Ministry for the Environment
Manatū Mō Te Taiao

Quantification of the Flood and Erosion Reduction Benefits, and Costs, of Climate Change Mitigation Measures in New Zealand

New Zealand Government

Disclaimer

This report represents work undertaken by Blaschke and Rutherford Environmental Consultants for the New Zealand Ministry for the Environment. The Ministry for the Environment does not accept any responsibility or liability whatsoever for any error of fact, omission, interpretation or opinion which may be represented in this report, however it may have occurred, nor for any consequences flowing from reliance on that information.

The document may be cited as:
Blaschke P, Hicks D, Meister A. 2008. *Quantification of the flood and erosion reduction benefits, and costs, of climate change mitigation measures in New Zealand.* Report prepared by Blaschke and Rutherford Environmental Consultants for MfE. Wellington: Ministry for the Environment. iv + 76 p.

Published in April 2008 by the
Ministry for the Environment
Manatū Mō Te Taiao
PO Box 10 362, Wellington, New Zealand

ISBN: 978-0-478-30223-3 (electronic)

This document is available on the Ministry for the Environment's website:
www.mfe.govt.nz

Ministry for the Environment
Manatū Mō Te Taiao

Contents

1	Introduction	1
	Terminology	2
	Patterns of deforestation, afforestation and reversion in the New Zealand landscape	3
	Information sources	5
2	Physical Effects of Afforestation and Reversion on Flood Occurrence and Other Hydrological Phenomena	7
	Research studies in small catchments	7
	Large catchment investigations	12
	Changes in flooding risk	14
	Conclusion: water yield, floods and low flows	18
3	Physical Effects of Afforestation and Reversion on Sediment Yield	21
	Summary of New Zealand data	21
	Large catchment investigations	25
	Conclusion: sediment yield	28
4	Physical Effects of Afforestation and Reversion Effects on Erosion	30
	Summary of New Zealand data	31
	Effect of afforestation/reversion patterns	37
	Conclusions: terrestrial erosion	37
5	Estimates of Monetary Benefits / Costs	39
	Introduction	39
	Concepts for valuation	40
	Monetary value of flooding reduction	42
	Monetary value of changes to low flows	43
	Monetary value of sediment reduction	44
	Monetary value of terrestrial erosion reduction	45
	Nationwide estimates	46
	Conclusion: monetary estimates	47

6 Recommendations on Methodology for a National Perspective 48
Introduction 48
Flood reductions and water yield 48
Monetary value of flood damage reduction 50
Sediment yield 50
Monetary value of sediment yield reductions 54
Terrestrial (on-site) erosion 54
Terrestrial erosion reductions: nationwide estimates of monetary value 57

7 Summary and Conclusions 59
Effects of afforestation and reversion on floods, low flows and water yield 60
Effects of afforestation and reversion on sediment yield 62
Effects of afforestation and reversion on terrestrial erosion 63
Summary of impact of afforestation on erosion under different scenarios 64
Targeting benefits of afforestation and reversion for sediment yield and erosion reduction 65

8 Bibliography 66

9 Acknowledgements 76

Tables

Table 1: Effects of land use on water yield 8
Table 2: Effects of land use on flood flows 9
Table 3: Effects of land use on low flows (from experimental catchments) 10
Table 4: Effects of land use on sediment yield 22
Table 5: Effects of land use on sediment yield 23
Table 6: Effects of land use on sediment yield 24
Table 7: Ranges in annual suspended sediment yield for medium to large catchments categorised by geology, dominant vegetation cover and rainfall 26
Table 8: Vegetation effects on terrestrial erosion (from storm damage surveys) 32
Table 9: Vegetation effects on terrestrial erosion (from point sample surveys) 33
Table 10: Effects on terrestrial erosion (from soil conservation effectiveness surveys) 34
Table 11: Monetary value of damage repair costs (averaged over farm area; sediment, flooding, and erosion damage combined) 44
Table 12: Range of percentage reductions in crop and pasture yield due to erosion 45
Table 13: Regional costs and benefits of soil conservation – a preliminary framework 58

1 Introduction

The Ministry for the Environment has commissioned a review aimed at:

- determining whether, with existing information and analysis, it is possible to make credible, 'order of magnitude', quantitative estimates of any flooding and erosion reduction benefits (or costs) associated with measures to sequester carbon dioxide or reduce emissions of greenhouse gases in New Zealand
- providing the initial estimates of the benefits (or costs); or where information is not available, to provide advice on an alternative methodology for measuring such benefits.

This work is a technical contribution to the development of appropriate New Zealand policies for climate change mitigation. Reductions in erosion and flooding are only two examples of the 'co-benefits' potentially available through certain climate change mitigation measures. However such reductions may be significant, for several reasons:

- New Zealand's rugged terrain, tectonic instability and short steep river catchments mean that we have high rates of natural and induced erosion and flood frequency
- there are many documented examples of physical and economic losses from such erosion and flooding
- there is some documentation of reductions in erosion and flooding through afforestation or reversion in certain environments.[1]

The research brief[2] involves three tasks:

1. (a) to define the circumstances under which tree establishment, as a climate change mitigation measure in New Zealand, will have significant flood and landslip reduction benefits (or costs), and then

   (b) to survey and summarise work that provides a credible quantitative estimate of the physical landslip or flood reduction benefit from tree establishment
2. to provide national estimates, where available, of *physical* co-benefits of climate change mitigation measures;[3] or advice on alternative methodology where such information is not available
3. to provide national estimates, where available, of *monetary* co-benefits of climate change mitigation measures; or advice on alternative methodology where such information is not available.

This report first discusses the available information sources. It then presents the detailed information about estimates of benefits and costs, in three chapters.

---

[1] As referenced in later 'approaches' chapters.

[2] Wording used in Request for Proposal; see later discussion of erosion terminology. We have referred to 'co-benefits' and 'co-costs' simply as 'benefits and costs', with the implicit assumption that these benefits and costs are linked to climate change mitigation measures.

[3] We have also considered adaptation measures.

Chapter 2 discusses reductions in flood peaks passing down rivers, and also discusses several other hydrological changes that may have economic implications; notably alterations to annual water yields and minimum low flows. Chapter 3 discusses reductions in sediment yield (the product of terrestrial erosion, delivered to waterways). Chapter 4 discusses reductions in terrestrial erosion (processes that affect soil on land). The physical effects of sediment yield are in or close to waterways.

Other published studies and contract reports describe carbon loss from erosion and sediment transport in New Zealand, relative to the carbon sequestration attributed to afforestation and reversion (eg, Tate et al, 2000; Page et al, 2004; Scott et al, 2006). These fluxes may be very significant for overall climate change mitigation policies; for instance carbon transported off-site by soil erosion is between 3 million (M) and 10M tonnes per year (although it has not yet been determined how much of this is volatilised, or how much is trapped through attachment to deposited sediment). The work of these authors leads to the suggestion that "erosive steeplands should be a global priority for tree-planting because of the double benefit of carbon sequestration and erosion reduction" (Scott et al, 2006). However, carbon reduction benefits from reduced flooding, erosion or sediment yield are excluded from Chapters 2 to 4.

In accordance with the brief, our review focuses solely on whether there are significant reductions in flooding, or erosion, or sediment yield. This question must be answered first, before attempting any quantification of associated carbon reduction benefits.

In each section we summarise published and unpublished information in a series of tables, but refrain from comment on the authors' scientific interpretation of their results; as this has already been done by several excellent published reviews, for which we provide references. Instead, we concentrate on interpreting what the results tell us, about circumstances under which tree establishment would have significant flood and erosion reduction benefits (or costs) in New Zealand. We then move on to discuss studies that estimate the monetary value of these effects (Chapter 5).

Finally we comment on the types of studies that could be undertaken to provide more reliable estimates, and some of the methodological and other issues in extending the work on quantification of benefits and costs of climate change mitigation measures in New Zealand (Chapter 6). The report ends with a set of conclusions (Chapter 7).

Terminology

The brief for this project referred to 'landslip' frequency and severity. We have assumed that the term 'landslip' was used synonymously with the internationally more common term 'landslide', as well as other types of mass movement erosion that occur in New Zealand. In this report we refer to *all* types of erosion occurring in New Zealand, including:

- mass movement erosion – movement of material under the influence of gravity
- fluvial erosion – transport of material by water
- wind erosion – transport of material by wind.

Some types of erosion, such as gully or streambank erosion, involve both gravity and water in the movement of materials, but for the purposes of this review it is not necessary to distinguish between types of erosion based on their mechanism. All types of erosion may be influenced, to a greater or lesser extent, by changes in land use or vegetation cover such as afforestation or reversion.

Patterns of deforestation, afforestation and reversion in the New Zealand landscape

New Zealand has a very high-energy geomorphic environment, characterised by high rainfall in the headwaters of most major catchments, high relief, high rates of tectonic and volcanic processes, and susceptibility to high-intensity extra-tropical rainstorms. Because of these determining factors, our *natural* rates of erosion are very high, even without the historical processes of deforestation that have occurred.

New Zealand was widely deforested in two major phases: one in the first couple of centuries of Polynesian settlement, and one during the expansion of European farming in the late part of the nineteenth century and early twentieth century (in some districts continuing well into the second half of the twentieth century). Extensive erosion and deposition followed both these phases, but in a complex pattern that reflects the geomorphology of the New Zealand landscape. Also, sedimentation and flooding responses to erosion are often long delayed, due to large volumes of sediment being stored in upstream river valleys by up to many decades – until some factor such as a further storm, earthquake or uplift triggers downstream movement or response.

In response to the European phase of deforestation and erosion, public agencies (mainly the New Zealand Forest Service and catchment boards) undertook extensive reforestation between the 1950s and 1980s, throughout the middle and upper reaches of catchments throughout the North and South Islands. Widespread afforestation was also undertaken by private companies but generally on land that was less steep and less erosion-prone, notably in the volcanic plateau on land that had been unsuitable for farming. These areas of widespread afforestation occupy blocks of land tens of thousands of hectares in extent, but are typically located within even larger catchments; and are separated by land under other uses.

Evidence for reduced terrestrial erosion in and sediment yields from these afforested areas has been summarised by Vaughan (1984), Wallis and McMahon (1995), Maclaren (1996), and Hicks (2000b).

During the 1980s and 1990s, extensive afforestation by private landowners took place in many regions. In contrast to the widespread public agency afforestation summarised above, private farm-scale afforestation is diffuse: a typical pattern is farm woodlots, cumulatively several tens of hectares, scattered across a hill country farm several hundred hectares in extent. As well as afforestation, widespread reversion to scrub has taken place in the middle reaches of catchments in many regions in areas where farming could not be sustained, or owners (both private or the Crown) did not wish to continue farming.

In addition, significant areas of deforestation, mainly of exotic plantations, have occurred in the last decade as owners reacted to relatively low prices for exotic forest products and high prices for farm (particularly dairy) products.

The balance of these processes of afforestation, deforestation and reversion is reflected nationally and regionally by ongoing change in the total areas of vegetation shown in surveys such as the Land Cover Data Base. Areas in exotic forest and regenerating scrub are subject to the greatest changes. Historical phases of change are reasonably well documented (McGlone, 1989; MacCaskill, 1974; McKelvey, 1995; Roche, 1994; Pawsey and Brooking, 2002).

More detailed historical discussion is beyond the brief of this project. This sketch merely sets a context for the patterns of afforestation that we seek to summarise in the following three chapters. These consider in more detail the likely consequences of increased afforestation under three scenarios of different intensity:

- incremental afforestation: diffuse afforestation by individual owners on their own properties that continue to also support farming
- wide-scale afforestation: whole properties changed in land use and afforested, affecting a large proportion of catchment or sub-catchment
- whole-catchment afforestation: Crown intervenes to afforest or promote reversion of whole catchment or sub-catchment.

As a background to discussion of the implications of these scenarios, it is useful to summarise the likely patterns of afforestation and reversion under each.

Large forests, established during the 20th century by public agencies such as the former New Zealand Forest Service or by private companies, occupy blocks of land tens of thousands of hectares in extent. But they are located within even larger catchments; and are separated by land under other uses. The Tarawera catchment, selected by NIWA as typical for an investigation of large-scale forestry's effect on runoff, has pine plantations on just 28% of its 900 square kilometres. It would be possible to find several other medium-sized catchments (100 to 1000 km^2) in the central North Island and in Nelson, where a larger percentage has been afforested. Elsewhere in the country, there would be almost no large or medium-sized catchments where blocks of planted forest cover more than 10% by area.

Afforestation by private landowners, in contrast, is diffuse. A typical pattern is farm woodlots, cumulatively several tens of hectares, scattered across a hill-country farm several hundred hectares in extent. When such a land use pattern is aggregated for medium-sized catchments (100 to 1000 km^2), small-scale afforestation might exceed 10% by area in some, for example in Northland and the hill country of the eastern North Island (Gisborne, Hawkes Bay, Wairarapa); the western North Island (King Country, Taranaki, Wanganui); the Marlborough Sounds, and parts of Nelson.

Public agencies such as the Department of Conservation, inheriting land from the former Department of Lands and Survey and other stewardship land, have few tracts on which wide-scale reversion has occurred. Perhaps the only instance of scrub reversion, on a scale of thousands of hectares, would be the farm settlements inland of Taranaki and Wanganui, cleared in the decades around 1900 and then largely abandoned at varying times afterwards. Such reversion, though un-measured by area, would occupy a substantial percentage of several medium-sized catchments, notably of the Ohura, Whangamomona, Whenuakura, Waitotara, Patea and Waitara Rivers.

Reversion on private farmland is more widespread, even though most single private landholdings are not large enough for large tracts of land to revert. However, on large farms in rough hill country, it is not uncommon for up to a few hundred hectares of land to be abandoned and reverting, as a large block at the back of a farm, that is otherwise clear and grazed. On easier hills, also on downlands and plains, small blocks of land individually less than ten hectares are allowed to revert for a purpose: riparian protection on a riverbank, or erosion control in a gully, or destocking a steep face that is difficult to graze and muster.

The proportion of medium-sized catchments occupied by such reverted land has not been specifically measured but could be (see Chapter 7). In the absence of quantitative estimates, our knowledge of the country's farming districts suggests to us that catchments where private reversion is in the 10 to 20% range, could be expected in the following regions: western

Northland, Waikato-King Country west of the Waipa River, farmed parts of inland Taranaki and Wanganui. Many catchments from Marlborough through Canterbury and central Otago to interior Southland might be added, on account of sparse woody scrub in retired tussock grasslands. Only in the Bay of Plenty east of Opotiki, the East Coast north of Tolaga Bay, perhaps the Catlins district of South Otago and the Waiau district of western Southland, might we expect reverted land on private farms to exceed 20% of catchments' area.

This list might be expanded somewhat under a scenario of wide-scale afforestation, in which whole properties are purchased for afforestation, for the purposes of permanent timber production and/or carbon storage – thereby affecting a larger proportion of a catchment or sub-catchment. There is reported investor interest in such possibilities (A Shrivastava, MAF, personal communication, August 2007). Current interest is focused on areas with proven forest growing conditions, such as the East Coast, inland Manawatu, and Northland. We suggest that such whole-farm purchases would not greatly expand the above list of regions where extensive afforestation could be anticipated.

Deliberate government intervention to afforest or promote reversion of a whole catchment or sub-catchment has been much more recent. Up till now, in the rare cases where the Crown or catchment boards / regional councils took ownership or management of extensive areas of hill country, this was driven by soil or nature conservation purposes. Very recently the Department of Conservation (DOC) has offered land to tender to commercial investors for climate change initiatives (Minister of Conservation, 2007). So far the projects described have involved six areas totalling about 40,000 hectares. The projects are being designed to either replant or promote natural regeneration of forest on land that was not in forest before 1989; or to undertake major pest control in order to remove animal pests (eg, goats) that emit methane, or in order to promote increased plant growth in the absence of such pests.

Target areas on the public conservation estate that are potentially suitable for such management have not been identified but are potentially very large. For example, 150,000 ha of forested hill country within Whanganui National Park and adjoining public conservation land are not currently receiving goat control yet have the potential for increased growth of woody biomass through goat control (Arand, 2007). Additionally, large areas of public land (in the order of hundreds of thousands of hectares) currently have a non-Kyoto forest land cover that is theoretically available for indigenous afforestation, although afforestation would undoubtedly not be sensible nor acceptable for a large proportion of this land.

Potential benefits of afforestation, reversion, or pest control of such land have so far been described by DOC solely in terms of greenhouse gas reductions. Associated potential benefits in terms of reduced flooding or erosion do not appear to have been considered, let alone other potential ecosystem or biodiversity conservation benefits.

Information sources

There is an extensive literature on the subject of benefits from soil conservation and afforestation, further discussed in Chapter 4. The literature that is relevant for this review of flood and erosion reduction benefits is highly dispersed; much of it is unpublished and was undertaken by agencies that have since been disbanded, hence the literature is difficult to obtain. We use both published and unpublished literature, but take a critical attitude to the reliability and applicability of either source. We have only examined New Zealand literature.

Information cited for our review includes:

- regional-average percentage reductions in eroded[4] area under different land uses, from State of the Environment reports by region councils since 1990
- storm-specific percentage reductions in eroded area under forest plantations, native scrub, and native forest (from storm damage surveys by local and central government agencies, 1970s–1990s)
- catchment-specific information on reductions in flood peaks, and sediment yields, from research investigations by a number of agencies
- a small number of reports attempting to put monetary values to reductions in flooding or erosion
- other reports available to us, from a range of sources.

Where appropriate we comment further on the literature sources (reliability etc) as we cite them.

Such a multiplicity of sources might lead to the expectation that there is a great deal of information on the subject. Unfortunately most of it is of low value for undertaking the sort of nationwide estimation that MfE seeks, particularly for flood-related issues.

To be reliable, flood frequency / magnitude data need to be collected long-term. Likewise, information about the extent and recurrence of terrestrial erosion, and the amount of sediment it contributes to waterways. It is true that these parameters have been measured long-term in some large New Zealand catchments, but land use in these catchments is mixed, and this makes interpretation of land-use effects difficult. There are some comparative investigations (paired catchment or before / after studies), in catchments where land use is uniform, but these are almost all short-term.

Furthermore, the variability of the New Zealand landscape means that a large number of studies need to be undertaken to achieve meaningful national estimates.

[4] We include all forms of terrestrial erosion in our assessment where data is available.

2 Physical Effects of Afforestation and Reversion on Flood Occurrence and Other Hydrological Phenomena

How floods are altered by the planting or clearance of forests, is well known. For many decades now, from boreal forests to equatorial jungles, hydrologists have carried out scientific investigations of the topic. New Zealand investigations have been reviewed by Waugh (1980), Fahey and Rowe (1992), Maclaren (1996), and most recently by Fahey et al (2004). Rather than duplicate their reviews, our intent is to summarise key findings, and discuss their relevance to MfE's brief ie, what do they actually tell us about the likely effect of afforestation or reversion carried out for the purpose of carbon sequestration?

Research studies in small catchments

These studies have been conducted in small catchments that have been entirely afforested or allowed to revert into scrub, or where standing forest or scrub have been cleared, specifically for the purpose of hydrological research. Relevant data come from two types of catchment investigation: where small catchments have been entirely afforested or allowed to revert into scrub; and where small catchments in standing forest or scrub have been cleared. Published summary data from these catchment investigations are grouped below into three tables, for water yield (runoff), floods, and low flows.

Table 1, from small catchment studies distributed throughout New Zealand, suggests a ubiquitous decrease in annual water yield when catchments are afforested or allowed to revert. A few of the reported decreases are quite small; most are in the 20 to 60% range; and some exceed 80%. All authors cited in Table 1 use the same hydrological statistic, averaged annual water yield. This enables direct comparison of their results. The only uncertainty when making comparisons, is the error margin inherent in averaging annual yields from a short record length. Few publications give the complete range of annual yield reductions.

Significant points to note about the published data in Table 1 are:

- water yields are averaged over several years (typically 10+ for standing forest, though as few as two for the pre-clearance vs post-clearance studies)
- in any one year, water yield reductions are greater or less than the average values
- most comment that reductions are greater in dry years and less in wet years are rainfall-driven.

Table 1: Effects of land use on water yield

Catchments	Region	Comparison	% change	Source	Comments
Waiwhiu	Northland	Pines vs pasture	–25	Rowe et al, 2003 – derived from Waugh, 1980	
Hunua	Auckland	Pines vs scrub and reverting pasture	–30	Herald, 1978	
Purukohukohu	Volcanic plateau	Pines vs pasture	–30	Rowe et al, 2003 – derived from Dons, 1987	
Purukohukohu	Volcanic plateau	Bush[5] vs pasture	–37	Dons, 1987	
Taita	Wellington	Pines vs pasture	–30	Claridge, 1980 and Jackson, 1973	67% of pasture catchment in grass
Taita	Wellington	Bush vs pasture	–6	Claridge, 1980 and Jackson, 1973	67% of pasture catchment in grass
Moutere	Nelson	Pines vs pasture	–81	Duncan, 1995	
Moutere	Nelson	Scrub vs pasture	–14 to –62	Duncan, 1980	
Kikiwa	Nelson	Pines vs pasture	12	McKerchar, 1980	Record length one year
Kikiwa	Nelson	Bush vs pasture	–4	McKerchar, 1980	Record length one year
Collins	Marlborough	Pines vs scrub and pasture	0	Riddell, 1980	
Kakahu	South Canterbury	Pines vs tussock	–45	Rowe et al, 2003 – derived from Davoren, 1986	
Berwick	Otago	Pines vs pasture	–43	Smith, 1987	
Glendhu	Otago	Pines vs tussock	–30	Fahey and Jackson, 1997a	67% of pine catchment afforested
Puketurua	Northland	Scrub	–18 to –34	Schouten, 1976	Pre- vs post-clearance, two years*
Glenbervie	Northland	Pines	–30 to –40	Rowe et al, 2003	Pre- vs post-clearance, dry years*
Glenbervie	Northland	Pines	–75	Rowe et al, 2003	Pre- vs post-clearance, wet year*
Maimai	West Coast	Bush	–43	Rowe and Pearce, 1994	Pre- vs post-clearance*
Big Bush	Nelson	Bush	–38	Fahey and Jackson, 1997a	Pre- vs post-clearance*

* Expressed as reversal of authors'% yield increase.

Table 2 (effects of land use on flood flows, from a subset of the same small catchment studies as Table 1) suggests very large decreases in flood peaks, but considerable variation in the magnitude of decreases measured in different parts of the country. Flood peak reductions are in

5 The term 'bush' is used throughout this report to refer to areas dominated by native forest or woody scrub species.

the range >90% to 30% for small floods; 70% to 50% for annual floods; and 50% to 20% for large floods.

Table 2: Effects of land use on flood flows

Catchments	Region	Comparison	% change	Source	Comments
Purukohukohu	Volcanic plateau	Pines vs pasture	–50	Rowe et al, 2003 – based on Dons, 1987	Small floods (less than annual)
Purukohukohu	Volcanic plateau	Pines vs pasture	>90	Rowe et al, 2003 – based on Dons, 1987	Large floods (greater than annual)
Purukohukohu	Volcanic plateau	Bush vs pasture	–89	Dons, 1987	Averaged peak flows
Taita	Wellington	Pines vs pasture	–35 to –80	Claridge, 1980; Jackson, 1973	Averaged peak flows, all floods each year
Taita	Wellington	Bush vs pasture	–7	Claridge, 1980; Jackson, 1973	Averaged peak flows, all floods each year
Moutere	Nelson	Pines vs pasture	–80	Duncan, 1995	Small floods (less than annual)
Moutere	Nelson	Pines vs pasture	–65	Duncan, 1995	Averaged peak flow, annual floods
Moutere	Nelson	Pines vs pasture	–50	Duncan, 1995	50-year flood
Kikiwa	Nelson	Pines vs pasture	40	McKerchar, 1980	Averaged peak flows, record length one year
Kikiwa	Nelson	Bush vs pasture	12	McKerchar, 1980	Averaged peak flows, record length one year
Berwick	Otago	Pines vs pasture	–67	Smith, 1987	Averaged peak flow, annual floods
Glendhu	Otago	Pines vs tussock	–50	Fahey and Jackson, 1997a	Averaged peak flow, annual floods
Maimai	West Coast	Bush	–37	Rowe and Pearce, 1994	Pre-clearance vs post-clearance, small floods*
Maimai	West Coast	Bush	–23	Rowe and Pearce, 1994	Pre-clearance vs post-clearance, large floods*
Big Bush	Nelson	Bush	–34 to –44	Fahey and Jackson, 1997a	Pre-clearance vs post-clearance, small floods*
Big Bush	Nelson	Bush	"marked"	Fahey and Jackson, 1997a	Pre-clearance vs post-clearance, large floods*

* Expressed as reversal of authors'% flood peak increase.

Points to note about Table 2 are that:

- there is no uniformity in the nature of published flood reduction values
- some of the published figures are for annual floods ie, averaged values for the largest floods each year
- others are for small floods or 'freshes' ie, averaged values for floods that occur frequently during a year
- others again are for large floods or 'storms' ie, averaged values for floods that occur infrequently
- record lengths vary from 2 to 10+ years, but in all instances except Purukohukohu and Moutere, are too short for statistically reliable flood frequency analysis.

So a lot of the variation in magnitude of flood peak reductions relates to statistical presentation of results. All the authors have measured the same thing ie, a time series of flood peaks, but they have analysed them differently. This makes comparison of their summary values difficult.

An important *non-effect,* not apparent from Table 2, is that reduced flood peaks do not necessarily indicate reduced flood volumes. Some of the publications indicate that afforestation results in somewhat broader, lower flood waves. These discharge much the same total volume of floodwater downstream, but over a longer period of time. Other publications are silent on this point.

Table 3 is derived from a smaller sub-set of catchment studies, because few have published data about the effect of afforestation on levels of low flow. These few, mainly from the South Island, suggest residual low flows in late summer-early autumn decline by at least one-fifth (except for two short-duration records from Nelson).

Table 3: Effects of land use on low flows (from experimental catchments)

Catchments	Region	Comparison	% change	Source	Comments
Purukohukohu	Volcanic plateau	Bush vs pasture	–29	Dons, 1987	Averaged annual low flow yield
Purukohukohu	Volcanic plateau	Pines vs pasture	–52	Dons, 1987	Averaged annual low flow yield
Moutere	Nelson	Pines vs pasture	–50	Duncan, 1995	Averaged annual low flow yield
Kikiwa	Nelson	Pines vs pasture	–7	McKerchar, 1980	Low flow yield, record length one year
Kikiwa	Nelson	Bush vs pasture	–4	McKerchar, 1980	Low flow yield, record length one year
Berwick	Otago	Pines vs pasture	–20	Smith, 1987	Averaged seven-day annual low flow
Glendhu	Otago	Pines vs tussock	–18	Fahey and Jackson, 1997a	Averaged seven-day annual low flow

Significant points to note about Table 3 are:

- almost all catchments have low to moderate annual rainfall (mean annual ranging from 800 to about 1400 mm)
- the situation in high-rainfall catchments is either unknown or not analysed (probably the latter, as low flows would have been routinely measured in several other small-catchment studies).

Several publications about other research catchments state that their low flows declined after afforestation; or that these increased when forest was felled; but the publications do not give citable low flow statistics. It is unclear whether their statements are based on analysed data, or visual observation of hydrograph traces; or merely assume that, because annual water yields decline, residual low flows necessarily fall. Accordingly these catchments do not appear in Table 3.

Implications for forestry or reversion established primarily for carbon sequestration

At first sight, the New Zealand research findings might be seen as implying that forestry or reversion will result in:

- a substantial reduction in annual water yield
- an even greater reduction in flood peaks
- a modest reduction in low flows.

The research findings have been well publicised, perhaps leading planners and policy analysts to expect that carbon sequestration may have significant benefits in terms of flood reduction, or costs by way of reduced water availability for agricultural or industrial use.

We draw attention to what the authors of already-published reviews say. Maclaren (1996), after discussing several New Zealand extrapolations of research data to large, partly-forested catchments, states:

> *These examples illustrate the need to put land use in context. Vegetation may have a trivial influence on hydrological characteristics, compared with topography, the extent and influence of precipitation, and the structure of the soil and parent rock. Certainly, considerable caution needs to be exercised when extrapolating findings from one catchment to another.*
>
> *To summarise: the benefit of forests in mitigating floods should not be overstated. Floods are common even in catchments of undisturbed native vegetation. Forests clearly can provide some smoothing of flood peaks in certain situations, but only in relatively small storm events and generally for small catchments and in areas close to afforested sub-catchments. Their main benefit lies in their ability to reduce sedimentation, if appropriate management practices are used.*

Fahey et al (2004) state:

> *Afforesting close to 100% of small to medium size catchments that were previously in pasture or tussock grassland may reduce annual water yields by up to 55% and low flows by at least 20%, but the full effects will not be seen until canopy closure 5 to 10 years after planting.*
>
> *Reversion of pasture to other forms of woody vegetation such as gorse, manuka or bracken will also reduce yields, but not to the same extent.*
>
> *In larger catchments the effects of planned afforestation on water yields and low flows are likely to be less pronounced, because plantings will be at different stages of development throughout the catchment. Excluding high water yielding areas such as riparian zones from planting, coupled with careful management practices, will also help keep reductions in water yield to a minimum. Plantation forests on land previously in pasture or tussock grassland can also reduce flood peaks by a half to a third.*

Fahey et al (2004) do not point out that the last sentence, like the others, is actually based on data from small catchments (generally less than 10 km^2). They remain silent on whether flood peaks in large catchments are likely to be dampened as much. However, the italicized paragraphs are unaltered verbatim quotations from recent peer-reviewed reviews by leading researchers. They are the best summary of afforestation effects on flood peaks in the New Zealand landscape available at this time.

Large catchment investigations

Few large-catchment studies of afforestation effects on river flows have been carried out in New Zealand. Dons (1986) measured a 13% decrease in annual water yield from the 900 km^2 Tarawera catchment (Bay of Plenty), after 28% of its area was converted from scrub and bush into pine plantation between 1964 and 1981. However, he attributed just 5% of the decrease to afforestation; the other 8% being due to lower rainfall. Pearce (1987) estimated a 30% reduction in water yield from 120 km^2 of land afforested between 1960 and 1986 in the upper Mangatu and Waipaoa sub-catchments (East Coast). The afforested land was 36% of sub-catchment area (155 + 183 km^2). Pearce's method entailed subtracting evapo-transpiration estimates from rainfall records.

Mulholland (2006) forecast a 230% increase in peak discharge, from proposed deforestation of 225 km^2 in Waikato sub-catchments between Wairakei and Atiamuri (57% of four sub-catchments' area). Volumes of flood runoff (into the Waikato River) were predicted to increase by 110–131 m^3/s in a 20-year flood, and 222–239 m^3/s in a 100-year flood. Mulholland's predictions were made by applying flood runoff changes from the Purukohukohu experimental basins (headwaters less than 1 km^2 where flood runoff is surficial and its volume is just 2% of storm rainfall) to flow records from the Mangakara and Waiotapu (catchments 22 km^2 and 232 km^2 where the bulk of floodwater emerges by rapid translatory groundwater flow through pumice and ignimbrite, and its volume is a larger percentage of rainfall). The forecast flood runoff increases appear substantial (an additional 1 cumec per square kilometre of deforested area in a 100-year flood), but need to be scaled back (in proportion to the ratio of surface to subsurface floodwater contributions) before they can be applied to larger Waikato sub-catchments.

Turning specifically to low flows, Woods and Duncan (1999) used the Tarawera catchment to calibrate a hydrological model that produced similar outputs to Dons' measurements. He and Woods (2001), using the same model to simulate a hypothetical 59% afforestation of the 544 km^2 Shag catchment (Otago), forecast a 45% reduction in low flows. In several medium catchments from Nelson through Canterbury to Otago, modelling studies by regional councils (unpublished but cited by Fahey et al, 2004) forecast that low flows will decline by more than 5%, if afforestation cumulatively amounts to more than 15% of catchment area.

These few investigations in medium or large catchments support Maclaren's (1996) and Fahey's (2004) caveats. They confirm it would be unwise to extrapolate absolute flows or percentage reductions in flows from small research catchments, where 100% of area has been allowed to revert or afforested, to the entire area of medium or large catchments.

Why this is so, can be elucidated by considering what happens when small-catchment data are extrapolated to unfarmed land, cumulatively less than 50% by area, diffused as small blocks through a larger area of farmed land. The runoff from a small block of afforested or reverting land reduces, by much the same percentage as small-catchment studies indicate. But this reduction is overwhelmed by 'normal' runoff entering the stream from a much larger area of surrounding farmland.

Taking a hypothetical example: if

- one-fifth of a sub-catchment is afforested, and the flood peak out of the afforested area reduces by 50%

then flood peak

- from the farmed four-fifths of the sub-catchment remains at 100%
- at the sub-catchment's outlet reduces by 10% overall.

What actually happens to a flood wave passing down a large river is somewhat more complex, because its catchment's flood response is not uniform. Quite apart from any vegetation effect, how fast a flood wave accumulates in the main channel, is influenced by:

- catchment shape (rounded, narrow, or regular)
- flow network topology (tributary branches numerous or sparse; long or short; junctions at wide or closely-spaced intervals)
- rainfall pattern (heavy rain falling on some sub-catchments but not others)
- hydro-geology (infiltration and storage of rainfall by soil and underlying rock, enabling either slow release of sub-surface runoff to channels, or fast surficial runoff).

Our example of a 10% reduction in flood peak at a partially afforested sub-catchment outlet, may diminish the catchment's flood peak in the main channel, but alternatively it may have little or no effect. The magnitude of the effect will depend on whether:

- the sub-catchment is a large or a small part of the total catchment area
- its water enters the main channel close to other tributary junctions or tens of kilometres apart
- rain in the sub-catchment is heavy or light relative to what falls elsewhere
- the sub-catchment geology delays runoff to a greater degree than in other tributaries.

The question of what part of a catchment is being afforested becomes relevant here. In the New Zealand landscape, catchment headwaters are mountainous terrain or steep rangelands that intercept orographic rainfall (a narrow band of rain falling where a front is forced up over high ground). The headwater's contribution to flood runoff is disproportionately large relative to their area; but little rain falls on middle catchments and floodplains, and these parts supply only a small proportion of flood runoff. Such orographic rainfall causes the frequent small floods that pass down New Zealand rivers each year, as well as many moderate floods (with return periods of 1 to 10 years). This is the circumstance where targeted afforestation of headwater sub-catchments will measurably diminish the floodwave that passes down a large catchment's main channel in small to moderate floods.

However, large floods (>10 year return periods) tend to be caused when a wide moisture-laden air mass moves off the sea, dumping heavy rain on middle-catchment and downstream locations as well as on headwaters. These are the damaging floods that erode riverbanks, silt up unprotected floodplains, and breach stopbanks. In these circumstances, afforestation of a middle-catchment or a floodplain will have the same effect on runoff as afforestation of headwater areas. Regrettably, because of the other factors that determine passage of a large floodwave down a main channel, the vegetation effect will be quite small. This is so even where a significant proportion of the catchment is afforested.

The above simple outline of factors affecting flood response will demonstrate that vegetation is just one amongst many, and why vegetation change in just part of a catchment does not cause a substantial drop in main-channel flood peak. Rowe et al (2003) discuss these factors in more detail.

For medium-sized and large catchments, it is also necessary to discuss whether a vegetation-induced change to flooding in the hydrological sense (flood waves passing down a river channel), translates to a change in flooding in the risk sense (damage to people, buildings, infrastructure and economic activities) when flood waves are sufficiently large to spill across a valley bottom or floodplain.

Changes in flooding risk

It is tempting to speculate, from a planning or policy analysis perspective, that even a small reduction (a few percent) in peak flood flows through afforestation and reversion might have a significant economic implication. This view could be supported, in a hydrological sense, from observed changes to flood flow curves under different land uses. Swabey (personal communication, 2007)[6] has commented:

> *Whenever a shift in the flow distribution curve occurs to a lower level, consequent issues are:*
>
> 1. *The floods may be slightly smaller, with most benefit coming at levels below the most extreme floods.*
> 2. *If fewer floods exceed protection levels (whether this is floodplain heights, floor levels, or stopbank levels), there will be a contemporaneous saving to the community.*
> 3. *Engineering design of future flood risk management methods will rely on the modified flow distribution curve, which now has a lower risk profile, meaning cost savings or enhanced protection levels will result.*
> 4. *The benefits of flood distribution translations to lower levels are not just about engineered protective works, but also about incremental change to natural systems like floodplains.*
> 5. *Floodplain flooding, which occurs at flow levels around the 100% to 10% annual return interval ie, once every 1–10 years on average, will be reduced too (even floodplain flooding of paddocks is damaging, particularly for farmers).*

There are definitely New Zealand catchments where the above implications have been realised as a consequence of climate-induced shift in a flow distribution curve, or as a result of engineering-induced shift (damming or diversion of river flow). Some early examples are described by Poole (1981). Day et al (2007) give a recent summary of the topic (though the detail appears to be in background documents). Unfortunately, there is no published evidence – nor has any convincing unpublished evidence come to our attention – for any New Zealand catchment where the above consequences have been achieved by afforestation-induced or reversion-induced shifts in a flow distribution curve.

---

6 Stephen Swabey, Ministry for the Environment, personal communication, 5 October 2007.

This negative finding is not what people expect. So the reasons why flood risk or damage reductions have not accrued from afforestation / reversion-induced hydrological changes, merit discussion here.

The discussion below is based on:

- accounts in Cowie (1957), who summarised damaging floods in New Zealand between 1920 and 1953 when very few rivers had comprehensive flood protection
- an analysis by Ericksen (1986) of floods from 1954 to 1985, decades when many large to medium-sized rivers had protective works installed along their downstream reaches
- because there is yet no nationwide summary of flood damage for 1986–2006, on personal recollection of news reports; discussions with regional council staff after events; and for some of the floods, personal observations.

1 Slightly smaller floods

Cowie's (1957) account indicates regular inundation of farms, infrastructure and urban areas, on mostly unprotected valley bottoms or floodplains; including many moderate (1–10-year) floods as well as the large (>10 year) or extreme events (such as 'Anzac rains' of 1938). 1920–1953 follows the main period of European deforestation in most New Zealand districts, so it is possible that damage by moderate floods was more frequent as a consequence (though Cowie does not comment on this point, preferring to attribute instances of flood damage to occurrence of particular catchment rainfall patterns).

Ericksen's (1986) account confirms that flood protection works (most designed to 20–50-year standard; some to 100-year or greater where rivers pass cities) have averted much damage to farmland and urban areas, by moderate floods (1- to 10-year) that formerly spilled over low-lying parts of now-protected floodplains. However he does not cite any instances of damage reduction on still-unprotected floodplains or valley bottoms, as a consequence of afforestation or reversion-induced changes in flood regime.

We are aware of several New Zealand catchments that had substantial vegetation change in their headwaters by 1986, either from deliberate afforestation (Waipaoa, Uawa, Waiapu, Esk, Awhea) or from reversion of abandoned farmland (Waitara, Whangamomona, Whenuakura, Waitotara). Our perception of the Wairarapa-Hawkes Bay-East Coast catchments is that rivers are aggrading, and there is ongoing damage to roads, bridges and farmland on valley-bottom floodways, even during moderate (<10-year floods). Our perception of the Taranaki-Wanganui catchments is that the river channels are incised, and damage during moderate (<10 year floods) is mostly bank scour or bank siltation; it takes a larger flood to spill over valley bottoms and cause flood damage (there have been three such events during the last 20 years).

2 Fewer floods exceed protection levels

Cowie (1957) reports instances of flood damage when stopbanks were overtopped eg, on the lower Waikato, the Manawatu, the Waimakariri, and the Clutha. It is clear from his account, that over-topping occurred because stopbanks were too low, poorly positioned, or incomplete, at a time when river protection was undertaken piece-meal by under-resourced local drainage boards.

Ericksen (1986) reports fewer stopbanks being overtopped. Again these were on older schemes where the standard of protection was low (20-year or less). He reports rather more instances of flood damage due to breach of stopbanks; and numerous occasions when there was considerable damage by back-up of tributary streams that were unable to discharge into the stopbanked floodways of main rivers. His analysis indicates that both causes of damage were associated with large floods (10 year or greater). Throughout his publication, he stresses that flood damage has decreased in frequency but paradoxically increased in magnitude along New Zealand's protected rivers – because more assets have established on protected floodplains (eg, houses, factories, crop-growers, horticultural producers), and so there is risk of greater damage when stopbank failure or overtopping does occur.

Our personal recollection of major New Zealand floods since 1986 is, that flood damage continues to be caused by the same mechanisms identified by Cowie and Ericksen. For example:

- South Canterbury 1986: Road and bridge damage, gravel deposition on pasture, some damage to houses, where rivers either breached or over-topped small stopbanks (D Hicks personal observation).
- East Coast 1988: Waipaoa stopbanks did not overtop during Cyclone Bola. Extensive farm siltation, road blockage and house damage occurred in two circumstances: where tributary streams backed up on the Gisborne plains behind stopbanks; or where main rivers spilled across unprotected floodplains on the Tolaga flats and Waiapu valley (D Hicks personal observation).
- Hutt Valley 1990: Stopbanks did not overtop. Local blockage of roads and damage to houses where tributary streams and stormwater drains backed up (D Hicks personal observation).
- Taranaki 1990: Waitara river stopbanks did not overtop, but almost breached, during Cyclone Hilda. Widespread siltation and road blockage on unprotected valley-bottom floodways, throughout eastern Taranaki hill country (P Blaschke and D Hicks personal observation).
- Lower Waikato 1997: Stopbanks held where designed to 50 or 100 year standard, but over-topped where designed to 20 year standard. Widespread inundation of farmland, limited road blockage and house damage (Environment Waikato staff, personal communications and unpublished report).
- Manawatu-Wanganui 2004: Wanganui, Rangitikei and Manawatu River stopbanks did not overtop, but Moutoa floodway spilled over due to uncontrolled flow (damaged flood-gate). Extensive bank collapse, paddock siltation, road blockage, bridge collapse and house damage along floodways of Rangitikei and Manawatu tributaries, where stopbanks were either breached or absent (Horizons Regional Council staff, personal communications and unpublished report).
- Whakatane and Waimana 2004: River stopbanks did not overtop, but extensive paddock inundation occurred after groundwater flow (through pumiceous alluvium) locally under-mined stopbanks (Environment Bay of Plenty staff, personal communications and unpublished report).
- Wairarapa 2006: Ruamahanga stopbanks did not over-top. Paddock inundation, gravel deposition and silting were confined to the design floodway which includes farmland (Greater Wellington staff, personal communications).

- Northland 2007: Heavy rain in eastern Northland (March and July) caused extensive inundation and silting on the Hikurangi flats from back-up of tributary streams; but the Wairoa stopbanks did not overtop here, or on the western side of Northland (where neither the March nor the July floods were big events). Flood damage to houses in Kaitaia (July) was due to localised stopbank overtopping on an overflow channel (Tarawhaturoa), not the main Awanui or its spillway (Whangatane), which performed to design specifications. There was much riverbank damage, paddock silting and road blockage in valley bottoms upstream (middle and upper reaches of Awanui lack stopbanks), particularly on one tributary (Victoria) which is still adjusting to re-alignment of its channel some 40 years ago. Flood damage to houses and road blockage in Kaeo (July) included over-topping along a short length of diversionary stopbank (the only one in the catchment), but otherwise was due to buildings and roads being on or close to an unprotected floodplain, now 0.5–1 metre higher due to long-term siltation, than when many of the houses were built. (NRC staff and local residents personal communications).
- The Awanui river in particular is a graphic example of how flood damage still occurs in a medium-sized catchment, despite widespread reversion and afforestation in its headwaters over the past 20 years. Damaged houses, roads and farmland along the Kaeo river are in areas settled over a hundred years ago, so cannot be attributed to recent developments creating new risks. The cause of higher flood levels here appears to be not land use change (over half the catchment is bush and scrub), but floodway siltation arising from channel constriction and sediment trapping by vegetation. (Northland Regional Council, 2007a, b; R Cathcart and N Mark-Brown personal communications).

Our conclusion from the above summary is that flood damage during major New Zealand floods is rarely caused by floods exceeding design protection levels on stopbanks on rivers. It is more often caused by unpredictable breaches of a weak point in a stopbank when the river is below bank-full stage; or overflow of backed-up tributaries onto land behind stopbanks when the river is close to bank-full; or spillage across floodways. We agree with the observation that:

> *these risks do not change even when afforestation is factored in. Essentially they are a given, no matter what the scenarios in the catchment and thus can be discounted in risk change considerations* (S Swabey personal communication.)

except that spillage across floodways may be reduced where siltation declines following afforestation.

3 Modified flow distribution curve with lower risk profile

We are not aware of any instances in flood design within New Zealand, where a river engineer has altered scheme design parameters or reduced scheme maintenance, in the expectation that flood peaks will reduce following headwater afforestation. There are certainly rivers where headwater afforestation has been carried out to assist river management (Waipaoa, Uawa, Waiapu, Awhea, Tauanui, Hiwinui). However scheme reviews, eg, Peacock et al (2000), and Gunn et al (2004), clearly state that afforestation has been carried out to reduce sediment yield, and thereby help maintain channel flood capacity.

These documents contain no evidence that afforestation has altered the hydrological parameters (peak, duration or frequency) of large floods; but the reviews (and additional scientific publications) confirm that in targeted catchments, channel aggradation has declined in downstream reaches since afforestation, and has reversed (started to degrade) in some (not all) headwater tributaries. They attribute maintained channel flood capacity and reduced flood damage to this effect (in part, alongside other factors such as good floodway operation). We shall discuss the evidence in Chapter 3 (sediment yield), confining our mention of it in the current chapter (hydrological changes) to an observation that afforestation-induced sediment yield reduction appears capable of reducing flood risk/damage.

4/5 Incremental change to natural systems, smaller floodplain floods

We acknowledge the possibility that afforestation of large areas within catchment headwaters may reduce hydrological parameters of moderate floods (1–10 years), enough for flood risk / damage to become less frequent on unprotected floodways and floodplains, simply through fewer moderate floods spilling across them. However, we must point out that there is currently no New Zealand flood study that can be cited either to support or disprove this possibility.

Conclusion: water yield, floods and low flows

Large changes in water yields, floods or low flows have been observed only in small catchments, where close to 100% of catchment area has been afforested or retained in native cover. The few published studies of partial afforestation in large catchments, all report much smaller changes in river flow.

Absolute flows or percentage reductions in flows, from small research catchments entirely under forest or scrub, should not be extrapolated to the entire area of medium or large catchments, if afforestation / reversion is patchy and occupies a small percentage of catchment area. Reduction in runoff from small blocks of afforested or reverting land is overwhelmed by ‘normal’ runoff from much larger areas of surrounding farmland.

Where afforestation / reversion occupies a large percentage of catchment area, flow changes can be forecast either by conventional hydrological techniques or by computer-generated flow models. However in this circumstance, vegetation-induced runoff reduction is dampened by other influences on river flow (notably channel network topology and basin hydrogeology).

Changes in flooding in medium to large catchments as a consequence of afforestation or reversion, are real in the hydrological sense. That means vegetation change does alter the frequency, magnitude and duration of small flood waves passing down a catchment’s main channel.

However, changes in flood hydrology do not translate to reductions in flood risk / damage (to people, buildings, infrastructure and economic activities), when moderate or large flood waves spill across a valley bottom or floodplain. There is documented evidence that much past flood damage in the New Zealand landscape has been caused by factors which afforestation or reversion cannot influence. These factors include under-designed flood protection schemes, unpredictable scheme failures (breached stopbanks, jammed floodgates, open or missing valves), and developments sited on flood-prone land.

Nevertheless, there are instances in the New Zealand landscape, where over-bank flooding (and associated flood risk/damage) has been reduced as a consequence of afforestation. In these instances, the mechanism is reduced sediment yield followed by channel degradation (which improves channel flood capacity). This mechanism will be discussed in Chapter 3.

Low flows

There is some evidence that changes in the frequency of low flows from partial afforestation or reversion in medium to large catchments, are sufficient to impact on water use. Decreases of 13% to 45% in minimum summer low flows have been measured or modelled, as a consequence of 2% to 59% of area being afforested, in several catchments over 500 km^2. In some other catchments (smaller but still medium-sized), modelling studies indicate that low flows will decline by more than 5%, if afforestation cumulatively amounts to more than 15% of catchment area.

In a catchment where a high proportion of flow is already allocated for commercial use (in the form of water permits), such a decrease would result in the regional council imposing temporary restrictions on take – something which already happens in dry summers – for longer than is currently the case. This would represent a real economic cost to permit-holders ie, would be an adverse effect of afforestation / reversion.

Summary of impact of afforestation on flooding under different scenarios

Diffuse reversion / afforestation, by individual owners on parts of their own properties (that continue to be farmed), will create a fragmented pattern of tree cover on just a small percentage of catchment area, in the midst of other land in pasture or tussock. This scenario will not appreciably alter even small flood waves (<1 year frequency) passing down the main channel of a catchment.

Widespread reversion / afforestation by owners changing land use on entire properties (dispersed amongst other properties that continue to be farmed), will create contiguous blocks of tree cover on a significant percentage of catchment area. This scenario will alter the magnitude and duration of small and moderate flood waves (1- to 10-year frequency) passing down the main channel of a catchment. Consequential reductions in overbank flooding and associated damage are possible on unprotected rivers; but for the few New Zealand catchments where there has been widespread afforestation / reversion, as yet there is no evidence that such reductions are attributable to vegetation-induced changes in flood frequency. On protected rivers there will be little or no reduction in overbank flooding and associated damage from small to moderate flood waves, because these events are contained by the flood protection works.

Whole-catchment reversion / afforestation by a public agency intervening to change land use on all properties (none of which continue to be farmed), will ensure tree cover on almost the entire catchment area. This scenario will substantially alter the magnitude and duration of small to moderate flood waves, but will just slightly alter large flood waves (>10-year frequency) passing down the main channel of a catchment. It will not reduce large flood waves enough to avoid overbank flooding and associated damage, either on unprotected or protected rivers, because vegetative retardation of runoff is outweighed by extreme rainfall during large events.

There are instances where extensive flooding and damage have been avoided in catchments following substantial but not complete headwaters afforestation (ie, a transitional scenario between widespread and whole-catchment planting. For these catchments there is evidence that the mechanisms are geomorphic, not hydrological (Kasai et al, 2005; Liebault et al, 2005). The rivers in these catchments pass more floodwater due to degradation of their channels, after sediment yield has been reduced by changes in land use. This mechanism can produce consequential reductions in flooding and damage during moderate floods on unprotected rivers; and during large floods on protected ones.

3 Physical Effects of Afforestation and Reversion on Sediment Yield

Sediment yield measures the product of terrestrial erosion (discussed in next chapter), delivered to waterways. High rates of sediment yield have physical effects in or close to waterways; for instance reduction in channel flood capacity, accretion on floodplain surfaces, deterioration of aquatic habitat, and restrictions to human use of river water. These effects need to be discussed separately from terrestrial erosion, which affects things on the land, close to the erosion site: soil, vegetation, and land use.

A river's sediment yield includes bedload (gravel and sand particles rolling or bouncing along its bed) as well as suspended sediment (silt and clay particles floating in water). Bedload rarely contributes more than 10–20% of total sediment yield, and is notoriously difficult to measure. Suspended load is somewhat easier to measure, and this parameter is discussed in most publications on the subject.

New Zealand investigations into suspended sediment yield under different land uses are viewed as an important contribution to the international literature. This is because they report some very high sediment yields from eroding grassed catchments, and also some significant reductions by afforestation. Also measured, though less well publicised, are sediment yields from natural vegetation that ranges from forest and successional scrub, to tussock grassland and wetlands.

Some early reviews of sediment yield, by Selby (1979) and O'Loughlin and Owens (1987), highlighted impacts of vegetation clearance and land use. Data for planted forests were reviewed at intervals by Vaughan (1984), Wallis and McMahon (1995), and DL Hicks (2000b); though with an emphasis on the effects of forest management practices rather than comparisons with other land use. Nationwide compilations of catchment sediment yield have been made by Adams (1979), Thompson and Adams (1979), Griffiths (1981, 1982), and DM Hicks et al (1996, 2003). The most recent review of published and unpublished data, by DM Hicks et al (2004), stresses geology and total rainfall as the main factors controlling sediment yield.

As done for flood flows, key findings from previous reviews are summarised and their relevance to MfE's brief discussed: ie, what do they actually tell us about the likely effect of afforestation or reversion carried out for the purpose of carbon sequestration?

Summary of New Zealand data

As for floods, relevant data come from two types of research: where small catchments have been entirely afforested or allowed to revert into scrub; and where small catchments in standing forest or scrub have been cleared. Some catchments are the same ones used for water yield investigations (see our Tables 1–3); though the next few (Tables 4–7) are supplemented by extra catchments where investigations of sediment yield have been published, but discussions of water yield are unavailable.

Table 4 gives measured sediment yield reductions from paired pine-pasture catchments distributed the length of New Zealand. With three exceptions, sediment yield reductions are substantial, though variable.[7]

Table 4: Effects of land use on sediment yield

Catchments	Region	Comparison	% change	Author	Comments
Glenbervie vs Scotsmans	Northland-Waikato	Pines vs pasture	–51	DM Hicks, 1990	Average annual yield difference*
Topuni vs Kokopu	Northland	Pines vs pasture	–59	DM Hicks, 1990	Average annual yield difference*
Upper Waitemata	North Auckland	Pines vs pasture	–27 to –96	Van Roon, 1983	Annual yield differences
Tairua	Coromandel	Pines vs logged	466	Lowe, 1998 personal communication	Annual yield differences
Purukohukohu	Volcanic Plateau	Pines vs pasture	–93	DM Hicks, 1990	Average annual yield difference
Pakuratahi	Hawkes Bay	Pines vs pasture	–68 to –87	Black, 1998 personal communication	Annual yield differences
Pakuratahi	Hawkes Bay	Pines vs pasture	–55	Fahey, 1999	Average annual yield difference
Moutere	Nelson	Pines vs pasture	–95	DM Hicks, 1990	Average annual yield difference
Pigeon	Nelson	Pines vs logged	2	DM Hicks, 1990	Average annual yield difference
Ashley	North Canterbury	Pines vs logged	0	Jackson, 1998 personal communication	Annual yield differences
Berwick	Otago	Pines vs pasture	–36	DM Hicks, 1990	Average annual yield difference

* Re-calculated from author's Glenbervie-Kokopu comparison.

Notes:

Record lengths are 20+ years down to 2.

For 8 investigations out of 11, sediment yields were measured for standing forest vs pasture or tussock.

Only three entail reversing post-deforestation yield increases (ie, reversing the calculation, not reversing the sign).

Most catchments are adjacent; some are on physically separate but similar terrain.

Catchment sizes are generally less than 5 km^2.

Some of the variability may be accounted for by differences in record length. Both annual, and averaged annual, sediment yields are strongly influenced by storm incidence during the period of record: records of only a few years' duration may or may not include extreme events that produce much of any catchment's sediment yield.

Mean annual rainfall is another cause of variation; catchments with low mean annual rainfalls also have few storms. Geology is a third; in some of the catchments hard rock strata limit sediment supply to streams. These factors are discussed further below (large-catchment investigations).

[7] The three exceptions are not pine-pasture pairs, but pine pairs where yields were calculated post-logging in one catchment, so are not directly comparable with the rest.

Sediment yield investigations in paired bush and pasture catchments are surprisingly few. Table 5 gives the known examples.

Table 5: Effects of land use on sediment yield

Catchment	Region	Comparison	% change	Author	Comments
Upper Waitemata	North Auckland	Bush vs pasture	–86 to –88	Van Roon, 1983	Annual yield differences
Hapuakohe	Waikato	Bush vs pasture	–50 to –75	Selby, 1976	Event yield differences
Whatawhata	Waikato	Bush vs pasture	–90	Quinn and Stroud, 2002	Annual yield differences
Purukohukohu	Volcanic plateau	Bush vs pasture	–63	Dons, 1987	Average annual yield difference
Tararua	Manawatu	Bush vs pasture	–91	Bargh, 1977, 1978	Annual yield difference (record length one year)
Maimai[8]	West Coast	Bush vs clear-felled	–87	O'Loughlin, 1980	Annual yield difference
Maimai	West Coast	Bush vs clear-felled	–93 to –98	O'Loughlin and Pearce, 1982	Event yield differences

Note that for six investigations out of the seven in this table, sediment yields were measured for standing forest vs pasture; just one entails reversing the calculation of post-bush-clearance yield increase.

The main point to note about Table 5 is that, with one exception, sediment yield reductions are substantially greater than 50%, and generally more than 80%.[9]

The sediment yield reductions, summarised in Table 5, will have been affected by short record length in particular. Nevertheless they clearly demonstrate that a substantial reduction in annual sediment yield can be expected where small catchments are retained in bush, compared to being clearfelled or converted to pasture. Large differences in sediment yield during individual events (reported by some but not all the authors) suggest that the amount of sediment yield decline under bush varies according to flood magnitude; but the published figures are too few to state what the ranges for a given flood magnitude may be.

There are few small-catchment studies of sediment yield from scrub vs pasture (Table 6). None of these are scrub-pasture pairs; all are instances where sediment yield was measured in a single catchment, before and after conversion. In all instances where comparisons are possible, sediment yields from standing scrub are substantially lower than from establishing pasture, by amounts ranging from 39 to 100%.

8 The very large reductions at Maimai were obtained by reversing the authors' calculations for sediment yield increase immediately after clear-felling, so are not a true comparison with established pasture. They are included here only because no bush-pasture or bush-tussock paired catchment studies appear to have been carried out, anywhere in the South Island.

9 The Taupo catchments are not true pair-wise comparisons between two catchments, being two groups of catchments: one predominantly bush, and the other predominantly pasture.

Table 6: Effects of land use on sediment yield

Catchment	Region	Comparison	% change	Author	Comments
Puketurua	Northland	Scrub vs pasture	–39 to –65	Schouten, 1976	Annual yield differences*
Tairua	Coromandel	Scrub vs cleared for forestry	–40	Swales and Hume, 1998 personal communication	Average annual yield difference
Otutira	Volcanic plateau	Scrub vs pasture	–51	Selby, 1972, Selby and Hosking, 1973	Event yields, runoff plots
Tararua	Manawatu	Scrub vs pasture	–70	Rennes, 1978	Annual yield difference**
Moutere[10]	Nelson	Scrub vs pasture	–98 to –100	Scarf, 1970	Annual yield differences, runoff plots

* Scrub cleared for pasture conversion.

** Record for one year only.

In Table 6, for three investigations out of five, sediment yields were measured for standing scrub vs pasture. The other two entail reversing the authors' figures for post-clearance yield increase.

Significant points to note about Table 6 are:

- pasture measurements were made in years 1 to 3 after scrub clearance, so percentage changes for well-established pasture may be less
- in all instances where comparisons are possible, sediment yields from standing scrub are substantially lower than from establishing pasture.

The small-catchment sediment yields in Table 6 are subject to the same limitation imposed by short record length, as the ones in Tables 4 and 5. Despite this limitation they confirm a general principle, that sediment yield from standing scrub is lower than from pasture. However the studies are really too few in number, and too sparsely distributed in the New Zealand landscape, to give any idea of how sediment yield might vary where scrub reversion occurs on different terrains.

Implications for forestry or reversion established primarily for carbon sequestration

At first sight, the New Zealand research findings from small catchment studies strongly suggest that forestry or reversion will substantially reduce sediment yield. They are mostly published research investigations, and their results are generally the ones that get cited in reviews and policy papers compared to unpublished work. However we caution that the small catchment studies:

- are few in number
- entail comparisons over short record lengths, typically less than five years
- have yield reductions that are strongly influenced by the occurrence of a few large storms (or in some instances, absence of large storms) during the observation period.

[10] The very large change in sediment yield reported for Moutere may be an artefact of small catchment size (less than 5 hectares), drained by a first-order stream.

The small catchment studies are also too sparsely distributed, to give any idea of how variable the base figures for sediment yield are, from either pasture or tussock. A substantial percentage reduction in sediment yield, after afforestation or reversion, will be of little benefit in a terrain where sediment yield from pasture is naturally low.

Large catchment investigations

Much better evidence about variations in sediment yield is available, from longer-term (decades long) NIWA records of sediment yield in medium to large catchments. These do not permit statistically testable comparisons, in the sense that few such catchments are entirely pasture, pine forest, or native vegetation. But many of them are dominated by a single vegetation cover and thus enable useful comparisons to be made. They also have the advantage, that suspended sediment has been measured on enough occasions to formulate a good rating curve, enabling reliable estimates of suspended sediment yield from long-term flow records.

Successive compilations of nationwide suspended sediment yield are available. The earlier ones (Thompson and Adams, 1979; Griffiths, 1981, 1982) are partial though informative. Recent compilations (DM Hicks et al, 1996; DM Hicks and Shankar, 2003) have the advantage of longer record lengths, more reliable rating curves, and better techniques for fitting rating curves to flow records. From these compilations, we have summarised ranges of sediment yield for catchments that are either predominantly pasture, tussock, pine forest; or bush and scrub (Table 7).

Table 7 illustrates the findings of DM Hicks and Shankar (1996) in particular. Comparing over a hundred catchments, they concluded that high sediment yields are associated with either unstable geological terrains, or high rainfall zones; and *particularly with areas within catchments where the two coincide.*

Furthermore, they concluded that these two factors over-ride vegetation or land use as controls of absolute sediment yield from a catchment.

Table 7: Ranges in annual suspended sediment yield (t/km^2/yr) for medium to large catchments categorised by geology, dominant vegetation cover and rainfall[11]

Geology	Forest and scrub		Tussock		Pasture		Pines	
	Low rainfall	High rainfall	Low rainfall	High rainfall	Low rainfall	High rainfall	Low rainfall	High rainfall
Volcanic	4–64	177–650	–	–	20–208	–	13–144	–
Sedimentary	211–301	451–1,200	–	–	65–20,300	–	21–7,045	–
Greywacke	148–988	356–7,000	44–490	1,079–3,850	79–1,961	–	4–46	–
Schist	336–8,750	4,500–29,600	2–200	1,208–5,210	4–8	–	2–10	–
Gneiss and granite	–	17–350	–	–	–	–	–	–

Sources: Adams, 1979; Thompson and Adams, 1979; Griffiths, 1981, 1982; DM Hicks, 1990; DM Hicks et al, 1996.

The data underpinning Table 7 provide strong evidence that a large change in a catchment's sediment yield can only be expected if afforestation / reversion is targeted onto unstable geological terrains. Conversely any reduction in sediment yield will be small, if afforestation / reversion is located on stable terrains.

Implications for forestry or reversion established primarily for carbon sequestration

The implications for sediment yield in large multi-land use catchment is well-illustrated by the one large catchment where the effect of afforestation on sediment yield has been directly measured: the Waipaoa, some 2206 km^2 on the East Coast. Part of the catchment headwaters, on crushed marine sediments, was planted in pines by the Forest Service between 1959 and 1982 in order to prevent expansion of large gullies that were supplying sediment to the river. Gully erosion averaged 2480 tonnes/hectare/year before afforestation, declining to 1550 tonnes/hectare/year after (De Rose et al, 1998). After Cyclone Bola in 1988, landslide density in forested sub-catchments ranged from 0 to 0.2 per hectare, compared with 0.4 to 3.2 per hectare in pasture sub-catchments (Page et al, 1999). Sediment accretion on the downstream floodplain declined from 89 mm/year (108-year average before afforestation) to 26 mm/year (37-year average during and after) (Gomez et al, 1998, 1999).

Suspended sediment yield near the river mouth is not known for the pre-afforestation period, because measurements only commenced in 1960. During and after headwater afforestation, suspended sediment yield averaged 6750 tonnes/km^2/year from the entire 2206 km^2 catchment area (DM Hicks et al, 2000). The contribution from afforested headwaters remained high, at 11,540 tonnes/km^2/year from approx. 154 km^2 afforested (DM Hicks et al, 2000), due to continuing erosion in several large gullies that could not be planted, and also to a change in river regime – the afforested headwater tributaries started cutting down through the sediment deposits that they had built up during 100+ years of pastoral farming (Trustrum et al, 1999).

[11] All figures are absolute sediment yield from a catchment (tonnes per square kilometre per year). Note that the sources used in this paper each have incomplete and contradictory ranges in their published papers. Table 7 gives the least and largest yields cited by any author. The resulting ranges should not be regarded as definitive, as they need to be refined by adding other NIWA sediment yields that exist but are not cited in the publications.

Reid and Page (2002) used some of these measurements to model how different patterns of afforestation might affect sediment delivery by landslides, by a random series of rainstorms over 100 years. Starting with a 'whole catchment in pasture' simulation, they estimated that the present mix of pasture and forest (about 7%)[12] has reduced landslide sediment delivery by 30%. They then simulated the effect of targeting 7% afforestation onto highly erodible land, producing a 50% reduction in landslide sediment delivery. Finally they simulated the effect of expanded afforestation, targeted onto the most erodible 50% of land, producing an 80% reduction.

These significant on-site reductions translate to at most a 16% reduction in sediment delivered to the river's downstream channel and floodplain, because landslides contribute just 10 to 20% of the Waipaoa's sediment yield (Reid and Page, 2002). In addition, they estimate gully contributions as 50% of the Waipaoa's sediment yield, and suggest that, as there has been a 38% reduction in contributions from gullies in the largely afforested Mangatu sub-catchment (citing De Rose et al, 1998), the same reduction might apply to gully contributions from afforested land in their computer simulations. If so, we note that this would translate to an additional 19% reduction in sediment delivered downstream. They caution that 30 to 40% of the Waipaoa's sediment yield comes from other, as yet-unmeasured sources. This percentage might go down if largely from earthflows and sheetwash (that can be afforested); or it might go up if largely from streambank collapse and channel scour (that cannot).

In more general terms, these results also reflect the 'dilution' of differences from one sub-catchment to the whole catchment: a process with a very pronounced effect on sediment yield in one sub-catchment, may not be significantly reflected in total sediment yield at the lower end of the catchment (where the assets at risk are generally situated).

The Waipaoa catchment results are discussed here in some detail, not just because they are the only instance of sediment yield changes being measured or modelled in a large catchment, but also because they verify three general principles that have been stated by reviews of data from elsewhere (Quinn and Cooper, 1997; DL Hicks, 2000b; DM Hicks et al, 2004):

- Where terrain is highly erodible on account of geological instability, suspended sediment yields remain initially high after terrain is afforested.
- The high yields persist for several decades due to 'lag effect', until sediment stored in and near the channels is transported downstream.
- Sediment yields gradually decline, relative to those from watercourses [rivers] on equivalent terrain still used for farming.

A further large catchment where afforestation established through catchment control schemes may have had an effect on downstream sedimentation, is the lower Waikato River, from about Lake Karapiro to the sea. In the last decade or so, channel scour and deepening in this reach has been documented (Environment Waikato staff, personal communication), which may have an effect on future sedimentation and flooding. Although large areas in the upper Waikato catchments have been retired under previous flood control schemes, quantitative effects on sedimentation have not been fully documented. A further complicating factor is the effect of the Waikato hydro-electric dam systems that have also been acting as sediment traps for many decades.

---

[12] This proportion will have increased somewhat since the time of Reid and Page's investigation.

In the Waipa catchment, Hill and Blair (2005) document sediment load reductions of more than 90% in entirely afforested small sub-catchments at the Whatawhata Research Station in western Waikato. Suspended sediment declined about 40% over an eight-year period in the Waitomo sub-catchment, resulting from planting riparian and erosion-prone areas.

Similar trends have been observed in the partly afforested Kaiwhata and Awhea catchments (eastern Wairarapa), though the results of bed level surveys have not been published (Ian Gunn, Greater Wellington Regional Council, Masterton, personal communication, 2007).

Conclusion: sediment yield

Small-catchment research studies provide conclusive evidence that afforesting or reverting close to 100% of small catchments, reduces averaged annual sediment yields by at least 50% and in most instances by greater than 80%.

Long-term sediment yield computations are available for many medium to large catchments nationwide. These indicate that high sediment yields are associated with unstable geological terrain or/and high rainfall zones. In these medium to large catchments, relative reductions of 50% or more in sediment yield, only translate to substantial reductions in absolute yield (tonnes per square kilometre per year), if afforestation and reversion are targeted onto the parts of catchments that have high sediment yields in the first place.

Substantial reductions cannot be expected immediately. The only published large-catchment investigation of afforestation effects on sediment yield (Waipaoa), shows a time-lag of several decades for reduction to work its way from headwaters to mouth. This is due to a large volume of sediment, already in channel storage, gradually being transported downstream.

The reduction in a catchment's sediment yield eventually translates to better flood capacity in the main channel, once its transport regime changes from aggradation to degradation. Better channel flood capacity helps control over-bank flooding (and associated flood damage) in two ways, by reducing the:

- likelihood that stopbanks may be overtopped in an extreme flood
- frequency of flooding by runoff behind stopbanks (tributaries can discharge during large floods, if water level in the main channel is lower).

However, increased channel flood capacity can also *increase* flood damage risk in another way, through undermining and breach of stopbanks by floodwater in a degrading channel.

Other benefits of reduced sediment yield are:

- improved water quality (fewer occasions when high suspended sediment prevents water take for irrigation, stockwater, industrial or urban supply)
- improved aquatic habitat (more suitable for recreation and fisheries)
- less sedimentation in reservoirs (maintains storage capacity)
- less sedimentation in estuaries and harbours (maintains navigation).

These benefits and their value are discussed in Chapter 6.

Summary of impact of afforestation on sediment yield under different scenarios

Diffuse reversion / afforestation will only reduce a catchment's sediment yield if located on geologically unstable land. The limited percentage of such land that would be converted to tree cover, precludes a large absolute yield reduction (tonnes per square kilometres per year) for an entire catchment.

Widespread reversion / afforestation will only reduce a catchment's sediment yield if located on geologically unstable land; but if targeted, would place tree cover on most such land. Whether absolute yield reduction (tonnes per square kilometres per year) will be large or small, depends on whether the geologically unstable areas are in high-rainfall or low-rainfall zones of a catchment.

Whole-catchment reversion / afforestation will reduce a catchment's sediment yield, because all geologically unstable land would be covered by trees. Absolute yield reduction (tonnes per square kilometres per year) will be large, provided some of the geologically unstable areas are in high-rainfall zones. This scenario entails establishing tree cover over large parts of a catchment where land is geologically stable, or low-rainfall, or both (so does not supply much sediment to rivers).

4 Physical Effects of Afforestation and Reversion Effects on Erosion

This chapter deals specifically with effects on terrestrial erosion (ie, loss of soil from the land surface), as opposed to sediment yield. Terrestrial erosion includes removal of soil by mass movement processes, as well as by water or wind. There is a tendency across New Zealand agencies to regard sediment yield as a corollary of erosion rate; and to view reductions in sediment yield to rivers and estuaries, as being the principal benefit of erosion or flood control. This view stems from a preoccupation with water quality and aquatic habitat, and ignores the onsite effects of terrestrial erosion. It ignores the reality that much terrestrial erosion debris either does not enter a watercourse; or if it does, is swiftly deposited back on land. It also neglects to recognise that terrestrial erosion scars and debris have on-site effects, economic as well as environmental. Blaschke et al (2000) note a similar lack of interest in the on-site effects of erosion (especially mass movement erosion) in the international literature as well.

This chapter concentrates on measured evidence of reductions in terrestrial erosion from afforestation and reversion. The 'bare ground' percentages in the tables are from surveys that have measured fresh erosion of all kinds (mass movement, water or wind).

Older reviews of erosion control in New Zealand (eg, MacCaskill, 1974; Poole, 1981) describe techniques that were widely used from the 1940s through the 1970s, but cite few measured reductions in erosion. Benefits are anecdotally described as being greater farm production, revenue from timber, or reduced damage repair costs.

Field surveys or aerial photographic surveys were carried out by the Ministry of Works and Development (MWD) or catchment boards from the 1940s, to ascertain the extent of erosion in catchments prior to designing soil conservation works schemes. The early surveys entailed assigning visual rankings of erosion severity (usually on a scale of 1 to 5) – a good procedure to determine priorities, but uninformative as regards effectiveness of works once installed, or the amount of erosion.

Measurements of erosion did not start until the 1970s, when university and MWD researchers and a few catchment board staff started to investigate differences in erosion amongst planted trees, compared with pasture and native cover. Their results started to appear as published papers and reports from the 1970s. It was not until the late 1990s that enough measurements had accumulated from around the country, to be compared and compiled. Some initial evaluations, carried out by staff of DSIR Land Resources, exist as internal reports (eg, Harmsworth and Page, 1991) or as contract reports (eg, Blaschke et al, 1992; Clough and Hicks, 1992). Since then several compilations have been published (notably Crozier et al, 1993; Glade, 1996; Glade and Crozier, 1996).

What follows is a summary of key findings from the unpublished reports (that contain more extensive data lists) as well as the published reviews. As with earlier sections, subsequent discussion will focus onto MfE's brief, ie, what do these summary data actually tell us about terrestrial erosion benefits of any afforestation or reversion carried out for the purpose of carbon sequestration?

Summary of New Zealand data

Table 8 summarises storm damage survey information about the spatial extent of soil erosion under pasture, planted forest, natural forest and scrub.

Points to note about Table 8 are:

- storm damage surveys since 1970, that compare pasture with bush or planted forest, show that the area of soil eroded by storms is consistently less (but not zero) where forest is planted or scrub is allowed to revert, or bush is retained
- reductions vary a great deal from survey to survey, but are mostly in the 50 to 90% range (when bush, scrub or forest data are re-computed as percentages of pasture data)
- publications give hectares eroded for each vegetation cover, and usually also express this figure as a percentage of surface area. Few give margins of error for the measurements.[13]

Table 8 confirms a widespread perception that less erosion occurs in forested or scrubby terrain, than on land in pasture. However bush and scrub do not provide total protection, especially in higher-intensity storms (a fact often overlooked by advocates of afforestation / reversion options).

Erosion data from state-of-environment surveys

A second source of information are regional point samples of erosion, collected by one of the authors (DLH) and colleagues since 1998 for seven of the country's regional authorities. Relevant data from these surveys are summarised in Table 9.

Points to note about Table 9 are that:

- The first three surveys give percentage of sample points eroded. This is not the same as percentage area eroded (despite some optimism in the accompanying contract reports, that this would be the case). They could only be used to estimate reductions in erosion, if one assumes that average area eroded per sample point is the same for different land uses.
- More recent surveys give percentage area eroded for each land use (from measurement of 1-hectare areas around each sample point). So they can be used to estimate reductions in erosion, for the regions concerned.

All surveys give standard errors for sample means; an indicator of reliability when extrapolating sample means to areas from which each sample was drawn (the regions).

---

[13] Regarding the last point, our reading of the publications is that authors have generally collected data at enough sites (sample areas, hillsides, observation points) within their study areas, to be able to calculate error margins. These could be expressed either as the standard deviation around an average value (variability within the area studied) or as the standard error of an average value (its representativeness as a sample mean, if extrapolated to a larger area represented by the sample). We suspect that most authors would have calculated one or the other, but did not see fit to include them in their published summaries.

Table 8: Vegetation effects on terrestrial erosion (from storm damage surveys)

Area	Region	Year	Pasture % area eroded or landslides per hectare (ls/ha)	Spaced trees in pasture % area eroded	Planted forest % area eroded or ls/ha	Natural forest and scrub % area eroded or ls/ha	Source of information
Hunua	Auckland	1968					Pain, 1969, 1971
Tangoio	Hawkes Bay	1971	<1%				Eyles, 1971
Hapuakohe	Waikato	1973	4.4%			1.1%	Selby, 1976
Otago Peninsula	Otago	1973	<1%				Leslie, 1973
Maimai	West Coast	1974				0.1-0.2 ls/ha	O'Loughlin et al, 1980
Banks Peninsula	Canterbury	1975	<1%				Harvey, 1976
Wellington	Wellington	1976	0.2 ls/ha				Eyles et al, 1978
Stokes Valley	Wellington	1976	0.3%				McConchie, 1980
Wairarapa	Wairarapa	1977	1.0–4.8 ls/ha				Crozier et al, 1980
Pakaraka	Wairarapa	1977	9.7%				Crozier et al, 1982
Gladstone	Wairarapa	1977	3.7–6.4%				Stephens et al, 1981
Wairoa	Hawkes Bay	1979	6.0%				Eyles and Eyles, 1982
Paeroa-Thames	Coromandel	1981	0.05 ls/ha			0.04 ls/ha	Salter et al, 1983
Waitahaia	East Coast	1982				0.1-0.3 ls/ha	Phillips, 1988
Ngatapa	Gisborne	1985	5.9%				Hawley and Dymond, 1989
Otoi	Hawkes Bay	1986	2.2%				Harmsworth and Page, 1987
East Coast	East Coast	1988	7.0%				Stephens and Trotter, 1988
East Coast	East Coast	1988	10.7%		0.6%		Phillips et al, 1990
Uawa	East Coast	1988	17.0%		2.0%		Marden et al, 1991
East Coast	East Coast	1988	0.4 ls/ha		0.2 ls/ha	0.1-0.03 ls/ha	Marden and Rowan, 1993
Waipaoa	Gisborne	1988	0.4–3.2 ls/ha		0-0.2 ls/ha		Page et al, 1999
Wairoa	Hawkes Bay	1988	2.9 ls/ha				Black, 1989
Pakuratahi	Hawkes Bay	1988	0.9%		0.1%		Fransen, 1996
Tutira	Hawkes Bay	1988	4.2%				Page et al, 1994
Aokautere	Manawatu	1988	1.5%				Jessen, 1989
Waitotara	Taranaki	1990	7.3%				Trustrum et al, 1990
Mangamingi	Taranaki	1990	9.6%		0.0%	0.3-1.0%	Pain and Stephens, 1990
Makahu	Taranaki	1990	7.0%				De Rose et al, 1993

Area	Region	Year	Pasture % area eroded or landslides per hectare (ls/ha)	Spaced trees in pasture % area eroded	Planted forest % area eroded or ls/ha	Natural forest and scrub % area eroded or ls/ha	Source of information
Makahu	Taranaki	1990	2.4%				Crozier et al, 1993
Wanganui	Wanganui	1992	20.0%		2.0%	0–3%	DL Hicks et al, 1993
Mahurangi	North Auckland	1998			2.3%		DL Hicks, 1998
Tararu	Coromandel	2003				1.8%	DL Hicks, 2006
Manawatu-Wanganui	Manawatu-Wanganui	2004	0.9%				Dymond et al, 2004

Table 9: Vegetation effects on terrestrial erosion (from point sample surveys)

Region	Area surveyed	Cropland, orchards	Dairy pasture	Drystock pasture	Exotic scrub	Natural scrub	Planted forest	Natural forest	Source of information
% points eroded*									
Manawatu-Wanganui	459 km^2, 1,580 points	–	–	2.7±1.0	0.0	4.8±3.3	0.0	1.9±1.7	Crippen, 1999
Auckland	2,500 km^2, 2,500 points	28.6±1.6	3.4±2.3	11.1±1.9	9±6.9	3.9±1.7	10±3.4	4.6±2.4	Hicks, 2000a
Gisborne	8,200 km^2, 4,100 points	32.6±14.0	–	6.4±1.4	0	7.5±3.1	5.6±2.8	2.4±1.8	Crippen and Scholes, 2001
Tasman		–	1.68±0.22	1.76±0.1	1.9±0.2	7.43±1.9	0.5±0.2	1.7±1.7	Burton, 2004
% area eroded*									
Waikato	24,488 km^2, 6,122 points	0.00	0.01±0.01	0.13±0.03	0.03±0.02	included in natural forest	0.01±0.01	0.03±0.02	DL Hicks, 2003
Wellington	8,156 km^2, 2,039 points	0.00	0.00	1.0±.0.20	0.1±<0.1	0.5±0.10	0.2±<0.1	0.5±0.1	Crippen and Hicks, 2004
Bay of Plenty	13,388 km^2, 3,347 points	<0.01	0.03±0.02	0.2±0.06	0.09±0.07	0.2±0.08	0.06±0.03	0.23±0.07	DL Hicks, 2005d

* Percentages are ± two standard errors at 95% confidence level

Table 10: Effects on terrestrial erosion (from soil conservation effectiveness surveys)

Locality	Area surveyed	Pasture % area eroded*	Spaced trees in pasture % area eroded*	Natural trees in pasture % area eroded*	Planted forest % area eroded*	Natural forest and scrub % area eroded*	Source of information
Waihora, East Coast	273 hillsides	11.3±1.7	2.7±1.1	Included with spaced trees	None in sample	None in sample	Hicks,1989b, 1992
Waimata	192 hillsides	8.3±1.4	None in sample	None in sample	3.2±0.6	4.7±1.9	Hicks,1989a, 1991b
Makahu, Taranaki	279 hillsides	3.5±1.2	None in sample	None in sample	0.6±0.5	1.0±1.0	Hicks, 1990
Tinui, Wairarapa	305 hillsides	1.2 scars/ha	0.2 scars/ha	Included with spaced trees	–	–	Hicks, 1991
Rangitikei	567 hillsides	4.0±0.7	1.5±0.5	Included with spaced trees	None in sample	None in sample	Hicks et al, 1993
Ohura, Taranaki	40 hillsides, 2,968 points	13±2.5	2.0±0.7	Included with spaced trees	–	–	Hicks, 2000c
Matahuru	97 km^2, 482 points	1.6±0.5	1.7±0.6	1.0±0.3	0.9±0.9	0.0±0.0	Hicks, 2005b
Mangarama	59 km^2, 507 points	1.4±0.4	1.0±0.5	1.1±0.4	0.0±0.0	1.3±1.6	Hicks, 2005a
Pokaiwhenua	472 km^2, 998 points	1.9±0.6	1.2±0.6	1.3±1.0	1.2±0.5	1.2±0.6	Hicks, 2005c
Waikato west coast	4,180 km^2, 1,045 points	1.4±0.7	0.0±0.0	0.5±0.5	0.0±0.0	1.8±1.7	Hicks, 2006a
Manawatu-Wanganui	483 sample areas of 1 ha	4.9±1.4	3.0±2.7	3.3±1.5	1.6±0.9	1.5±1.2	Hicks and Crippen, 2004

* Percentages are ± two standard errors at 95% confidence level

Data in Table 9 confirm that eroded areas are reduced where land has been afforested, or allowed to revert or remain in bush. Given the large sample sizes (region-wide) and the small error margins, there is some certainty about these reductions.

The reason why reductions vary so greatly from one region to the next, is that in some, storms or wet winters preceded the date of survey. The surveys are literally ‘moment in time’ snapshots with an aerial survey camera.

Erosion data from soil conservation effectiveness surveys

A third source of information are some surveys of the effectiveness of tree planting as a means of soil conservation. These were undertaken intermittently at the request of a few regional councils wishing to find out how their tree plantings had performed in the wake of storms or wet winters. Table 10 summarises key data.

Points to note about Table 10 are:

- all surveys give percentages of soil surface area, bared by fresh erosion of whatever form. The percentages include deep-seated mass movements (slumps and earthflows) as well as shallow mass movements (soil slips and debris avalanches); also fresh erosion by running water (sheetwash, rills, gullies and streambank collapses)
- standard errors for sample means in Table 10 are somewhat large. If a sample mean of say 2% were extrapolated, the true value typically would be 1 to 3%. So percentage reductions based on these datasets are less certain, than ones based on regional datasets (Table 9).

Table 10 shows that eroded areas reduce, where tree plantings are ‘sufficient’ (closed canopy established over most or all unstable parts on a hillside). Where this is so, substantial reductions have been measured for spaced trees in pasture (whether planted or natural), for close-canopy afforestation, and for close-canopy scrub reversion / bush retention. Reductions in erosion are minimal where tree plantings are ‘insufficient’ (established on just some unstable parts in the case of spaced plantings, or not yet closed canopy in the case of afforestation).

The surveys in Table 10 do not differentiate whether trees are more effective at stabilising shallow mass movements than deep-seated ones. Nor do they differentiate tree-planting’s effectiveness for control of gully and streambank erosion, from its effectiveness for control of mass movement. Their aim was to assess soil conservation trees’ effectiveness ‘as planted’ irrespective of where.

Considerable scientific information about the effectiveness of tree planting in different situations is already available. For useful summaries, refer Thompson and Luckman (1993) and Phillips et al (2000).

Implications for forestry or reversion established primarily for carbon sequestration

Benefits of reduced erosion occur on-site and are proportionate to the extra area of soil protected from erosion. They can become significant and take the form of:

- saved pasture growth, stock shelter and stock fodder, where trees are space-planted on farmland
- timber yield, on afforested land (minus the costs of loss of pasture production from the same land)
- saved costs through not having to apply fertiliser, spray weeds or scrub, or incur other grazing costs (such as fencing and stock control) on marginal or reverting land.

The question arises, how can base figures from Tables 8 to 10 be used to estimate nationwide reductions in terrestrial erosion? It is near-impossible to apply the base figures. A brief explanation of why this is so, follows.

Some geological structures, and some soils, are more susceptible to erosion than others. Clearly these effects are present in surveys that have been carried out in different parts of the country. It would be tempting to say that Gisborne-East Coast data, for instance, apply to other terrain with shattered and crushed marine sedimentary rocks; or that Waikato-Bay of Plenty data represent typical reductions for terrains mantled by airfall tephra. However the second source of variation – storm rainfall – precludes making extrapolations along these lines.

Mass movement erosion, in particular, does not commence until storm rainfall exceeds a threshold value (Crozier and Eyles, 1980), then increases in proportion to rainfall, but tails off to an asymptotic maximum where rainfall is very high (Omura and Hicks, 1992). The publications cited in Table 8 confirm this, reporting very little erosion where storm rainfall was less than 100 mm, and antecedent conditions were dry. Where more than 100 mm of continuous rain fell, eroded area increased in proportion (though not indefinitely), as average area eroded did not exceed c.20%. Where antecedent conditions were wet, mass movements were triggered by quite small rainfalls, sometimes only 5 to 10 mm, falling as intense bursts; but again, their accumulated areas did not exceed c.20%.

Each eroded area listed in Tables 8 to 10 pertains to a particular combination of storm rainfall and antecedent soil moisture. Unfortunately there are not enough of them to plot the relationships as graphical curves for the most common vegetation cover (pasture), let alone the rest. In the absence of such curves, it would be foolhardy to extrapolate specific percentages out of the tables onto similar terrain elsewhere. To do so, would be to say that the same levels of erosion will always be attained whenever there is a storm.

An alternative is to re-compile data from Tables 8 to 10, expressing eroded areas amongst tree cover, as percentages of eroded area in open pasture for each survey. This approach does not provide exact estimates, but at least supplies scientifically defensible minima and maxima that can be applied to terrain elsewhere:

- spaced trees in pasture (whether planted or natural), reduce terrestrial erosion by 21 to 100%
- close-canopy afforestation reduces terrestrial erosion by 10 to 100%
- scrub reversion / bush retention reduces terrestrial erosion by 18 to 100%.

Three caveats must be attached to these ranges. Firstly, Tables 8 to 10 contain four instances (out of 28 surveys with comparable data) where erosion has increased rather than reduced. Second, these exceptions, plus the enormous range in reductions from the other 24, show that how much erosion is controlled – within the minima and maxima – depends on factors such as standard of tree planting and condition of reverting scrub. A more lengthy discussion of these factors is given by DL Hicks (1995).

Effect of afforestation/reversion patterns

The discussion in Chapter 2 cast doubt on a significant flood reduction effect from the afforestation / reversion. Chapter 3 also noted that sediment reduction can be a significant off-site effect, but is strongly site-dependent.

Terrestrial erosion differs from both flooding and sediment yield in that not just the effect, but also the benefits, accrue on-site. Consequently these benefits are ubiquitous wherever afforestation and reversion are allowed to happen on private land, even if their pattern is diffuse. Although unlikely to expand across more than 10 to 20% of catchments' area in future years (see Chapter 2 discussion), these low percentages will translate to a large number of hectares where on-site reductions in erosion can be expected.

Attention is also drawn to two features of the soil conservation effectiveness surveys (Table 10), that seem to have a bearing on carbon sequestration proposals:

- Erosion can be reduced by space-planted trees in grazed pasture; though not as much as by close afforestation.
- Whether there are substantial reductions, depends on sufficiency of tree planting ie, it needs to extend over most of the unstable area.

If government is looking for forms of carbon sequestration that have erosion reduction as a significant additional benefit, then climate change mitigation incentives should include space-planted trees in pasture. The amount and permanence of carbon sequestration, associated with such plantings, perhaps also deserves greater investigation than it has received until now.

Conclusions: terrestrial erosion

Storm damage surveys, state of environment surveys, and soil conservation effectiveness surveys, provide enough data for us to conclude that large areas of soil can be protected from erosion by:

- spaced planting of trees in pasture
- close-canopy afforestation
- scrub reversion
- bush retention

in the following circumstances:

- where land is erodible
- where sufficient trees are planted (on most or all of the unstable area)
- and tree or scrub cover is maintained.

These circumstances can be achieved by the diffuse patterns of afforestation and reversion on private land, because their effects and benefits occur on-site.

However there is a substantial technical problem with estimating their magnitude. It would be scientifically invalid to extrapolate absolute areas eroded (whether expressed as hectares or percentages) from one catchment to another, in the absence of information about storm rainfall characteristics and antecedent soil moisture conditions.

An alternative approach is to apply an ‘envelope’ of reductions from Tables 8 to 10 – for instance the least and largest measured reductions in area eroded amongst reverting scrub relative to open pasture – to some area where scrub reversion is proposed. This does not provide an exact forecast of what will happen, but it does supply a scientifically defensible estimate of the minimum and maximum effects of scrub reversion on terrestrial erosion. This possibility is explored in the discussion on methods for national estimation (Chapter 7).

Summary of impact of afforestation on erosion under different scenarios

Diffuse reversion / afforestation (defined in Chapter 1) will only reduce terrestrial erosion if located on erosion-prone land. This scenario would ensure tree cover on some but not all such land in a catchment. Nevertheless it could have large benefits (saved soil, land retained in production, reduced land management costs), because the benefits occur on-site, in direct proportion to area of erodible land covered.

Widespread reversion / afforestation (defined in Chapter 1) will also only reduce terrestrial erosion if located on erosion-prone land; but if targeted, would ensure tree cover on most such land in a catchment. Whether the scenario’s benefits will be small or large, depends on how much of the catchment is erodible.

Whole-catchment reversion / afforestation (defined in Chapter 1) will reduce terrestrial erosion, because it would ensure tree cover on all erosion-prone land in a catchment. Its benefits will be large, provided a substantial part of the catchment is erodible. However this scenario also entails tree cover on other parts where land is not subject to erosion (and where no benefits from erosion control could be expected).

For areas already in forest, further effects on the incidence of erosion would require major changes in the condition of canopy and understorey vegetation, through sustained control of the animal pests that affect quantity or quality of vegetation (eg, deer, thar, goats and possums). Establishing the linkages between animal densities, vegetation response and on-site erosion incidence has been very elusive in the past.

5 Estimates of Monetary Benefits / Costs

Introduction

The preceding three chapters have indicated circumstances under which tree establishment could significantly reduce flooding, sediment yield, or terrestrial erosion in New Zealand. These are summarised as follows:

Natural environment

- Erodible lowlands and hills (but not mountains or catchment headwaters with naturally very high erosion rates).
- Areas where there are frequent high intensity rainfalls (storms).

Land use / human settlement

- Areas in grass or tussock cover prior to afforestation.
- Areas of planted forest or scrub reversion or bush regeneration established more than 5–10 years (threshold date varies).
- Areas of spaced tree planting on erodible hill country that is still farmed – *applies only to reduction of terrestrial erosion effects.*
- Areas upstream of urban or rural infrastructure or intensive agriculture on lowland floodplains or other flood-prone landforms – *applies only to reduction of sediment yield effects.*

These are the characteristics of the terrain that could most usefully be targeted in afforestation and reversion policies.

This chapter reviews available information about the benefits and costs of these reductions. Where unavailable, it proceeds to discuss methods whereby the information might be obtained (Chapter 6).

Concepts for valuation

The basic approach to environmental valuation is to place values on the services that the natural environment provides. These services have value to society because people derive utility from their use, either directly or indirectly. People also value ecosystem services they are not currently using.

This approach to valuation is utilitarian (anthropocentric), in that any value is derived from the utility *people* derive from the services. Other values exist such as socio-cultural and intrinsic values; while these should be considered in resource management decisions, no tools to quantify these values have been developed.

The approach to the valuation of benefits resulting from policies or programmes follows the following steps:

1. Identify the changes to ecosystem services brought about by decisions, policies, or programmes (eg, to plant forest that lead to changes in erosion, sedimentation and water yield).
2. Quantify these changes using physical measures (areas saved from erosion, tonnes of sediments).
3. Quantify the impacts caused by these changes on ambient environmental quality (increase flood risk, water quality) and environmental services.
4. Determine the impact on capital, humans and animals (damage, recreation, aesthetics).
5. Place a value on those impacts.

A typology for impacts[14] (Step 4 above) include:

- flood effects:
  - increased flood severity
  - water damage to farmland and settlements
  - infrastructure damage (to bridges, roads, power supply)
  - livestock losses
- sedimentation effects:
  - decreased channel flood capacity
  - silt damage to farmland and settlements
  - increased flood severity
  - reduced water quality (processing, recreation, fishing)
  - biological degradation (habitat loss)
  - water storage loss for irrigation and hydro-electric dams
  - navigation (need for increased dredging etc)

[14] See also Krausse et al 2001 for a detailed classification of erosion and sedimentation effects.

- soil erosion effects:
  - loss of agricultural production
  - on-farm damage to infrastructure (tracks, fences)
  - increased conservation spending (private and public)
  - direct property damage (residential)
  - off-farm infrastructure (road/rail, bridges, utility network)
  - recreational facility damage
  - other effects, such a loss in farmer confidence, visual effects, etc.

The previous chapters have dealt with the first of these three steps. They have identified and quantified, where possible, the impact (in terms of benefits or costs) of afforestation on water yield, sediment yield, and soil erosion.

This chapter discusses valuation of those impacts (benefits and costs). The measure of value taken in this approach is peoples' willingness to pay. For many goods and services, this value is reflected in what people are willing to pay in the market, and prices therefore reflect value. Many ecosystem services and impacts, however, are not traded in the market – even though they clearly affect society's well-being ie, they reflect real costs and benefits.

To measure non-market goods and services, alternative approaches have been developed to discover the values people hold for them. Non-market valuation techniques can be divided in two main groups:

a. Revealed preference approaches. Information is obtained on people's buying behaviour, or substitutes and complements of environmental goods and services. That information is used to derive a value for them. Approaches such as the Travel Cost Method, Hedonic Price and Defensive Expenditure fall in this category.

b. Stated preference approaches. People are directly asked (through surveys) about their willingness to pay or willingness to accept compensation for changes in environmental goods and services. Approaches such as Contingent Valuation and Choice Methods fall in this category.

Monetary valuation of the benefits / costs of climate change mitigation measures will require the use of a mixture of non-market valuation techniques, and cost approaches.

A fundamental difficulty with the estimations of monetary values requested in MfE's brief for this review is the specificity of the estimates required. There are a relatively large number of estimates of the costs associated with a given environmental problem, eg, flooding, sedimentation, or soil erosion. There are also many studies of the economics of different land uses, and the economic benefits and costs of changing from one land use to another. There are also a growing number of studies on the economic benefits of some ecosystem services.[15] Examples of all of these studies are cited in Chapters 6 and 7 of this report. Some sources cited in the previous three chapters also provide information on economic values of the physical changes described.

---

[15] These include Patterson and Cole (1999), Ensis and NZIER (2006a, b), Morten (2006), and Butcher (2006). See also http://www.doc.govt.nz/templates/MultipageDocumentPage.aspx?id=40121 for a summary of recent Department of Conservation work on the value of ecosystem services provided by public conservation lands.

However, the brief for this review calls for a subset of all three types of estimates: examining the estimates of just some types of ecosystem services, resulting from just some types of land use change, in response to just some types of environmental problems. No known studies address exactly this subset of issues.

A few relevant valuation studies deal with the economic costs of soil erosion and/or benefits of erosion reduction. There are many estimates of the economic costs of flooding, both from specific flood events and national estimates for all large floods over a specified time period. However, no studies relate these costs to specific land uses.

The separation of costs of sediment and terrestrial erosion is difficult to make rigorously. This is because reducing erosion may reduce sediment yield, which may in turn reduce flood risk and damage. With care, a separation can be made; but past catchment cost-benefit analyses have generally not attempted to do so. A further general comment about the studies cited is that they are very site-specific. Mitigating erosion and sedimentation in isolated catchments may have few benefits to society, while the same erosion and sediment yield in a catchment close to population and highly valued land could be disastrous. Nationwide estimates are therefore pretty well impossible, unless more studies are done of representative catchment situations (which can then be scaled up).

Monetary value of flooding reduction

Economic costs of flooding are known to be substantial. Flooding is estimated to have cost New Zealand insurers $247 million between 1995 and 2004, excluding government compensation payments (Bicknell et al, 2004). Current government programmes for flood risk management emphasise the economic value of improving flood management strategies.

Systematic attempts to estimate the monetary value of reductions in flooding first appeared as part of flood control schemes and catchment control schemes. These schemes, implemented from the 1940s onwards, initially by the Ministry of Works and Development (MWD) and later by catchment boards, entailed substantial expenditure of government funds, so cost-benefit analyses were required by Treasury. They were sometimes undertaken by MWD staff, but more often commissioned from the then Ministry of Agriculture and Fisheries (MAF, now Ministry of Agriculture and Forestry). Many of these earlier reports have recently been sighted and several of them are still accessible.

However, in these surveys:

- reductions in flood damage have been estimated *ex ante*, by superimposing scheme design parameters on historical information about extent of past floods
- benefits appear to have been costed in proportion to postulated reductions in floodwater extent (and associated sedimentation); not by survey of affected landowners
- attached monetary values pre-date the 1980s economic reforms. Costs of erosion control, values of farm production etc cannot be simply updated by applying Farm or Commodity Price Index values or similar.

For these reasons we do not consider these reports as suitable sources of data for present-day estimates of flood reduction benefit.

After 1987, central government demanded better information about costs and benefits of flood and erosion control before issuing funds. In response, agencies commissioned several studies, at catchment or regional scale, that were more rigorous in their methods. These provide more reliable, and realistic estimates of monetary benefit.

The first in this category was Ministry of Works and Development's review of the East Coast Project (ECP) (Cowie et al, 1987). The ECP began in the late 1960s as a response to already chronic land degradation problems. It was aimed at the promotion of regional economic and social development, and the establishment of productive forests. Cost-benefit analysis was undertaken on the basis of commercial forestry returns, rather than valuation of soil conservation benefits. Such benefits had been achieved in part, but only to the degree that afforestation had proceeded (at best one-quarter of target land). Taking into account the costs of afforestation and loss of grazing production, the review concluded: because of lower effective Government subsidy rates for soil conservation, few comprehensive soil conservation programmes were likely to continue in the region.

The current East Coast Forestry Project is the ECP's continuation, as a response to Cyclone Bola (in 1988) and the worsening erosion problem on the East Coast. It has since been reviewed at five-year intervals. In the first review (1998), a very simple analysis was made of the benefits of a reduction in flood risk (hence flooding costs avoided), using the recalculated cost of the Cyclone Bola disaster. The flooding benefits from afforestation (assuming all target land being planted) were estimated to lie between $1 million and $18 million. However, this estimate was crudely done and the calculations were more to show the magnitude of possible benefits than to portray accurate values.

In the Waikato, Project Watershed was established by Environment Waikato in 2000 to deal with ongoing soil erosion, river management and flood protection in the Waikato and Waipa catchments. Interventions include riparian fencing and planting and planting of other erosion-prone slopes. Some monitoring of the effectiveness of these actions has been initiated (B Peploe, Environment Waikato, personal communication). No cost-benefit analysis has yet formed part of this monitoring, but is likely to be included in a review of the project to be undertaken.

In the Manawatu-Wanganui region on 15/16 February 2004, a rainstorm varying between 150 and 200 mm affected many parts of the region. It caused 62,000 landslides over an area of c. 10,000 km^2 (Dymond et al, 2006). MAF surveys summarised by Trafford (2004) estimate the undifferentiated costs of damage from landsliding, flooding, and siltation to be $170 million.

Monetary value of changes to low flows

We are not aware of any literature directly valuing the cost of reduced low flows through afforestation / reversion on downstream land uses in New Zealand. Such effects have been the source of some policy debates in South Island regions, but our impression is that they would not apply to large areas of afforestation, nationally.

Monetary value of sediment reduction

Some relevant information was collected by catchment boards, regional councils, or MAF, in the course of several ad hoc responses to storms during the 1980s to early 1990s. These were reviewed by Clough and Hicks (1993), and a summary of the more useful data appears in DL Hicks (1995: table 4), copied below as Table 11.

We consider the estimates in Table 11 to be reliable. They were selected because they can be under-pinned by real costs and returns, collected for the area where an investigation was carried out. Estimates from other publications or unpublished reports were rejected, as they appeared to be extrapolated from generalised farm costs and returns, civil cost estimates etc.

However, there are several disadvantages in applying the Table 11 estimates to carbon-sequestration-related sediment reduction:

- they are now 12+ years old, and few in number
- sediment-specific components can only be isolated by going back to source documents
- it is unclear how sediment-specific components could be attached to similar terrain in other parts of the country.

Table 11: Monetary value of damage repair costs (averaged over farm area; sediment, flooding, and erosion damage combined)*

Nature of repair	Minimum $/ha	Maximum $/ha
Fences	5.86	44.13
Tracks	1.35	25.62
Buildings	1.43	10.91
Pasture re-sowing	0.62	12.93
General clean-up	2.91	3.76

Note: Costs date 1988–1992.

* Source: DL Hicks (1995: table 4).

Some extra information is contained in a valuation of the benefits and costs of soil conservation to the Bay of Plenty region (Weber et al, 1992). The study was conducted by a mixture of direct costs analysis and a survey of willingness to pay for soil conservation benefits. The benefits and costs of all types of soil conservation (not just afforestation) were evaluated and ecosystem service benefits other than soil conservation investigated. Soil erosion was addressed as a problem specifically in regard to its effects on water quality. This is tantamount to a cost-benefit analysis of soil conservation works, in terms of their value for reducing sediment and nutrients in receiving waters. The report concluded that soil conservation was a worthwhile activity from an economic perspective, with a net present value of at least $2.7 million to the region at an internal rate of return of 11.3%.[16] This study did not isolate flood and erosion reduction benefits.

---

[16] As with many regional council valuation studies, this report focussed heavily on the relationship of private to public benefits, in order to provide a basis for rating.

Monetary value of terrestrial erosion reduction

There is an extensive literature on the subject of benefits from soil conservation. The first published evidence from New Zealand was bulletins and pamphlets produced by the Soil Conservation and Rivers Control Council from 1945 to 1973. These promoted diverse soil conservation practices: burning control, pasture oversowing, aerial topdressing, tree planting, runoff diversion, gully repair. They cited reduced erosion and increased farm production, on the soil conservation reserves and experimental farms where these techniques were trialled. Clough and Hicks (1993) reviewed these early publications, considered that they contained anecdotal descriptions of perceived benefits that may well have been real, but lacked rigorous measurements to which monetary values might be attached.

Establishment of the Water and Soil Science Centres in 1974 led to another series of miscellaneous publications and publicity leaflets. Some of these reported scientifically measured effects of various soil conservation practices eg, reduced erosion, improved soil properties, better vegetation cover, pasture and timber yields. Their papers in scientific journals discussed the measurements and sometimes attached estimates of their monetary value, but ironically were not accessible to the farming community. A 'plain language' compilation of information from these documents has been published by MAF (DL Hicks, 1995). Its summary of the reductions in crop and pasture yield due to erosion is reproduced below as Table 12.

Table 12: Range of percentage reductions in crop and pasture yield due to erosion*

Erosion process	Minimum reduction (%)	Maximum reduction (%)
Surface erosion, cropland	–18	62
Surface erosion, pasture	–40	78
Surface erosion, tussock	–28	93
Deep mass movement, pasture (initial)	–43	77
Deep mass movement, pasture (re-grassed)	–7	–39
Shallow mass movement, pasture (initial)	–65	80
Shallow mass movement, pasture (re-grassed)	0	42

* DL Hicks (1995: table 3).

Information about the extent to which these reductions have been reversed through soil conservation practices, is scattered through the text of Hicks' compilation. It does not appear as a single table. Several regional council, central government, and research organisation reviews of erosion control in the period 1996–2006 have used these numbers, but do not appear to have attempted attaching monetary values.

More recently, the economic, environmental and social impacts of afforestation in the East Coast region were studied by McElwee (1998). He modelled farm-scale and regional effects of full afforestation with pine and space planting with poplars. At the farm scale, both pine and poplar forestry had a greater Net Present Value than pastoral farming. At the regional scale, his results indicated the same order of NPV relative returns of the three land uses. He noted further implications in terms of environmental and social values at the regional scale:

Overall, therefore, it appears that planting large stations [compared to smaller farms which are more profitable to individual investors at the farm scale] would maximise employment and soil protection, and may also maximise NPV ... Thus by encouraging forestry development on the severely eroding land classes which are typical for large stations, the East Coast Forestry Project may well be helping to maximise employment and the financial return to the East Coast regions as well as achieving the stated goal of controlling soil erosion.

Nationwide estimates

All work mentioned so far has looked at local costs and benefits. Ericksen (1984) attempted the first nationwide estimates of flooding costs. His review contains some aggregated data for major floods between 1960 and 1984. It appears reliable, being based on insurance claims for property damage, production losses from farmland, and repair costs for river protection works. However the review needs updating to present-day dollar values.

A study by Krausse et al (2001) is the first attempt at estimating national economic costs of soil erosion and sedimentation in New Zealand. The authors use a framework modified from earlier work by Clough and Hicks (1992), as well as American approaches.

Krausse et al (2001) estimate average annual cost to be $127 million (for soil erosion and sedimentation combined), but caution (with commendable honesty) that their estimate is order-of-magnitude ie, the true figure could be anywhere between $12.7 million and $1270 million. However, because the authors have attempted to err on the conservative side when estimating, their true value is likely to be higher than the mean estimate of $127 million. Furthermore, the highest component of costs is lost agricultural production, estimated at $37 million annually. They note that predicted changes in climate patterns for New Zealand include increased storminess in many regions and drier conditions in eastern New Zealand. Both trends would increase lost agricultural production from mass movement in hill country and surface erosion, respectively.

This study should be compared with an earlier estimate of an annual cost of erosion of $30 million for rural land and $3 million for urban land (Hawley, 1984, quoted in Glade and Crozier, 1996). This figure is almost certainly an underestimate: for example it gives a direct cost of only $1.52 million for the on-site cost of erosion in Cyclone Bola, compared with the usually quoted cost of more than $100 million for the total costs of the damage caused in that storm.[17]

[17] Although this review includes only New Zealand material, it could be noted that the Glade and Crozier (1996) review cites a yearly cost of direct damage from landslides of NZ$243–743million in Japan. This estimate is relevant as Japan's area is roughly comparable to New Zealand's (370,000 km^2 and 270,000 km^2 respectively) and has similarities in terrain and rainfall. The Japanese estimate is likely to comprise mainly infrastructural damage and not the costs of lost agricultural production.

The Krausse et al (2001) study, although still the best national estimate of the costs of soil erosion, is simply an aggregation of data on different costs. It does not attempt the type of first-principles approach summarised at the beginning of this chapter, and its range of costs spans two orders of magnitude. The authors discuss why they were unable to produce a better estimate.

Briefly:

- national agencies (the former MWD, MfE and MAF) and regional agencies (catchment boards and regional councils) have never systematically collected or collated data about storm damage or costs for more than a few years at a time
- costs of erosion and flood damage are known only for a few events that have been well-documented eg, Cyclone Bola; these are too few to be a reliable basis for making nation-wide estimates.

Finally, there is an important qualification to any estimate of costs of soil erosion: they cannot be directly correlated to benefits from afforestation / reversion. Some costs of soil erosion are not relevant to afforestation / reversion, and in many other categories the costs and benefits are not equivalent. For example, the large loss of pasture production value associated with hill-country mass-movement erosion would represent a cost, not a benefit of afforestation or reversion – because afforestation / reversion would take the land out of pastoral production.

Conclusion: monetary estimates

It is clear from the works cited above, that there is plenty of information available on local benefits. Some of it has already been extrapolated to nationwide estimates, but these are either outdated, or have large uncertainties. There may be ways to get around the absence of reliable nationwide information, for instance by using regional information, where these are of sufficient quality and resolution.

The studies discussed mainly looked at total costs (not the change in the costs due to an increase in areas planted). Only a few of the studies actually tried to calculate the benefits of some of the changes in ecosystem services (loss of damages, water quality improvement).

Quantification of those benefits at nationwide scale will require new information on areas to be afforested and reverted. For greater certainty, they will also need updated information about reductions in erosion and sediment yield, changes in flood risk and magnitude, changes in damages, and changes in ecosystem services (direct and indirect).

These possible methods are discussed in the next chapter.

6 Recommendations on Methodology for a National Perspective

Introduction

This chapter describes options for refining the work reported on in this review to obtain better national (or in some cases regional) estimates of benefits and costs of afforestation and reversion measures.

Flood reductions and water yield

We do not recommend that MfE proceed with an attempt to quantify the nationwide value of carbon-sequestration-related flood reductions, or other changes in water yield.

To summarise our reasons:

- Diffuse reversion / afforestation by individual owners, on parts of their own properties, will not appreciably alter even small flood waves (<1-year frequency) passing down the main channel of a catchment.
- Widespread reversion / afforestation by owners changing land use on entire properties, will alter the magnitude and duration of small and moderate flood waves (1-to 10-year frequency). Consequential reductions in overbank flooding and associated damage are possible on unprotected rivers; but on protected rivers there will be little or no reduction.
- Whole catchment reversion / afforestation by an agency intervening to change land use on all properties, will substantially alter the magnitude and duration of small to moderate flood waves; but this will only slightly alter large flood waves (> 10-year frequency). This scenario will not reduce large flood waves enough to avoid overbank flooding and associated damage, either on unprotected or protected rivers.

Should MfE wish to verify that flood reduction effects are indeed small in medium to large catchments, two hydrological models are currently available (summarised below). We suggest that it is unnecessary to undertake hydrological modelling for every catchment in the country. Such an exercise, apart from being expensive, is likely to replicate the same hydrological response many times. More information could be obtained from a single catchment, with a diffuse pattern of land use and ownership. Successive model runs, stepping up the percentage of afforested / retired land from 10 to 90% in 10% increments, would demonstrate what is likely to happen.

Watyield

The water balance model 'Watyield' was developed by Landcare Research, funded by MFE's Sustainable Management Fund, initially for use by the Tasman District Council. It is intended to predict the effects that a land cover change may have on the water balance in a large catchment, where there are limited data on climate, soil and vegetation.

Input data required are:
- daily rainfall
- monthly evapotranspiration
- estimates of% interception for each cover type
- estimates of soil water parameters (for grouped soil types)
- two base flow parameters.

Outputs are:
- soil water storage
- daily, monthly or annual water yields
- minimum annual seven-day low flows.

It has been initially calibrated on three catchments ranging from 3 km^2 through 23 km^2 to 369 km^2, with good results reported (Fahey et al, 2004). Instances of its subsequent use have not come to our attention, but may exist.

Topnet

The 'Topnet' model was designed by NIWA for continuous simulation of catchment water balance and river flow.

Model inputs are:
- rainfall time series
- temperature time series
- digital elevation data for catchment
- vegetation type (probably best sourced from LCDB2)
- soil type (grouped, from NZLRI or NZ Soils Database)
- sub-basin boundaries
- drainage network branches (linking sub-basins).

Model outputs are changes in:
- sub-basin plant canopy storage
- sub-basin root zone storage
- sub-basin saturated zone storage
- sub-basin runoff time series
- flow routed through the drainage network.

Although designed to model river flows, Topnet can also be used to model effects of land use change, as altering the averaged vegetation characteristics of a sub-basin also alters other model characteristics: canopy storage, aerodynamic roughness and albedo (used to calculate evaporation), and root zone storage (used to calculate transpiration and runoff).

Fahey et al (2004) report that Topnet has been used to model land use change in at least two large medium-sized catchments, Tarawera: 900 km^2 (Woods and Duncan, 1999), and Shag: 544 km^2 (He and Woods, 2001).

Topnet is used for flood routing investigations in the course of NIWA's contractual work. They often form part of feasibility investigations for commercial agencies eg, power companies, irrigation ventures. Results do not appear in the public domain, unless the agencies' proposals proceed to applications for resource consent. Reports may be public for a few instances of flood routing for regional councils.

Other models eg, forest cover flow change

Many other models are used overseas for rainfall-runoff assessment. One in particular, forest cover flow change, is specific to forest land cover changes and their effect on river flows. We have not discussed these as we are unaware of their use in the New Zealand landscape.

Monetary value of flood damage reduction

Our preceding recommendation is not to proceed with an attempt to quantify value of flood reduction, This relates to flood reduction in the hydrological sense ie, changes in the frequency, duration and magnitude of flood waves passing down a channel. Chapter 2 contains evidence (summarised above) that such changes are real, but too small to affect over-bank flooding.

Chapter 3 indicates that afforestation / reversion can reduce overbank flooding (and associated damage) by another mechanism: improved channel flood capacity as a consequence of reduced sediment yield. A monetary value could be attached to flood damage reduction through this process; the relevant recommendation appears under our sub-heading 'Monetary value of sediment yield reductions' (below).

Sediment yield

We recommend that MfE proceed with at least one study, to identify land in catchments nationwide, where sediment yield reduction could be a significant benefit of carbon-sequestration-related afforestation and reversion.

The rationale, from our reading of the publications, and also the information in several relevant unpublished reports, is that afforestation and reversion can cause substantial reductions in sediment yielded from river headwaters towards the downstream parts of medium to large catchments.

However, they do not invariably do so: the effect is not ubiquitous. It depends on afforestation and reversion being targeted towards parts of catchments that are both geologically unstable and high rainfall.

Where this combination exists, afforesting or reverting fairly small percentages of a catchment's area can result in proportionately much larger percentage reductions in the catchment's sediment yield.

The preceding point holds true so long as these small pockets are targeted onto erodible land. This is despite the likely diffusion of carbon-sequestration-related afforestation or reversion as numerous small pockets within larger areas of private farmland. This point is particularly important for any carbon sequestration initiative if sediment yield reduction is sought as a benefit.

We also caution that such a nationwide catchment study would reveal many catchments where much of the potential sediment reduction effect has already been achieved. Clough and Hicks (1993) point out that 5.9 million hectares of land were reserved as protection forests by the former New Zealand Forest Service between 1919 and 1987 (not just forest, but also scrub, tussock and alpine vegetation); and that a further 2.9 million hectares of similar land were reserved as national parks and scenic reserves by the former Department of Lands and Survey. This includes most catchments west of the South Island's main divide, from Fiordland to Nelson; to catchments that have their headwaters in the North Island's axial ranges from the Rimutakas to the Raukumaras; and to large western North Island catchments from the Wanganui to the Awakino.

Further reductions would have occurred in the last 20 years by land withdrawal from grazing through the tenure review process in the South Island high-country tussock lands, and the creation of a high-country conservation park system. In both the North and (to a lesser extent) the South Island, reductions would also have occurred through ongoing reversion in marginal hill country districts that are less accessible and not generally desirable for alternative land uses.

Nevertheless, our knowledge of the New Zealand landscape points at many other catchment headwaters where land is for the most part privately owned, with large areas farmed. In the North Island these include:

- many (not all) catchments in the Northland and Auckland regions
- Waikato west coast catchments north of the Awakino
- small Taranaki and Wanganui catchments with headwaters close to the coast
- sub-catchments west and north of the Rangitikei and Manawatu
- catchments draining the hill country from East Cape to Cape Palliser.

In the South Island they include many sub-catchments that have their headwaters in tussock country well east of the main divide (though not main river headwaters that rise on the divide).

Should MfE wish to proceed with our recommendation, the necessary data are already to hand, stored in several public agencies' geographic information systems. A database at NIWA's Hydrology Centre in Christchurch (DM Hicks and Shankar, 2003) already contains:

- boundaries for catchments draining to the sea (variable size from less than 100 km^2, to in excess of 10,000 km^2)
- boundaries for medium-sized sub-catchments (variable size, but generally in the 100 to 1000 km^2 range)
- vegetation categories from the Landcover Database, second edition (LCDB2)
- modelled sediment yields for different terrain-vegetation-rainfall combinations within each catchment.

With this database as a starting point, we suggest it would be worth:

- overlaying cadastral information for land parcels, aggregated by ownership (public, Maori communal, company, private individual)
- calculating percentage area in each category of ownership
- then calculating percentage catchment area occupied by natural forest, planted forest, natural scrub and planted scrub, within each ownership category.

The GIS procedures could be undertaken nationwide by one of several agencies that possess the data (Linz, Terralink, Landcare Research, NIWA); NIWA might be in the best position given that it is the national research agency for measuring sediment yield. The procedures would provide MfE with reasonably recent and accurate figures for the percentage of each catchment presently occupied by privately owned land under woody vegetation (existing contributions to carbon sequestration). It could also provide the percentage occupied by farmland or tussock grassland (potentially available for carbon sequestration initiatives). These data could be provided both for terrains (see below) identified as having high sediment yields, and for terrains identified as not having these.

The percentage of medium-sized catchments are occupied by such reverted land, could also be derived by overlay of catchment boundaries on the Landcover Database (LCDB). Comparison of certain catchments between the first and second editions of the LCDB, or possibly between the Vegetation Map of New Zealand from the early 1980s (Newsome 1987) and the first edition of the LCDB (late 1990s), could more closely identify recent trends.

In undertaking this exercise, it should be kept in mind that private landowners will be receptive to afforesting or reverting only part of the area potentially available, regardless of the policy package available. However it seems to us that identifying where these potential areas are (ie, the target land) are essential precursors to any attempt at estimating what the sediment yield reductions might be. This is irrespective of whether the target lands are in fact on terrain with high sediment yields, and of what percentage of each catchment's area they occupy,

We understand that MfE has nationwide estimates of land cover. If not done so already, a regional break-down of the figures would be most worthwhile in this regard, or a break-down by catchment within regions. It is the latter that is needed, to identify where the target land is.

Should MfE wish a more detailed pattern of spatial information than is available from the existing NIWA sediment yield model results (GIS layer and map), two others sources could be used.

CREAMS

The CREAMS model, operated by NIWA's Water Quality Centre at Hamilton, was developed in the United States to predict changes in water quality as a result of agricultural land use practices. NIWA has successfully adapted it to New Zealand conditions, using the model to support research and contract investigations since about 1990. Its investigations have focussed on livestock exclusion from riparian zones, fertiliser application, and cultivation practices. As CREAMS incorporates a vegetation layer, it is capable of modelling catchment-wide land use change also. CREAMS is based on daily or event rainfall and utilises GIS data for slope, soil and vegetation cover on small areas within a catchment. It calculates runoff and water quality parameters for each element, by a modified version of the Universal Soil Loss Equation (USLE); it then aggregates them to catchment-mouth suspended sediment yield, phosphate load, nitrate load, and biological oxygen demand (by event or by year).

The data input and computer time required to run CREAMS would preclude its use for nationwide estimates. However as a tried-and-tested water quality model, it has value for detailed investigation of sediment yield reduction within particular catchments that can be regarded as test cases.

Sednet

The Sednet Model is a GIS-based model and designed to provide a sediment summary budget per sub-catchments within a watershed (measured as tonnes per year). The model was originally developed at the University of Canberra in Australia, and recently adapted by Landcare Research to fit New Zealand's environmental parameters.

The model accounts for catchment sediment transport, various erosion types (earth-flows, hillslopes, banks and gullies) and is able to track sediment shifts downstream for an entire watershed. It predicts how much sediment will make it to the coast and from where the sediment and nutrients are coming. It also demonstrates how the sediment loads change with different land management, and over long time-scales – ie, pre-settlement sediment loads as compared to current sediment loads.

The model utilises a series of environmental parameters including landform information, floodplain information, daily stream / river flow rates, rainfall information, evapo-transpiration information, land use information, riparian vegetation information and known / modelled erosion information (eg, information from the New Zealand Empirical Erosion Model, NZEEM, see below). It has been applied for all the sub-catchments within the Manawatu River watershed under varying land use and erosion scenarios, but has yet to be tested or utilised elsewhere in New Zealand.

Monetary value of sediment yield reductions

We are less optimistic about recommending that MfE proceed with an attempt to quantify the nationwide value of sediment yield reductions. The rationale lies in our reading of the few available publications, plus our knowledge of many unpublished reports that have attempted to do this in past years. We conclude that while the monetary value of reductions in sediment yield has often been quantified (eg, as farm production from areas of pasture that are no longer silted) this was rarely done on a sound basis: the 'saved' production was hypothetical, not measured.

Should MfE wish to proceed with such a study, we recommend that it be done in a single region – perhaps in just one catchment within that region. A proposal along these lines (but for two full regions) has recently been developed by Ensis and New Zealand Institute of Economic Research (Ensis and NZIER, 2006b). We consider it better to have reliable values from a single thoroughly investigated catchment, than incomplete or unreliable ones from a study that spreads time and computer modelling resources thinly across too large an area.

A key element in calculating reliable monetary values would be to identify a catchment where local government agencies already have good records of historical costs for items such as silt clearance, regrassing, road repair, drain cleaning, channel dredging, gravel extraction. The Waipaoa (East Coast), Whareama (Wairarapa), Motueka (Tasman), and possibly Taieri (Otago) catchments, are promising candidate catchments.

Good historical records, and some monetary estimates, may be available for several of Environment Waikato's Project Watershed sub-catchments (for example, Ritchie, 2000; Hill and Blair, 2005); also from current Environment Waikato initiatives for reducing sedimentation into Lake Taupo (currently not factored into benefit-cost analysis). Hill and Blair categorise the benefits resulting from soil conservation in the Middle Waikato Pilot Project, including economic benefits, but do not quantify these.

In Chapter 3 we mentioned improved channel flood capacity as a significant benefit. It does not appear to be an element in past cost-benefit analyses of sediment yield reduction (that focus on over-bank sedimentation or water quality issues). We suggest that it be included in a future catchment-based study.

Other catchments with records of bed level change following partial afforestation are the Waipaoa, Waiapu (East Coast), and Awhea (Wairarapa); possibly also the Esk (Hawkes Bay) and Pomahaka (Otago).

Terrestrial (on-site) erosion

Nationwide extent of carbon-sequestration-related reductions in terrestrial erosion could be estimated, if MfE wishes to do so. As with sediment yield, the identification of land potentially available, and whether it is on erodible or stable terrain, are essential first steps to take before attempting any estimates.

In our view, the only safe use of storm damage survey data for estimation at present would be to calculate the range of reductions observed (from Table 8), take the minimum value (about 50%), and say that this value will be equalled or exceeded during storms, where land is afforested or allowed to revert. This would be a crude approach, but better than nothing. The Institute of Geological and Nuclear Sciences (GNS) is also continues to maintain an as-yet unpublished database of studies of rainfall-induced landsliding (grouping the studies by erosion terrain) (Page in preparation). Once more readily available, this database may be a way to refine estimates by attaching different percentage reductions to ‘erosion terrains’.

Erosion surveys for regional state-of-environment reports seem a much better source of data about reductions attributable to afforestation or reversion. These surveys have the advantages of being region-wide, with large sample sizes, and tight error margins relative to sample means. Percentage reductions, estimated by ratio of sample means from Table 9, can be applied directly to each region where a survey was carried out: from this can be estimated what would happen if x% were afforested / allowed to revert. Survey data currently exist for seven of the country’s 15 regions / unitary authorities: Auckland, Waikato, Bay of Plenty, Gisborne, Manawatu-Wanganui, Wellington, and Tasman. A disadvantage of these surveys is that it would be statistically invalid to apply the percentage reductions to other regions (that don’t have any points included in the samples). Point sample surveys would need to be carried out in the other regions, before attempting estimates.

We do not recommend that MfE use soil conservation effectiveness surveys as a source of data for regional or national extrapolations: the sample sizes for these surveys are somewhat small, and error margins are large relative to sample means. They would create uncertainty, if percentage reductions were calculated from the data in Table 10 and applied elsewhere. The data are, however, useful for carbon sequestration initiatives, in the sense that they can be cited as demonstrating a consistent pattern of reductions in terrestrial erosion where trees are space-planted in pasture, as well as where land is afforested, or allowed to revert.

Two models are available from Landcare Research, which may be suitable for further work on nationwide estimates of erosion, as follows.

New Zealand empirical erosion model

The New Zealand Erosion Estimation Model appears to be the most promising way for estimating nationwide reductions in terrestrial erosion, if specific land types and percentages of land were to be afforested / reverted. This is based on recent work by Landcare Research with collaboration from other Crown Research Institutes (CRIs): it partitions the New Zealand landscape on the basis of rock type, landform (especially slope angle), and rainfall – the factors controlling erosion. The resulting groupings are called erosion terrains. The use of these terrains in combination with land use / land cover factors, as done in the New Zealand Empirical Erosion Model, is a promising development towards a more comprehensive and picture of erosion and sedimentation effects nationally.

NZEEM is an empirical model that predicts mean annual soil loss from annual rainfall, type of terrain and percentage of woody vegetation cover. It is calibrated on about 200 sediment yield data sets from most regions in New Zealand. NZEEM is claimed to be applicable to all types and sizes of catchments. It is a national development of an earlier study examining landslide susceptibility in the Manawatu-Wanganui region, validated by the incidence of erosion in the 2004 floods in that region (Dymond et al, 2006). It also builds on earlier work resulting in a database and digital map of mean specific sediment yield (kg / km^2 / yr) produced by NIWA and Landcare as part of a project funded by the Foundation for Research Science and Technology (FRST), for studying carbon transfers associated with erosion (DM Hicks et al, 2004).

Land environments of New Zealand

LENZ (Land Environments of New Zealand) is an environmental classification intended to underpin a range of conservation and resource management issues. It is based on the fact that, rather than occurring randomly, species tend to occur in areas having similar environmental conditions. As a consequence, similar environments tend to support similar groups of plants and animals, provided they have not been substantially modified by human activity. LENZ uses these species-environment relationships by identifying and modelling climatic and landform factors likely to influence the distribution of species. LENZ uses these factors to define a landscape classification that groups together sites with similar environmental conditions, independently of current vegetation cover.

LENZ was originally envisioned as a framework for conservation management that would take advantage of the natural relationship between the environment and species distributions. However, it has had a much wider application. This is because the environmental factors that control the distributions of many land based plants and animals (temperature, water supply, availability of nutrients, etc) are also factors that provide major constraints on human land uses such as agriculture, horticulture, and forestry. Therefore it has been used to identify sites where similar problems are likely to arise in response to human activities, or where similar management activities are likely to have a particular effect.

Our supposition at the beginning of this project was that LENZ might be used in a similar way to group environments with particular erosion / sediment yield characteristics. However, the particular climate and landform parameters used for LENZ ie, those predicting dominant vegetation species distributions, are not necessarily the same ones determining erosion and sediment generation. A different set is needed for erosion. The approach described above for NZEEM and its associated terrain classification now seems more useful, unless a modification to the LENZ modelling is made: it should draw on the specific climate and terrain attributes that are critical in erosion or sediment generation (we understand these are also available on Landcare Research databases).

Terrestrial erosion reductions: nationwide estimates of monetary value

Attaching monetary values to reductions in terrestrial erosion is a difficult proposition. There may be ways to get around the absence of reliable nationwide information, for instance by using regional information, where it is of sufficient quality and resolution. Potentially usable studies (mainly recent ones commissioned by regional councils) are identified in our Chapter 6. They include benefit-cost analyses carried out for Environment Waikato's Project Watershed, and an economic analysis of afforestation and poplar planting compared with farming on the East Coast of the North Island (McElwee, 1998). The recent proposal from Ensis and NZIER to MAF, to undertake one or two new regional assessments, may also come into this category.

Table 13 shows a preliminary and partial framework for setting out regional costs and benefits of soil conservation. It is based on unpublished work carried out by one of the authors (DLH) for Greater Wellington Regional Council in 1994. That work identified items for which data collection appeared feasible at the time. Table 13 shows in a matrix format (no actual data values are presented) how those data items could be adapted for evaluating the different afforestation and reversion scenarios discussed in this report.

McElwee's approach is particularly interesting, even though it was taken without any consideration of the climate change mitigation potential of permanent afforestation and reversion. His study provides a good insight into multiple values of afforestation and reversion options on a farm and regional scale. It would be a useful model for further refinement to address the specific monetary estimates of benefits and costs of afforestation and managed reversion options for carbon sequestration.

Finally, we stress again the difficulty in providing the estimates requested in this project, ie, flooding and erosion benefits or costs associated with afforestation or reversion undertaken for the purposes of climate change mitigation or adaption. Estimates in either physical or monetary terms are difficult. However, it seems clear to us that for the greatest benefits to be realised, afforestation or reversion needs to the targeted at the type of land described at the beginning of Chapter 5. This will provide a full spectrum of ecosystem services, including greenhouse gas reduction, biodiversity protection, and soil and nutrient retention, as well as the erosion and flood reduction functions dealt with in the present report.

Table 13: Regional costs and benefits of soil conservation – a preliminary framework

Scenario» Characteristic	Land retirement (reversion)	Diffuse afforestation (farm woodlot)	Pole planting within pasture	Widescale afforestation (whole farms)	Whole catchment afforestation
Target land Area of erodible land already covered (ha) Area of erodible land required (ha) Area of erodible land required (% of region) Soil erosion in storms (average% loss of residual soil cover) Storm frequency (average return period of damaging storms)					
On-site costs (for land yet to cover) Landowners costs to implement Lost pastoral production (Su/yr averaged) Lost pastoral production (gross margin $/yr In-forest damage repair					
On-site benefits (land already covered + still to cover) Reduction in on-farm erosion damage repair Quantifiable reduction in on-farm damage repair Value of annual production on treated land • timber • carbon credits • other products					
Off-site costs (land yet to cover) Local government costs to implement Central government costs to implement Flow-on effects to regional economy • Jobs lost from farm contracting, food processing etc • Added value and multiplier effects of jobs lost					
Off-site benefits (land covered + still to cover) Sediment entering rivers (% reduction) Quantifiable reduction in infrastructure repair Flow-on effects to regional economy • Jobs gained in silviculture, harvesting etc • Added value and multiplier effects of jobs gained • Other jobs/added value etc gained (eg, tourism, transport, services)					

Note: All $ costs averaged inflation-adjusted costs over maximum available time of records.

7 Summary and Conclusions

1. This review, commissioned by the Ministry for the Environment is aimed at:
   - determining whether, with existing information and analysis, it is possible to make credible, 'order of magnitude', quantitative estimates of any flooding and erosion reduction benefits (or costs) associated with measures to sequester carbon dioxide or reduce emissions of greenhouse gases in New Zealand
   - providing the initial estimates of the benefits (or costs), or where information is not available, to provide advice on an alternative methodology for measuring such benefits.

2. This report present detailed information about estimates of benefits and costs, in three sections:
   - physical effects of afforestation and reversion on flood reduction
   - physical effects of afforestation and reversion on sediment yield
   - physical effects of afforestation and reversion on erosion reduction.

3. The issue of what part of a catchment is being afforested or reverted is crucial to understanding the above responses to land use change. Vegetation cover is just one among many factors affecting response. We consider the likely consequences of increased afforestation under three scenarios of different intensity:
   - incremental afforestation: diffuse afforestation by individual owners on their own properties that continue to also support farming
   - wide-scale afforestation: whole properties changed in land use and afforested, affecting a large proportion of catchment or sub-catchment
   - whole-catchment afforestation: Crown intervenes to afforest or promote reversion of whole catchment or sub-catchment.

4. We then discuss studies that estimate the monetary values of these effects, and comment on the types of studies that could be undertaken to provide more reliable estimates; and some of the methodological and other issues in extending the work on quantification of benefits and cost of climatic change mitigation measures in New Zealand.

5. There are many sources of information relevant to flooding, sediment yield and erosion occurrence under different land uses in New Zealand, but most are of low direct value for the purposes of this review. In particular, flood frequency / magnitude studies are either short-term, or undertaken in catchments where land use is mixed; this makes regional extrapolation and interpretation very difficult.

6. The reported studies for sediment yields, flood flows and erosion under different land uses have high variability, even within similar environments. Few studies provide margins of error for results. As a result it is very difficult to provide predictions of likely physical responses to land use changes, even before the monetary value of such changes is considered.

Effects of afforestation and reversion on floods, low flows and water yield

7. Reductions in flood peak under forest compared to pasture of 30% to 90% have been measured during small (up to annual) floods, but are lower (20% to 50%) in large floods, and cannot be expected during extreme floods.

8. Reduced flood peaks do not necessarily indicate reduced flood volumes. Afforestation results in somewhat broader, lower flood waves, that discharge much the same volume of floodwater downstream but over a longer period of time.

9. Planted or regenerating forest reduces annual water yield (typically by 20% to 60%) compared with pasture. The amount of reduction depends on local rainfall and evapo-transpiration.

10. Measured reductions in low flows under forest compared to pasture are in the range 0% to 50%. If these lower flows result in reduced water availability for downstream uses in dry seasons, then this is a cost imposed by afforestation, not a benefit.

11. Large changes in flood peaks, water yields or low flows have been observed only in small catchments, where close to 100% of catchment area has been afforested or retained in native cover. The few published studies of partial afforestation in large catchments, all report much smaller changes in river flow.

12. What happens when measurable flood reductions in small sub-catchments are added together in a large catchment, is complex, depending on many factors in the catchment topology. Vegetation change in only some parts of a large catchment does not cause a substantial drop in main-channel flood peak. Widespread afforestation would be needed across most of a large catchment area, for any measurable reduction in main-channel flood peak to occur.

13. A marginal reduction in flood peak during a large or extreme flood, would not ensure that water level will not reach over a stopbank, nor that property damage or production loss will not be caused by other forms of flooding.

14. Absolute flows or percentage reductions in flows, from small research catchments entirely under forest or scrub, should not be extrapolated to the entire area of medium or large catchments, where afforestation / reversion is patchy and occupies a small percentage of catchment area. Under a ‘diffuse afforestation’ scenario, reduction in runoff from small blocks of afforested or reverting land is overwhelmed by ‘normal’ runoff from much larger areas of surrounding farmland. Only under a ‘whole catchment afforestation’ scenario would it be valid to extrapolate flow reductions from small research catchments.

15. It should therefore not be assumed that afforestation for carbon sequestration may reduce floods enough for damage reduction benefits in any catchment, whether small or large, so long as the pattern of afforestation / reversion remains diffuse.

16. A flood reduction large enough for damage reduction benefits to accrue might be expected if a large percentage of a catchment is afforested or allowed to revert. However, a changed flow distribution curve does not avert many of the most common causes of flood damage, such as breach of stopbanks.

17. We do not recommend any attempt to quantify nationwide carbon sequestration-related flood reductions. Should MfE wish to verify that flood reduction effects are indeed small in medium to large catchments, two hydrological models are currently available: Watyield or Topnet. We do not recommend the use of other models unless there is prior evidence of their calibration for use in the New Zealand landscape.

Summary of impact of afforestation on flooding under different scenarios

18. Diffuse reversion / afforestation by individual owners on parts of their properties (on which farming use also continues), will create a fragmented pattern of tree cover on a relatively small percentage of catchment area. This scenario will not appreciably alter even small flood waves passing down the main channel of a catchment.

19. Widespread reversion / afforestation by owners changing land use on entire properties will create contiguous blocks of tree cover on a significant percentage of catchment area. This scenario will alter the magnitude and duration of small and medium flood waves passing down the main channel of a catchment. However there will be little or no reduction in overbank flooding and associated damage, because these impacts become substantial only during large events.

20. Whole catchment reversion / afforestation by a public agency intervening to change land use on all properties, will ensure tree cover on almost entire catchment area. This scenario will substantially alter the magnitude and duration of small to medium flood waves, but will only slightly alter large flood waves (>10-year frequency) passing down the main channel of a catchment. It will not reduce large flood waves enough to avoid overbank flooding and associated damage.

Monetary value of flood reduction

21. Early estimates of flood reduction benefits and costs pre-date the 1980s economic reforms, and the differences in the economic environment between then and now make their use invalid. A few regional and national studies since 1987 provide a more useful framework for analysis of flood reduction values but their costs and benefits do not directly correspond to afforestation / reversion effects.

22. Given that flood reduction effects attributable to afforestation or reversion are too small to avert large floods overtopping stopbanks, and unlikely to affect other large-flood thresholds, consequential flood damage reductions are unlikely. There seems little point in proceeding with an attempt to quantify the monetary value of any associated benefits.

Effects of afforestation and reversion on sediment yield

23. Sediment yield investigations show that substantial reductions in annual sediment yield can be expected where small catchments are retained in bush or scrub, compared to being clearfelled or converted to pasture. The same can be expected where small catchments are planted in exotic forest on former pasture and tussock.

24. Where terrain is highly erodible, sediment yields in watercourses remain high during initial afforestation with exotic species or initial reversion to scrub.

25. The high yields persist for several decades due to ‘lag effect’, until sediment stored in and near the channels is transported downstream. Sediment yields gradually decline, to levels below those in watercourses on equivalent terrain still used for farming.

26. These research findings are either from small catchments, or from medium-sized catchments where unstable headwaters have been substantially afforested. It would be erroneous to assume from them, that forestry or reversion will substantially reduce sediment yield in all situations.

27. Other evidence about variations in sediment yield is available on a NIWA database, from longer-term measurements of sediment transport in medium to large rivers. These data indicate that high sediment yields are associated with either unstable geological terrains or high rainfall zones; and particularly with areas within catchments where the two coincide.

28. On a national scale, sediment yield is controlled by geology and climate, more than by vegetation cover. The highest sediment yields come from catchments vegetated by what is generally perceived as ‘intact’ native forest and scrub, because catchments in the most erosion-prone climates and geologies are more likely to remain in native vegetation, than to be developed for commercial land use.

29. Afforested or reverting catchments may still have high residual sediment yields. Nevertheless the NIWA dataset confirms that, where an area within a catchment has the same erosion-prone geology, sediment yield is generally lower from parts that are forested or scrub-covered, than from parts in pasture or tussock.

30. Necessary data for nationwide land identification are already to hand, stored in several agencies’ geographic information systems. With this data it would be possible to overlay cadastral information for land parcels, aggregated by ownership type.

31. We recommend that MfE proceed with at least one study to identify land in catchments nationwide, where sediment yield reduction could be a significant benefit of carbon-sequestration-related afforestation and reversion.

32. This procedure would provide reasonably accurate figures for the percentage of each catchment presently occupied by privately owned land under woody vegetation (existing contributions to carbon sequestration), as well as the percentage occupied by farmland or tussock grassland (potentially available for carbon sequestration initiatives); both on terrains identified as having high sediment yields, and on terrains identified as not.

Summary of impact of afforestation on sediment yield under different scenarios

33. Diffuse reversion / afforestation will only reduce a catchment's sediment yield if located on geologically unstable land. The limited percentage of such land that would be likely to be converted to tree cover, precludes a large absolute yield reduction for an entire catchment.

34. Widespread reversion / afforestation will only reduce a catchment's sediment yield if located on geologically unstable land; but if targeted, could result in tree cover on most such land. Whether absolute yield reduction will be large or small, depends on whether the geologically unstable areas are in high-rainfall or low-rainfall zones of a catchment.

35. Whole-catchment reversion / afforestation will reduce a catchment's total sediment yield, because all geologically unstable land would be covered by trees. Absolute yield (tonnes per square kilometre per year) reduction will be large, provided some of the geologically unstable areas are in high-rainfall zones.

Monetary value of sediment reduction

36. We are less optimistic about recommending an attempt to quantify the nationwide value of sediment yield reductions. Although past attempts to quantify these monetary values have produced a range of estimates, their authors generally acknowledge a high margin of error, due to scarcity of sound field-collected information about sedimentation's impacts.

37. Should MfE wish to proceed with a new attempt, we recommend that it be done in a single region, perhaps in just one large catchment within that region. It would be better to have reliable values from a single catchment, than unreliable ones from a study that attempts valuations over a wide area where supporting data do not exist. A key element in calculating reliable monetary values would be to identify a catchment where local government agencies already have good records of sedimentation, as well as historical costs of repair.

Effects of afforestation and reversion on terrestrial erosion

38. Storm damage surveys since 1970 show that the area of soil eroded by storms is consistently less where forest is planted, scrub is allowed to revert, or bush is retained, than under pasture. Reductions are mostly in the range of 50% to 90%.

39. Point samples for recent state of the environment reports provide regional estimates of eroded area under planted forest, natural forest and scrub. These are anything from 10% to 100% lower than the area eroded under agricultural land uses.

40. Soil conservation effectiveness surveys since 1988 confirm the reduced levels of terrestrial erosion under planted forest, natural forest and scrub. They also show that erosion can be reduced by space-planted trees in grazed pasture; though not as much as by close afforestation.

41. Investigations of afforestation and reversion have been carried out widely enough in the New Zealand landscape to allow confidence that the measured reductions are real and substantial.

42. Because the reductions occur on-site and are proportionate to the extra area of soil protected from erosion, benefits to the individual landowner can become significant, additional to off-site and public good benefits.

43. The nationwide extent of carbon sequestration-related reductions in terrestrial erosion is worth estimating, if MfE wishes to do so. The effects and associated benefits are not limited by either the fragmented nature of afforestation and reversion for carbon sequestration (unlike flood effects), or by location of the fragmented land parcels (unlike sediment yield).

44. As with sediment yield, the identification of land potentially available for carbon sequestration, and whether it is on erodible or stable terrain, are essential first steps to take before attempting any estimates.

45. Once this is done, the most promising way to estimate nationwide reductions in terrestrial erosion, if specific land types and percentages of land were to be afforested / reverted, appears to us to be the New Zealand Erosion Estimation Model (NZEEM).

Summary of impact of afforestation on erosion under different scenarios

46. Diffuse reversion / afforestation will only reduce terrestrial erosion if located on erosion-prone land. This scenario would ensure tree cover on some but not all such land in a catchment. Nevertheless it could have large benefits (saved soil, land retained in production, reduced land management costs), because the benefits occur on-site, in direct proportion to area of erodible land covered.

47. Widespread reversion / afforestation will also only reduce terrestrial erosion if located on erosion-prone land; but if targeted, would ensure tree cover on most such land in a catchment. Whether the benefits will be small or large, depends on how much of the catchment is erodible.

48. Whole-catchment afforestation and reversion will reduce terrestrial erosion, because it would ensure tree cover on all erosion-prone land in a catchment. Its benefits will be large, provided a substantial part of the catchment is erodible. However this scenario also entails tree cover on other parts where land is not subject to erosion (and where no benefits from erosion control could be expected). For areas already in forest, further effects on the incidence of erosion would require major changes in the condition of canopy and understorey vegetation, through sustained control of the animal pests that affect quantity or quality of vegetation.

Monetary value of terrestrial erosion reduction

49. Attaching monetary values to reductions in terrestrial erosion is a very difficult proposition. Some data from North Island hill-country regions are available, but there are not enough such studies for the data to be nationally extrapolated.

50. Recent regional and national estimates of soil erosion costs and soil conservation benefits provide a useful framework for analysis, but costs given are imprecise and not particularly useful for estimating benefits and costs specifically associated with afforestation / reversion.

51. As with sediment yield, it may be better to rely on a single indicative well-done catchment study, rather than to commission regional or nationwide estimates when satisfactory data to support them do not exist. Potentially usable studies include benefit-cost analyses carried out for Environment Waikato's Project Watershed and Lake Taupo retirement schemes, and an economic analysis of afforestation and poplar planting compared with farming on the East Coast of the North Island.

Targeting benefits of afforestation and reversion for sediment yield and erosion reduction

52. The greatest benefits in terms of sediment yield and erosion reduction will be obtained from land with the following characteristics:
    - erodible lowlands and hills (but not mountains or catchment headwaters with naturally very high erosion rates)
    - areas where there are frequent high-intensity rainfalls
    - areas in grass or tussock cover prior to afforestation
    - areas of planted forest or scrub reversion or bush regeneration established more than 5–10 years (threshold date varies)
    - areas of spaced tree planting on erodible hill country that is still farmed (applies only to reduction of terrestrial erosion effects)
    - areas upstream of urban or rural infrastructure or intensive agriculture on lowland floodplains or other flood-prone landforms (applies only to reduction of sediment yield effects).

53. Afforestation and reversion targeted in this way will provide a full spectrum of ecosystem services, including greenhouse gas reduction, biodiversity protection, and soil and nutrient retention; as well as the erosion and sediment yield reduction functions described in this report.

8 Bibliography

This list gives sources of hydrological, sediment and erosion data cited in the review, as well as other source relating to economic evaluations, etc. All sources are listed, whether publications, unpublished reports or personal communications.

Adams J. 1979. Sediment loads of North Island Rivers, New Zealand – a reconnaissance. *New Zealand Journal of Hydrology* 18: 36–48.

Arand J. 2007. *Conservation Management Contribution to a Low Greenhouse Gas Economy.* Unpublished paper, Strategy and Policy Group, Department of Conservation.

Bargh B. 1977. Output of water, suspended sediment, phosphorus and nitrogen from a small forested catchment. *New Zealand Journal of Forestry* 7: 162–71.

Bargh B. 1978. Output of water, suspended sediment, phosphorus and nitrogen from a small agricultural catchment. *New Zealand Journal of Agricultural Research* 21: 29–38.

Bayfield MA, Meister AD. 1998. *East Coast Forestry Project Review.* Report to Ministry of Agriculture and Forestry. Ministry of Agriculture and Forestry, Wellington.

Bergin DO, Kimberley MO, Marden M. 1995. Protective value of regenerating tea tree stands on erosion–prone hill country, East Coast. *New Zealand Journal of Forestry Science* 25: 3–19.

Bicknell K, Cullen R, Hughey K, Meister A, Meyer-Hubbert G, Smallman, C. 2004. *Preliminary Study of Environment Research, Science and Technology Benefits.* Report for Ministry of Research, Science and Technology. Agribusiness and Economics Research Unit, Lincoln University.

Black R. 1989 unpublished. *Reversing the erosion trend on erodible hill country, East Coast North Island*. Internal report, Hawkes Bay Catchment Board.

Black R. 1998 personal communication. Sediment yields from Pakuratahi and Tamingimingi catchments (from unpublished LR contract reports to Carter Holt Harvey).

Blackie S. 1992 unpublished. *The on-site and off-site costs and benefits of property protection, a Waikato analysis*. B Mgmt Studies investigation, University of Waikato, Hamilton.

Blake G. 1973 unpublished. *Runoff and sediment data before and during land development, Otutira experimental catchment*. Internal report, Water and Soil Division, Ministry of Works and Development.

Blaschke PM, Eyles GO, DeRose RC, Hicks DL. 1992. *Physically Sustainable Land Uses in the Taranaki Region.* DSIR Land Resources Contract Report 92/27, for Taranaki Regional Council.

Blaschke PM, Trustrum NA, Hicks DL. 2000. Impacts of mass movement on land productivity: a review. *Progress in Physical Geography* 24: 21–52.

Burton A. 2004 unpublished. *Point sample survey of erosion*. Internal Report, Tasman District Council.

Butcher Partners. 2006. *Economic Benefits of Water in Te Papanui Conservation Park: Inception report.* Contract Report for Department of Conservation.

Claridge G. 1980. *Studies of Water Quantity and Quality at Taita and their Possible Significance to the Nelson Situation*. In: Proceedings of a Seminar on Land Use in Relation to Water Quantity and Quality, Nelson 1979, pp. 14–39. Nelson Catchment Board.

Clough P, Hicks D. 1992. *Soil Conservation and the Resource Management Act*. NZIER Contract Report to Ministry of Agriculture and Fisheries.

Clough P, Hicks D. 1993. *Soil Conservation and the Resource Management Act (Summary).* MAF Policy Technical Paper 93/2, Ministry of Agriculture and Fisheries.

Cowie C. 1957. *Floods in New Zealand, 1920–1953.* Ministry of Works and Development, for Soil Conservation and Rivers Control Council.

Cowie B, Bettjeman W, Hicks DL. 1987. *East Coast Project Review.* Ministry of Works and Development, Wellington.

Crippen TF. 1999. *Hill country erosion monitoring survey for the State of the Environment Report.* Contract report to Manawatu-Wanganui Regional Council.

Crippen TC, Hicks DL. 2004. *Soil Intactness Assessment of the Wellington Region.* Contract report to Wellington Regional Council.

Crippen TC, Scholes P. 2001. *Gisborne Point Sampling Provisional Data Summary and Comments*. Contract report to Gisborne District Council.

Crozier MJ. 1969. Earthflow occurrence during high intensity rainfall in eastern Otago, New Zealand. *Engineering Geology* 3: 325–34.

Crozier MJ. 1993. Management issues arising from landslide and related activity. *New Zealand Geographer* 49: 35–7.

Crozier MJ, Eyles RO. 1980. *Assessing the Probability of Rapid Mass Movement*. In: Proceedings of the 3rd Australian and New Zealand Conference on Geomechanics, Wellington, NZ Institute of Engineers, pp. 247–51.

Crozier MJ, Eyles RJ, Marx SL, McConchie JA, Owen RC. 1980. Distribution of landslips in the Wairarapa hill country. *New Zealand Journal of Geology and Geophysics* 23: 575–86.

Crozier MJ, Eyles RJ, Marx SL, McConchie JA, Owen RC. 1982 unpublished. *Mass Movement Erosion, Wairarapa*. Victoria University contract report to NWASCA and Wairarapa Catchment Board.

Davoren T. 1986. *Land use basin program: comparison of hydrological indices from different land use types*. Internal report WS1032, Hydrology Centre, Water and Soil Division, Ministry of Works and Development.

Day T (ed). 2007. *Managing Risk: A draft New Zealand protocol.* Flood Risk Management Governance Group, Centre for Advanced Engineering, Canterbury University, for NZ Local Government Association and Institute of Professional Engineers of New Zealand.

DeRose R. 1994. *Effect of rainfall intensity on the spatial density of shallow landslides in a small watershed, Taranaki, New Zealand*. In: Proceedings of the International Symposium on Forest Hydrology, Tokyo, Japan, pp. 391–8.

De Rose R, Trustrum NA, Blaschke PM. 1993. Post-deforestation soil loss from steepland hillslopes in Taranaki, New Zealand. *Earth Surface Processes and Landforms* 18: 131–44.

De Rose R, Gomez B, Marden M, Trustrum NA. 1998. Gully erosion in Mangatu Forest, New Zealand, estimated from digital elevation models. *Earth Surface Processes and Landforms* 25: 1045–53.

Dons A. 1986. The effect of large-scale afforestation on Tarawera River flows. *New Zealand Journal of Hydrology* 25: 61–73.

Dons A. 1987. Hydrology and sedimentary regime of a pine, native forest and pasture catchment in the central North Island. *New Zealand Journal of Forestry* 17: 161–78.

Duncan MJ. 1995. Hydrological impacts of converting pasture and gorse to pine plantation and forest harvesting, Nelson. *New Zealand Journal of Hydrology* 34: 15–41.

Duncan MJ. 1980. *The Impact of Afforestation on Small Catchment Hydrology in Moutere Hills, Nelson*. In: Proceedings Seminar on Land Use in Relation to Water Quantity and Quality, Nelson 1979, pp. 61–90. Nelson Catchment Board.

Dymond JR, Hicks DL. 1986. Steepland erosion measured from historical aerial photographs. *American Journal of Soil and Water Conservation* 41: 252–5.

Dymond JR, Ausseil A-G, Shepherd JD, Buettner L. 2006. Validation of a region-wide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand. *Geomorphology* 74: 70–9.

Ensis, NZIER. 2006a. *Understanding and Evaluating the Ecosystem Services of Planted and Regenerating Forests.* Contract Report POL 129 by Ensis and New Zealand Institute of Economic Research to Ministry of Agriculture and Forestry, Wellington.

Ensis, NZIER. 2006b. *Evaluating the Ecosystem Services of Planted and Regenerating Forests in Selected Regions.* Contract Report POL 129 by Ensis and New Zealand Institute of Economic Research to Ministry of Agriculture and Forestry, Wellington.

Environment Waikato. 2001. *Project Watershed.* See http://www.ew.govt.nz/regionalservices/rivercatchment/waikato/index.htm.

Ericksen NJ. 1986. Creating Flood Disasters? New Zealand's need for a new approach to Urban Flood Hazard. *Water & Soil Miscellaneous Publication 77.* Ministry of Works for National Water and Soil Conservation Authority, Wellington.

Eyles GO. 1983. The distribution and severity of present soil erosion in New Zealand. *New Zealand Geographer* 39: 12–28.

Eyles RJ. 1971. Mass movement in Tangoio soil conservation reserve, Hawkes Bay. *Earth Science Journal* 5: 79–91.

Eyles RJ, Eyles GO. 1982. *Recognition of Storm Damage Events.* In: Proceedings of the 11th NZ Geography Conference, Wellington, pp. 118–23.

Eyles RJ, Crozier MJ, Wheeler RH. 1978. Landslips in Wellington City. *New Zealand Geographer* 34: 58–74.

Fahey BD. 1998 personal communication. Sediment yields from Glendhu Forest catchments (from unpublished project reports, FRI).

Fahey BD. 1999 unpublished. *Pre-harvest sediment yields: a comparison between pasture and forest.* Environmental Working Group Meeting Notes, LIRO.

Fahey BD, Jackson RJ. 1997a. Hydrological impacts of converting native forests and grasslands to pine plantations, South Island, New Zealand. *Agriculture and Forestry Meteorology* 84: 69–82 (cited by Fahey et al, 2004).

Fahey BD, Jackson RJ. 1997b. Environmental effects of forestry at Big Bush Forest. *New Zealand Journal of Hydrology* 36: 43–71.

Fahey BD, Rowe LK. 1992. *Land Use Impacts*. Chapter 15 in: Mosley MP (ed) *Waters of New Zealand*. New Zealand Hydrological Society.

Fahey BD, Marden M, Phillips CJ. 2003. Sediment yields from plantation forestry and pastoral farming, coastal Hawkes Bay. *New Zealand Journal of Hydrology* 42: 27–38.

Fahey BD, Duncan M, Quinn J. 2004. *Impacts of forestry*. In: Harding J, Mosley P, Pearson C, Sorrell B (eds) *Freshwaters of New Zealand*, pp. 33.1–33.16. NZ Hydrological Society and NZ Limnological Society.

Fransen P. 1996. *A Model of Slip Erosion Risk, Central Hawkes Bay Coastal Hill Country*. Project Report 59, LIRO.

Fransen P, Brownlie R. 1996. Historical slip erosion in catchments under pasture and radiata pine forest, Hawkes Bay hill country. *New Zealand Forestry*: 29–33.

Glade T. 1996. The temporal and spatial occurrence of landslide-triggering rainstorms in New Zealand. *Heidelberger Geographische Arbeiten* 104: 237–51.

Glade T, Crozier MJ. 1996. Towards a national landslide information base for New Zealand. *New Zealand Geographer* 52: 29–40.

Gomez B, Eden D, Peacock D, Pinkney E. 1998. Floodplain construction by recent rapid vertical accretion, Waipaoa River, New Zealand. *Earth Surface Processes and Landforms* 23: 405–13.

Gomez B, Eden D, Hicks DM, Trustrum N, Peacock D, Wilmshurst J. 1999. Contribution of floodplain sequestration to the sediment budget of the Waipaoa River, New Zealand. In: Marroitt S, Alexander J (eds) *Floodplains: Interdisciplinary approaches*, pp. 69–88. Special Publication 163, Geological Society of London.

Grant PJ. 1982. Coarse sediment yields from the upper Waipawa river basin, Ruahine Range. *New Zealand Journal of Hydrology* 21: 81–97.

Griffiths G. 1981. Some suspended sediment yields from South Island catchments, New Zealand. *Water Resources Bulletin* 17: 662–71.

Griffiths G. 1982. Spatial and temporal variability in suspended sediment yields of North Island basins, New Zealand. *Water Resources Bulletin* 18: 575–83.

Griffiths G, Hicks DM. 1980. Transport of sediment in mountain streams: performance of a measurement system. *New Zealand Journal of Hydrology* 19: 131–6.

Gunn I, et al. 2004 unpublished. *Lower Ruamahanga Flood Protection Scheme Review.* Greater Wellington Regional Council report.

Harmsworth G, Hope G, Page M, Manson P. 1987. *An Assessment of Storm Damage at Otoi in Hawkes Bay*. Publication 10, Soil Conservation Centre, MWD.

Harmsworth G, Page MJ. 1991. *A Review of Selected Storm Damage Assessments in New Zealand.* Scientific Report 9, DSIR Land Resources.

Harvey MJ. 1976 unpublished. *Site Tolerance in Urban Subdivision*. Paper presented to New Zealand Association for Soil Conservation Conference, Palmerston North.

Hawley JG. 1984. *Slope instability in New Zealand*. In: Spedin IG, Crozier MJ (eds) Natural Hazards in New Zealand, pp. 88–103. UNESCO, Wellington.

Hawley JG, Dymond JG. 1989. How much do trees reduce landsliding? *Journal of the American Society for Soil and Water Conservation* 43: 495–8.

Hayward J. 1980. *Hydrology and Stream Sediments in a Mountain Catchment.* Special Publication 17, Tussock Grasslands and Mountain Lands Institute.

He H, Woods RW. 2001 unpublished. *Assessment of the Impact of Forestry Plantation on Low Flows in the Shag River Catchment using the Topnet Model*. NIWA contract report to Otago Regional Council (cited by Fahey et al, 2004).

Herald J. 1978 unpublished. *The Influence of Afforestation in Radiata Pine on the Runoff of a Small Catchment in the Hunua Ranges, Auckland*. Paper presented to New Zealand Hydrological Society Symposium, Auckland.

Hicks DL. 1989a. *Storm Damage to Bush, Pasture and Forest.* Technical Record PN2, DSIR Land Resources.

Hicks DL. 1989b. *Farm Conservation Measures' Effect on Hill Country Erosion*. Technical Record PN3, DSIR Land Resources.

Hicks DL. 1990. *Landslide Damage to Pasture, Pine Plantations, Scrub and Bush in Taranaki.* Technical Record 31, DSIR Land Resources.

Hicks DL. 1991a unpublished. *Effect of Soil Conservation Tree Plantings on Damage Sustained by the Whareama Catchment during the Storm of 8–11 April 1991.* Contract report to Wellington Regional Council, DSIR Land Resources.

Hicks DL. 1991b. Erosion under pasture, pines, scrub and indigenous forest. *New Zealand Forestry* 26: 21–2.

Hicks DL. 1992. Impact of soil conservation on storm-damaged hill country grazing lands in New Zealand. *Australian Journal for Soil and Water Conservation* 5: 34–40.

Hicks DL. 1994 unpublished. *Sustainability of Pastoral Farming in the Hill Country; and Options for Sustainable Land Management.* Contract Report, Wellington Regional Council.

Hicks DL. 1995. Control of soil erosion on farmland. *MAF Policy Technical Paper* 95/4.

Hicks DL. 1998 unpublished. *A Method for Monitoring State of the Hill Country Environment*. Contract report to Manawatu-Wanganui Regional Council.

Hicks DL. 1998 personal communication. Percentage area affected by landslides in mature pine forest at Mahurangi (from unpublished contract report to Carter Holt Harvey).

Hicks DL. 2000a unpublished. *Soil Erosion in Auckland's Hill Country*. Contract report to Auckland Regional Council.

Hicks DL. 2000b unpublished. *Sediment Generation and Discharge in Plantation Forests: A collation and review of the New Zealand evidence*. Contract Report to Carter Holt Harvey Ltd.

Hicks DL. 2000c unpublished. *Notes on Land Use in the Ohura Catchment, December 2000*. Contract report to Manawatu-Wanganui Regional Council.

Hicks DL. 2003 unpublished. *Soil Intactness and Disturbance in the Waikato*. Contract report to Environment Waikato.

Hicks DL. 2005a unpublished. *Soil Conservation Survey of the Mangarama Catchment.* Contract report to Environment Waikato.

Hicks DL. 2005b unpublished. *Soil Conservation Survey of the Matahuru Catchment.* Contract report to Environment Waikato.

Hicks DL. 2005c unpublished. *Soil Conservation Survey of the Pokaiwhenua Catchment.* Contract report to Environment Waikato.

Hicks DL. 2005d unpublished. *Soil Intactness and Disturbance in the Bay of Plenty.* Contract report to Environment Bay of Plenty.

Hicks DL. 2006a unpublished. *Erosion and Soil Conservation Status of Waikato West Coast Catchments*. Contract report to Environment Waikato.

Hicks DL. 2006b unpublished. *Condition of Disturbed Surfaces in the Tararu Catchment, 2003.* Contract report to Environment Waikato.

Hicks DL, Crippen TC. 2004 unpublished. *Erosion of Manawatu-Wanganui Hill Country during the Storm of 15–16 February 2004.* Contract report to Manawatu-Wanganui Regional Council.

Hicks DL, Fletcher JR, Eyles GO, McPail CR, Watson, M. 1993. *Erosion of Hill Country in the Manawatu–Wanganui Region 1992: Impacts and options for sustainable land use.* Contract report LC9394/51 to Federated Farmers and Manawatu–Wanganui Regional Council, Landcare Research.

Hicks DM. 1990 unpublished. *Suspended Sediment Yields from Pasture and Exotic Forest Basins.* Paper presented to New Zealand Hydrological Society Symposium, Taupo.

Hicks DM. 1994. *Storm Sediment Yields from Basins with Various Land Uses in the Auckland Area.* Technical Publication 51, Auckland Regional Council.

Hicks DM, Shankar U. 2003. *Sediment from New Zealand Rivers.* Miscellaneous Series Chart 79, NIWA.

Hicks DM, Hill J, Shankar U. 1996. *Variation of Suspended Sediment Yields around New Zealand: The relative importance of rainfall and geology.* In: Proceedings of a Symposium on Erosion and Sediment Yield, Exeter, pp. 149–56. IAHS Publication 236.

Hicks DM, Gomez B, Trustrum NA. 2000. Erosion thresholds and suspended sediment yields, Waipaoa River basin, New Zealand. *Water Resources Research* 36: 1129–42.

Hicks DM, Quinn J, Trustrum N. 2004. *Stream Sediment Load and Organic Matter*. In: Harding J, Mosley P, Pearson C, Sorrell B. Freshwaters of New Zealand, pp. 12.1–12.16. NZ Hydrological Society and NZ Limnological Society.

Hill R, Blair I. 2005. *Middle Waikato Pilot Project: A review of soil conservation research and catchment environmental monitoring*. Environment Waikato Technical Report 2005/16.

Jackson RJ. 1973. Catchment hydrology and some of its problems. In: Proceedings Soil and Plant Water Symposium, Palmerston North, pp. 73–80. *DSIR Information Series 16.*

Jackson R. 1998 personal communication. Sediment Yields from Ashley Forest Catchments (from unpublished project reports, FRI).

Jessen MJ. 1989. *Urban land use capability survey of the Aokautere area, Palmerston North.* Contract report to Palmerston North City Council by DSIR Land Resources.

Kasai M, Brierley GJ, Page M, Marutani T, Trustrum NA. 2005. *Impacts of land use change on patterns of sediment flux in Weraamia catchment, New Zealand. Catena* 64: 27–60.

Krausse MK, Eastwood C, Alexander RR. 2001. *Muddied Waters: Estimating the economic cost of soil erosion and sedimentation in New Zealand.* Landcare Research New Zealand, Palmerston North.

Leslie DM. 1973. *Map of quaternary deposits and surfaces, Otago Peninsula.* Soil Survey Report 3, DSIR Soil Bureau.

Liebault F, Gomez B, Page M, Marden M, Peacock D, Rochard D, Trotter C. 2005. Land-use change, sediment production and channel response in upland regions. *River Research and Applications* 21: 739–56.

Lowe A. 1998 personal communication. Sediment yields from Tairua and Riverhead forest catchments (from unpublished project reports, FRI).

MacCaskill L. 1974. *Hold this Land: A history of soil conservation in New Zealand.* Whitcombe and Tombs.

McGlone MS. 1989. The Polynesian settlement of New Zealand in relation to environmental and biotic changes. *New Zealand Journal of Ecology* (Suppl)12: 115–219.

Maclaren P. 1996. *Environmental Effects of Planted Forests in New Zealand*. Bulletin 198, Forest Research Institute.

McKelvey P. 1995. *Steepland Forests: A historical perspective of protection forestry in New Zealand.* Canterbury University Press, Christchurch.

Marden M, Phillips C, Rowan D. 1991. *Declining Soil Loss with Increasing Age of Plantation Forests in the Uawa Catchment, East Coast Region.* In: Proceedings of the International Conference on Sustainable Land Management, Napier, pp. 358–61. Hawkes Bay Regional Council.

Marden M, Rowan L. 1993. Protective value of vegetation on tertiary terrain before and during Cyclone Bola, East Coast. *New Zealand Journal of Forestry Science* 23: 255–63.

McConchie JA. 1980. Implication of landslide activity for urban drainage. *New Zealand Journal of Hydrology* 19: 27–34.

McElwee H. 1998 unpublished. *The Economic, Environmental and Social Impacts of Afforestation of Hill Country Farmland in the East Coast*. M Mgmt Studies thesis, University of Waikato, Hamilton.

McKerchar AI. 1980. *Hydrological characteristics of land use catchments in the Nelson area.* In: Proceedings of a Seminar on Land Use in Relation to Water Quantity and Quality, Nelson 1979, pp. 122–36. Nelson Catchment Board.

Minister of Conservation. 2007. *Major climate change initiative on conservation land.* Press release, 4 July 2007, Office of the Minister of Conservation.

Morton M. 2006 unpublished. *Ecosystem Services: Making markets work.* Working paper, Environment and Natural Resources Section, New Zealand Treasury, Wellington.

Mulholland M. 2006. *The effect of land use change on the flood hydrology of pumice catchments.* Technical report 2006/35, Environment Waikato.

Newsome PF. 1987. The vegetative cover of New Zealand. *Water & Soil Miscellaneous Publication No. 112*. Ministry of Works and Development, Palmerston North.

Northland Regional Council. 2007a unpublished. *Staff reports for resource consent applications for the Awanui River Flood Management Plan.*

Northland Regional Council. 2007b unpublished. *Staff report on Kaeo flood risk reduction remedial works.*

O'Loughlin CF. 1980. *Water Quality and Sediment Yield Consequences of Forest Practices in North Westland and Nelson*. In: Proceedings of a Seminar on Land Use in Relation to Water Quantity and Quality, Nelson 1979, pp. 152–171. Nelson Catchment Board.

O'Loughlin C. 1981. Methods for assessing slope erosion and non–channel sediment sources in upland regions. *New Zealand Journal of Hydrology* 20: 80–89.

O'Loughlin CO, Owens IF. 1987. *Our dynamic environment.* In: Holland PG, Johnston WB (eds) *Southern Approaches*, pp. 59–90. New Zealand Geographical Society.

O'Loughlin CL, Pearce AJ. 1982. *Exceptional Storm Influences on Slope Erosion and Sediment Yield in Small Forest Catchments, North Westland, New Zealand.* In: Proceedings of the First National Symposium on Forest Hydrology, Melbourne, pp. 84–91.

O'Loughlin CF, Rowe LK, Pearce AJ. 1978. Sediment yields from small forested catchments, North Westland. *New Zealand Journal of Hydrology* 17: 1–15.

O'Loughlin CL, Rowe LK, Pearce AJ. 1984. Hydrology of mid-altitude tussock grasslands, upper Waipori catchment: I. *New Zealand Journal of Hydrology* 23: 45–59.

Omura H. 1983. Fundamental studies on forecasting of landslide area caused by heavy rainfall. *Shizuoka University Forestry Bulletin* 7: 1–38.

Omura H. 1984. *Resistance Index Map to Forecast Quick Shallow Landslide in Japan*. In: Proceedings of the Interpraevent Symposium, Villach, pp. 159–66.

Omura H, Hicks D. 1992. *Probability of Landslides in Hill Country*. In: Bell D (ed) Landslides: Proceedings of the 6th International Landslide Symposium, Christchurch, pp. 1045–9.

Owen RC. 1981. Soil strength and microclimate in the distribution of shallow landslides. *New Zealand Journal of Hydrology* 20: 17–26.

Page MJ. In preparation. Studies on rainfall-induced landsliding arranged by landscape terrain. GNS Science report.

Page MJ, Trustrum NA. 1997. A late Holocene lake sediment record of the erosion response to land use change in a steepland catchment, New Zealand.. *Zeitschrift für Geomorphologie, Neue Folge* 41: 369–92.

Page MJ, Trustrum NA, Dymond JR. 1994. Sediment budget to assess the geomorphic effect of a cyclonic storm, New Zealand. *Geomorphology* 9: 169–88.

Page MJ, Reid LM, Lynn IH. 1999. Sediment production from Cyclone Bola landslides, Waipaoa catchment. *New Zealand Journal of Hydrology* 38: 289–308.

Page MJ, Trustrum NA, Gomez B. 2000. Implications of a century of anthropogenic erosion for future land use in the Gisborne-East Coast region of New Zealand. *New Zealand Geographer* 56: 13–24.

Page MJ, Trustrum N, Brackley H, Baisden T. 2004. Erosion-related soil carbon fluxes in a pastoral steepland catchment, New Zealand. *Agriculture, Ecosystems and Environment* 103: 561–579.

Pain CF. 1969. The effect of some environmental factors on rapid mass movement in the Hunua Range, New Zealand. *Earth Science Journal* 3: 101–7.

Pain CF. 1971. Rapid mass movement under forest and grass in the Hunua Ranges, New Zealand. *Australian Geographical Studies* 9: 77–84.

Pain CF, Stephens PR. 1990. Storm damage assessment using digitised aerial photographs. *New Zealand Geographer* 46: 21–5.

Patterson M, Cole A. 1999. *Assessing the Value of New Zealand's Biodiversity.* Occasional Paper No. 1, School of Resource and Environmental Planning, Massey University, Palmerston North.

Pawsey E, Brooking T (eds). 2002. *Environmental Histories of New Zealand.* Oxford University Press, Melbourne.

Peacock D, Turner W, Marden, M. 2000. *Waipaoa Flood Protection Scheme Review.* Gisborne District Council.

Pearce AJ. 1980. *Water Yield Consequences of Vegetation Changes*. In: Proceedings of a Seminar on Land Use in Relation to Water Quantity and Quality, Nelson 1979, pp 172–99. Nelson Catchment Board.

Pearce AJ, Rowe LK, O'Loughlin CL. 1984. Hydrology of mid-altitude tussock grasslands, upper Waipori catchment: II – water balance, flow duration and storm runoff. *New Zealand Journal of Hydrology* 23: 60–72.

Pearce AJ, O'Loughlin CL, Jackson RJ, Zhang XB. 1987. *Reforestation: on-site effects on hydrology and erosion, eastern Raukumara Range, New Zealand.* In: Proceedings Symposium on Forest Hydrology and Watershed Management, pp. 489–97. IAHS Publication.

Petch A. 1981 unpublished. PhD thesis, University of Waikato.

Phillips C. 1988. Geomorphic effects of two storms on the upper Waitahaia river catchment, Raukumara Peninsula. *New Zealand Journal of Hydrology* 27: 99–112.

Phillips C, Marden M, Pearce AJ. 1990. *Effectiveness of reafforestation in prevention and control of landsliding during large cyclonic storms*. In: Proceedings of the 19th IUFRO Conference, Montreal, pp 340–9. IUFRO.

Phillips C, Marden M, Miller D. 2000. *Review of Plant Performance for Erosion Control in the East Coast Region*. Landcare Research Contract report for MAF Policy.

Poole AL. 1981. *Catchment Control in New Zealand.* Miscellaneous Publication, National Water and Soil Conservation Authority.

Quinn J, Collier K. 1997. *Stream ecosystem protection in New Zealand hill land farming.* Proceedings of the International Conference on Nature Conservation in Production Environments, Taupo. SEMS, University of Auckland.

Quinn J, Cooper AB. 1997. Land-water interactions at Whatawhata, New Zealand: introduction and synthesis. *New Zealand Journal of Marine and Freshwater Research* 31: 569–77.

Quinn J, Stroud M. 2002. Water quality and sediment and nutrient export from New Zealand hill land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research* 36: 409–29.

Quinn J, Cooper AB, Williamson RB. 1993. Riparian zones as buffer strips: a New Zealand perspective. In: Bunn SE (ed) *Ecology and Management of Riparian Zones in Australia*, pp. 53–87. Griffith University.

Reid L, Page M. 2002. Magnitude and frequency of landsliding in a large New Zealand catchment. *Geomorphology* 49: 71–88.

Rennes L. 1978 unpublished. *Field and Laboratory Studies of the Movement and Reactions of Phosphorus in Soils.* PhD thesis, Massey University (cited in Cooke JG, 1979, An overview of the effects of rural land use on water quality in New Zealand, Internal Report HSC 79/32, Water and Soil Division, Ministry of Works and Development).

Riddell JM. 1980. *The Effects of Land Use Changes on the Water Yield of the Collins Catchment, Nelson*. Internal Report WS 197, Hydrology Centre, Water and Soil Division, Ministry of Works and Development.

Ritchie H. 2000. *Good Farm Management? A review of hill country resource management issues in the Waikato region.* Environment Waikato Technical Report 2000/15.

Robinson A. 1981. *Summary of Land Development's Effects on Runoff and Erosion*. Internal report, Water and Soil Field Party, Nelson District Office, Ministry of Works and Development.

Rogers NW. 1978. *The Nature and Causes of Shallow Translational Landslides in the Hapuakohe Range*. MSc thesis, University of Waikato.

Roche MR. 1994. *Land and Water: Water and Soil Conservation and Central Government in New Zealand 1941–1988.* Historical Branch, Department of Internal Affairs, Wellington.

Rowe LK, Pearce AJ. 1994. Hydrology and related changes after harvesting native forest catchments and establishing Pinus radiata plantations. *Hydrological Processes* 8: 281–97 (cited by Fahey et al, 2004).

Rowe LK, Jackson R, Fahey B. 2003. *Land Use and Water Resources: Hydrological effects of different vegetation covers*. Contract report to Ministry for Environment, Landcare Research.

Russ LM. 1984. *Photo-interpretation of the Te Manawa O Tuhoe Storm Damage Area.* Internal report, Soil Conservation Centre, MWD, Aokautere.

Salter R, Crippen T, Noble K. 1983. *Storm Damage Assessment of the Thames–Te Aroha Area Following the Storm of April 1981*. Publication 1, Soil Conservation Centre, Ministry of Works and Development.

Scarf F. 1969. *Some Runoff Results from Moutere Soil Conservation Station*. Water and Soil Division, Ministry of Works and Development (cited in Wilkie D, 1973, Moutere Soil Conservation Station Water and Soil Division, MWD).

Scarf F. 1970 . Hydrological effects of cultural changes at Moutere experimental basin. *New Zealand Journal of Hydrology* 9: 142–62.

Scott DT, Baisden T, Davies-Colley R, Gomez B, Hicks DM, Page M, Trustrum N, Tate K, Woods R. 2006. Localized erosion affects national carbon budget. *Geophysical Research Letters* 33: L01402.

Schouten CJ. 1976. *Origin and Output of Suspended and Dissolved Material from a Catchment in Northland, New Zealand, with Particular Reference to Man-induced Changes*. Publication 23, Physical Geography and Soil Science Laboratory, University of Amsterdam.

Schouten CJ, Terzaghi W, Gordon Y. 1981. *Summaries of Water Quality and Mass Transport for Lake Taupo Catchment*. Miscellaneous Publication 24, Water and Soil Division, Ministry of Works and Development.

Selby MJ. 1967. Erosion by high–intensity rains in the lower Waikato. *Earth Science Journal* 1: 153–6.

Selby MJ. 1972. Relationships between land use and erosion in the central North Island. *New Zealand Journal of Hydrology* 11: 73–87.

Selby MJ. 1976. Slope erosion due to extreme rainfall: a case study from New Zealand. *Geografiska Annaler* 58a: 131–8.

Selby MJ. 1979. Slope stability studies in New Zealand. In: Murray DL, Ackroyd P (eds) *Physical Hydrology: New Zealand experience*, pp. 120–34. NZ Hydrological Society.

Selbey MJ, Hosking PJ. 1973. The erodibility of pumice soils of the North Island. *New Zealand Journal of Hydrology* 12: 32–56.

Smith PJ. 1987. Variation of water yield from catchments under grass and exotic forest, east Otago. *New Zealand Journal of Hydrology* 26: 175–84.

Stephens PR, Trotter CM. 1989. Landslides spotted by SPOT. NWASCA *Streamland* 75.

Stephens PR, Trustrum NA, Hicks DL. 1981. *Experimental survey of catchment condition, Gladstone district, Wairarapa.* Internal Report 25, Soil Conservation Centre, Ministry of Works and Development.

Swales A, Hume T. 1998 personal communication. Bare ground percentages before and after logging (from unpublished NIWA contract report to Carter Holt Harvey).

Tate KR, Scott N, Parshotam A, Brown L, Wilde R, Giltrap D, Trustrum N, Bomez B, Ross D. 2000. A multi-scale analysis of a terrestrial carbon budget: Is New Zealand a source or sink of carbon? *Agriculture, Ecosystems & Environment* 82: 229-246.

Thompson SM, Adams J. 1979. Suspended load in some major rivers of New Zealand. In: Murray D, Ackroyd P (eds) *Physical Hydrology: New Zealand experience*, pp 213–28. NZ Hydrological Society.

Thompson RC, Luckman PG. 1993. Performance of biological erosion control in New Zealand soft rock hill country. *Agroforestry Systems* 21: 191–211.

Trafford L. 2004. *Storm: Civil emergency – storm and flood report*, 181–216. Horizons Regional Council, Palmerston North.

Trustrum NA, Dymond J, DeRose RC, Blaschke PM. 1990 unpublished. *Bare Ground Percentages from Aerial Photographs of Hill Country after Cyclone Hilda.* Contract report to Taranaki Regional Council, DSIR Land Resources.

Trustrum NA, Gomez B, Page MJ, Reid LM, Hicks DM. 1999. Sediment production, storage and output: the relative role of large magnitude events in steepland catchments. *Zeitschrift für Geomorphologie, Supplementband* 115: 71–86.

Van Roon M. 1983a unpublished. *Calculation of Mass Transport by Streams, and Yields under a Variety of Land Uses*. Working report, Auckland Regional Authority.

Van Roon M. 1983b. *Water Quality in the Upper Waitemata Harbour and Catchment.* Technical report, Auckland Regional Authority.

Vaughan L. 1984. *Logging and the Environment: A review of research findings and management practices*. LIRO Report, 75 p.

Wallis G, McMahon S. 1995. *The Impacts of Forest Management on Erosion and Sedimentation: A New Zealand review*. LIRO Report, 15 p.

Waugh JR. 1980. *Hydrological Effects of the Establishment of Forests.* In: Proceedings of a Seminar on Land Use in relation to Water Quantity and Quality, Nelson 1979, pp. 218–49. Nelson Catchment Board.

Weber JA, Lynch RJ, Meister AD. 1992. *Benefits and Costs of Soil Conservation in the Bay of Plenty Region.* Department of Agricultural Economics and Business, Massey University, Palmerston North.

Woods RA, Duncan MJ. 1999 unpublished. *Modelling the Cumulative Effects of Patchy Intermittent Land Use Change on Water Yield and Low Flow at Many Locations in a River Basin.* Paper presented to New Zealand Hydrological Society Symposium, Napier (results cited in Fahey et al, 2004).

9 Acknowledgements

We acknowledge with thanks many people who assisted with the preparation of this review. First and foremost Chris Livesey, Ministry for the Environment, who initiated the project and provided helpful and cheerful advice throughout. We also received helpful logistical assistance from Lisa Johnston, Sarah Davies and Mike Barton (Information Centre) from the Ministry for the Environment. Finally we would like to thank the following for very useful advice, information and review comments: Peter Stephens, Stephen Swabey and Trecia Smith (Ministry for the Environment), Avinash Shrivastava and Peter Lough (Ministry of Agriculture and Forestry), Joseph Arand (Department of Conservation), John Dymond, Richard Gibb and Kevin Tate (Landcare Research), Mike Page and Noel Trustrum (GNS Science), Peter Clough (NZIER), Bruce Peploe (Environment Waikato), Bob Cathcart and Nigel Mark-Brown (Northland Regional Council) and Andrew Burton (Tasman District Council).