MUDDIED WATERS

Estimating the national economic cost of soil erosion and sedimentation in New Zealand

Michael Krausse, Callum Eastwood, Robert R. Alexander

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14 September 2001

Lance Dixon
Earthquake Commission
PO Box 311
Wellington

Dear Lance

Muddied Waters

Over a year ago Callum Eastwood, Rob Alexander or myself contacted you to discuss the costs of soil erosion to your organization, or to the country as a whole. We greatly appreciated your assistance without which the work could not have been completed. A personal copy of the final report is enclosed with our thanks.

If you have comments that you would like to send us, please do so. In particular, if you find residual errors or omissions we would like to hear about them so that they can be corrected.

Additional copies of the report are available through Manaaki Whenua Press, PO Box 40, Lincoln 8152 (http://www.landcare.cri.nz/mwpress/Catalogue/Soils).

With thanks

Michael Krausse

Michael Krausse
Callum Eastwood
Rob Alexander

Enc.

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Manaaki Whenua
Landcare Research

Palmerston North, New Zealand
2001

CATALOGUING IN PUBLICATION

Krausse, M. K., 1963-
Muddied Waters: estimating the national economic cost of soil erosion and sedimentation in New Zealand / Michael Krausse, Callum Eastwood, Robert R. Alexander. – Palmerston North, N.Z. : Landcare Research New Zealand, 2001.

ISBN 0-478-90344-6

I. Eastwood, Callum R. II. Alexander, Robert R. III. Title.

UDC 631.459(931)

Cover photograph: Ngatapa Valley. Gisborne Storm of 25th July, 1985. *Gisborne Herald*

Edited by Anne Austin
Layout and typesetting by Jemma Callaghan
Printed by Massey University Printery

**Published by Landcare Research, PO Box 40,
Lincoln 8152, New Zealand.**

Foreword

Research on the economic impacts of soil erosion in New Zealand has focused on the on-site costs of soil loss in the form of production loss and storm damage. Subsidisation and implementation of soil conservation measures have primarily been justified through maintenance or improvement of farm productivity levels. A greater understanding of the cost and relative ranking of impacts may help national policy-makers to consider private and societal responsibilities for erosion damage and preventative actions.

This report collates financial information on the on-site and off-site effects of soil erosion in New Zealand. In doing so it:

- develops an *analytical framework* to help assess the relative magnitude of erosion and sedimentation impacts in New Zealand
- identifies *data that currently exist* on New Zealand soil erosion costs;
- ascertains where there are *knowledge gaps*; and
- provides some guidance to future policy by identifying the relative contribution of individual effects to the aggregate costs of soil erosion.

A detailed assessment of the economic cost of soil erosion was hampered for several reasons by a lack of data for many of the impacts identified in the framework.

a) Quantification difficulties

Relevant information on the related costs of soil erosion generally required some broad assumptions to extrapolate to the desired scale. Many damaging effects occurring as a result of soil erosion are small and diffuse in nature, and so extremely difficult to aggregate. In addition, while there is a considerable history of geomorphological research into the frequency and severity of erosion events in New Zealand, there have been few attempts to quantify the long-term economic costs.

b) Lack of institutional incentives for maintaining soil erosion-related information

Organisations that bear many of the costs of soil erosion damage generally appear unaware of the specific magnitude of these costs. None explicitly identify erosion costs in their accounting or management systems, nor is a single person clearly responsible for reviewing the impacts. Additionally, the diffuse nature of these effects provides little incentive for individual companies or environmental management organisations to collect specific data on soil erosion damage.

c) The cost of data collection

Existing data are less accessible than in the past, largely as a result of the regionalisation of environmental management and the sale and fragmentation of national services with a related increase in concerns over commercial sensitivity.

As the collection of data is complex and the precision of many figures is poor, the final estimate of damage costs provides only an indication of the order of magnitude of the actual costs, and should be viewed with significant caution. The true value is likely to exceed our estimate of $126 million/annum as we have erred on the conservative side in developing estimates.

The final value estimated in this report raises issues for New Zealand soil erosion policy. Current expenditure on the prevention of additional erosion is approximately $26 million, a significant proportion of the value of our remaining damages. The relative magnitude of the figures suggests that immediate large reductions in damage may not be achievable through increasing expenditure on soil conservation.

This project formed part of a national-good science programme funded by the Foundation for Research, Science, and Technology (FRST). A joint Landcare Research/Massey University initiative, the project collated financial information from existing data sources to quantify the on- and off-site effects of soil erosion.

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Introduction

Accelerated soil erosion is a significant issue for New Zealand land managers and policy-makers. A high natural erosion rate is driven by geologically young landforms, active tectonic uplift, and a maritime climate with relatively frequent, intense storm events. Land clearance and land management practices have exacerbated erosion, leading to soil loss rates with serious implications for sustainable management of our national soil resource (De Rose et al. 1995). Off-site impacts of soil erosion may also occur on a regional or national scale, involving infrastructure damage and flood plain and coastal sedimentation. Such impacts can range from the specific and obvious, for example damage to roads, farm fences and tracks, to the diffuse and intangible, such as increased sediment in waterways.

Both international and local soil erosion research has concentrated on the on-site costs of soil loss in the form of production loss and storm damage (Blackie 1992). Subsidisation and implementation of soil conservation measures have primarily been justified through maintenance or improvement of farm productivity levels. International estimates of soil erosion-damage in recent decades have indicated that off-farm damage may be greater than that on-farm (Crosson 1984; Clark et al. 1985; Ribaudo & Young 1989; Fox et al. 1995).

It is important, but particularly difficult, to provide estimates of the off-site benefits of targeted erosion control, research and policy. Despite the on-site costs of soil loss, there are often insufficient incentives for land users to implement erosion control measures that surpass the level required to mitigate on-farm erosion damage (Ribaudo & Young 1989). This leads to downstream externalities. Such a market failure establishes the need to estimate the level of on- and off-site damages, providing national policy-makers with the information needed to consider private and societal responsibilities for erosion damage and preventative actions.

Research Objectives

The primary objective of this project was to estimate the annual national costs of soil erosion and sedimentation as a means of developing a comprehensive inventory and relative ranking of their impacts. Secondary objectives included:

- identifying *data that currently exist* on New Zealand soil erosion costs;
- ascertaining where there are *knowledge gaps*; and
- providing some guidance to future policy by identifying the relative contribution of individual effects to the aggregate costs of soil erosion.

Highlighting categories of greatest economic cost indicates where research, advice or incentives may be targeted for greatest marginal damage reduction. Conversely, identifying knowledge gaps will show the 'holes' in current policy that need addressing. A national estimate of costs will also raise awareness of, and trigger increased discussion on, soil erosion issues.

The economic cost component of this project is not definitive. The annualised cost estimate should demonstrate the areas in which erosion causes economic damage and should provide an order of magnitude estimation of these costs, but does not represent a precise final figure.

Literature review

Introduction

Estimating the national cost of soil erosion initially requires identification of the impacts of erosion. A list of impacts, and of information about their size and the costs they generate, was compiled by reviewing the international literature. This chapter identifies those impacts relevant to New Zealand, as well as possible sources of data about their magnitude and economic impact.

An international framework – the case of the United States

Clark, Haverkamp and Chapman conducted the first national investigation of the off-farm impacts of soil erosion in the United States in 1985 (Clark et al. 1985). For their analysis, Clark et al. split off-farm impacts into in-stream and off-stream categories (Table 1). They estimated the off-site costs of erosion at US$6.1 billion per annum. This point estimate has been criticised by several authors (Ribaudo 1986; MacGregor et al. 1991; Crowder 1987; Smith 1992), largely because of the relative lack of precision. Clark et al., however, explicitly discuss the validity and precision of their estimates in some detail. In particular, they place considerable emphasis on the value range within which costs fall rather than on the criticized point estimate. Their primary objective, as is ours, was to identify the order of magnitude of the problem and the relative importance of the various contributing factors.

Assumptions and limitations of the Clark et al. framework

The work by Clark et al. is the only major economic analysis conducted to estimate the effect of soil erosion on a national scale, and is important to our project not only for the approach used, but also for the comments it provoked from subsequent authors. In their report, Clark et al. identify the limitations of their estimation techniques and the figures produced. Initially, not all the impacts identified were solely the result of soil erosion, for example, dissolved pollutant runoff to waterways that can occur without associated soil erosion. However, because erosion is the critical element in the process, and due to the difficulty in attributing part of an impact to soil erosion, segregation of the two processes is not attempted. The final economic cost estimates are acknowledged by the authors to be indicative rather than definitive, due to lack of complete data and difficulties in valuing that data in monetary terms.

Throughout their report, Clark et al. identify other inherent limitations in data approach and quality. Consideration of these limitations provided a guide to possible issues in our project. Out of the methodological issues identified in the US study, the most relevant to our report are discussed below:

- Clark et al. provided estimates of the annual cost of erosion on a national scale. Crowder (1987) and Ribaudo and Young (1989) later repeated the impact calculations to derive regionally based results. These results show that regional estimates can be more time-consuming and rely on a higher quality and quantity of data than those on a broader national scale. We found this to be the case also when searching for information on New Zealand soil erosion costs, where regional estimates were very point-specific and difficult to extrapolate meaningfully to a national estimate.

- Both our study and that of Clark et al. use a range of value estimators – damage costs, repair costs, and soil conservation expenditure. Indirect, or multiplier, effects have been excluded.
- The benefits of controlling erosion and runoff are not likely to be as great as the costs estimated in this study because erosion is a complex, dynamic process. Reducing the generation of sediment will only gradually and partially reduce the movement of sediment in fluvial systems. For example, reactivation of material deposited on streambeds and in river channels will partially compensate for reductions of iron sediment inputs from hill slopes.
- Many of the costs of increased soil erosion are already sunk. Clark et al. use the example of a silted lakeside marina that has been replaced with a completely new facility. Soil erosion control works will never recover the costs of abandoning and replacing the old marina because the new marina is already built and functional. Similarly, in the New Zealand context, we have not accounted for the historical capital investment in catchment works. Neither have we captured the historical loss in productivity from eroded areas, or the past investments made in road construction and urban development to reduce the risk of erosion.
- In the report by Clark et al., some potentially significant impacts were identified but were not able to be quantified. Serious difficulties arise, for example, in assigning biological damage values to the impacts of pollutants on different species. Even if actual damages to a species could be estimated, there are also problems in estimating appropriate economic values of the species themselves. While recognising that biological damage may have formed a large portion of the total damage, Clark et al. are not prepared to attempt an estimate, given the lack of appropriate available information. A similar situation exists in New Zealand with regard to information about biological damage, and we did not attempt to estimate these damages (see p. 27, Biological degradation).
- Other assumptions are made in sections of Clark et al.'s damage estimation, including arbitrarily assuming a range of flood damages, after calculating a point value. The lack of data in both Clark et al.'s and our study has required some wide-ranging assumptions, for example, the extrapolating of regional figures supplied by Tranz Rail (see pp. 24 and 33).

Critical evaluation of Clark et al. (1985) by subsequent authors

Clark et al.'s damage estimates are referred to in many publications on related topics, particularly in the decade following release of the report. The information is commonly used to demonstrate the potential severity of erosion in the USA (often quoting only the point estimate), or the relative significance of off-site costs. Few authors have critically reviewed the methodology or results. Macgregor et al. (1991) commented on the omission of several potentially significant categories of loss due to sedimentation without identifying what these categories were. Similarly, Ribaudo (1986), without elaborating on specific examples, suggested that the 'data and methods used cast some doubts' on the reliability of the figures produced. In the years following Clark et al.'s report, Ribaudo published several papers incorporating minor adjustments in Clark et al.'s original methodology. Most of these adjustments use the same data manipulated to present regional estimates. It is interesting to note, therefore, that while some of the methods used and assumptions made by Clark et al. are broadly criticised, more up-to-date work on the subject has still used most of the original data (Ribaudo 1986; Smith 1992). This indicates that although this type of information may not be complete or precise, it is still worth collecting and presenting because it provides a useful indication of current erosion cost data, and acts as a starting point for future research on the topic.

In 1992, Smith used both the Clark et al. (1985) and Ribaudo (1986) data but emphasised a number of limitations with the Clark data including its age, incomplete nature (particularly for biological-related damages), and the fact that the original source of the aggregate loss estimate mixed different concepts of the monetary value of resources. On the latter point, Smith comments that:

> Willingness to pay (WTP) was used to value recreation, while incremental social values were assumed to correspond to mitigation costs arising from treatment, dredging, replacement capacity to provide equivalent water services to those impacted by off-farm erosion. The aggregate estimates include primarily use-related benefits. Option and existence values were not considered (p. 1079).

A particular issue that arises from Clark et al.'s work is the treatment of expected future costs of soil erosion. Crowder (1987) criticises the discounting of lost reservoir capacity by Clark et al. because the process used makes generic assumptions about the discount rate and time until capacity has to be replaced. He also notes that they fail to incorporate uncertainties over alternative water supplies, energy prices, future water demand, and increasing costs of construction.

These concerns are largely acknowledged by Clark et al. in their original report, as outlined previously. The authors are clear that the data have limitations, and place strong caveats on the interpretation of the results because of the uncertainty. Their main assertion is that the estimates are correct within an order of magnitude. We conclude that none of the comments made or points raised in the relevant literature since 1985 have significantly discredited the approach adopted by Clark et al. We are therefore confident that adopting a similar approach to Clark et al. is appropriate for the objectives we have set for this project.

The US study also helped identify the range of soil erosion impacts for this project, and suggested potential data sources for erosion-related costs.

Table 1 Clark, Haverkamp and Chapman (1985) – Off-farm impacts of erosion in the US

Impacts	Description
In-stream	
Biological	Degradation of aquatic flora and fauna
Recreational	Adverse impacts on fishing, boating, swimming, number of accidents
Water-storage facilities	Lost storage capacity, contaminants
Navigation	Dredging, accidents, delays, engine damage
Other in-stream uses	Commercial fishing, preservation values, hydro-turbine abrasion, decreased capacity
Off-stream	
Flood damage	Increased flood height/volume, reduced productivity, lost lives
Water conveyance facilities	Sediment removal, maintenance costs, weed control
Water treatment facilities	In addition to filtration
Other off-stream uses	Costs to industrial/municipal use, irrigation

A New Zealand framework

Significant differences obviously exist between the United States and New Zealand. Our active geology, small population and strong agricultural base ensure that any framework for this country, along with relative ranking and magnitude of damage costs, would be different from the one developed for the United States.

There have been no previous attempts to estimate a national economic cost of soil erosion in New Zealand. Economic assessments of erosion are limited to scattered efforts to quantify economic damages from major storm events such as Cyclone Bola. Clough and Hicks (1992) produced a comprehensive framework highlighting and categorising the effects of soil degradation particular to New Zealand, both on- and off-site (Table 2). The Clough and Hicks framework was developed as a guide to categories of damage that should be quantified (Hicks pers. comm. 2000). Until this report no one has taken up the challenge.

The on-site impacts identified in the Clough and Hicks framework focus on agricultural production. The off-site degradation categories include some more abstract concepts such as changes in aesthetic amenity due to slip scars. While their division of the forms of degradation into on- and off-site impacts follows that adopted in previous work, impacts are listed in a higher degree of detail. In reality, the diffuse and often imprecise form in which soil erosion costs are commonly quoted make it difficult to estimate them at such a fine level of detail as presented in Table 2.

The report by Clark et al. (1985) and the framework designed by Clough and Hicks (1992) proved the two most useful pieces of literature for development of our methodology, the former being similar to our stated objectives if larger in scale, and the latter providing useful direction for application in the New Zealand context. Clough and Hicks are additionally useful because they identified on- and off-site erosion damage costs, whereas Clark et al. only investigated the latter.

An important contribution by Clough and Hicks to our work is the identification of the marginal impact soil erosion has on the level of costs attributable to flooding. They recognise that sediment carried in flood waters can contribute to increased flood risk, increased water filtration costs and reduced aquatic production. In our framework, we address the significance of these sediment impacts by separating them from what we have termed *soil erosion effects* (see Table 3).

Table 2 Clough and Hicks (1992) – Effects of soil degradation in New Zealand

Forms of degradation	**Description**
On-site	
Reduced vegetative production	Pasture loss, lower crop yields
Lowered animal performance	Reduced feed conversion, decreased health
Damage to fixed structures	Fences, tracks, bridges, dams
Disruption to site operations	Changed stock rotation, increased transport
Off-site production effects	
Reductions in adjoining site outputs	Spread of pests
Processing losses	Value added on lower output
	Lost scale economies
Off-site community/environmental effects	
Increased sediment loading	Increased flood risk
	Increased lateral erosion risk
	Increased water filtration costs
	Reduced aquatic production
	Reduced aesthetic amenity
Visual detraction of slip scars	Reduced aesthetics of slips
Increased dust nuisance	Wind-eroded soil
Off-site transitory effects	
Infrastructure disruption	National utilities and transport

An Analytical Framework

Introduction to the project approach

This chapter outlines the analytical framework developed for our project. The lessons learned from reviews of past approaches in this field led us to design our framework to identify the main impacts of soil erosion, but to keep the level of detail consistent with the potential data sources available (Table 3). Impacts are therefore considered on a broad national scale, as opposed to specific localised events.

Similarly, estimates are of total impact regardless of erosion cause or type. While it may be interesting to differentiate between natural and anthropogenically enhanced erosion rates, there are rarely sufficient data to make this distinction. Neither is there a strong economic justification for differentiating between natural and accelerated erosion. While the *type* of response will often be related to the cause or particular erosion process, the *level* of investment in the response (damage repair or prevention) is more likely to be related to the value of what is being protected.

Table 3 **Framework for economic costs of soil erosion to New Zealand**

Effects	Explanation
Soil erosion effects	
Agricultural production loss	Reduction in pasture and crop productivity from soil loss
Farm infrastructure damage	Cost of repairs to tracks, bridges and fences
Direct private property damage	Loss to residential/industrial structures
Road/rail infrastructure damage	Landslide erosion damage to national road and rail network
Utility network damage	Repair and maintenance of telephone and electricity network
Recreational facility damage	Repair of walking tracks, huts, public facilities
Loss of visual amenity	Aesthetic impact of slip scars
Other soil erosion effects	Changes in farming confidence
Sediment effects	
Increased flood severity	
Insured loss	Flood costs covered by public or private insurance
Production loss	Loss of production due to sedimentation on flood plain
Reduced water quality	
Consumption	Costs of filtering sediment from urban drinking water
Processing	Filtering costs, loss of machinery efficiency, increased wear
Recreation	Loss of fishing days, swimming, boating
Sedimentation	
Water storage loss	Costs associated with lost storage in reservoirs and dams
Navigation	Costs associated with sediment in ports
Reticulation	Costs associated with sediment in irrigation canals, hydro canals, and drainage ditches
Biological degradation	Loss of aquatic habitat (surface water and marine)
Other sediment effects	Dust nuisance

Categorising erosion damages as either on- and off-site implies the demarcation of specific boundaries to the 'site'. Soil erosion is not limited to within individual property boundaries, therefore the Clough and Hicks' categorisation leaves room for confusion; for example, if damage occurs across a boundary is it then termed as on- or off-site damage? Our framework is split into *soil erosion* and *sediment* effects. These roughly equate to the on- and off-site effects categories used by Clough and Hicks (1992). However, they are specifically termed to recognise the two different ways in which soil erosion can cause economic impacts. The impacts can be either quite direct, for example, where a slip knocks over a power pole, or diffuse, such as erosion increasing the sediment levels in a waterway subsequently influencing flood capacity of channels, aquatic habitats, etc. Within this soil erosion/sediment distinction, the subcategories are drawn from both Clark et al. (1985) and Clough and Hicks (1992).

Category components – Soil erosion effects

The framework categories adopted cover all the possible impacts of New Zealand soil erosion. Impacts have been classified as either *soil erosion effects* or *sediment effects*, as explained in the following section. They have then been divided into sub-categories according to the form of impact or the potential data source. The categorisation of soil erosion impacts helps identify where the primary costs occur or where information is lacking. The categories under this heading relate to impacts derived from direct soil erosion, for example, a slip or the loss of soil from an area of land. Also included is erosion due to floodwaters, for instance, stream bank erosion.

Agricultural production loss

This subcategory includes losses to vegetative production and animal performance through the direct impact of soil erosion in agricultural systems. It is based on estimates of losses in pasture and crop production due to the initial loss and then gradual regeneration of the regolith and soil.

Farm infrastructure damage

Farm infrastructural damages occur where slips impact on fencing, non-residential buildings, roading and water reticulation. This section includes the disruption to operations that results from such damage, for example, the disruption to a stock rotation due to loss of access or fencing problems.

Damage to private properties

While the direct impact of soil erosion on residential houses and commercial or industrial properties is included in this section, damage to properties from floodwater sediment is not (see Increased flood severity pp. 17–18).

Road/rail infrastructure damage

One of the significant costs incurred from a high rainfall event is damage to the transport network. Slips can wash onto or undermine roads, bridges or railway lines, and sediment can be deposited by flooding. The subsequent impacts can be broken down into two subcategories:

- repair costs related to remedying the erosion effects or sedimentation;
- delay or diversion costs associated with road/rail blockage and the time taken to clear or repair the road.

Soil erosion can have both direct and indirect impacts on the road and rail network: for example, the closure of a road due to a landslip would classify as a direct impact, while sediment deposited by floodwaters would fall into the more indirect 'sediment effects' category. Due to the interwoven nature of these impacts and the difficulty in separating the costs due to the current Tranz Rail and Transit accounting systems, all costs to the road and rail network through soil erosion and sedimentation will be listed in this subcategory.

Utility network damage

National utilities are also damaged during storm events. The major erosion-related damage is caused when soil slippage dislocates poles or lines for telephone and electricity reticulation.

Recreational facility damage

Soil erosion impacts on recreational facilities such as walking tracks, bridges and huts. Often such recreational infrastructure is located in wilderness areas that have high incidences of natural erosion and a propensity to erode when disturbed and the soil exposed. The Department of Conservation is responsible for the bulk of these types of recreational facilities in New Zealand; however, the facilities managed by local authorities in municipal parks, reserves or esplanades may also incur some erosion costs.

Loss of visual amenity

The visual amenity values of a site may be detracted by soil erosion scars. This could be experienced by either the landowner or visitors to the area. Any impact on tourism through erosion is also included in this category. It is difficult to determine whether soil erosion would actually have a negative impact on tourism, especially in relation to visitors of international origin, because they may view erosion scars as a common part of the New Zealand landscape.

Other soil erosion effects

There are several possible erosion cost areas that involve intangible costs or relatively minor impacts. These include the loss of farmer motivation and confidence due to repeated erosion. Clough and Hicks (1992) also suggest that there may be ecological costs borne from direct erosion of indigenous vegetation remnants on farms. Valuing the importance of such areas as habitat for native flora and fauna is extremely difficult and has not been attempted in New Zealand.

One effect of soil erosion that may have a significant future economic cost is the loss of soil carbon to the marine environment and the atmosphere. The magnitude of this effect is still a subject of research, and its economic cost will depend on the values set for carbon emissions through international negotiation. There is currently insufficient information to estimate the relative magnitude of this potential economic cost.

Category components – Sediment effects

Impacts identified in this category occur through the less direct costs associated with erosion when soil enters a waterway and is suspended and/or redistributed downstream. They are often referred to as off-site or in-stream impacts. It is difficult to isolate the marginal contribution of sediment to flood damage because flood damage data rarely distinguish clearly enough between types of damage to allow for differentiation of the impacts of the water-borne sediment from that of the water. There may also be additional impacts of floods related to dissolved pollutants in the water, which are also difficult to isolate from sediment impacts.

Increased flood severity

Severe flooding occurs almost annually throughout New Zealand, producing significant associated costs, with private insurance claims for flood damage averaging $23 million annually since 1975 (NIWA 2000). Impacts of flooding can be wide-ranging, for example, damage to houses, industrial properties, municipal infrastructure, road, rail, energy and telephone reticulation, and pastoral and horticultural crops when sediment settles out of floodwater. There can also be a consequent loss of economic activity for the flood-hit region, and loss of human life, along with other psychological human impacts (Ericksen 1971).

The presence of sediment in floodwater can impact on the flood volume and extent of damage to human infrastructure and pastoral land. Sediment leads to aggradation of riverbeds, increasing the potential for overtopping of flood protection works. Soil and debris washed into a river channel can lessen river capacity during flood flows (Planning and Development Committee 1989). Erosion from steep erodible hills in many North Island East Coast river catchments has resulted in such riverbed aggradation (Planning and Development Committee 1989).

Sediment carried in floodwaters stains wallpaper and household items and increases cleanup costs in urban areas after flooding. Deposition of sediment on floodplains can have some beneficial effects through increased fertility, but this is often outweighed by the loss of the current year's crop, or negated by deposition of relatively sterile silt, sand or gravel, as, for example, after the Opuha dam collapse in 1997. Costs can also derive from deposition of sediment in drains and roadways, for example, in the Pukekohe region where clearing of such sediment presents a significant cost to local authorities (Basher et al. 1997b).

In our framework, the impacts of increased flood severity through sediment in floodwaters is broken into two categories, due to availability of data:

Insured loss

Losses of property and income are the primary form of economic cost involved with increased flood severity. These losses can be quantified through estimates of flooding-related insurance claims.

Non-insured production loss

Sediment in floodwaters can cause production losses through sedimentation of floodplain areas. This damage is often not covered under standard insurance claims and can be diffuse because flooding and subsequent sedimentation can mildly affect large areas of river terraces and be written off by land users.

Reduced water quality

Suspended sediment impacts on water quality. These impacts can be felt through:

Consumption

There are possible costs involved with filtering municipal drinking water supplies, or even individual supplies in rural areas. Water used for consumption requires a high level of water quality; therefore filtration is required for even low levels of sediment, and rigorous filtration is needed for high sediment concentrations.

Processing

Firms drawing water for use in their production practices may incur a cost through excessive sediment in waterways. Filtration may be required before use, but not necessarily to the purity levels of drinking water. Sediment in water coolant systems and turbines can lead to higher maintenance costs and less efficient operation, or the need to install filtration equipment. Possible examples are the use of water for industrial cooling, processing of fresh fruit and vegetables, abattoir operations, and hydro-electric power generation.

Recreation

Soil erosion and sedimentation affect recreation primarily through changes in the aesthetic value of water due to increases in suspended sediment. Sediment impacts on recreational values can include reduced aesthetic appeal, and poorer fishing, swimming and other recreational activities (Blackie 1992). While it is difficult to measure such effects, given that most are based on non-market values, turbid water can reduce consumer surplus by decreasing people's enjoyment of water-based activities, by increasing costs of going elsewhere to engage in the activity or changing to a different form of recreation, or by stopping the recreation altogether. There can be some overlap of this category with biological effects where recreational pursuits are based on biological factors, for example, sedimentation of a waterway may reduce the numbers of fish present and/or reduce the pleasure received by the angler. Arguments could be presented to support inclusion of such effects in either the biological or recreation category and therefore the specific categorisation of such forms of data requires justification.

Biological degradation

In their US study, Clark et al. attempt to place a value on the economic cost of biological degradation, in particular on sediment impact on aquatic organisms. Although information uncovered suggests that the cost of biological damages is significant, their predominantly non-market value make economic cost estimation difficult. Downstream habitat protection is a major factor in Regional Councils imposing conditions on property developers to minimise excessive sediment run-off. This preventative expenditure is one component of costs incurred to avoid biological degradation by soil erosion.

Water quality can also impact on the *commercial* use of aquatic organisms, such as near-shore fisheries and aquaculture. Sediment can have an impact on aquatic organisms both directly, through disruption of physiological process, and indirectly via disruptions to the food chain or the organism's habitat.

Sedimentation

Water storage

Sedimentation in hydro-electric dams can impact on efficient water use by decreasing the time between generation cycles. Sedimentation of reservoirs can lead to water shortages in dry periods. High sedimentation rates can necessitate the construction of excess capacity to trap sediment, and may reduce the functional life of the reservoir (Krieger et al. 1989). In extreme cases there may be an associated increase in reservoir surface area, increasing evaporative losses (Krieger et al. 1989); this is unlikely, however, given the temperate climate and the small size of New Zealand reservoirs. The water quality implications of highly sedimented water entering water storage facilities is addressed in Processing, p.18.

Navigation

Sedimentation in and around port facilities disrupts efficient port operation. Economic damage costs arise from dredging expenditure to maintain shipping channels, increased shipping accidents due to poor water clarity, and abrasion and other damage to marine equipment (Krieger et al. 1989).

Reticulation

Sediment can clog water conveyance facilities used for irrigation and drainage, and can also provide a growth medium for aquatic plants that may further clog drains. Dredging is a major cost associated with these impacts.

Other sediment impacts

Other impacts that do not fall logically into the categories described above are included in this category. Dust nuisance effects, for example, are sediment related but are less constrained in their geographical impact.

Application of the framework

The application of the framework in this study is limited to two types of economic cost associated with soil erosion: damage-related costs (repair, insurance payouts, production loss); and avoidance or prevention expenditure. These are the most easily quantified because they reflect actual expenditure and are limited to direct costs. Indirect or secondary effects of damage or productivity loss caused by erosion or sedimentation (often called multiplier effects) are not included in this assessment because their estimation adds further technical complexity and difficulties to data collection.

The initial approach to information collection for this project involved reviewing national soil erosion literature to determine the extent of economic values placed on soil erosion impacts. The review covered published non-market valuation studies and historical MAF and DSIR reports, as well as other relevant reports. Senior members of the soil conservation community were also consulted on the location of relevant information.

The literature review identified a lack of information appropriate, in both form and scale, for a national estimate of erosion costs. Several reports quoted economic costs for on-site damages after significant rainstorm events. The data were very specific to the particular topography, geology, and land-use practices of each region, and therefore difficult to extrapolate credibly to a national scale. Storm reports generally focussed on the most tangible and easy-to-measure aspect of erosion damages, for instance, on-farm costs and community infrastructural damages, while ignoring more diffuse impacts such as recreational and biological values. Included in the stated damages is the marginal impact of sediment carried in floodwaters. No examples were found of an attempt to isolate the role of sediment in flooding costs.

After it was apparent that applicable published data were not available, the data collection approach was altered. Each framework category was re-assessed to identify organisations or institutions operating on a national or near-national scale that might incur soil erosion-related damages relevant to each category. Examples are the Earthquake Commission of New Zealand, responsible for covering landslip damage to residential properties, and Transit NZ, responsible for repair of the national roads network affected by erosion. The specific information-collection process undertaken for each framework category is explained in the next chapter.

Estimating the costs for New Zealand

Introduction

This chapter details what data are available for the types of erosion damages identified in the preceding chapter. The damage estimation methods and specific damage estimates by type are discussed in the following chapter. Breaking this part of the report into two chapters demonstrates more clearly that although the framework is designed to cover all aspects of erosion-related damages in New Zealand, an actual economic cost estimate could only be attributed to a small portion of these damages.

Soil erosion effects

Agricultural production loss and infrastructural damage

Data available in New Zealand on on-site effects of soil erosion in agriculture are limited to a number of damage estimates for major storm events published in reviews (Clough & Hicks 1992; Harmsworth & Page 1991) and in storm-specific damage reports (Basher et al. 1997a, 1999; Hicks 1988; Hicks 1992; Hicks et al. 1993; Korte 1988, unpubl. report). While most data are concerned with characterising erosion damage, only some storm damage assessments, e.g., Hicks et al. 1993, Korte unpublished, estimate the economic costs of damage.

In most cases, farmers, agricultural consultants, scientists or valuers have made these damage estimates soon after the event. In only one case was a follow-up analysis done (McPhail in Hicks et al. 1993). Farmers were interviewed again 10 months after the event to check the consistency of their earlier predictions of the costs incurred. While the revised data varied little from the initial estimates (within 2%), detailed analysis of farm accounts from six properties failed to show the marked influence on financial performance suggested by the surveys. This disparity between perception and financial data raises questions about the accuracy of farmer-based erosion damage estimates, particularly when they are made soon after the event and while the immediate effects of the event are foremost in people's minds. Nevertheless, point-based estimates of erosion damage are often the only available data describing the impact of erosion events.

In this study, on-site costs for two generic forms of erosion have been estimated: mass movement (land slipping, gully erosion, earth flow, debris avalanches); and surface erosion (rilling, sheet wash, wind erosion). Costs of mass movement erosion have been split into damage costs and costs of lost productivity but have been estimated across all agricultural land uses. No data have been found on the economic costs of mass movement erosion in production forestry. Only lost productivity costs have been calculated for surface erosion, because damage to structures from surface erosion is uncommon. Separate estimates have, however, been made for productivity losses in pastoral farming and in arable cropping. In the latter case, regular soil surface cultivation leads to significantly increased rates of surface erosion.

Direct private property damage

The damage to private property directly from soil erosion relates primarily to the effect of a slip on a building or other private infrastructure. The damage caused by flooding and sedimentation is not included here; this is addressed in sediment effects, p. 25. There are no recent nationally published figures describing the damage caused by landslip on private property. Claims for such damage are primarily addressed by the Earthquake Commission of New Zealand (EQC).

The EQC is a statutory corporation responsible for providing insurance against loss or damage caused by earthquake, volcanic eruption, hydrothermal activity, tsunamis and natural landslips to properties already insured against fire. This insurance covers damage caused by landslides on and around residential buildings (up to eight metres from the building) and on access ways to dwellings. The Commission provides replacement insurance cover of up to $100,000 plus GST for dwellings and up to $20,000 plus GST for residential contents. There is also limited cover provided for land loss by any of the above hazards plus storm or flood, and this amount of cover is additional to the figures noted above (EQC 1999).

Road and rail infrastructure damage

Previous reports, such as Ericksen (1986), have indicated that damage to road and rail infrastructure from erosion is significant. Several storm damage reports have quantified this damage in monetary terms, but these estimates apply to specific events and in specific areas. They are therefore difficult to extrapolate to a national annual estimate. As Transit NZ is responsible for the national state highway network, and Tranz Rail owns the national rail network, our approach was to contact both for a current national average of the costs of damages to road and rail infrastructure.

Obtaining precise figures on the cost of soil erosion to the national roading network was difficult for two reasons. There is no specific erosion-related accounting area and therefore the costs from slips and eroded roadsides are incorporated with other road-wearing processes. Second, changes in the accounting systems used by Transit NZ and Transfund in the last decade meant that only one year of data on preventative maintenance expenditure was available.

Erosion-related costs are isolated to three accounting categories. *Emergency works*, defined as 'unexpected work requiring urgent reinstatement or provision of a safe trafficable highway; and non-routine maintenance works to protect the serviceability of the road asset and to minimise the threat of road closure', primarily pertains to erosion-related damage (Transit NZ 1999). There is also an accounting area termed *Preventative maintenance*, which specifically applies to:

- i.) new works that protect existing roads from sea or river damage
- ii.) drainage installed to drain incipient slips
- iii.) toe weighting of unstable slopes
- iv.) work to overcome changes in a river's course or bed level that threaten roads, bridges, or other roading-related structures, but which is not attributable to one climatic event (Transfund1996).

Most, if not all, the expenditure under this category will be erosion-related. A third category, *construction* of new roads or structures, may include expenditure on infrastructure redesigned due to erosion risk; for example, the recent Stockman's Hill realignment in Waikato. Identifying erosion-related costs from this category is more difficult because projects vary from year to year and are often implemented after considering more than one factor.

Tranz Rail is responsible for the maintenance of their own railway lines throughout the country. They, too, do not have a specific erosion-related accounting category, but do have one labelled 'weather-related incidents'. Discussions with Tranz Rail staff suggest that these effects predominantly pertain to soil erosion caused by slipping or by floodwaters.

Utility network damage

Storm damage reports have indicated that, due to soil erosion, significant damage can occur to electricity and telephone networks, primarily in the form of pole disturbance. Before the recent restructuring of the electricity industry, individual power boards were responsible for energy retail and reticulation. Privatisation and restructuring of the electricity industry in New Zealand has lead to commercially owned companies being responsible for line maintenance.

Telecom New Zealand is responsible for the national telephone lines, covering an area similar to that of the electricity line companies combined. As with many other organisations approached during this project, Telecom does not have a specific accounting area in their annual budgeting system to identify erosion-related damage. Damage is attributed to a 'cause code' after repair, depending on how the technician perceives the root cause of the fault, for example 'storm/flood damage' or 'slip/earthquake'. Telecom staff made an estimate of the annual cost of damage by cause, by multiplying the average cost of repairing a fault by the number of faults recorded against each 'cause code'.

Recreational facility damage

The Department of Conservation (DOC) manages a national conservation estate of nearly one-third of New Zealand's land area. Public facilities on the estate include over 970 huts, 11 000 kilometres of tracks and 1070 road and track bridges. From a budget of approximately $174 million, the Department spends $42 million annually on 'Provision of recreation opportunities: access, facilities and services', which includes maintenance on tracks and structures. Senior DOC staff were contacted and asked to estimate the Department's annual spending on soil erosion-related maintenance and repair of huts, buildings, bridges and tracks.

The Department has recently completed an inventory of visitor facilities and developed a 'Visitor Asset Management' database. The intention is that the computer-based system will allow detailed interrogation of the database by keyword, for example 'erosion', within 2 years, permitting more accurate analysis of the causes of failure or damage to facilities.

Loss of visual amenity

Anecdotal evidence from major storm events suggests that the visual and psychological effect on farmers of widespread slipping is significant and debilitating. Initial damage estimates are frequently far higher than the actual eroded area because of the visual impact of debris (which quickly revegetates) beneath landslide scars. In recent years, commentators have also raised the possibility of the obvious visual impact of mass movement erosion triggering environmentally based trade sanctions against New Zealand's primary produce. While this aspect has been included in the assessment framework, no quantitative information was found to indicate the present or potential costs involved.

Other soil erosion impacts

Other impacts identified earlier (p.17) are not addressed because lack of applicable information meant no values could currently be placed on them.

Sediment effects

Increased flood severity

The precise marginal impact of sediment in floodwaters is dependant on many factors, including population numbers and predominant land uses in the flooded area. A review of literature and consultation with prominent flood researchers in New Zealand (N.J. Ericksen, pers. comm., University of Waikato, Hamilton, N.Z.; A. Poninghaus, pers. comm., University of Auckland, Auckland, N.Z.) failed to reveal the proportion of flood damages that could be attributed to the sediment in New Zealand floodwaters.

Clark et al. (1985) attempted to attribute a proportion of flood damages to the impact of sediment. They used a range of 15 to 30 percent for the proportional impact of sedimentation in total urban damages, and 5 to 10 percent for the proportional impact of sedimentation in other flood damages. The authors also adopted ranges for sediment impact on increasing flood heights (9 to 22 percent of total flood damages), and the contribution of sediment to loss of life during flood events. Unfortunately, detailed information about flood characteristics and types of damage is not available for flood-related damages in New Zealand. We used Clark's information and arguments to adopt arbitrarily a value of 15 percent to represent the marginal impact of sediment in New Zealand floodwaters.

Insured loss

The Earthquake Commission was the predominant insurance cover provider for flood damages up to 1984/85, but now covers only flood damage to land around residential dwellings. These costs are included in landslip estimates discussed in Direct private property damage, p.23, above. The private insurance industry currently covers all other insurable aspects of flooding damage. The Insurance Council of New Zealand (ICNZ), representing fire and general insurers, collects information dating back to 1968 on private insurance claims from large storm events but not from smaller incidences of flooding and sedimentation. The Council is currently preparing a database to identify annual insurance payouts for flooding damage by region. Information on annual flood damages will be provided for the benefit of insurance companies, and will consist of a flood-damage map of the country displayed on a secure section of the Internet.

The information supplied to us by ICNZ shows average payouts by the private insurance industry between 1987 and 1999 of $13 million per annum. These applied only to large storm events and did not include Earthquake Commission payouts or payouts for small isolated events. A model of flood losses published by Ericksen (1986) in an analysis of the trends in the costs of flood damage from 1968 to 1984, provides a method of establishing total insured flooding losses. In the absence of comprehensive recent data, the data and model developed by Ericksen, adjusted for inflation, have been used to estimate damage costs in this category.

Production loss

The loss of production due to sedimentation of productive flood plains may have a significant impact on individual farmers/growers in flood-prone areas, e.g., the losses to viticulture and cash cropping farms on the Waipaoa flood plain in 1988. The regular losses at a smaller scale on recent river terraces, however, may be more significant. These well-drained, flat, fertile areas are often the most productive areas on hill country sheep, beef, and dairying properties, or are important for calving or lambing. The loss of these areas can be more significant than their absolute area, given their role in the annual feed budget and stock movement cycle.

Although the impacts associated with sediment on production loss appear to be significant, no data on the scale of the economic costs involved have been located.

Reduced water quality

Consumption

The impact of sediment on urban water supplies is primarily the cost of filtration to remove it. Our estimate of these costs is based on the amount of filtration required at the Palmerston North water treatment plant. The local authority responsible for this plant does not separate the cost imposed by sediment from soil erosion, and personnel at the plant indicated that this would be the case for most such water treatment facilities in New Zealand. It was decided that approaching other local authorities would not significantly improve an estimate based on scaling up from the single sampling point.

Processing

While the filtration and damage costs incurred from sediment in water used in the processing industry are potentially significant, no cost estimate could be obtained for this category.

Recreation

Sediment in waterways has an impact on recreational opportunities, such as water contact sports and fishing. Anecdotal evidence suggests significant costs of lost fishing days to professional fishing guides from turbid streams and rivers. Lost recreational fishing days to the public may be even more significant. We are aware of a number of willingness-to-pay studies for recreational fishing, but these are not matched by data on the loss of days for fishing or other recreational pursuits because of turbidity, and so we were not able to estimate the cost of these losses.

Biological degradation

The impact of sediment on aquatic flora and fauna is primarily a non-market cost, although there are some commercial implications for shellfish production and inshore marine fishing. Although this category may be expected to contribute a significant cost to the overall erosion damage estimate, little work has been conducted to attribute economic values to biological degradation from sediment, and this lack of data prevented an estimate of the relevant economic costs.

Sedimentation

Water storage

Crowder (1987) identified four possible economic cost components attributable to sedimentation of hydro-dams and water reservoirs in the United States:

- extra capacity built into a new dam specifically to allow for predicted sediment yields
- measures taken to prevent sediment from entering a dam or reservoir
- sediment dredging
- lost capacity replaced by new dams or a water source.

The impact of water storage capacity loss on operating efficiency is not a widespread problem in New Zealand according to the electricity-generation companies that were contacted. Generating companies acknowledge that sediment build-up is occurring, but the rate of sedimentation and the depth of New Zealand hydro-lakes mean that the impact on water storage and economic performance is insignificant. A high-profile and high-cost exception is the Clyde system. Over $420 million was spent stabilising potential slips before commissioning the high dam at Clyde (Ministerial Review Committee 1990). Sedimentation of the Roxborough Dam has been identified as a contributing factor to increased flood heights in the upstream town of Alexandra. In September 2000, Contact Energy and the New Zealand Government jointly committed $21.6 million to purchase flood-affected properties and construct new flood protection to reduce damage caused by high river levels.

Turbine-wear is a significant cost to generating companies, and sediment is one cause of wear. This appears to be a more significant issue in the shallower lakes fed from erosive catchments in the North Island. In one case, the generating company elected to dredge parts of a reservoir to remove coarse pumice contributing to turbine wear.

In summary, erosion-related costs are not often specifically identified by generating companies. In most cases this is because the problem is relatively insignificant and the costs involved in precise monitoring of sediment and its impacts are unwarranted. In addition, measurements of some effects, e.g., damage to turbines, are confounded by general ageing and other causal factors. The Clyde scheme is a significant exception to this conclusion.

Navigation

Sedimentation costs for navigation in New Zealand mainly involve dredging access and docking areas in ports. These data are collected but are commercially sensitive. However, a major port company provided us with information, and this was extrapolated to establish a national estimate for navigation erosion-related costs.

Water conveyance

Sedimentation of irrigation canals creates costs in the form of dredging and irrigation machinery wear. The annual national dredging cost estimate was based on costs from a major irrigation scheme management company and converted to a value per hectare of land irrigated. The cost of incorporating a sediment trap structure in an irrigation canal is not included in the estimate. Several major schemes, including the Waiau/Balmoral, have a sand trap designed to allow larger particles to settle before water moves through the race system.

Other sediment impacts

There are additional indirect costs that are smaller in scale relative to those discussed above, or are significant in specific regions, for example, the costs imposed from wind erosion in the form of dust nuisance on downwind properties. This is predominantly an issue in Canterbury, Wairarapa and Hawke's Bay. While some commentators have indicated costs from individual events of up to $200,000, the impacts are generally too diffuse to estimate. On-site costs of wind erosion are included in the estimates of agricultural production loss.

Summary

There are many categories in our framework where a lack of applicable soil erosion data does not allow an estimate of economic damage. Table 4 illustrates both areas where there was enough information to allow an economic estimate to be made, and where an estimate was not attempted.

Reasons for the unavailability of data are briefly identified in the third column. It should be noted that even if a damage cost was estimated, the information uncovered often applied only to one aspect of the subcategory. For example, the estimate for direct private property damage only includes residential properties because no information was found for commercial property damage.

Table 4 Availability of economic damage data for soil erosion in New Zealand

Costs estimated	Costs not estimated	Reason not estimated
Soil erosion effects		
Agricultural production loss		
Farm infrastructure damage	Farm infrastructure damage	
Tracks, fences	Dams, culverts	Data not transferable
Soil conservation expenditure	Soil conservation expenditure	
East Coast Forestry Project	Unsubsidised soil conservation	No data found
Regional soil conservation		
Direct private property damage	Direct private property damage	
Residential	Commercial properties	Commercially sensitive
Road/rail infrastructure	Road/rail infrastructure	
Damage	Road realignment	Data not in a useable format
Preventative maintenance		
Utility network damage		
Recreational facility damage	Loss of visual amenity	No data found
	Other soil erosion effects	
	Loss in farmer confidence	No data found
Sediment effects		
Increased flood severity	Increased flood severity	
Insured loss	Production loss	No data found
Reduced water quality	Reduced water quality	
Consumption	Processing	Commercially sensitive
	Recreation	No data found
Biological degradation	Biological degradation	
Developers' expenditure	Habitat loss	No data found
Sedimentation	Sedimentation	
Water storage loss (limited data)	Water storage loss	Commercially sensitive
Navigation		
Reticulation	Other sediment effects	No data found

Specific economic costs estimates due to soil erosion

Introduction

The actual erosion cost estimates derived in this project are specified in this chapter, which concludes with a framework representing the total estimated annual cost of soil erosion to New Zealand. Commercial sensitivity led to aggregation of data for some categories in the framework.

Actual estimated soil erosion effects

Agricultural production loss

Mass movement erosion

The costs of lost productivity on hill-country farms is based on an estimate of the amount of mass movement erosion, its effect on grass production, and the effect of the loss in production on stock carrying capacity. An estimation technique proposed by Forbes (1984) has been used to transform data from individual storms of varying return periods (magnitudes) into an annual estimate of the expected level of erosion. Damage from storms is characterised by the area of scar damage generated. Using Forbes' (1984) approach, the annual expected area of eroded land can be estimated as a percentage of land susceptible to mass movement erosion (0.26 percent).

The value of the consequent loss of productivity has been estimated using De Rose et al.'s (1995) expected pasture production recovery curve for areas lost to slipping. A transformation of the expected pasture production curve into financial productivity using average gross margin and stocking rate data for pastoral farming on soft rock hill country (Oliver & Burtt 1995) has been used to estimate the present value of the lost productivity caused by mass movement erosion ($1,385/ha eroded). To estimate the annual value of lost productivity, this present value is applied to the expected area of newly eroded land calculated by multiplying Clough and Hicks' (1993) estimate of agricultural land susceptible to mass movement (3 478 900 ha) by the 0.26 percent annual erosion derived from Forbes (1984) above.

This method provides an estimated present value of both the short- and long-term loss in production of $12.5 million per annum due to mass movement erosion.

Surface erosion

Surface erosion can occur via a range of processes (sheet, rill and wind). Measurement of erosion rates has most commonly used direct measurement of short-term changes in soil depth or areal activity of the radio nuclide tracer 137Cs. Neither of these methods can identify the mechanics of soil movement, so generating separate estimates for wind and soil erosion is not possible. Further, because most measurements have been taken in response to extreme or specific storm losses where there is a single major erosion process in operation, the data set is discontinuous and it is extremely difficult to estimate an average rate.

Estimates of surface erosion rates are dependent on the scale at which erosion is measured. For example, Basher et al. (1995) identify significant soil redistribution but no net soil loss within a paddock under cropping in the South Canterbury down lands. Similarly, losses at plot scale exceeded 10 t/ha during extreme events at Pukekohe but averaged 21 t/ha/annum at paddock scale in the same locality (Basher et al. 1997b).

The above data also highlight the range width of surface erosion rate measurements in New Zealand. Basher and Painter (1997) quote measured wind erosion rates of <0.2 t/ha/annum background erosion up to storm event losses of >30 000 t/ha. Other recent measurements include mean annual erosion rates of 10–16 t/ha/annum from degraded paddocks under intensive cropping in Manawatu and Canterbury (Basher et al. submitted).

Data from which to estimate the cost of lost productivity in arable cropping from surface and wind erosion are sparse and vary widely. There is sufficient consistency only to estimate that the average annual loss of soil from arable cropping areas due to surface erosion processes is in a range between 0.2–21 t/ha/annum and to assume that the likely mean is in the order of 10 t/ha/annum. To convert these estimates to a measure of financial cost requires information about the effect of incremental soil loss on yield.

Hunter and Lynn (1988) used the soil chemical properties of a particular soil to estimate the nutrient losses associated with surface erosion losses and the cost of replacing these nutrients with fertiliser. This approach underestimates the costs of soil loss because it takes no account of the impact of the loss in soil physical properties, for example, water holding capacity. Smyth and Young (1998) use data from Aveyard (1983) and the method outlined in Mallawaarachchi et al. (1996) to estimate reductions in crop yield due to surface and rill erosion in New South Wales. This work is underpinned by soil loss/productivity relationships published by Aveyard (1983), which are based on measurements of soil loss and crop yield from long-term plot trials.

We could find no similar soil or region specific measurements of productivity loss due to surface soil erosion in New Zealand. Clough and Hicks (1992) quote some data but no studies examined specifically isolate average annual loss in productivity caused by ongoing erosion. Some early studies quote yield differences at a single point in time between uneroded sites and sites affected by significant adverse events. Others assess management interventions that improve productivity both by reducing surface soil erosion and by influencing other factors. For example, modified tillage practices reduce surface soil erosion but also affect soil structural properties and biochemical processes.

In this report we have used Basher and Painter's (1997) estimates of soil loss described above, relationships between amount of soil loss (t/ha) and percentage decreases in potential yield (Aveyard 1983), and an average gross margin of $750/ha across all arable crops. Using these, we estimate that the cost of surface soil loss in New Zealand is in the range of $3.45 to $10.45 million per annum ($8–$25/erodible ha), with a point estimate of $6.9 million per annum.

Measurements of the level of surface soil erosion under pasture and its impact on pasture productivity are even scarcer than for arable agriculture. An estimate of lost productivity in pastoral agriculture due to surface erosion has therefore been generated by multiplying an average stocking rate of erodible land (10 SU/ha) by the average return per stock unit on eroded land (Korte unpublished) to give an estimated annual return per hectare of \$210/ha. A one-percent loss in productivity due to surface erosion, derived from Clough and Hicks (1992), was applied to the annual average return above, providing an estimated loss of \$2.1 per erodible hectare farmed. This was then multiplied by the total agricultural land (excluding arable) susceptible to surface erosion, or 8 389 200 ha (Clough & Hicks 1992; Statistics NZ 2000), giving a final estimate of pastoral productivity loss due to surface erosion of \$17.6 million.

Totalling the estimates for costs of lost productivity gives an overall agricultural production loss estimate of \$36 million per annum. The process adopted to generate this figure required major generalising assumptions. As a result, we believe that the likely losses fall somewhere in the range \$10–\$100 million per annum.

Farm infrastructure damage

Annual damage to farm infrastructure was estimated by using the expected annual area of eroded land (0.26 percent) derived from Forbes (1984), as explained above, and combining it with a generalisation of Korte's (unpublished) regression between scar and debris area and infrastructural damage (fences, tracks). This is estimated at \$248.1 per hectare of scar and debris tail, which, using an average 1:1.5 ratio between erosion scar and debris tail, implies a cost of \$620.25 per hectare of slip scar. Clough and Hicks' (1993) estimate of agricultural land susceptible to shallow mass movement (3 478 900 ha) was then used to calculate an expected annual national damage cost of \$5.6 million. The estimate does not include damage to farm buildings and dwellings, which is addressed in the following section.

Direct private property damage

While the Earthquake Commission has been responsible for damage costs to residential property for several decades, a change in accounting and recording systems from 1997 meant that only one full financial year of data, 1998/99, was readily available, in addition to parts of the 1997/98 and 1999/2000 years. Officials at EQC commented that 1998/99 had produced the highest level of erosion-related costs in the previous 5 years; this is corroborated by Transit NZ figures for roading damage during the same year. An annualised monthly average cost has therefore been used to give the best possible estimate from the data available.

The data presented by the EQC included both paid claims and open claims, though the lack of long-term figures is a concern. An estimate was obtained from EQC officials on the likely percentage payout from open claims, and this was added to those already settled. The total cost of damage to private residential property estimated in this way is \$5.7 million per annum. We are reasonably confident that this estimate refers directly to erosion-related costs.

The high costs incurred in the 1998/99 financial year, over one-third of the time period analysed, may have acted to inflate the estimate somewhat. However, while damage costs in 1998/99 were high, there is no evidence to suggest they were exceptionally so. 1992/93 and 1987/88 were years of similar storminess and relatively high damage costs. On the other hand, claims submitted to the EQC face a payout cap even if the cost of repair is significantly greater than the stated limit; therefore, the actual damage costs may be higher than those provided by the Commission. Similarly, the EQC data do not apply to non-residential properties and so account has been included for damage to commercial buildings, again leading to a potential underestimate.

Road/rail infrastructure damage

Transit NZ is responsible for maintaining the state highway network in New Zealand, but there are also thousands of kilometres of local roads administered by local authorities. Transfund apportions funding to Transit and to local authorities. According to annual reports, emergency works expenditure in 1998/99 was $34.5 million for state highways and $18.5 million for local roads, totalling $53 million. However, the same type of works amounted to only $23.5 million in 1995/96, and to $19.9 million in 1997/98 (complete data were not available for 1996/97). The anomaly was due to a significant number of storms in the first half of the 1998/99 financial year, leading to expenditure more than double the budgeted annual amount. An estimate of $25 million/annum expenditure on emergency works as a result of erosion has been used in this study. The authors believe this is a reasonable estimate, given the data available and Transit NZ's annual budget estimates in recent years, which we assume to be based on historical records not available publicly.

Similarly, only 1 year's data were available for expenditure on preventative maintenance (1998/99). In the absence of other data, expenditure in this year ($2.3 million) was assumed to be representative of other years. Although there were a significant number of storm events in 1998/99, the definition of Transit NZ's preventative maintenance category suggests that expenditure is independent of actual damage in any given year.

Costs of new construction designed to reduce failures caused by soil erosion are not included in the framework estimate due to the lack of publicly available information about the justification for individual projects. The potential contribution of such expenditure to the total costs of soil erosion is high, with $192 million and $232 million spent in 1997/98 and 1998/99 respectively for construction projects on local roads and state highways. If five percent of these projects were related to erosion, another $10 million per annum would be added to the costs associated with soil erosion.

Tranz Rail is the privately owned and operated New Zealand rail company. As with Transit NZ, Tranz Rail does not specifically record costs of erosion, but does account for 'weather-related incidents'. Estimates of these costs for the last 4 financial years were obtained from one of the three accounting regions. On advice from Tranz Rail management, this figure was scaled up to obtain a national annual average. No data were available on expenditure to prevent damage to the rail network by soil erosion.

Utility network damage

Approximately 30 companies are responsible for electricity line maintenance in New Zealand. Two rural companies were asked to estimate the amount they spent on line maintenance as a result of erosion. A figure of five to six poles per year per region was postulated, at an average cost of $2,500 per pole. Assuming constant damage costs across all rural line companies, a national cost estimate of utility network damage is $300,000 per annum.

Telecom management supplied data based on the average fault repair costs as outlined in Utility network damage, p.24. We adjusted these figures to reflect the actual impact of erosion. Storm/flood damage data are not all erosion-related, and therefore 15 percent of the figure quoted by Telecom was used (see p.25 for explanation of this ratio). Some of the costs included in the second category will be due to earthquakes. Based on our estimate of the proportional impact of earthquakes, 90 percent of this category was attributed to erosion-related damage.

Totalling the two cause-codes gave an annual telephone line damage estimate of $550,000. Adding these costs to electricity reticulation companies gives an estimate of $850,000 annually for utility network damage.

Recreational facility damage

Senior DOC staff indicated that the cost of erosion-related repair and maintenance is approximately $400,000 per annum, with additional costs due to flooding amounting to $250,000 per annum. For simplicity and transparency, the flooding portion of total DOC-related erosion costs is retained with the other DOC data. The marginal impact of sediment in floodwaters is addressed in the same fashion for the DOC data as for other flood-related data in this report, with a value of 15 percent used (see p.25). The proportion of the $250,000 flood-related damage attributed to sediment was therefore $37,500, and total erosion related spending by DOC annually is approximately $440,000.

Actual estimated sediment effects

Insured loss due to increased flood severity

Ericksen (1986) estimated that nine major floods in a 16-year analysis period (1968–1984) cost $1.3 billion, and that when additional losses from smaller flood events are added, the total annual average loss equates to around $80 million ($1984). Extrapolation to 1998 gives an annual average of $108.7 million. Fifteen percent of flood-damage costs have been used as an estimate of the marginal contribution of soil erosion and sedimentation, based on estimates quoted in Clark et al. (1985). This gives a total estimate of the annual average loss due to the marginal impact of sediment in floodwaters of $16.3 million.

Reduced consumptive water quality

Approximately 10 percent of total water treatment costs can be attributed to sediment filtration (Water supply engineer, Palmerston North City Council, Palmerston North, N.Z., pers. comm.). Assuming constant per capita costs for supplying water in New Zealand cities (population centres over 30 000), a national estimate can be made. Christchurch has been excluded because its source of water is solely from bores, which generally do not require sediment filtration. Rural water supplies, which are usually only minimally treated, are also excluded. Using this approach, our estimate of the national costs of filtering potable water supplies is $2.8 million per annum.

Sedimentation impacts on water storage and power generation

The major cost of sedimentation on water storage in New Zealand has been the stabilisation costs of the Clyde dam construction project. Assuming a 100-year design life, the additional $420 million expenditure is equivalent to an annualised cost in the order of $42 million. Arguably, however, the deep-seated instability that this work was intended to stabilise goes beyond the generally understood concept of soil erosion. The annualised cost of the Alexandra flood compensation package is in the order of $0.15 million per annum since the construction of the Roxborough dam. In the absence of evidence of similar cases, we have used this as our annual national estimate of costs associated with lost water storage capacity. Given that this can be attributed to one of over 40 dams, this is likely to be a conservative estimate for this category.

Sedimentation impacts on navigation

Ports of Auckland's website suggests that commercial ports in New Zealand dredge a total of about 500 000 m^3 of sediment annually in their maintenance operations. From informal discussions with port companies, we understand that dredging costs range from approximately $\$5/m^3$ to $\$40/m^3$, and average $\$15/m^3$ across all ports. These data suggest a national estimate of port dredging costs in the order of $7.5 million per annum. Although little sediment dredged from harbours is directly deposited by terrestrial erosion processes, the difficulty in separating sediment delivered by rivers and stormwater outlets from that generated by coastal erosion processes has led to us assume that all sediment has been generated by the former.

Sedimentation impacts on water conveyance

From irrigation companies' information, we have estimated that dredging of irrigation channels and sediment ponds costs approximately $1/irrigated hectare/annum. This leads to a national estimate of $580,000 per annum.

Regional Council soil erosion spending

Direct expenditure on soil conservation programmes has been estimated from the 15 Regional Council and Unitary Council annual reports for the year ending June 1999. While expenditure on statutory planning has been excluded where possible, a proportion of expenditure on maintaining and enhancing flood and catchment works is included (15%), as are proportions of monitoring and environmental education initiatives from some Regional Councils where they include soil conservation initiatives. Both public and private contributions to projects under these programmes have been included. The total estimate of $18.5 million/annum is an underestimate of total expenditure on soil conservation expenditure as it excludes all expenditure that is independent of Regional Council support. However, this may not be significantly large, given that many Councils have easily accessible subsidy programmes in place.

Central government soil erosion spending

With the demise of centralised funding for soil and water conservation through the National Water and Soil Conservation Organisation, direct central government expenditure in this area has declined markedly. Arguably only two areas of expenditure are still directly related to soil erosion and conservation.

East Coast Forestry Project

Until recently, this project, initiated in 1991, had regional development, employment and soil conservation objectives. In a recent review (Bayfield & Meister 1998), soil conservation was recognised as the primary objective of the project, and ongoing expenditure was confirmed. On average, $2.7 million per annum has been invested in this project over the past 3 years.

Research

Publicly funded research has not been included as a component of central Government soil erosion spending. There are three reasons for this:

- research funds are not generally generated for a particular project, but set aside and contested for between competing projects. The amount of funding allocated to the contestable research pool is not a function of the specific issues being researched, but a reflection of the value society places on the development of new knowledge.
- the correct measure of the value of a research project, in this case, is the difference between the total cost of the research and the opportunity cost of the research that was foregone through funding the project. While the first element might be estimated, it is not possible to estimate the second.

- it is not possible to link research projects directly with specific outcomes. While there may be some justification for including purely operational research in these estimates (for example, an engineering study for reducing slips onto a particularly vulnerable stretch of road), there is insufficient publicly available information to analyse the exact purpose and outcome of each research project.

Given the complexity of these issues we have elected to exclude this category from consideration.

Table 5 Economic costs of soil erosion and sedimentation in New Zealand

Effects	Cost ($millions) $NZ1998
Damage costs (lost production, repair costs)	**103.2**
Soil erosion effects	
Agricultural production loss	37.0
Damage to infrastructure	
Farm infrastructure damage	5.6
Direct private property damage	5.7
Road/rail infrastructure damage	26.3
Utility network damage	0.8
Recreational facility damage	0.4
Loss of visual amenity	n/a
Other	n/a
Sediment effects	
Increased flood severity	
Insured loss	16.3
Production loss	n/a
Reduced water quality	
Consumption	2.8
Processing	n/a
Recreation	n/a
Biological degradation	n/a
Sedimentation	
Water storage loss (incomplete data)	0.2
Navigation	7.5
Water conveyance	0.6
Other	n/a
Avoidance / Prevention Costs (soil conservation)	**23.5**
Regional authority expenditure	18.5
Private expenditure	n/a
East Coast Forestry Project	2.7
Road preventative maintenance	2.3
Road realignment	n/a
Control measures associated with urban development	n/a
Total expenditure associated with soil erosion	**126.7**

Note: A significant non-quantifiable effect is the loss of cultural values associated with degradation of the landscape, reduction in water quality and loss of traditional food sources.

Discussion

A major objective of this project was to identify the types of costs generated by soil erosion in New Zealand, and the availability of data to quantify these. As demonstrated in the preceding section, deriving a full and firm estimate was hampered by a lack of data for many of the impacts identified in our framework. Additionally, when information was available it was often hard to collect and not always of high quality. Further, broad assumptions were necessary to generate national, annual estimates. We suggest a number of reasons for this.

Quantification difficulties

A primary issue in collecting data for this study has been the difficulty of quantifying some effects that, in economic terms, are likely to be significant costs of soil erosion. One of our major goals was to identify where, and in what form, information existed on the costs associated with New Zealand soil erosion. The results outlined above exhibit that up-to-date, accurate, and relevant information is the exception rather than the norm in each of the categories researched.

In an attempt to quantify the economic damages of flooding in New Zealand, Ericksen (1986) stated that the magnitude and type of losses from flooding are poorly recorded and remain relatively obscure. This holds true for the economic costs of soil erosion. If any relevant information was found, it generally required some broad assumptions to extrapolate to the desired scale.

Diffuse nature of effects

Many damaging effects that occur as a result of soil erosion are small and diffuse in nature and extremely difficult to aggregate. Their significance may be collectively large at a national scale, yet small at the individual level. One example is the small-scale sedimentation effects on flood plain production discussed earlier. While hundreds of hectares of land are affected by overtopping and sedimentation each year, each farming unit has only a proportion of their total land area affected. Few regions have a monitoring system in place at a resolution that picks up events of this type.

Lack of economic assessment of physical research

There is a considerable history of geomorphological research into the frequency and severity of erosion events in New Zealand. Much of the focus, however, has been on quantifying the impact of particular storm events. In more recent years, long-term erosion rates have been studied but at a spatial scale much larger than the average size of land management units. Similarly, there has been research into the economic impact of some storm events (Hicks et al. 1993; Korte 1988, unpubl. report). With the exception of work by De Rose et al. (1995) and the work that preceded it, however, there has been little attempt to quantify the long-term economic effects of erosion at a scale appropriate to those business enterprises affected by it, such as farms, forests and orchards.

Data collected for this study suggest that, on average, the annual expected cost of lost production from erosion damage to an individual farm, orchard, or forest, is relatively small. This is despite the potential for major effects on an individual property hit by an extreme event, and the very significant national cost when effects are aggregated across all properties. Consequently, commonly observed strategies like compensatory applications of fertiliser after adverse events, rather than widespread conservation planting before such events, may be economically rational for the individual land owner.

There is a need for more research into how to assess the probability of financial loss due to erosion damage and how to design appropriate risk management strategies for individual property managers. The elements of potential strategies are well documented and understood – pole planting, retirement, conservation woodlots, pasture improvement, compensatory fertiliser, over-sowing, riparian planting, etc. However, a simple means of assessing an economically efficient mix for an individual property, and the balance between public and private interest in funding that mix, has not yet been developed.

Regional Councils take a range of approaches to addressing soil conservation. Their major investment is in maintaining large-scale catchment and flood prevention programmes with a mix of levy and public funding. Some Councils invest significantly in grant schemes, others in education and facilitation. The effectiveness of the field programmes promoted by Regional Councils and Catchment Boards before them has been tested many times, and the factors influencing their success or failure are well understood. There is also a reasonable amount of work on the economic efficiency of such programmes, although most of it is forecast in reports prepared to justify the initiation of catchment management programmes. Nevertheless, there are some significant studies of actual programmes (Weber et al. 1992).

The effectiveness of the strategies employed to promote these programmes is less well tested, particularly in the deregulated and decentralised period following the enactment of the 1991 Resource Management Act. Without the necessary research, it remains impossible to determine the economic efficiency of the recent programmes and to determine whether increased expenditure in soil conservation is warranted.

Lack of institutional incentives for maintaining this information

The organisations that bear much of the economic damage caused by soil erosion do not generally appear to be aware of the specific magnitude of these costs. None explicitly identify erosion costs in their accounting or management systems, nor is a single person clearly responsible for reviewing the impacts. There could be a variety of reasons for this.

For some, the problem might not be significant enough to warrant time and effort in isolating soil erosion as a cause of damage. This is probably the case with many of the electricity line companies where fewer than five power poles are affected per year. For others, where the costs might be more significant, the costs and debates about the philosophical desirability of preventative action act as disincentives to determining the precise cause of any particular damage. For example, the conservation estate is concentrated in mountainous, erosion-prone terrain, and the Department of Conservation has a policy of not interfering with natural processes. Apart from keeping huts and tracks away from obvious erosion areas, there appear to be few preventative works DOC can carry out to minimise their annual soil erosion costs.

Costs of data collection

In addition to problems of data availability, it is clear that existing data are less accessible than in the past. This is largely the result of the regionalisation of responsibility for environmental management, and the sale and fragmentation of national state monopolies.

Decentralisation of responsibility for environmental management

Less than two decades ago, the National Water and Soil Conservation Authority (NWASCA) administered a national budget for soil conservation, drainage and flood prevention. This was then distributed to a number of regional catchment authorities. Since the late 1980s, the funding of environmental management issues has been devolved to local government, specifically 15 regional or unitary councils, which has led to increased difficulty in aggregating information on national soil conservation spending. The more significant difficulty is in rationalising the diverse range of approaches to management and funding that are used. Some regional councils budget and manage by issue or environmental effect, others by statutory function, and others use a hybrid approach. It is therefore quite difficult to isolate expenditure on a particular environmental issue across all councils.

Privatisation of major utilities

The privatisation of major utilities has similarly added to the number of commercial organisations managing the effects of soil erosion. It is not yet clear whether the scale of these smaller units will improve or reduce the quality of management and financial data collected. The privatisation and fragmentation has arguably seen a marked decline in the information collected and used by some of the companies now managing the resource. Anecdotal evidence suggests this is primarily an issue of scale, with the largest companies maintaining management systems at least as comprehensive as the government agency that preceded them.

Commercial sensitivity

An additional factor constraining the level of financial information available from newly formed competitive state-owned enterprises, or their private equivalents, is the concern for commercial sensitivity. An example of this is found in a series of flood events within a catchment system resulting in a hydroelectric power-generating company receiving heavy criticism for allowing properties to be inundated. Residents argued that a major contributing factor was reduction in storage capacity of a reservoir due to sedimentation, and that the company had taken insufficient remedial action to maintain the reservoir capacity. The company concerned was reluctant to provide detailed information about the costs associated with sedimentation.

Conclusions

This study is a first attempt to quantify the economic impacts of soil erosion in New Zealand. New Zealand is geographically, environmentally, topographically and economically distinct from much of the United States, where the only other major effort of this type has been attempted. Several characteristics of the New Zealand experience are brought to light in such an exercise.

One such characteristic is the difficulty in delineating divisions between natural and man-made erosion or between agricultural and urban effects of erosion. No attempt was made in this study to make such distinctions. Another is the effect of New Zealand's relatively steep, short rivers and low population density, which leads to infrastructure damage and agricultural production losses being the major soil erosion costs, in contrast to the United States where sedimentation effects (recreation, water storage, navigation) are the major costs.

A further characteristic of the New Zealand study is the paucity of data from which to build the estimates. Our decentralised system of erosion control and the privatisation of major utilities have contributed to a fragmentation of the data available for assessment. In addition, the diffuse nature of erosion effects provides little incentive for individual companies or environmental management organisations to collect specific data on soil erosion damage.

As outlined in this report, the collection of data was complex, and the accuracy of many of the figures is questionable. The final value estimate is to be viewed with significant caution. It is our intention that the result be considered no more than an order of magnitude estimate. We stress that we can say only that the *true* value is likely to be closer to $127 million than it is to $1270 million or to $12.7 million. As we have attempted to err on the conservative side when estimating, the true value is likely to be higher than our estimate.

The question arises as to what significance this analysis may have for soil erosion policy in New Zealand. The estimates do not provide any indication of the size of erosion damage costs avoided due to past and present conservation expenditure and, therefore, the rate of return on soil conservation investment cannot be derived from this work. Estimates of damage costs avoided are difficult to make and generally rely on extrapolation from pre-investment damage records. Neither do the estimates made in this report provide information on the rate of depreciation of the current soil conservation "assets" (catchment works, soil conservation planting, etc.) and whether current expenditure is sufficient to offset that depreciation.

The analysis shows that current expenditure on the prevention of additional erosion is a significant proportion of the estimated value of annual damage costs. This suggests there may be little opportunity for major reductions in damage costs with marginal increases in conservation expenditure. However, because little information is available on the efficiency of existing expenditure, it is difficult to draw any firm conclusions on that issue. Given the natural propensity toward soil erosion in New Zealand, declining returns to investment in soil conservation could be expected at some point, but it is unclear whether that is true of our present position.

The survey also demonstrates that the ability to determine and implement an efficient soil conservation strategy for New Zealand is hampered by decentralisation and privatisation of former Government services and responsibilities. This is not only because of the lack of easily accessible information but also because of the regionalisation of soil conservation policy and funding. This has been recognised by central Government in its decision to fund the East Coast Forestry Project, which supports soil conservation in a region less able to fund such programmes from local resources.

Prioritising projects at a regional level using benefit cost analysis on a project-by-project basis falls significantly short of the ideal, given the differences between regions in rating base, propensity for erosion, and values being protected.

Finally, the analysis provides some indication of the balance between public and private interest in the impacts of soil erosion. Most of the soil erosion impacts in the framework developed for this study would traditionally be termed on-site effects. Similarly, sediment effects would traditionally be termed off-site effects. Given their often diffuse nature, it is not surprising that the latter effects proved most difficult to quantify. Off-site costs were 26% of the total costs quantified; however, a number of potentially significant off-site costs were not estimated (biological degradation, carbon loss, the contribution of erosion to losses in agricultural production from flooding).

The ranking of avoidance cost estimates is consistent with a rational response to the type and relative size of the damage effects. Transit NZ's expenditure on road realignment and preventative maintenance is consistent with the significant erosion damage costs the roading network incurs. Regional Councils' investment in flood and erosion control reflects the costs to the wider community of uncontrolled flooding and erosion. The discontinuity between the loss in potential agricultural productivity to the nation caused by soil erosion, and the lack of incentive for private land owners to invest in soil conservation is the significant anomaly highlighted by the study. This issue is not well-addressed in the RMA, where existing land uses have pre-emptive rights. The differences between regions in rating base and propensity for erosion mean that a national approach to this issue is likely to be more efficient than a regional one.

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The authors would like to thank:

Attlewell Irrigation
Central Power
Contact Energy
Department of Conservation
Earthquake Commission
Eastland Networks
Electrical Engineers Association of New Zealand
Fish and Game New Zealand
Insurance Council of NZ
Meridian Energy
Mighty River Power
Ministry of Emergency Management
Palmerston North City Council
Port of Auckland
Rangitata Diversion Race Company
Telecom NZ
Todd Corporation
Transit NZ
Tranz Rail
United Networks Ltd