative cover and employ land use management strategies that minimise soil disturbance. When surface planting is not feasible, such as on construction sites and during forest harvesting, engineered solutions are available.

The Soil Conservation Technical Handbook (Anthony and Hicks, 2001) provides a comprehensive summary of practical soil erosion prevention and rehabilitation techniques for different types of erosion in New Zealand (also see Phillips et al., 2008). Common soil conservation practices include:

- Spaced or close tree planting on hill slopes and stream banks
- Retiring erosion-prone land from pasture (scrub and indigenous forest reversion)
- Fencing gullies and waterways to prevent stock access, and fencing off erosion prone land for targeted management
- Cultivation control (e.g. timing and method selection)
- Pasture (e.g. over-sowing and species selection) and grazing management
- Earthworks and structures to slow runoff (e.g. terracing, debris dams, and suitable drainage)

Production woodlots and forests of Radiata Pine and Douglas fir are commonly used to control soil erosion on exposed, steep hill country in New Zealand (McElwee, 1998; Halliday and Knowles, 2003), and are effective at enhancing dust deposition and reducing wind erosion (McGowan and Ledgard, 2005). Under mature trees there are reductions in erosion (i.e. sediment generation), sediment yield, nutrient export, smaller flood peaks, and improvements in soil structure on eroded soil. It should be noted that some forms of erosion, particularly deep-seated landslides, can still occur under forests. However, the controls that forests place on landscape hydrology and slope stability are generally effective in reducing the incidence of soil erosion. For example, afforestation of whole catchments can reduce sediment load to waterways by 50-90% (Hill and Blair, 2005). The risk of erosion increases during forest harvesting and re-establishment of the next rotation, although this can be managed by use of low impact logging techniques and riparian buffers around waterways (Klock, 1976; Healey, 2000; Fahey et al., 2003; Hill and Blair, 2005; Phillips et al., 2005; Eyles and Fahey, 2006; Marden et al., 2006). Furthermore, radiata pine roots have been found to retain about 40% of their original mass six years after harvest and almost 20% of their original mass 11 years after harvest (Garrett et al., 2008), and thus may provide some erosion control benefits over the transition period that would otherwise be absent under pasture. Profitability analyses of farm forestry have shown that woodlots of radiata pine may be more profitable than pastoral farming, particularly on land with a low livestock carrying capacity (Halliday and Knowles, 2003; Hansen et al., 2004).

Poplar species are commonly used for controlling soil slip and gully erosion, and can be planted in the presence of livestock and on wetter soils (Wilkinson, 1999; Knowles, 2006). Additional potential uses are as supplementary stock fodder during periods of drought and trace element supply or soil decontamination (Fung, 1999; Robinson et al., 2005). Individual trees dramatically influence the microclimate beneath partial and closed canopies, with implications for pasture productivity, plant spacing and tree management (Guevara-Escobar et al., 2002; 2007; Douglas et al., 2006a; 2006b). Profitability analyses are generally marginal, due to a significant reduction in pasture productivity under mature poplars from shading effects (i.e. a 20-30% reduction after 20 years at 50-100 stems ha^{-1}) (Hill and Blair, 2005).

Native plants have relatively slow growth rates compared to exotic species, and thus have an initial disadvantage for stabilising eroded subsoils (Harris, 1982). Despite this slow start, native species can be effective for erosion control. For instance, Bergin et al. (1995) evaluated shallow landslide damage under regenerating scrub (i.e. manuka and kanuka) on East Coast hill country compared to pasture, and found a reduction in landslide damage of 65% under 10 year old stands increasing to 90% under 20 year old stands. Natives are commonly used for reducing and mitigating surface and stream bank erosion processes, providing soil protection in the construction industry, and sediment control in riparian buffer strips (Phillips and Marden, 2006). The effectiveness of planted trees (either exotic or native) for erosion control is dependent on tree species, site characteristics, stocking rate and rotation age (Halliday and Knowles, 2003; Knowles, 2006; Phillips and Marden, 2006; Phillips et al., 2008).

Pimental et al. (1995) suggested that the implementation of appropriate soil conservation strategies in the US has the potential to reduce erosion rates by 2 to 1000 times. Reforestation of soft rock terrain in the headwaters of the Waipaoa River catchment in the East Coast region of New Zealand reduced gully-derived sediment yields from 27,000 t km^{-2} yr^{-1} to 11,000 t km^{-2} yr^{-1} over a 24 year planting program (Marden et al., 2005).

The willingness to pay for soil conservation is influenced by the landowner and society's perception of the on-site and off-site impacts of soil erosion, their attitude towards undertaking soil conservation, awareness of available techniques, physical site characteristics, financial capacity, economic drivers, and institutional support (Barbier, 1990; Barbier, 1996; Araya and Asafu-Adjaye, 1999; FAO, 2001; Asrat et al., 2004). From a farmer's perspective, the on-site costs of soil erosion and benefits of soil conservation are of primary concern. The participation of farmers in mapping soil erosion at the catchment level helps to increase their awareness of the severity of local erosion problems, while financial analyses undertaken at the farm level allow the farmer to assess the costs of soil erosion and the benefits of implementing soil conservation measures (Tenge et al., 2007). From society's perspective, the off-site impacts of soil erosion are also of concern. Identification and valuation of the off-site costs and benefits of soil erosion allows for the design of land use policies and assessment of implementation costs and priorities (Barbier, 1996; Pretty et al., 2000; Hein, 2007).

In New Zealand, government support towards soil conservation includes specific legislation and strategies promoting sustainable land use (e.g. the Resource Management Act 1991), funding for community conservation groups, research on biophysical interactions and soil conservation technology, 'State of the Environment' monitoring, and provision of advice (Roach, 1994; Fenemor et al., 2003; O'Connor, 2003). The East Coast Forestry Project is a central government initiative to encourage the large-scale planting of commercial forestry on erosion-prone private land in the East Coast region (Ministry of Agriculture and Forestry, 2007). A tendering process is employed whereby applicants submit forest development plans for funding consideration (Rhodes, 2001).

Erosion measurement and monitoring techniques

Practical techniques for monitoring soil erosion under New Zealand conditions were reviewed by Lambrechtsen and Hicks (2001). This information was restructured by Hicks (2001) to summarise the main methods in a cross-referenced document. The methods available for monitoring soil erosion in New Zealand are as follows:

- Field measurement with survey instruments, global positioning systems or approximation with various devices (e.g. tapes, clinometers, altimeters)
- Field measurement with tracers, soil profile descriptions, soil probe or auger
- Aerial photographic measurement with stereo-plotters, digital techniques, approximation by various methods (e.g. dots, grids, planimeter), and point sample measurement
- Hardcopy or digital measurement off satellite images, or automated digital classification
- Measurement from runoff plots, stream discharge or vegetation

The purpose of the assessment and the scale of impact strongly influence the selection of measurement technique. For example, runoff plots are more suitable for sheet erosion measurement whereas gully erosion and mass movement is better measured at the catchment-scale (Clark, 1996; Blaschke et al., 2000; Lal, 2001; Poesen et al., 2003; Boardman, 2006). Sequential aerial photographs and digital elevation models are commonly used to monitor eroded volumes of catchment-scale processes (e.g. gully erosion) over the short to medium term (< 70 years) (Poesen et al., 2003; Martinez-Casasnovas et al., 2005). Boardman (2006) recommends monitoring all erosion types at specific representative areas over long periods of time to assess current and future erosion rate estimates.

Use of empirical equations, such as the Universal Soil Loss Equation (USLE), can be used to provide estimates of average sheet and rill erosion rates over the long term. The USLE equation is not suitable for short-term estimation of erosion rates, use at the catchment scale, or for areas where appropriate factor values have not been determined (i.e. crop and conservation practice factors, rainfall and soil erosivity indices) (Clark, 1996). Modifications of the USLE and development of other parametric models have addressed other scenarios (Starr et al., 2000; Lal, 2001). There are also other models that deal with surface erosion but few models to account for the range of erosion processes operating in New Zealand.

Regional state-of-environment reporting of soil erosion requires a consistent approach to the collection, compilation, and reporting of data to enable aggregation at a national level. Stephens et al. (1999) reviewed the design and methodology in use, or proposed by, regional councils to measure hill country erosion in New Zealand. For a consistent approach that would enable aggregation of data to a national level, they recommended the use of the New Zealand Land Resource Inventory (NZLRI), the Land Cover Database (LCDB), and supplementary vegetation and land use information to assess the hill country areas susceptible to erosion. This information is combined with monitoring of soil depth change at benchmark sites to enable reporting of soil erosion variability over time on a national scale.

The economics of hill country erosion and soil conservation

There is now an extensive body of literature pertaining to the physical extent and effects of erosion, and on the measures that can be used to contain it (briefly considered above). Much of the research tended to be focused on localised erosion, with the response measures also dependent on location-specific factors. Also, most of it did not explicitly look at the economic costs of erosion damage and the costs of measures to ameliorate it. If some consideration of the economics was given, the focus tended to be on only a subset of effects such as on-farm effects rather than external impacts.

Evaluating the costs of erosion may allow for the implementation of soil conservation measures to be prioritised. Furthermore, economic analysis can allow for the comparison between different conservation technologies to assess the most efficient allocation of resources as well as balancing costs with effectiveness and financial benefits.

Economic frameworks for assessment of effects

Erosion is a natural process which is exacerbated by, but not wholly attributable to, the use and management of land by people. It can be identified from its various physical manifestations and effects on the landscape but in economic terms, the significance of erosion is dependent on the consequences for resource use and human well-being (i.e. how does it affect the value people derive from the environment?). The economic effects of erosion in a particular locality will usually comprise:

- Lost productivity from affected properties, relative to a less eroded state, due to reduced output caused by effects of erosion (and deposition);

- Additional resources and expenditures spent on containing, repairing and living with erosion.

In economic terms, erosion control or mitigation measures are worthwhile as long as the costs of control are less than the erosion costs avoided. This means that the economic definition of erosion is somewhat more fluid than the physical definition: minor soil movements are still erosion in a physical sense, but if they have no appreciable impact on human activities then there is no economic value in their mitigation. The economic literature talks of an 'economically optimal' level of erosion, where the cost of an extra unit of mitigation is equal to the value of additional erosion costs avoided (Crosson, 1997). To the extent that changing demands and available technologies lead to changes in the price of land outputs and inputs to mitigation measures, such an optimal level will move over time. Finding the optimum level also depends on having appropriate information about the long term consequences of soil degradation and the degree of precaution exercised in dealing with uncertainties in that information.

Economic categorisation of effects

In the literature dealing with the economics of erosion, the effects of erosion are generally subdivided into two broad categories: (1) on-site effects (i.e. effects occurring on the properties where erosion takes place) and (2) off-site effects (i.e. downstream effects, usually resulting from sediment deposition on other properties or in watercourses). Another distinction that is sometimes made is between direct effects (i.e. those arising on properties directly affected by erosion and deposition) and indirect effects (i.e. those arising on properties not directly affected, such as costs arising from erosion induced disruption to transport arteries or in the flow of produce available to be processed). However, the distinction between temporary and longer-term effects is often not made, because both types of effects are captured in a discounted cash flow or cost-benefit analysis over time.

The following framework of effects is suggested for considering the economic effects of hill country erosion in New Zealand:

- On-site effects; those directly felt by the properties experiencing erosion,
- Off-site effects; those directly impinging on activities off-site, largely due to sedimentation and deposition, and
- Indirect effects; those affecting entities as a consequence of a direct effect felt elsewhere, such as a processing plant that suffers reduced value added from changes in supply from

primary producers, or similarly other primary producers who rely on the affected properties for part of their business.

Some variation in the characterisation of effects exists in the literature, depending on the nature of specific studies and the data available to them. Much literature focuses on the on-farm or on-property direct impacts of erosion, but a more comprehensive assessment of costs would need to also look at off-site or sedimentary effects of erosion, and at the consequences of lowering the rate of erosion across an area. There is also variation in the coverage of off-site or sedimentary effects in erosion studies. Some are restricted to relatively tangible effects, such as damage to infrastructure and increasing sediment load in waterways, but consequences could also be extended to include less tangible effects such as impacts on landscape and amenity or biodiversity.

The assignment of specific effects to the above framework is still somewhat open to interpretation. For example, repair of damage to network infrastructure such as roads (from flooding) or power lines (from dust) could be regarded as an off-site effect or as an indirect effect further removed from the direct effect of erosion whereas some damage repairs might be caused by more direct impacts (e.g. washouts on roads). The categorisation is not critical provided all effects associated with particular types of erosion are recorded against it but not double counted. A list of specific effects within the above framework is given in Table 1.

Table 1. Framework for categories of soil erosion effects (Source: NZIER)

On-site Effects

- Erosion induced losses of crop yield
  - Measures of physical dimensions or erosion
  - Measures of net productive value loss
- Increased cost of remedial measures
  - Increased use of fertiliser to replace lost nutrients
  - Adoption of less erosive but more costly management practices
  - Repairs to damaged structures
  - Disruption to site operations
- Loss of soil carbon

Off-site Effects

- Proximate property damage
- Run-off, sedimentation, and nitrification
  - Deterioration of water quality
  - Treatment costs for downstream users
  - Impact of flow modulation and flood frequency
    - Flood damage, disruption, and recovery
  - Impacts on navigation
  - Deleterious health effects from reduced water quality
  - Deterioration of recreation and amenity values
  - Habitat degradation
- Visual detraction
- Dust nuisance
  - Impacts on individuals and households
  - Impacts on power supply
  - Impacts on road safety and maintenance
    - Injuries from dust-induced accidents
      - Medical treatment expenses
      - Lost productivity
      - Aversion to injury (willingness to pay)
    - Property damage from dust accidents
    - Emergency service attendance
  - Impacts on air travel
  - Impacts on human health
- Coastal deposition, nitrification, and habitat change

Indirect effects

- Production effects
  - Disruption to connected properties
  - Processing effects
    - Value added loss on lower throughput
    - Scale economies lost
  - Infrastructure disruption
    - Transport network repair costs
    - Transport delay or diversion costs
    - Utility network disruption

Implications for public policy development

The most critical aspect of categorisation is the distinction between on-site and off-site effects, given the economic premise that public policy is best directed to addressing externality effects rather than interfering with private commercial decisions and risk taking.

Some authors argue that landowners have sufficiently well-defined property rights to have the right incentives to make sound, long term decisions on the use of their land and protection of value in their properties (e.g. Crosson, 1997). An implication of this is that policy is probably better directed towards managing off-site effects than assisting landowners to adopt practices that will mostly benefit them. Reinforcing that implication is the inference from a number of empirical studies of the costs of erosion that off-site impacts of erosion may have far larger economic costs than the on-site impacts (Colaciccio et al., 1989, Crosson 1997). Nevertheless, if erosion is imposing undue external costs because landowners are not taking them into account, some policy may be justified in targeting landowners. For instance, if there are failures in the market for information about what soil conservation measures are most likely to enhance social value in different circumstances, promotion of soil conservation aimed at landowners could be justified if it delivered a greater off-site benefit. Intervention logic would suggest it is only worthwhile to assist private gains in this way if they also create external benefits sufficient to justify the intervention costs. The externalities implicit in soil conservation are:

- Landowners will fail to take account of effects falling outside their properties (i.e. off-site),
- Landowners may fail to take account of long term effects of their actions in deterioration of their property value – an argument that depends on the expectation that the market will fail to adequately reflect that deterioration in property value, and
- Landowners may be unable to access the information they require to make fully informed decisions about the long term impacts on their property (bounded rationality).

Economic methods and approaches

Financial and economic analysis allows for comparison between different practices (e.g. implementation of soil conservation measures) against a base case scenario. The results can be used to assess the most efficient allocation of resources. Financial analysis refers to the market-price costs and benefits resulting from a particular project on an individual or group, while economic analysis also considers social costs and benefits (Enters, 1998; FAO, 2001). For example losses in a financial analysis typically relate to the value of damage to individual properties or businesses, without consideration of the impact of these losses on other agents in the economy. They are often equated to the value of insurance claims, although these clearly exclude the value of non-insured losses. Losses in an economic analysis are broader in scope, and ideally would account for both the initial damage resulting from an adverse event, and also the flow-on effects on other sectors of the economy.

The economic impacts of soil erosion and soil conservation can be appraised using the following methods (Vesely, 2006):

- Cost-benefit analysis – determines the net benefit or cost of a particular scenario from an economic perspective. Cost-benefit analysis uses decision criteria such as 'Net Present Value' (NPV), 'Benefit-Cost ratio' (BCR), and the 'Internal Rate of Return' (IRR).
- Computable general equilibrium models – use a system of equations derived from economic theory to model how an economy might react to changes in policy, technology or other external factors.
- Optimisation models – integrated economic-environmental models that are used to assess the most efficient combination of variables to optimise the objective (i.e. maximise profit, minimise soil loss).
- Simulation models – using integrated economic-environmental models (as above) to simulate future scenarios.
- 'Total Factor Productivity' – incorporates external environmental costs and benefits into productivity calculations to assess sustainable productivity performance.

A similar list of methods is provided by Calatrava-Leyva and Gonzalez-Roa (2001), with the addition of:

- Econometric estimation of a profit or damage function to estimate effects of changes in productivity;
- Resource accounting studies, encompassing both on-site and off-site effects of soil erosion and conservation.

The approaches listed above are not mutually exclusive and may draw on elements of each other. For instance, a cost-benefit analysis may draw on information derived from econometric analysis of the calculation of production functions or cost functions. However, these can be data intensive and complex to produce. A cost-benefit analysis may also use resource accounting studies to populate its scenarios of effects with and without erosion and associated control measures. More commonly cost-benefit analysis will use more basic indicators of value gained and lost. For instance changes in the average return per hectare caused by erosion on land of a particular type. Such estimates are less precise but may be sufficient to indicate that erosion is enough of a problem to justify spending a little more to control it. They may even be sufficient to indicate that an element of assistance to landowners (such as information provision) would have a bigger pay-off in off-site benefits. Estimates of total economic values, involving complex non-market valuation techniques need only be resorted to when they are likely to be crucial to the results. Even in such cases, economic valuations of environmental attributes such as landscape amenity or biodiversity have in practice rarely determined decisions with substantial resource implications.

Cost-benefit analysis

Cost-benefit analysis requires a comprehensive understanding of the impacts of soil erosion and the effectiveness of soil conservation methods to reduce soil erosion and maintain pasture yields and other benefits. These impacts are then translated into monetary terms (Enters, 1998; Tenge et al., 2005). The detailed breakdown of costs and benefits in relation to specific land uses and landforms allows for more effective analysis, advice and management than a broad regional approach (Walpole, 1994). One of the criticisms of this approach is the use of generic data or data obtained from other settings when site-specific information is lacking (Calatrava-Leyva and Gonzalez-Roa, 2001).

There is a broad choice in the scope of coverage of a cost-benefit analysis. At its simplest a cost-benefit analysis may be confined to the effects on individual properties, in which case it is largely focused on the on-site private costs and benefits of alternative courses of action. More useful in a public policy setting are those that incorporate both on-site effects and the tangible off-site or sedimentary effects (e.g. sediment impacts on neighbouring properties and water quality, some indirect production losses), which cover both private and some external costs and benefits. More challenging are those analyses that are extended to include intangible external effects (e.g. changes to landscape amenity and biodiversity), which require use of economic non-market valuation techniques. As these techniques tend to be costly to implement, contentious in their results, and often over-ridden by political or judicial decisions, such studies are less common than those that concentrate on more tangible effects.

There is a choice of three decision criteria for use with cost-benefit analysis. NPV analysis evaluates the difference between the present value of the benefits and costs, over a defined period at a specified discount rate. The BC ratio assesses the ratio between the present value of the benefits and the costs, again using a specified discount rate over a defined period. For a project to be economically viable the NPV must be positive, and the BC ratio must be greater than 1. NPV and BC ratio are therefore driven off the same set of calculations: the NPV shows the scale of the net benefit, the BC ratio shows its return per unit input. The IRR is an alternative method that derives the discount rate at which the NPV is zero, i.e. the discount rate is not specified but emerges from the calculation. For a project to be economically viable the IRR must be at least as high as the return from the next best alternative investment.

These three decision criteria allow for ranking of different scenarios; however their reliance on valuing attributes that are often not directly quantified means that the individual results should be interpreted with care. Choosing the right discount rate (used to compute the present day value of net returns), time horizon (for costs and benefits to be realised), and valuing labour (family inputs versus wage rates for different genders, age, skill level) is important (Enters, 1998; Thao, 2001; Vesely, 2006). Sensitivity analysis using a range of discount rates and time frames can overcome the difficulty of specifying appropriate rates (Clark, 1996; Stocking and Lu, 2000).

Computable general equilibrium models

Computable general equilibrium models complement conventional cost-benefit analysis by using models of inter-industry transactions in the economy to examine how a shock or change to one sector's performance flows through to the rest of the economy. They are therefore aimed at estimating the indirect effects of adverse events that might result from soil erosion. They have been applied to estimate the impact of specific events such as floods, earthquakes, power black-outs and sudden price rises in key commodities, where there is a definite shock to the economic system that can be modelled. They are less suited to a process like erosion that exerts a continuous strain on economic production, and no empirical studies of erosion using this approach have been found.

Optimisation and simulation models

Optimisation and simulation models integrate economic attributes with biophysical attributes using mathematical relationships. An optimisation model will find the most efficient combination of instruments (i.e. management alternatives, policy change, technological change) to meet the modelling objectives within a given set of constraints (model parameters) (FAO, 2001; Vesely, 2006). While integrated models are a good tool for simulating complex interactions and reducing laborious calculations, the simplification of complex phenomena means that model inputs, assumptions, calibration, and interpretation of results should be considered and applied with appropriate caution (Vesely, 2006).

Pacini et al. (2004) used an optimisation model to evaluate farm-level environmental and economic tradeoffs under previous and existing multi-objective environmental policies - specifically the impact of the Agenda 2000 policy reform on the sustainability of organic farming in northern Tuscany. The model used linear programming that integrated site characteristics (e.g. soil properties and climate), farm management practices, and economic information. Model results indicated that a reduction in soil erosion was the only notable environmental improvement under the existing policy guidelines. However, this came at the expense of much higher socio-economic cost (for support schemes). Sensitivity analysis allowed optimisation of environmental benefits versus socio-economic costs.

Stonehouse (1997) used a simulation model (GAMES) to predict fluvial erosion and phosphorus loadings to waterways under different tillage methods in the Kettle Creek catchment, southern Ontario, Canada. The results were input into an empirical soil conservation-economics model (SOILEC) to assess the long-term impacts on soil productivity (crop yields) and farm revenues. The GAME results were also used to assess potential improvement in water quality from reductions in sediment and phosphorus loadings under different tillage methods. Stonehouse found that all on-farm conservation measures were effective in reducing soil degradation, downstream water quality impact, and externalities for society. However, only conservation tillage systems under selected crop and farm management capability situations were profitable to farmers. Given the lack of profitability to farmers, the implementation of soil conservation measures may need to be enforced rather than voluntary. Other studies have also highlighted this point (e.g. Harris, 1982).

An issue raised by such results is what is the intervention logic that would require farmers to undertake actions that are not profitable for them? There may be a case in net benefit terms for requiring such action if it would yield a larger increment of external benefit than the increment of cost incurred, but that also raises the question of whether farmers should be assisted or compensated for bearing costs to achieve an external benefit. If there is some market failure (such as information deficiency), or some institutional barrier blocking the incentive for worthwhile measures to be adopted, it may be more efficient for public agencies to tackle these barriers to adoption rather than enforcing property owners to do so.

Environmentally adjusted Total Factor Productivity

Environmentally adjusted Total Factor Productivity (TFP) is a measure of sustainable productivity, and is a useful approach for assessing the impacts of technological or environmental change on productivity. TFP is mathematically defined as the ratio between the quantity of output (e.g. pasture yield) to the quantity of input (e.g. fertilisers, pesticides, and damage costs resulting from soil erosion). Growth in TFP (an increasing index) indicates a decline in the cost of inputs required to produce a given quantity of output, that is, a more productive outcome (Vesely, 2006).

Nanere et al. (2007) evaluated how TFP results change when off-site soil loss and damage costs arising from broadacre agriculture in Australia are accounted for. The TPF results suggest that adjusting for the environmental impacts of soil erosion can result in high or low agricultural productivity depending on the assumptions made regarding damage costs of erosion. Use of the TFP approach to assess sustainable development requires a comprehensive database of both market and non-market input information.

Econometric estimation of production functions may be used to establish TFP, although such studies are usually focused on farm production without reference to external effects. They may also be used to estimate productivity loss if they include variables that change under the impact of erosion.

The productivity loss approach treats soil as any other asset in that its direct use value equals the present value of expected future income contribution, so decline in productivity results in decline in value (Torras, 2003). The value of soil erosion (VSE) can be calculated as:

$$VSE = (Rp_r – Cp_c)/i$$

Where R = agricultural income attributable to a given area without erosion,

p_r = proportional income loss resulting from erosion,

C = operating cost (machinery, labour, etc),

P_c = proportional change in cost resulting from erosion, and

i = interest rate

A less data intensive approach is the replacement cost method, which estimates the cost of restoring productivity of eroded sites to their pre-erosion level. In the case of sheet erosion from arable land this may be approached by estimating the cost of chemical replacements to replenish the nutrients lost to erosion, and requires only information on soil nutrient concentrations and the prices of chemical fertilisers (Torres, 2003). For hill country erosion replacement costs could be broader to include the cost of stabilisation works, reseeding and restoring soil fertility, and it could also include a component of lost production if stock that might otherwise graze an eroded site need to be excluded during the restoration period.

Valuation methods and approaches

The literature reveals a broad range of approaches to economic valuation of erosion. As with any cost-benefit analysis, the valuation techniques employed reflect a trade off between obtaining a theoretically defensible estimate and pragmatic decisions based on the information available at the time. The choice of techniques also reflects the purpose of the analysis. Analyses that aim to measure the full social cost may need recourse to complex, costly, and sometimes controversial techniques of non-market valuation to gauge the strength of welfare effects on health, environmental quality, and so on. But many analyses are limited to quantification of more tangible effects that can be picked up through market-based valuations or replacement costs or costs avoided by implementing a particular measure. The scope of the examination of soil erosion determines the complexity of any analysis and the types of economic valuation method that are needed.

Evaluating the costs of erosion requires identification, quantification, and monetary valuation of the costs and benefits of soil erosion. Methods for valuation of costs and benefits of erosion can be categorised as follows (Vesely, 2006; Barnard and Dunningham, 2007):

- Cost-based (market value) methods – estimate the value of what might be gained or lost from changes in the condition of the resource using market-based indicators (e.g. valuing soil productivity based on changes in crop yield after an erosion event). Methods included in this category include the 'Productivity Change' approach, 'Replacement Cost' approach, 'Market Prices' approach, and 'Opportunity Costs' approach.
- Surrogate market value methods – estimate the value of the resource (e.g. soil quality) using the market-value of another attribute (e.g. land prices). Methods include 'Hedonic Pricing' and the 'Travel Cost' approaches.
- Stated preference (hypothetical market) methods – estimate the indirect value of the resource based on willingness to pay or preference for a particular outcome. Methods include 'Contingent Valuation' and 'Choice Modelling' approaches.

Vesely (2006) & Barnard and Dunningham (2007) can be referred to for more detail on the different methods. These two publications undertake a comparative evaluation of methods to assess the values of soil quality and the ecosystem services of plantation forests in New Zealand, respectively.

In estimating the national cost of soil erosion, the general approach followed in the international literature is to distinguish between on-site and off-site soil erosion impacts (Pimental et al., 1995; Clark, 1996; Enters, 1998). Valuation of the on-site effects concentrates on the impacts of soil erosion and soil conservation on soil quality, crop or pasture production, and direct storm damage. These effects are commonly valued using the Replacement Cost method (Pimental et al., 1995; Cohen et al., 2006; Martinez-Casasnovas and Ramos, 2006; Hein, 2007; Nahuelhual et al., 2007) and to a lesser extent using the Productivity Loss method (Lu and Stocking, 2000b; Uri, 2000). Valuation of the off-site effects of soil erosion is more problematic than on-site effects due to difficulty in quantifying and valuing the effect of soil erosion and sedimentation on water quality, ecological diversity, flood severity, and associated damage. The selection of valuation method(s) will depend on the level of information available for the specific off-site impact.

Colombo et al. (2003) used the Contingent Valuation method to estimate the benefits of a soil erosion control program as perceived by the general public in the Alto Genil catchment in southern Spain. The majority of survey respondents (97%) were aware that soil erosion was a problem and were willing to pay for a publicly-funded program to reduce erosion by creating vegetation strips. However, attempting to place dollar values on how much they would be willing to pay meant that most respondents revised downwards the value they placed on soil conservation. The results suggest that the Contingent Valuation method may overestimate the value of soil erosion control programs from society's viewpoint. Colombo et al. (2006) expanded this study to refine the willingness to pay (WTP) estimate and compare the Contingent Valuation and Choice Modelling approach in the same catchment. Both methods were suitable to evaluate the off-site effect of soil erosion and produced similar WTP value estimates. Tuan and Navrud (2007), in their comparison of the Contingent Valuation and Choice Modelling approaches in valuing a cultural heritage site in Vietnam, also found that both methods produced similar results and can be successfully used in cost-benefit analyses.

Krause et al. (2001) have assessed the national cost of soil erosion in New Zealand. In their study, the impacts of soil erosion were identified as either soil erosion or sediment effects, in comparison to the on-site and off-site framework described above. The rationale behind this framework was to avoid the problem of defining the on- and off-site boundary. Cost estimates for soil erosion and sediment effects were evaluated using direct damage costs, agricultural productivity loss, water filtration, repairs, and maintenance costs. Where quantitative information was not available for a particular soil erosion or sediment effect, the cost analysis was not undertaken.

Reported economic costs of erosion and benefits of mitigation

Empirical studies of the economic value of soil erosion and soil conservation fall into two broad types. Some studies attempt to value the aggregate costs of erosion to a country, a region, or even the whole world, making assumptions about how much productivity is reduced by, and how much additional expenditure is incurred because of, erosion activity in the area of interest. The alternative is a more micro-focused approach to examining the incremental costs and benefits of soil conservation measures that limit further erosion. These studies tend to be localised in scope and hence limited in drawing generalisations about erosion and conservation effects, but they are useful for policy purposes, as they provide insight into the marginal costs and marginal benefits of moving from the current position.

A drawback with aggregate estimates is that they lack a clearly defined counter-factual against which to compare them. For instance, it is unlikely that there would be zero water treatment costs if erosion and resultant sedimentation of waterways were substantially reduced. Knowing the present level of costs is less important than knowing how net return from human activities (reflecting productivity and costs) responds to a little more or less activity towards erosion control. This would enable movement towards the socially optimal level of erosion, where the marginal cost of erosion equals the marginal cost of erosion abatement.

Note that Appendix 2 has the cost values reported below standardised to NZ$/km^2.

Description and evaluation of reported information at different scales

Farm scale

There are a relatively large number of studies that focus on the financial costs and benefits of erosion and soil conservation at the farm-scale. This may be related to direct damage costs and agricultural productivity loss after specific storm events, long-term agricultural productivity loss from inappropriate land use and management, or the cost-benefit analysis of different soil conservation measures (Crosson, 1997; Glade, 1998). Farm-scale studies of economic costs are very site-specific, and difficult to extrapolate to a regional or national scale.

Catchment and regional scale

Catchment and regional-scale studies in New Zealand have focused on the economic impacts and benefits of land use change (e.g. afforestation on the East Coast) or direct damage costs from large storm events (e.g. flood damages) (Luckman et al., 1995; Glade, 1998; McElwee, 1998; Phillips and Marden, 2005). The availability of comprehensive economic data from catchment and regional studies is much less abundant than in the farm-scale literature. This is due to insufficient understanding of the biophysical impacts of soil erosion, sedimentation and soil conservation, and the non-market nature of many effects (Clark, 1985; Dixon, 1990; Barbier, 1995). For example, the proportion of flood damage costs that can be directly attributed to sedimentation from soil erosion is not well defined (Krause et al., 2001). Even assessment of total flood damage is not straightforward in New Zealand, given the lack of consistent recording of insurance and other economic costs covering recent events, including damage to non-insured properties, damage to infrastructure networks, disruption costs and so on.

National scale

There is even less information on national costs of soil erosion. The majority of this information is for the US, with some key references being relatively old (Clark, 1985; Colacicco et al., 1989; Pimental et al., 1995). Pimental et al. (1995) provided on-site and off-site cost estimates of soil erosion for the US, collating damage cost and erosion rate information referenced elsewhere. The national costs of soil erosion in that study were significantly higher than other national estimates (e.g. Crosson, 1997), and the lack of information on the underlying analysis methods resulted in scepticism about the estimated costs (Crosson, 2003). Boardman (2006) states that the average rate of erosion of 17 tons ha^{-1} yr^{-1} (15.4 Mg ha^{-1}) used by Pimental et al. (1995) was based on 12 experimental plots in Belgium, and is inadequate to provide a national estimate of erosion rates in the US.

Hajkowicz and Young (2002) estimated infrastructure damage costs arising from land and water degradation in Australia and the economic impact of soil conservation. Williams and Young (1999) assessed the cost of wind erosion to South Australia, including the estimated cost to human health. Pretty et al. (2000) estimated the off-site costs of agriculture in the UK. The costs attributed directly to soil erosion are based on damage costs to transportation networks and channel degradation.

Krause et al. (2001) conducted the first national economic cost assessment of soil erosion and sedimentation in New Zealand. The authors use a modified framework based on earlier work by Clough and Hicks (1992) with similar objectives to US work on national cost assessments. The cost assessment is limited to direct damage-related costs and avoidance or prevention costs due to the availability of actual expenditure information. Indirect costs are not included as the effects have not been fully quantified and valued.

Soil erosion costs

To be consistent with the approach of Krause et al. (2001), the following sections summarise reported economic costs of soil erosion and benefits of soil conservation in terms of soil erosion and sediment impacts, rather than on-site and off-site impacts.

National cost estimates

Krause et al. (2001) estimated the economic cost of soil erosion in New Zealand as \$75.8 million (equivalent to NZ\$95.2 million in 2008) yr^{-1}. Loss of agricultural production accounts for \$37 million (equivalent to NZ\$46.5 million in 2008), and the remainder is due to direct damage costs. Indirect costs were not accounted for due to lack of available data. This includes intangible and relatively minor costs such as loss of visual amenity, loss of farmer motivation and confidence, and loss of indigenous biodiversity.

Pimental et al. (1995) estimated the total on-site and off-site cost of erosion in the US as US\$44 billion (equivalent to NZ\$113 billion in 2008) yr^{-1}. Approximately US\$37 billion (equivalent to NZ\$95 billion in 2008) yr^{-1} can be attributed to soil erosion effects, mainly due to agricultural production loss (US\$25 billion; equivalent to NZ\$64.2 billion in 2008). These results differ significantly from previous national estimates of soil erosion. For example, Crosson (1997) estimated agricultural productivity loss as US\$100-\$120 million (equivalent to NZ\$182.2-218.7 million in 2008) yr^{-1} using results from the US Department of Agriculture's Erosion Productivity Impact Calculator (EPIC) model. There is a lack of detail of the empirical models developed by Pimental et al. (1995) used to assess current rates of erosion in the US. The estimated costs of erosion by Pimental et al. (1995) also differ from the general consensus that off-site costs of erosion are greater than on-site costs (Colacicco et al., 1989).

The national cost of erosion in Zimbabwe is estimated as US$127.8 million (1983 dollars; equivalent to NZ$541.1 million in 2008) (Norse and Saigal, 1994). Such cost is estimated to exceed 16% of agricultural GDP, equivalent to 3% of the country's total GDP. This value is based on the cost of replacing lost nutrients from the soil, with nutrient leaching rates assessed from experimental plots and extrapolated to the national scale. Norse and Saigal (1994) highlighted the limitations of this approach, particularly the lack of attention to other interrelated physical processes influencing soil erosion and productivity loss, and the off-site and indirect effects such as the social costs of declining food security.

Direct damage costs from agricultural soil erosion in the UK are estimated as £14 million (equivalent to NZ$40.7 million in 2008) (Pretty et al., 2000).

Regional and catchment scale cost estimates

Direct landslide damage costs for historical rainstorms in New Zealand are provided in Glade (1998). The reported costs range between US$0.02-$9.19 million (equivalent to NZ$0.05-22.9 million in 2008) per region and event. Direct landslide damage costs after Cyclone Bola in the East Coast region were US$1.78 million (equivalent to NZ$4.4 million in 2008), increasing to $70.65 million (equivalent to NZ$176 million in 2008) on inclusion of productivity loss and indirect damage costs such as planning, engineering design, and maintenance (Glade, 1998). The estimated total damage cost from the July 1992 storms in the Manawatu-Wanganui region was in excess of $4.5 million (equivalent to NZ$6.3 million in 2008) for 83 hill country properties seeking financial assistance (Hicks et al., 1993).

Total costs are highly dependent on the type and level of costs included. For example, the estimated cost of wind erosion in South Australia ranges between A$3 million and A$23 million (1999 dollars) depending on whether emerging research findings on the relationship between wind erosion, dust and asthma are included (Williams and Young, 1999).

Sedimentation costs

National cost estimates

Krause et al. (2001) estimated the economic costs of sedimentation effects in New Zealand as $27.4 million (equivalent to NZ$34.4 million in 2008) yr^{-1}. This value includes damage costs from flooding, drinking water treatment facilities, water storage, navigation and water conveyance facility dredging and maintenance. Costs relating to agricultural production loss, processing water treatment, recreation, biological degradation and other diffuse impacts were not assessed due to a lack of available data.

The economic cost of sedimentation in Australia resulting from a predicted 1% to 10% decline in water quality is estimated as A$42-$123 million (equivalent to NZ$61.6-180.5 million in 2008) over 20 years from 2000 to 2020. This cost is comprised of infrastructure damage costs to reservoirs, channels, and sediment clean up by local government and road and rail operators. Current damage costs are not presented. Estimated downstream damage and water treatment costs from potential increases in salinity and turbidity concentrations in Australia are greater than the damage costs from soil erosion and sedimentation (Hajkowicz and Young, 2002).

The off-site cost of erosion in the US has been estimated as US$17 billion (equivalent to NZ$43.7 billion in 2008) yr^{-1} by Pimental et al. (1995). This includes damage costs from wind erosion, in-stream and off-stream damages. The in-stream and off-stream damage effects approximate the sedimentation effects defined by Krause et al. (2001). The total combined cost of in-stream and off-stream damage estimated by Pimental et al. (1995) is US$7.4 billion (equivalent to NZ$19 billion in 2008) yr^{-1}. An earlier assessment of the in-stream and off-stream costs of sedimentation in the US by Clark (1985) ranged between US$3.2 billion and $13 billion, with an average of US$6 billion yr^{-1} (1980 dollars). The cost on a regional basis can be high. For example, Moore and McCarl (1987) estimated water treatment, channels, culvert and drain maintenance costs in the Willamette Valley, Oregon, as US$5.5 million (equivalent to NZ$22.4 million in 2008) yr^{-1}. The Willamette Valley catchment is approximately 1.6 million hectares, roughly equivalent in size to the Auckland region.

Costs and benefits of mitigating erosion and sedimentation

Krause et al. (2001) estimated the national economic cost of soil conservation measures as $23.5 million (equivalent to NZ$29.5 million in 2008) yr^{-1}. This estimated value was based on reported Regional Council direct expenditure on soil conservation programs, annual investment in the East Coast Forestry Project ($2.7 million yr^{-1} in 1998, equivalent to $3.4 million in 2008 dollar terms), and road maintenance. Private expenditure, road realignment costs, and urban development erosion control costs were excluded due to lack of available financial information. The annual budget for afforestation programs under the East Coast Forestry Project is $6.5 million. With actual costs significantly below budget ($3.4 million in

2005), there is potential for increased afforestation to be undertaken (Bayfield and Meister, 2005).

Pimental et al. (1995) estimated a national investment of US$8.4 billion (equivalent to NZ$21.6 billion in 2008) yr^{-1} is required to reduce erosion rates from approximately 17 tons ha^{-1} yr^{-1} (15.4 Mg ha^{-1} yr^{-1}) to 1 ton ha^{-1} yr^{-1} (0.9 Mg ha^{-1} yr^{-1}) in the US. This equates to 19% of the total estimated cost of erosion in the US of US$44 billion (equivalent to NZ$113 billion in 2008) yr^{-1}. Colacicco et al. (1989) indicated that the US federal government has spent US$15 billion (equivalent to NZ$61.3 billion in 2008) on soil conservation practices from the 1930's to late 1980's (i.e. approximately $0.3 billion yr^{-1}; equivalent to NZ$1.2 billion in 2008).

With the current interest in emerging carbon markets, a number of studies (e.g. Lal, 2006; Sparling et al., 2006) have looked at the potential value of erosion control practices that have the potential to result in increased carbon sequestration in the soil, in some cases identifying a substantial potential value that could provide enhanced incentive for landowners to invest in soil conservation. Erosion usually results in decreased primary productivity of crops, which in turn reduces carbon storage and organic carbon returned to the soil (Gregorich et al., 1998). However, soil erosion and terrestrial sedimentation may also establish ecosystem disequilibria that promote carbon sequestration, particularly where upland soil is deposited into wetland systems with high primary productivity (McCarthy and Richie, 2002). For instance, Sparling et al. (2006) calculated the net present value of carbon in three different soil types in New Zealand to be between $518 and $722 per hectare. However, there is as yet no means of translating this into a real value for landowners, because the high transaction cost of verifying carbon storage in the soil means that this sequestration is not counted in most of the carbon instruments that are currently being traded.

Overall net costs

Krause et al. (2001) estimate the national economic cost of soil erosion and sedimentation in New Zealand at $126.7 million (equivalent to NZ$159.1 million in 2008) yr^{-1}. They caution that their value is a conservative estimate only. Although the true value is likely to be slightly greater than this estimate, it is not likely to be more than an order-of-magnitude greater. A number of potentially significant costs were not estimated due to difficulty with quantifying the diffuse nature of some effects and the point sample (project by project) collection of data.

An estimate of total costs of erosion in New Zealand is presented in Table 2. This would suggest that almost 30% of total estimated cost is due to agricultural production loss, a similar proportion due to damage to property and infrastructure, around 21% is due to off-site sediment effects and 19% due to soil conservation and other avoidance measures already in place.

Table 2. Summary of national costs of soil erosion in New Zealand (Source: Krausse et al., 2001) including equivalent values in 2008 dollar terms.

Nationwide costs of soil erosion	**Cost** ***NZ$m (1998)***			**Cost** ***NZ$m (2008)***
Damage costs (lost production, repair etc)				
Soil erosion effects				
Agricultural production loss	37.0	*29.2%*		46.5
Damage to infrastructure				
Farm infrastructure damage	5.6	*4.4%*		7.0
Direct private property damage	5.7	*4.5%*		7.2
Road/rail infrastructure damage	26.3	*20.8%*		33.0
Utility network damage	0.8	*0.6%*		1.0
Recreational facility damage	0.4	*0.3%*		0.5
Loss of visual amenity	na			
Other	na		30.6%	
Erosion Sub-total	**75.8**	***59.8%***		**95.2**
Sediment effects				
Increased flood severity				
Insured loss	16.3	*12.9%*		20.5
Production loss	na			
Reduced water quality				
Consumption	2.8	*2.2%*		3.5
Processing	na			
Recreation	na			
Biological degradation	na			
Sedimentation				
Water storage loss (incomplete data)	0.2	*0.2%*		0.3
Navigation	7.5	*5.9%*		9.4
Water conveyance	0.6	*0.5%*		0.8
Other	na			
Sediment Sub-total	**27.4**	***21.6%***		**34.4**
Damage & lost production sub-total	**103.2**			**129.6**
Avoidance/prevention (conservation) costs				
Regional authority expenditures	18.5	*14.6%*		23.2
Private expenditure	na			
East Coast Forestry Project	2.7	*2.1%*		3.4
Road preventive maintenance	2.3	*1.8%*		2.9
Road realignment	na			
Control measures with urban development	na			
Avoidance Sub-total	**23.5**	***18.5%***		**29.5**
Total soil erosion costs	**126.7**	***100.0%***		**159.1**

More recently, the *State of the Environment Report 2007* (Ministry for the Environment, 2007) claimed that hill country erosion is estimated to cost New Zealand between \$100 and \$150 million per year. The source of this estimate is unclear, but could be derived from an update of the Krausse et al. (2001) estimate. The Krausse et al. (2001) analysis provides a useful framework with which to view erosion costs, not just nationally but also regionally. However, it is an aggregate, not a marginal, estimate.

Summary

New Zealand is characterised by areas of high relief, a variable and intense maritime climate, and high rates of tectonic uplift and volcanic processes. As a result, New Zealand has high natural rates of erosion. These rates have been exacerbated by anthropogenic activities such as widespread deforestation and agricultural development of hill country. Ten million hectares (69%) of New Zealand’s land area is classified as hill country, with slopes greater than 12° and located below an altitude of 1,000 m above sea level.

The susceptibility of hill country to erosion is largely controlled by the inter-relationship of climate, topography, rate of tectonic uplift, and the underlying geology. In the North Island, approximately 200,000 ha of hill country have a severe to extreme erosion potential. These are mostly located in the East Coast region, with smaller areas in inland Taranaki, Northland and the Coromandel. The geology of the hill country landforms is soft crushed rock on the East Coast, soft rock in inland Taranaki and deeply weathered rock in Northland and the Coromandel. Mass movement is the most common type of erosion, particularly soil slip and earthflow erosion. In the South Island, less than 103,000 ha of hill country have a severe to extreme erosion potential. There, surface erosion is the dominant erosion type, particularly sheet erosion. Severe erosion areas occur on hard rock terrain in central Otago, Canterbury and Marlborough.

Erosion has long-term impacts on soil fertility and productivity. Recovery of topsoil properties and pasture on landslip scars to pre-erosion levels has been estimated as taking more than 80 years. The redistribution of soil organic matter during erosion and deposition in depressions and waterways has implications for carbon sequestration and greenhouse gas emissions. Further research is required to assess the magnitude and extent of carbon sequestration under different land uses at different locations.

Sediment impacts occur when eroded soil enters a waterway and settles or is redistributed further downstream. Specific impacts from sediment may include increased flood severity, reduced water quality, biological degradation, and sediment accumulation. Historical damage costs from flooding and downstream sedimentation have been significant. However, it is currently unclear what proportion of flood magnitude and damages (and their costs) can be attributed to the quantity of sediment in streams originating from erosion.

Control of erosion is largely achieved with wide-spaced or close-spaced tree and shrub plantings. Radiata pine and Douglas fir are commonly used for woodlots or areas requiring mass stabilisation, such as the East Coast region. Poplars are common on flatter, wetter slopes, although profitability analyses indicate marginal returns compared to pasture or radiata pine. Erosion is less likely under forest cover compared to scrub or pasture. The effectiveness of planted trees (exotic or native) for erosion control is dependent on tree species, site characteristics, stocking rate, and rotation age.

The economic impacts of soil erosion and sedimentation can be assessed in financial or economic terms, as can the benefits from soil conservation measures. Economic analysis can assist with the formation of effective land use policies, targeting areas for priority. A range of techniques are available for valuation of erosion and soil conservation impacts and cost-benefit analyses. The most common of these include Cost-benefit analysis for farm-level assessments.

Estimation of the economic costs of soil erosion in New Zealand is limited to one key study. Krause et al. (2001) estimated the national cost of soil erosion and sedimentation based on estimates of agricultural productivity loss and direct damage costs to farm infrastructure, transport, and utility and recreation networks. The national cost of soil erosion and sedimentation in New Zealand is estimated as $126.7 million yr^{-1} ($159 million in 2008 dollar terms). Additional research into costs of other erosion impacts is required, such as water quality and biodiversity degradation. These costs were not estimated due to the difficulty of quantifying the diffuse nature of some effects and the point nature of data collection.

Estimation of damage costs on a regional or catchment basis in New Zealand is more abundant. This information generally focuses on direct damage costs or loss of pasture productivity after large storm events. Information on sedimentation costs is minimal, similar to the national study by Krause et al (2001).

3 Recommended economic approach

The literature review has shown a broad consensus in the approach to measuring the economic costs of erosion, but also some variation in how costs are measured. The review has highlighted a number of choices in defining the economic measurement of erosion.

A fundamental choice is whether aggregate or marginal costs are the focus of examination. For most economic policy purposes, marginal measures are more useful – i.e. how the level of erosion changes in response to erosion prevention activity. However, they are also likely to be most dependent on site-specific factors and control variables, making it more difficult to draw generalisations with wide applicability.

Another fundamental choice is the framework of analysis used, and the methods that go into it. For economic policy purposes the pre-eminent framework of analysis is cost-benefit analysis, as this is designed to identify the effects of marginal or incremental changes with specified policies or actions in comparison to a 'counter-factual' without them. It is also able to cover both on-site and off-site effects, and account for effects that occur over different points in time, which is crucial for accumulative effects of erosion over time. The other frameworks identified in the literature – computable general equilibrium models, optimisation models, simulation models, total factor productivity, econometric models aimed at production functions – complement cost-benefit analysis and may provide valuable inputs to it. However, they represent just one way of providing the pieces for the cost-benefit 'jig-saw' and may be limited by site specificity and complex data requirements.

A cost-benefit analysis has a malleable framework which can be adapted according to the scope of interest and also to suit data availability. The most narrow cost-benefit analyses concentrate on property level effects and are largely confined to impacts on private owners, differing from a private financial analysis only in stripping out financial considerations (like subsidies) from the fundamental resource use implications. More common is a cost-benefit analysis that encompasses on-site effects and at least some of the tangible off-site and sedimentary effects, and hence covering both private and external effects and more closely approaching estimates of community-wide well-being. Wider still is a cost-benefit analysis that also covers the more intangible external effects, with recourse to non-market valuation techniques such as contingent valuation and choice modelling. As these valuation techniques tend to be complex and costly, and the cause-and-effect links between erosion and intangible effects tend to be more uncertain, the use of such techniques has yet to become accepted as a routine part of cost-benefit analysis for environmental policy development.

While in principle marginal effects examined through a cost-benefit framework may be most useful for policy purposes, there is relatively limited existing data of this type in the literature. What then can be said about the economic costs of hill country erosion and benefits of mitigation in New Zealand?

An approach to measuring the costs of erosion needs to encompass both on-site (erosion) and off-site (sedimentation) effects of erosion. For policy purposes it is useful to distinguish locations with high economic value at risk from erosion from areas with low value at risk. Furthermore, it would be useful to distinguish mitigation measures, not only in terms of their costs, but also in terms of their effectiveness in reducing soil erosion.

The economic value at risk due to soil erosion is a function of both susceptibility to erosion and its effects (reflecting physical characteristics such as slope, geology, soil type, land cover, climate) and the value of the land to human well-being. That value of the latter may be estimated by various means:

- The present value of the stream of net income from the property, which could be indicated by projecting net property income or gross margins per hectare from sustainable land uses,
- The value of structures and infrastructure that do not yield an obvious net income, which can be inferred from depreciated replacement value of assets such as buildings or roads, or, less specifically, from the improvement value on capital valuation rolls, and
- The value of resources (principally water) used in processes that would be affected by changes in the level of erosion.

Combining physical models that identify the susceptibility of land to erosion and deposition or sedimentation with information on the economic value at risk for land-based spatial units within individual catchments could provide a relative measure of the expected value of erosion effects in each catchment. Considering the effectiveness of different mitigation options in each catchment provides a relative measure of the expected value of erosion avoided by each option in each catchment. Comparing the cost of each mitigation option against the value gained from erosion avoided provides a measure of the net benefits to be obtained in different locations, and a means of prioritising use of limited resources to achieve the greatest net benefit.

The approach overlays indicators of economic value over physical data, such as slope, land cover, and landslide risk. Even at a fairly high level of comparison – using average values per hectare of a particular land type or per property – the approach will enable sorting of areas and allow attention to be directed to where both physical susceptibility to erosion (and its effects) and economic value at risk is greatest, rather than solely focussing on areas with the greatest physical susceptibility. After the initial prioritisation and screening-out of areas with lowest value at risk, it may be necessary to drill down in more detail to compare two or more locations to determine which would provide the greatest economic benefit from further mitigation action.

4 Development of an analytical framework

In order to implement the recommended economic approach, a spatially-enabled, analytical decision framework is required. The framework needs to incorporate the economic value of property or infrastructure at risk with the physical susceptibility to hill country erosion and sedimentation, and the likely benefits of mitigation in order to improve the prioritisation and evaluation of some remedial actions (e.g. tree planting). The economic solution to prioritisation is to subject remedial actions to a comparative analysis to identify which one would yield the greatest economic benefit from the resources expended in remediation and avoidance of expected erosion costs.

While there are aggregate estimates of the cost of erosion in New Zealand, a more useful approach for policy purposes and prioritisation is an incremental analysis of how net erosion costs change in relation to preventive or remedial activity. In the context of Table 2 (above), for instance, a relevant question is; would an increase in the avoidance or preventive category, if implemented, achieve a reduction of greater magnitude in the erosion and sediment effects categories, so as to reduce the overall cost of erosion? A second question is; what precisely are the preventive activities that could be implemented to achieve this effect? Conceivably these expenditures would encompass both new expenditures (e.g. on tree planting or land contouring) in addition to opportunity costs from activities forgone (e.g. reducing grazing intensity of some lands).

Previous studies have indicated that the information needed to adequately answer the above questions is incomplete at the national level, and is likely to be even scarcer at regional level. Estimates of the impacts of erosion-related events, such as Cyclone Bola or the floods of February 2004, are not undertaken in a systematic way, but rather prepared on an ad hoc basis to meet pressing needs at the time (such as determination of assistance schemes), with responsibility for collecting such data spread across regional, district, and national bodies (NZIER, 2004).

Nevertheless, while the quantitative information is incomplete, a qualitative framework can be put together that links land susceptible to erosion and the values at risk of its consequences. This provides a screening guide to prioritising actions that maximise the value protected per unit cost of erosion prevention (i.e. that are economically efficient and most beneficial to New Zealand at large).

A pragmatic approach would be to assemble quantitative and qualitative information in a form that enables comparison of remedial or avoidance options and allows for the screening-out of the least promising options. If available resources do not stretch to implementing all those that remain, further work on filling in the information gaps may be considered to refine the choices for prioritisation.

Intervention logic

The intervention logic would imply that, given a choice between a remedy with large on-site benefits and small off-site benefits, or one with small on-site benefit and large off-site benefits, priority would be given to the latter, other things held constant. Clearly property owners are unlikely to change their activities to achieve a greater external benefit unless the measures taken are worthwhile to them (or at least leave them no worse off). So the criteria for prioritisation of actions involve finding measures that:

- Maximise the expected value gained from the costs incurred in implementation,
- Provide an expected net benefit, or at least break-even, from the perspective of the land owners expected to implement them, and
- Given two or more options with the same expected net benefit, the one with the largest external (public) benefit is chosen in preference to those with a large on-site (private) benefit.

There are other premises for intervention that would give different results. One might be an overarching aim of sustainable land management, where sustainability is defined in terms of retaining soil and land in its current state (or reverting to a state with a less degraded status than currently) on the grounds that degradation is an irreversible change in meaningful human timeframes, and that erosion at anything above a background natural level represents a depletion of the life-sustaining capacity of the soil. This premise would be in accord with the natural science literature which notes that, in many parts of the world, the rate of soil degradation is now exceeding the rate of natural soil development.

The economic consequence of the above premise is that, although land qualities might be preserved, the costs of other activities are likely to be increased by the priority given to land protection. For instance, measures to protect so-called 'elite' (versatile and highly productive) soils, which are usually located on flat areas adjacent to cities and are easy to build on, are likely to increase the costs of urban development. Under current market conditions the value of produce from such soils has not risen sufficiently to ensure their retention for agricultural purposes over urban developments, so it is economically efficient to convert these areas to higher valued urban uses than to retain them for primary production. The balance of conversion and retention would change with more explicit accounting, using measures that internalise any externalities from the conversion, for the full effects of conversion. Similarly, the level of soil conservation would change if the external consequences of non-conservation were taken into account. The practical question for the case study to explore was how best to take account of the full consequences of erosion and its mitigation in a way that can usefully guide policy, without collapsing under the weight of its data requirements.

Assessment approaches

A broad policy question is where to target effort and resources towards erosion mitigation in order to achieve the largest net social benefit? This question underpins all public policy interventions, from the most light-handed measures (e.g. putting out information about risks and remedies) to the more heavy-handed interventions such as public works and regulations. In terms of the framework outlined in Table 2, this question revolves around where would an increase in preventive activity have the greatest impact in reducing on-site and sedimentation costs of hill country erosion?

A first stage in answering this question would be to divide the region into zones distinguished by the key characteristics that determine its susceptibility to erosion, deposition, or flooding. For instance, if susceptibility to erosion is determined by such factors as slope, underlying geology, and vegetative cover, units could be grouped according to variations in these determining factors.

A second stage would be to map the values at risk from erosion damage. This could be a function of the annualised value of current production, plus the value of any infrastructure at risk of damage from erosion effects. Sources for this information might include:

- Current production:
  - Net farm income (or gross margins) per hectare per year times effective area of the representative farm type,
  - Annualised net present value of forestry, and
- Infrastructure at risk:
  - With public infrastructure (such as roads and power lines), identify the location and density of such infrastructure; values are more problematic but could be inferred from annual maintenance costs for such infrastructure specific to the areas from bodies such as local councils, Transit New Zealand, Department of Conservation and so on,
  - For private structures, the improvements component of capital valuation for rating purposes could provide a first approximation.

A potential difficulty involved in this stage of the approach would be how to match the resolution of such factors as erosion risk with that of the other data. For instance, valuation data are typically held on a property basis, where a single property may encompass areas of land susceptible to erosion, deposition, and flooding. Ideally within-property details of land uses and the locations of infrastructure are required — council databases and Agribase for rural properties are potential sources of detail.

A third stage would be to identify the current erosion prevention and containment activities of both public agencies and private bodies. The annual plans and accounts of regional councils and territorial authorities should provide information on current and capital expenditures, which need to be assigned to the particular land units within their jurisdictions. If it is not possible to pinpoint expenditures to particular locations, the default position would be to use averages (e.g. the annual cost of flood-bank maintenance per kilometre multiplied by the length of flood-bank in a particular catchment or land unit).

The information can then be combined and maps and tables of costs and benefits can be compiled that compare different mitigation scenarios. Two frameworks to achieve such an analysis are presented. The first is a catchment-based framework that follows common practices for land-based evaluations. While the first approach does make use of spatial data, the second framework is built from the bottom up and is completely reliant on, and would fully exploit, high resolution spatial data and analyses, and is thus referred to as the spatial framework.

A catchment-based framework for erosion management decisions

The economic information required to assist in prioritising erosion prevention or mitigation work (soil conservation) is illustrated in a simplified, high level form (Table 3). The framework is a condensed version of that provided by Krausse et al. (2001) (see Table 2) and compares two hypothetical zones based around catchment areas.

Table 3. Comparison of erosion costs and mitigation options for two hypothetical zones.

		Zone 1		Erosion effects		Zone 2		Erosion effects	
Damage costs (lost production, repair etc)			**Status quo**	**Option 1**	**Option 2**		**Status quo**	**Option 1**	**Option 2**
Soil erosion effects			*$m/yr*	*$m/yr*	*$m/yr*		*$m/yr*	*$m/yr*	*$m/yr*
Agricultural production $m/year		398.0	8.0	7.0	7.5	208.0	4.2	3.8	4.0
Infrastructure $m		4,907.0	2.5	2.1	2.3	2,002.0	1.0	0.8	0.9
Other $m									
	Value at risk	**5,305.0**				**2,210.0**			
	Erosion Sub-total		**10.4**	**9.1**	**9.8**		**5.2**	**4.6**	**4.9**
Sediment effects									
Flood severity	Expected value of damage per year		1.8	1.5	1.8		1.2	1.0	1.1
Water quality	Treatment costs per year		5.4	5.2	5.3		3.5	3.4	3.5
Sedimentation	Other sedmentation repairs per year		3.6	3.5	3.6		2.1	1.9	2.0
Other									
	Sediment Sub-total		**10.8**	**10.2**	**10.7**		**6.8**	**6.3**	**6.6**
Avoidance/prevention (conservation) costs									
Regional authority expenditures			1.2	1.2	1.2		0.7	0.7	0.7
Private expenditure			4.2	4.0	4.1		3.8	3.6	3.7
Road preventive maintenance			0.2	0.2	0.2		0.2	0.2	0.2
Road realignment			0.1	0.1	0.1		0.1	0.1	0.1
Other									
Control measures				0.9	0.4			0.9	0.4
	Avoidance Sub-total		**5.7**	**6.4**	**6.0**		**4.8**	**5.5**	**5.1**
Total soil erosion costs			**26.9**	**25.7**	**26.5**		**16.8**	**16.4**	**16.6**
Discount rate	10%	Benefit Cost Ratio		9.79	7.62		BCR	2.40	2.41
		Net Present Value $m		8.8	3.0		NPV $m	2.2	1.0

For each zone, the value at risk of erosion is summarised as an estimated annual agricultural (and forestry) production on erosion-prone land, and the capital value of infrastructure and other property improvements (Table 3). The erosion effects under current conditions (the status quo) and two alternative options for applying erosion control (soil conservation) measures to the characteristics and circumstances of each catchment zone are compared. These estimates depend on projection of current land uses, technologies, and costs and prices under known technologies. If any of these factors change significantly then that can either be allowed for explicitly in the modelling for each zone or by weighting the results of the comparison according to where value at risk is increasing most.

The cost of erosion and sedimentation under the status quo scenario depends on:

- The extent to which current erosion levels reduce the effective productive area,
- The proportion of infrastructure repairs and maintenance that can be attributed to the effects of erosion,
- An expected cost value (annual average) of consequences of erosion-derived sediment, particularly flood damage, water treatment, and repairs to damage resulting from sedimentation effects (e.g. dredging to clear water channels or retain navigation), and
- The identifiable annual costs incurred by regional authorities, private entities, road maintenance authorities, and others to counter the effects of erosion and sedimentation.

The cost of erosion and sedimentation under the alternative erosion control options depend on the technical assessment of the costs and consequences of those different options. For instance, if a programme of production tree planting (e.g. radiata pine stands) reduces the susceptibility of erosion on a particular class of land, this is likely to:

- Reduce the loss of effective area due to erosion over time, but will also:
  - reduce the effective area available for agricultural production (grazing) and
  - replace areas of formally grazed land with production forestry with its own income stream and operational costs,
- Reduce the damage caused by erosion to infrastructure and other structures, and
- Reduce the sediment deposited on adjoining land and into waterways, with downstream (and off-site, possibly public) consequences (mainly benefits).

These effects have a time related component because control measures may improve the rate of recovery of eroded land as well as reducing the probability of further erosion occurring. Some control measures may take longer to become fully effective than others. This means it is the average annual effect of each option over its lifetime that needs to be compared against continuation of the status quo.

The hypothetical figures presented in Table 3 are relative to the current estimated situation. For instance, in Zone 1, if erosion effects of $8 million per year could be eliminated, agricultural production could potentially be increased by the same amount over the current $398 million. In economic terms, that would be a welfare gain, as would a saving of $2.5 million if erosion damage to infrastructure were eliminated. The options do not eliminate erosion effects and costs, but they can be expected to reduce most of them, except for the cost of the control measures themselves.

The figures in Table 3 indicate:

- Whether each control option is worthwhile (i.e. has incremental benefit greater than costs) — this is indicated by the Net Present Value (NPV), which in the table is calculated over 25 years at a 10 % discount rate, and shows that all the options would result in net benefits in this example,
- Which of the control options has the greatest return on investment — this is indicated by the benefit-cost ratio which is calculated alongside the NPV, and
- In which of the zones would control measures yield the greatest net benefit for the community — this is indicated by the NPV, but would also be strongly suggested by the relative size of the value at risk in the two zones, should information be insufficient to complete the NPV analysis. Clearly, the framework suggests that, in this example, priority should be given to the implementation of soil conservation measures in Zone 1.

The steps required to implement the framework are:

1. Define zones within catchment areas which encompass areas of erosion-prone land and areas onto which eroded material would be deposited either directly or indirectly through sediments deposited streams, to produce an erosion effects risk map;
2. Estimate in broad terms the current value of production in each zone: for land-based enterprises such as agriculture, horticulture, and forestry, this can be the annualised value (i.e. the annual average present value of a stream of outputs over a number of years of current land uses and technologies) as represented by gross margins per hectare for different types of land; for non-land-based activities the annualised capital value of property is a proxy for annual rental values expected from the property, the land value component reflecting pure location and development potential, the improvements component reflecting the value of structures;
3. Combine the land-based production value and value of structures (improvements) with the erosion effects risk map into a map of value at risk across each catchment per year;
4. Use current observations to estimate the degree to which current levels of erosion reduce the effective productive land area, and hence productive value of the land of particular class across the zone; similarly, the cost of structural damage caused by current erosion (as indicated by specific repair expenditures on slips and subsidence);

5. Estimate annual average costs associated with sedimentation in the catchment, including flood damage costs, water quality treatment costs, other sedimentation repairs (e.g. ditch clearing etc);
6. Estimate annual average avoidance/prevention costs from specific expenditures of regional councils, road maintenance authorities, and the level of private expenditures on erosion containment and remediation (e.g. poplar planting, debris dam development);
7. To the extent they can be defined, the above (points 4 to 6) estimates provide the status quo of erosion effects in each catchment against which alternative control options can be compared;
8. For each control option (e.g. wide-spaced poplar planting and continued grazing versus the planting of a stand of production trees in key sediment source areas) estimate the changes in production (accounting for the off-set of losses of pasture production in some areas with gains in others and future revenue from forest production) expected and the reduction in infrastructure damage and sedimentation costs as a consequence of reduced erosion and sedimentation risk, valued as a present value of a stream of annual increments over the same period of analysis and converted to annualised values;
9. Compare each option against the status quo to provide incremental added costs and benefits, and a discounted analysis can be applied to the up front costs and long term stream of benefits to yield net present values and benefit cost ratios.

A spatially-based framework for erosion management decisions

With the collection of extensive spatial data at increasingly fine resolutions, higher resolution economic modelling and evaluation becomes possible. While probably still not of the resolution required for the development of individual farm plans such as the Whole Farm Plans of Horizon Regional Council's Sustainable Land Use Initiative (SLUI), it is technically feasible to perform modelling at the within-farm level using paddock- or even sub-paddock-sized spatial units, here referred to as land management units. The greater level of local accuracy should allow for more accurate aggregated figures for a landscape or region, hence increasing the accuracy of regional and national investigations of erosion and mitigation scenarios.

The proposed methodology for performing highly detailed erosion cost and mitigation benefit studies follows the same principles as described for the catchment-based framework analysis but with additional data and steps as described below.

Data development for the spatially-based framework

The estimation of economic costs and the benefits of mitigation at the land management unit level require the collation and further development of extensive spatial GIS data on:

- The risks of erosion and sedimentation impacts (both on-site and off-site, as listed in Table 2) in addition to the potential costs associated with these impacts, using the approaches described in the catchment-based framework, and
- On-site and off-site costs of mitigation measures. Note that the focus of this report is on land-based mitigation efforts such as land retirement into un-grazed woody vegetation, wide-spaced tree planting (allowing for continuation of grazing), and establishment of production forest stands. Other works such as debris dams on farms, and road and stream bank protection works (e.g. debris catch fences) are also options but require a different modelling approach not covered here. Land-based mitigation ultimately involves some modification agricultural land management practices or partial land use change and so the opportunity costs of these changes are incorporated in the framework.

For the most effective control of erosion from land with the greatest risk of erosion, a permanent woody vegetation cover may be required. Examples of land requiring permanent cover are, from Horizon Regional Council's SLUI: gullies, highly eroded marginal land potentially already in bush though still grazed, land with existing extreme to severe erosion or in the process of being severely eroded and areas too small or too isolated for commercial forestry to be considered. The options here are for:

- Retirement of land — requires stock removal and exclusion (fencing) and may also require pest management to encourage faster regeneration, and
- Permanent forest sinks for carbon credits — only possible for pasture land without prior woody vegetation. Options here are to allow reversion to indigenous woody cover, with the reversion actively managed and enhanced by plantings, or the purposeful planting of exotic trees such as radiata pine for faster rates of carbon sequestration.

For land areas with less severe erosion risk levels, production forestry or farm-forestry are mitigating land uses with economic returns. However, for forestry operations to be cost-effective, issues such as site productivity (in relation to tree growth) and the economics of harvesting – including issues such as road access, costs of logging, and distance to ports or market – need to be considered. Finally, the more moderate the erosion risk level, the more likely it is that widely-spaced tree plantings in key locations – allowing the continuation of grazing and hence continued returns from pastoral farming – will be effective.

The biophysical drivers for determining the cut-off between permanent woody vegetation cover and forestry, between forestry and widely-spaced tree plantings, and between widely-spaced trees and clear pasture are a function of the desired reduction in sedimentation from existing erosion and the desired reduction in the risk of further erosion. However, for decisions at the individual farm level, the effect of land use change on the farm economics is also important. At the catchment or regional level, the economics of mitigation is similarly important. The framework described here focuses on the development of the economics of cost-benefit scenarios at the lowest unit of spatial measurement available from the data (e.g. per hectare if available) hence the method is suitable for farm, regional, and national levels of analysis.

Methodology of the spatially-based framework

The basic structure and sequence of the methodology is shown in Figure 1. It is based on the approach developed by Polglase et al. (2008), accessed through Ensis, the joint venture between Scion and CSIRO, and involves the following steps:

1. Development of plantation production systems and other planting scenarios
    a. Determine the nature of the production systems to be modelled: timber production, pulp-wood production, bio-energy supply, or carbon sequestration plantings,
    b. Provide the tree growth rates for each system,
    c. For each system, define initial tree spacing, age and density of thinning, the time of harvest (where required), and the split of products into various pathways and destinations. Information on local costs of establishment, maintenance, harvesting, and product prices are also required.
2. Construction of spatial surfaces using a GIS
    a. Existing data layers may need to be collected from various sources and some new layers may need to be generated. The data layers required would include

existing vegetation cover, existing processing facilities, road and other transport infrastructure, and 'profit at full equity' for agricultural land uses.

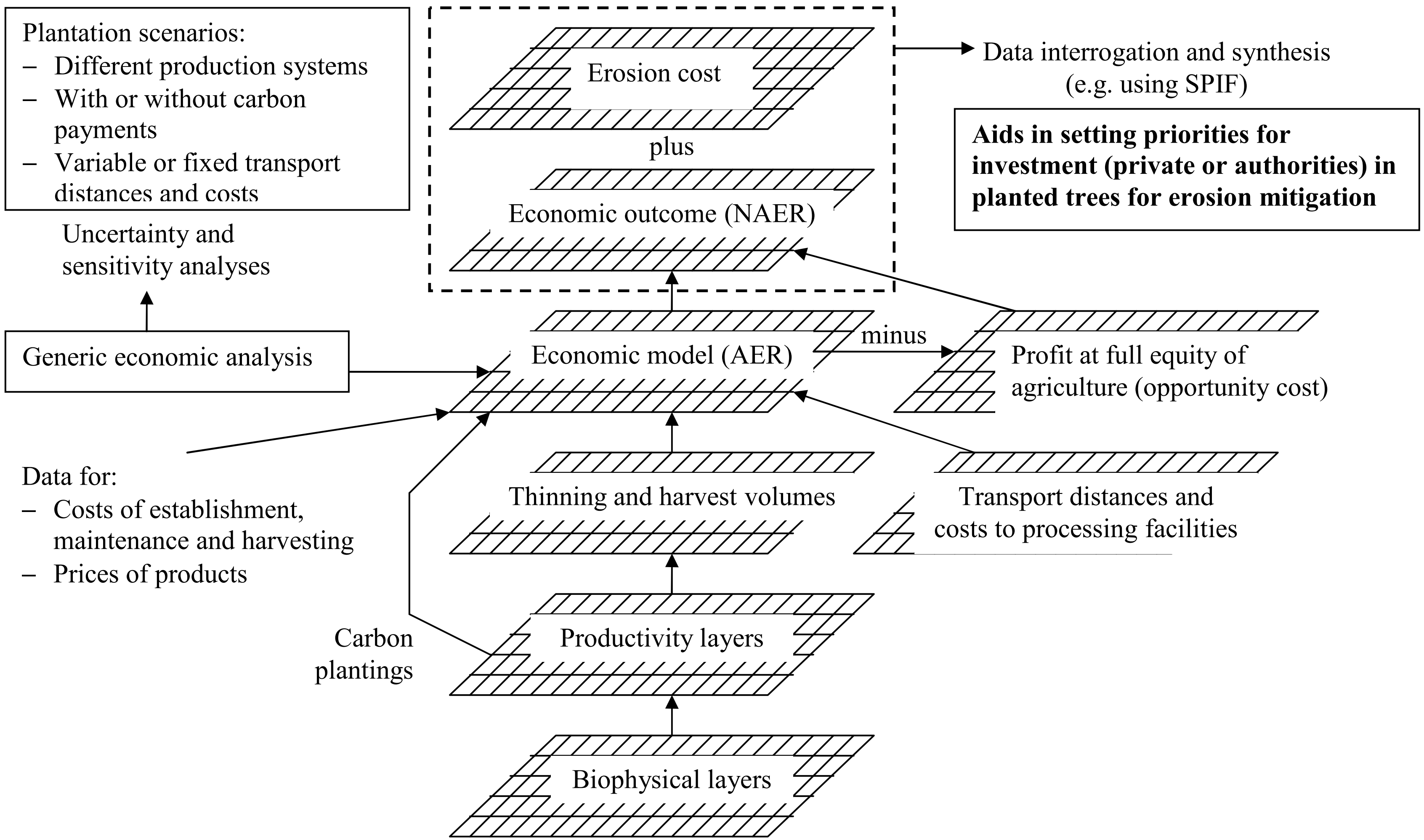
3. Tree growth prediction
    a. Compilation of an extensive data-set to be used for model calibration and validation,
    b. Obtain data on drivers for growth of new production systems (e.g. carbon forests),
    c. Run growth models for the production systems to generate spatial outputs for volume of product at times of commercial thinning and harvest, or amount of carbon sequestered.
4. Economic modelling
    a. Compute generic economic calculations for above systems using an economic spreadsheet or software such as Forecaster,
    b. For each scenario, capture inputs that are not spatially explicit at the minimum resolution scale such as costs of establishment, maintenance, harvesting, and products generated and their values. Costs of harvesting may depend on factors such as the volume of stems harvest, steepness of the terrain, and road infrastructure,
    c. The spatial model then reads, for each minimum unit of resolution (e.g. 1ha), depending on the production system, the thinning volume, harvest volume, amount of carbon sequestered, and other relevant data,
    d. The model then calculates for each product stream, distance to markets and transport costs to derive a value for Annual Equivalent Return (AER) at destination gate. The AER is an annualised Net Present Value that 'normalises' calculated profitability to enable comparison of longer rotation crops with the annual returns derived from conventional agricultural enterprises (Hobbs et al., 2007),
    e. The values for AER are then subtracted for each minimum unit from the values of the layer 'profit at full equity' of the preceding agricultural land use (the opportunity cost of the land) in order to determine values of the Net Annual Equivalent Return (NAER),
    f. Output values can be summed in a number of ways, such as for each production system, or on a farm, catchment, district, or regional basis,
    g. Uncertainty and sensitivity analysis is performed to identify the main parameters and inputs that affect predicted economic outcomes.

5. Erosion mitigation impacts
    a. New spatial layers would need to be developed for the cost of erosion under the status quo and alternative mitigation options (approaches for this are in the section on the catchment-based framework),
    b. An economic comparison can then be made of the returns from changing land use to planted trees versus no response to existing erosion and risk of further erosion under the existing land use (i.e. blanket pastoral grazing).
6. Multiple impact assessment
    a. The Scenario Planning and Investment Framework (SPIF) (CSIRO, 2007) could then be used to develop a number of scenarios and to identify areas where the combination of profitability and erosion mitigation benefit is greatest.

The main outputs of interest that could be produced using the spatially-based framework include:

- Economic outcomes including the AER and NAER to the farmer or investor,
- Uncertainty and sensitivity analysis of the economic model to demonstrate the main factors controlling calculated profitability,
- Combination of the costs of erosion and benefits of the mitigation of erosion, together with the costs and income associated with different mitigation activities, and
- Data synthesis and interrogation that summarises results into quantifiable metrics.

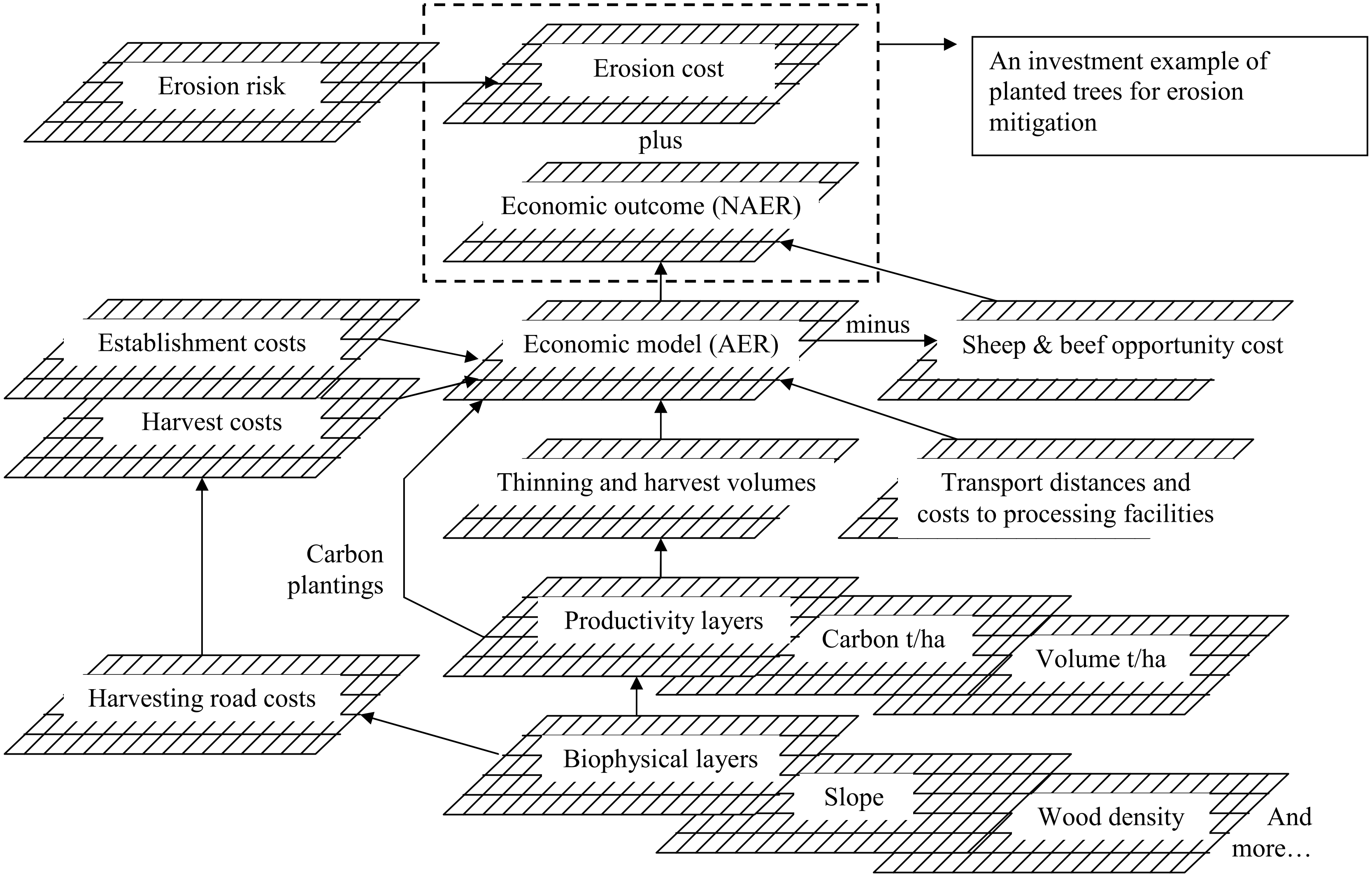
Figure 1. Schematic flow diagram of the development processes for the spatially-based framework.



Examples of specific data inputs to the spatially-based framework

In order to more fully illustrate the spatially-based framework outlined in fairly generic terms above, some of the specific data layers that could be used in the implementation of the approach are described. A schematic flow diagram illustrating the incorporation of more specific data layers into the spatially-based framework is given as Figure 2. Data layers such as predicted erosion risk, the gross margin per ha of sheep and beef grazing, wood density, harvesting road costs, and transport distances to ports or other markets represent some of the information that would be required to fully assess (both in spatial and absolute terms) the economic costs and benefits of controlling hill country soil erosion in a region like the Manawatu using production forest plantings and to guide the optimal (both in terms of biophysical need and net economic return on investment) location of those plantings for mitigating the erosion problem.

Figure 2. Schematic flow diagram illustrating the use of more specific input data layers within the spatially-based framework.



Maps of some of the data layers required were developed and are presented here.

A component of harvesting costs is the harvesting road construction costs. An example of such as surface has been developed on the basis of slope, soil type, a terrain complexity index, and expert knowledge on harvesting road costs in relation to these factors (Figure 3).

In order to determine the transport distances and costs, potential destinations for wood and fibre products need to be determined. The importance of identifying market locations for these products is highlighted in Figure 4, which shows an example of the differences between distances to export ports alone, compared to distances to ports and other potential markets such as co-generation plants.

A carbon productivity layer showing the mass (Mg) of CO_2 equivalent (Figure 5) has been calculated from, among others, a wood density layer (Figure 6). The mass of carbon sequestered can then be converted to financial income using data regarding the value of carbon sequestered from a carbon credit scenario.

Figure 3. Estimated harvesting road costs data layer.

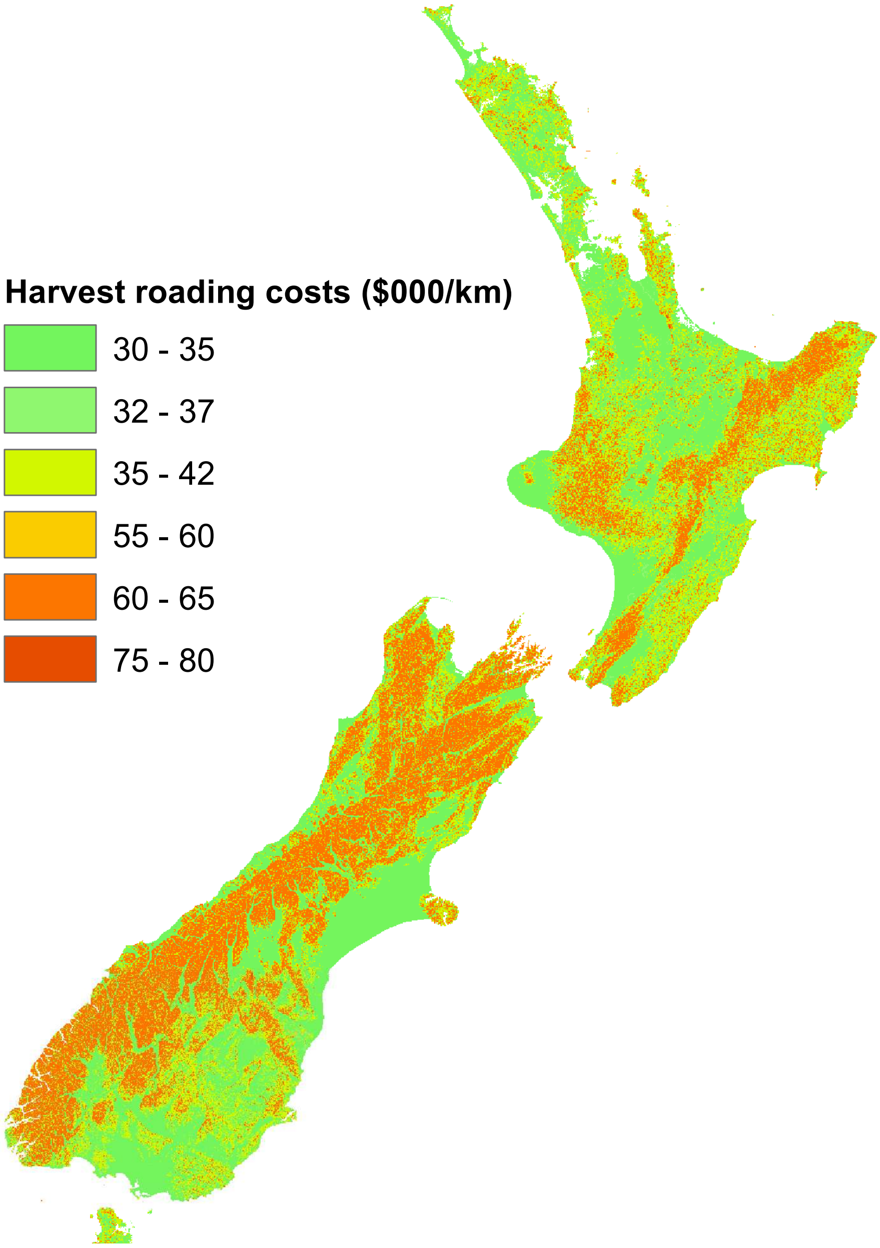


Figure 4. Forest wood fibre requiring transportation to (a) export ports compared to (b) more local co-generation plants.

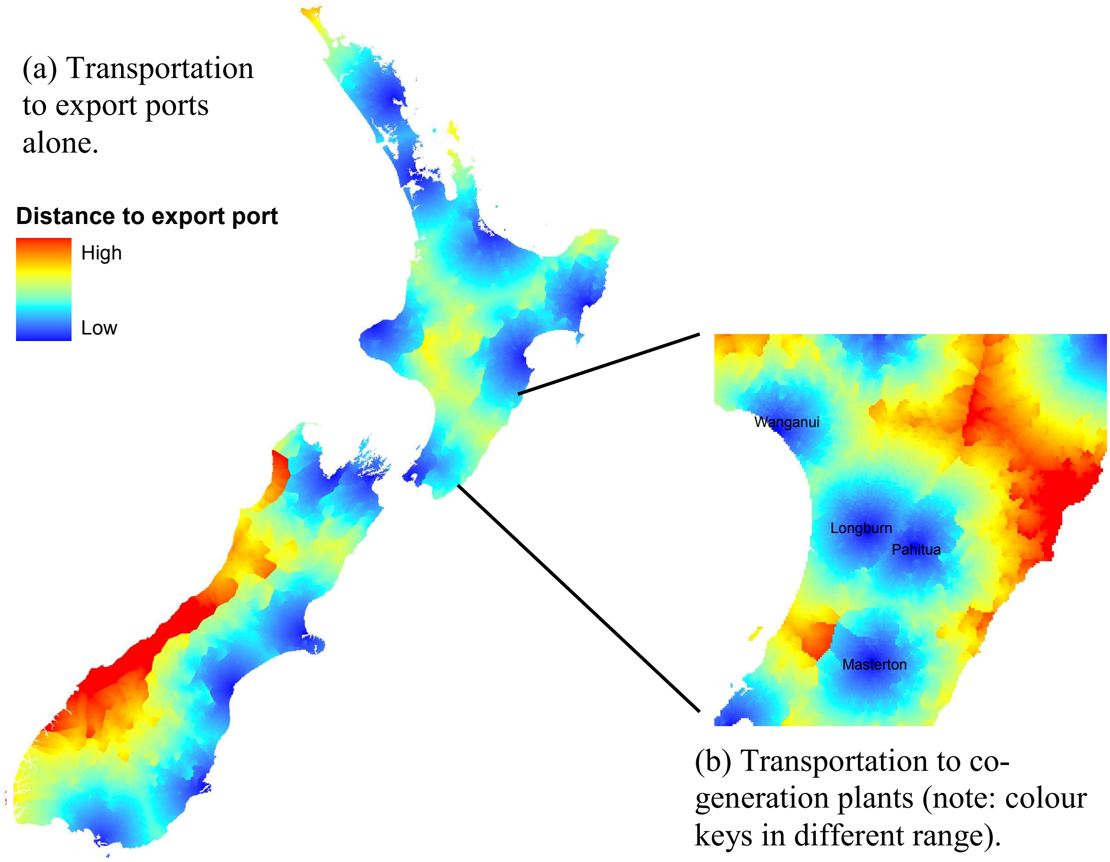


Figure 5. Mass (Mg) of CO_2 equivalent for carbon sequestration calculations.

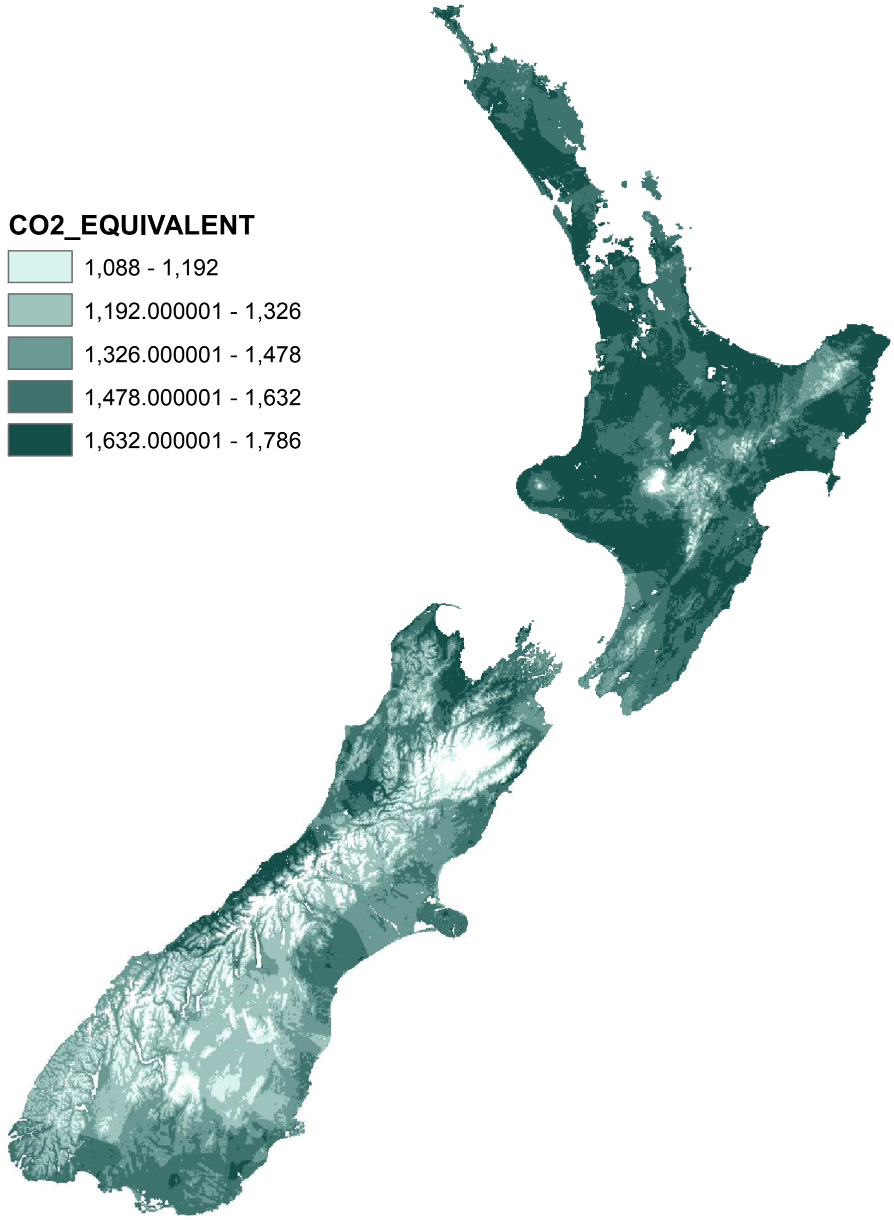
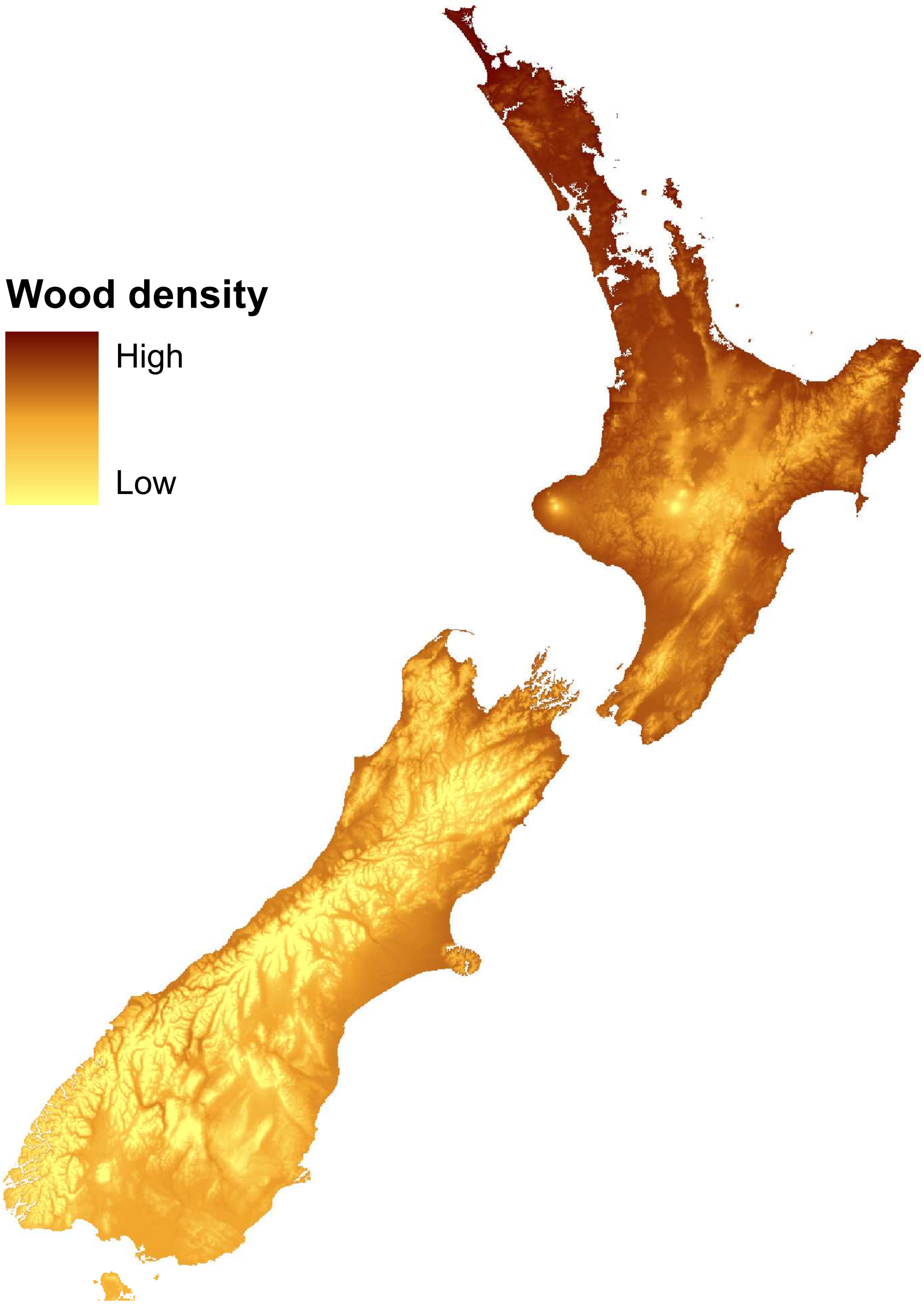


Figure 6. Wood density distribution in New Zealand.



5 General summary, conclusions, and recommendations

The impacts of hill country erosion on soil fertility and carbon storage in New Zealand have not been overly-well studied, although some work has been done locally and internationally. The loss of fertility and carbon from hill country soils has implications for farm or forest productivity and, in turn, the economic value of the land. Therefore, more work towards a better understanding of erosion-induced changes in soil fertility and carbon storage and the economic value of these changes is recommended to help support better assessments of the overall costs of erosion.

It is inherently difficult to determine what proportion of the economic costs incurred by flood damage can be attributed to increased levels of sedimentation and greater flood peaks resulting from accelerated hill country erosion. Further work is require to address this issue in order to achieve more accurate estimates of the erosion-derived economic costs (c.f. the total cost of flood damage of which not all can be attributed to erosion).

Tree plantings of suitable design are widely considered to be reasonably effective for mitigating or limiting hill country erosion. However, a profitability analysis study has shown that production woodlots of radiata pine may be a more profitable alternative than pastoral agriculture in some areas. It is recommended that further research into hill country land use optimisation be undertaken to determine the most effective (in terms of erosion control and economic return) locations and designs of production woodlots within hill country farms.

A range of economic analysis and valuation techniques are available for the assessment of the economic costs of erosions and the benefits of its mitigation. In broad terms, a costs-benefit analysis approach is recommended, in combination with the use of various other techniques for establishing non-market values of the more intangible off-site effects, for the assessment of the costs of erosion and benefits of mitigation. However, the availability of suitable data is likely to be a key limitation. With respect to the prioritisation of mitigation activity or investment, it is recommended that economic value at risk be defined in a spatial sense and that this information be used in association with information on the physical susceptibility to erosion and sedimentation in order to identify the locations where erosion control would be most effective.

The national annual cost of erosion and sedimentation in New Zealand has been estimated to be around $159 million per year (in 2008 dollar terms) by Krausse et al. (2001). However, this figure does not include effects on less-tangible effects like water quality decline and biodiversity loss. Therefore, it is recommended that further research be undertaken towards quantifying the costs of these effects.

An analytical framework for implementing the recommended economic approach and prioritising the establishment of soil conservation plantings (primarily woodlots) in terms of location was developed and described. Two variations on the framework were detailed – a catchment-based framework and a fully spatially-based framework – with the latter requiring a greater input of high-resolution spatial data than the other. It is recommended that further work be undertaken, in close association with relevant regional councils, to trial the implementation of frameworks for prioritising soil conservation activity within a region.

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Appendix A: The value of adverse events

The "economic impacts" of an event such as erosion or land slip are defined here as "the difference between what did happen and what would have happened without the event regarding the consumption of goods and services and the management of resources".

It is important to distinguish between *economic* and *financial* losses. Financial losses typically relate to the value of property damage of individual homes or businesses, without consideration of the impact of these losses on other agents in the economy. Financial losses from natural disasters are often equated to the value of insurance claims, although these clearly ignore the value of non-insured losses.

Economic losses are much broader in scope. As well as accounting for the initial damage resulting from a hazard event, they also incorporate the flow-on effects on other sectors of the economy. A breakage in lifeline infrastructure is an obvious example of how an impact in one sector – for instance, electricity transmission – has potentially significant consequences for the rest of the economy.

Consistently estimating losses across events requires a framework for classifying these impacts. A method typically used to estimate the costs of a natural disaster is to categorise the losses into tangible and intangible losses, which are each further subdivided into direct and indirect losses.

Tangible losses relate to those which can be relatively easily valued via some market price; intangible losses, on the other hand, affect items for which no observable market exists, and are thus considerably more difficult to accurately estimate. The direct costs of a flood event, for example, result from the physical contact of flood water with damageable property. Indirect costs reflect the flow-on impacts of direct damage (e.g. transport disruption) throughout the rest of the economy.

All losses, both direct and indirect, may be assessed via surveys of affected households and businesses, but a more practical approach is to only survey directly-affected parties and use economic modelling techniques to estimate the indirect effects. This modelling typically relies on the use of background data about the inter-sectoral linkages in the affected economy, such as that contained in input-output tables, and using multiplier-type analysis or computable general equilibrium modelling, to estimate the effects flowing from direct damage.

GDP (or, at a sectoral level, value added) is often used as a measure of the economic loss arising from a hazard event. However, there are subtle but significant differences between the value of assets damaged or destroyed in an adverse event, and the change in GDP caused by that event. In essence, the former measures changes to the affected region's balance sheet (i.e. the change in a "stock" variable), while the latter measures the change in production-based income accruing to the region (i.e. a "flow" variable). There are clear links between balance sheet and production impacts that must be considered when estimating the losses accruing from any natural hazard, but it is not simply a case of adding stock and flow impacts together in order to estimate total loss.

GDP is a measure of production,[1] and as a measure of loss, it also ignores many of the sectoral transfers that arise following an event. It does not explicitly account for non-production related transactions, including the payment of insurance claims by insurers and disaster relief by government or non-profit organisations. In the national accounting framework, these non-production flows are recorded in the income-outlay accounts, "below the line" of the GDP calculation. Thus, explicitly accounting for these flows, which can often be substantial in the context of an adverse event, requires consideration of more than GDP alone.

Disasters also provide opportunities for increased activity in some sectors, *viz*, those involved in the reconstruction effort. These increases have a positive impact on GDP. In fact, since many of the losses caused by a hazard affect non-GDP variables (in particular, assets i.e. balance sheet items), these increases in activity can be enough to more than offset any reductions brought about by the event, giving rise to the seemingly perverse result that hazards generally can be GDP-enhancing! The remedy is simply to not use GDP as the sole metric of loss.

The total economic cost of a past adverse event can be ascertained through a combination of ex-post surveying and economic modelling techniques. Such losses can also be estimated ex-

[1] Alternatively, given the national accounting identity GO-IC=C+I+G+X-M, GDP equates to a measure of the income earned via production (i.e. GO-IC = VA) and to the value of final expenditure necessary to achieve that production (i.e. C+I+G+X-M). Regardless of the GDP measure used – production, income or expenditure – all GDP flows relate directly to the production activity of a particular period.

ante. For example, *ex ante* flood costs can be determined for a hypothetical flood event, characterised by values for flood depth, water velocity, etc, and given a relationship between those flood characteristics and likely damage. For events that are relatively common (such as floods) it is easier to determine expected values of damage in different settings than is the case for events that are infrequent.

One often overlooked issue is determining the economic value of property immediately prior to damage. Surveys typically question respondents about asset loss (or damage) without supplementary questions aimed at determining the remaining useful life of those assets. Thus, respondents may respond by recording the replacement value – that is, the value of a brand new equivalent – for a damaged asset, rather than the estimated value of that asset given its age. The consequence of this is an overstatement of the value of loss caused by the disaster since the value of the pre-event asset base has effectively been overstated. This issue has a parallel in insurance claim data as discussed below.

Insurance data have several distinct advantages over surveying. Claims information is readily accessible, relative to the process of survey development, distribution, enumeration, etc. Many insurance companies publish aggregated claims information for hazard events, either independently or via an industry body (as is the case with the Insurance Council of New Zealand ICNZ). Governments that provide top-up cover (again using New Zealand's EQC as an example) are also likely to publish payout information. However, insurance data have disadvantages which affect the extent to which they represent economic losses. The biggest issue is that of under- or un-insurance. The Insurance Council's own estimates are that between 25% and 40% of property is under- or uninsured. The converse suggests that anywhere between 60% and 75% of all direct losses are covered by insurance policies, and are thus not borne within the region of the event. Indirect tangible losses are more likely to be met locally; business disruption losses are typically not well insured against.[2]

In some instances, the cost of obtaining insurance cover is prohibitively high. This was illustrated in the 2004 floods in the lower North Island, where most farmers suffered uncovered losses due to prohibitively high premium payments. Under-insurance is a related but arguably lesser problem in which sums insured are not adequate to cover the assets protected.

[2] National Business Review, "Under Insurance Tackled", April 16, 2004, p10.

Even with flooding, the most commonly occurring adverse natural event in New Zealand, past estimation of losses has been sporadic, and at no time has a consistent flood loss estimation methodology been employed across a number of events. Thus, current flood costs, in terms of (say) average annual costs, can not be known with certainty, nor pinpointed to particular localities.

The data available are incomplete as insurance costs dominate the values given. Furthermore, the insurance cost does not indicate what items are included: business interruption costs, life and medical insurance payouts, and insured agricultural losses cost might or might not be included in the ICNZ values.

Systematic and centralised recording of floods and their impacts is necessary if reliable, consistent estimates of actual losses are to be made. The rate of increase in flood risk over time will be influenced by three factors: climate change; the rate at which the value of the properties and infrastructure at risk increase; and the rate at which building takes place in flood-risk areas.[3]

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[3] Risk is defined as the product of probability and consequence.

Appendix B: Standardised reported cost values

Reference	Cost category	Date	Currency	Reported cost	NZ$ equiv.	CPI	March 08 NZ$ equiv.	Land area	March 08 NZ$ equiv.
				($m)	($m)	(1044)	(NZ$m)	(km2)	(NZ$/km2)
Hicks et al., 1993	1992 Man-Wang storm damage	1992	NZ		4.5	741	6.3	22,199	285.42
Krause et al., 2001	Soil erosion costs	1998	NZ		75.8	831	95.2	266,895	356.72
Krause et al., 2001	Agricultural production costs	1998	NZ		37	831	46.5	266,895	174.13
Krause et al., 2001	Sedimentation costs	1998	NZ		27.4	831	34.4	266,895	128.95
Krause et al., 2001	Soil conservation costs	1998	NZ		23.5	831	29.5	266,895	110.59
Krause et al., 2001	East Coast Conservation	1998	NZ		2.7	831	3.4	266,895	12.71
Krause et al., 2001	Overall erosion costs	1998	NZ		126.7	831	159.1	266,895	596.26
Glade, 1998	NZ Landslide damage min	1988	US	0.0	0.0	632	0.05	266,895	0.19
Glade, 1998	NZ Landslide damage max	1988	US	9.2	13.9	632	22.9	266,895	85.76
Glade, 1998	NZ Landslide damage Bola direct	1988	US	1.8	2.7	632	4.4	266,895	16.61
Glade, 1998	NZ Landslide damage Bola+indirect	1988	US	70.7	106.5	632	176.0	266,895	659.27
Moore & McCarl, 1987	US Willamette Valley water works	1984	US	5.5	8.2	383	22.4	16,000	1,403.02
Pimental, 1995	Total US erosion costs	1992	US	44000.0	80262.7	741	113,010.5	9,826,630	11,500.44
Pimental, 1995	Total US soil erosion costs	1992	US	37000.0	67493.6	741	95,031.6	9,826,630	9,670.82
Pimental, 1995	Total US agricultural loss	1992	US	25000.0	45603.8	741	64,210.5	9,826,630	6,534.34
Pimental, 1995	Total US Off-site costs	1992	US	17000.0	31010.6	741	43,663.2	9,826,630	4,443.35
Pimental, 1995	Total US Instream & Off stream cost	1992	US	7400.0	13498.7	741	19,006.3	9,826,630	1,934.16
Pimental, 1995	Conservation investment	1992	US	8400.0	15322.9	741	21,574.7	9,826,630	2,195.54
Colaccio, 1989	50 year Soil conservation costs	1982	US	15000.0	19280.2	328	61,287.1	9,826,630	6,236.84
Colaccio, 1989	Ave annual Soil conservation costs	1982	US	0.3	0.4	328	1.2	9,826,630	0.12
Crosson, 1997	US Agricultural production loss min	1997	US	100.0	143.2	821	182.2	9,826,630	18.54
Crosson, 1997	US Agricultural production loss max	1997	US	120.0	171.9	821	218.7	9,826,630	22.25
Norse & Saigal, 1994	Erosion cost in Zimbabwe	1983	US	127.8	191.7	370	541.1	390,580	1,385.37
Pretty et al., 2000	UK direct agricultural erosion cost	1996	UK	14.0	31.4	806	40.7	243,820	167.03
Hajkowicz & Young, 2002	20 yr Australian sedimentation min	1996	AUS	42.0	47.6	806	61.6	7,686,580	8.02
Hajkowicz & Young, 2002	20 yr Australian sedimentation max	1996	AUS	123.0	139.4	806	180.5	7,686,580	23.48

Sources: Estimates - various; Exchange rates, CPI – RBNZ. Latest CPI is March 2008, so figures updated with March quarter figures from base year to present. CPI figures from before 1998 taken from the CPI calculator on RBNZ website.