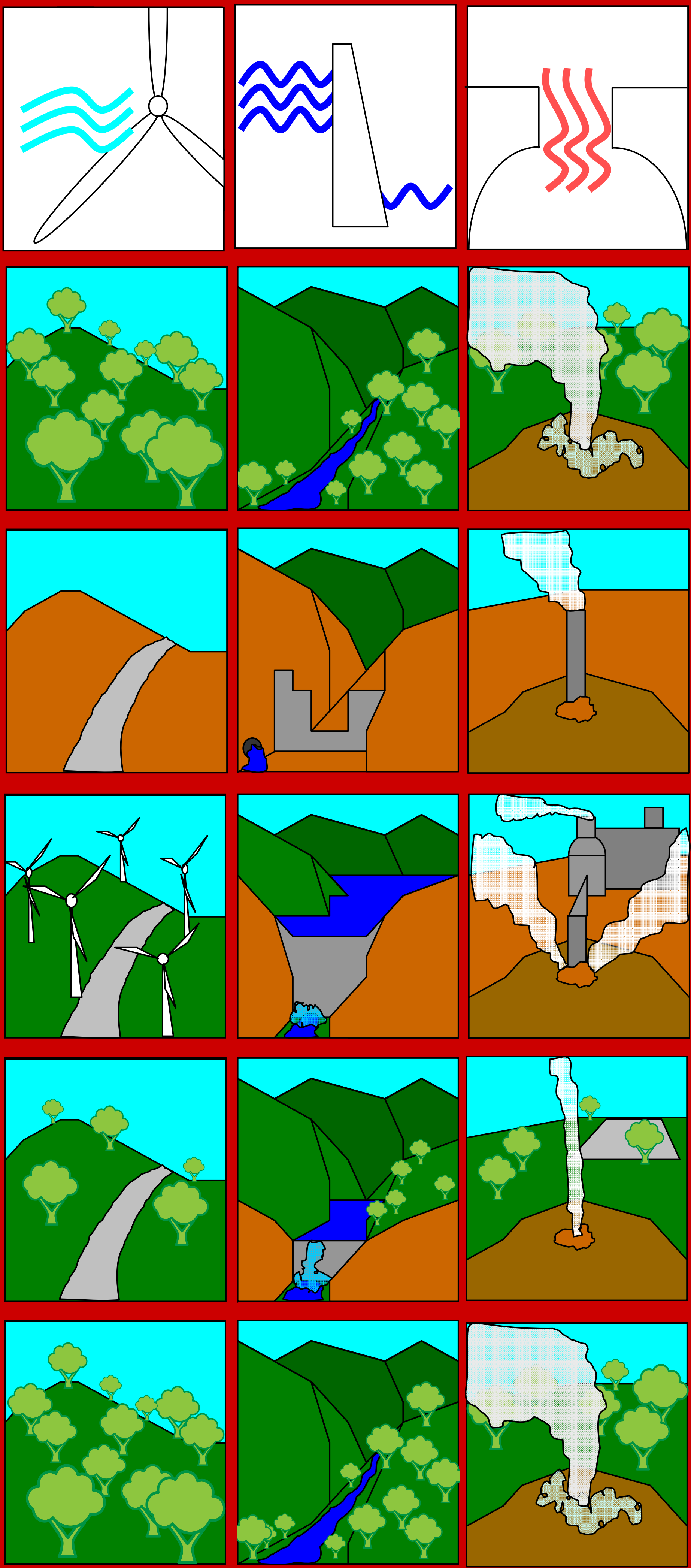


Reversibility of Renewable Energy Developments

SPX Consultants
Sustainable Infrastructure

October 2008

Reversibility of Renewable Energy Developments

Prepared by

SPX Consultants
11A Polygon Rd
PO Box 25953
St Heliers
AUCKLAND

T - +64 9 575 5758 www.spx.co.nz

October 2008

Quality Information

Prepared By: Kevin Oldham

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
0	28 October 2008	First Edition	Kevin Oldham	

Table of Contents

1.0 Introduction **1**
1.1 Purpose 1
1.2 Copyright and Limitations 1
1.3 About the Author 1
2.0 Background **2**
2.1 Resource Management Act 2
2.2 NZ Government Policy on Renewable Energy 3
2.2.1 National Policy Statement 3
2.2.2 NPS Policy 3 - Reversibility of Adverse Effects 4
2.2.3 Section 32 Analysis - Reversibility of Adverse Effects 4
2.3 Definitions 4
2.3.1 Reversible 4
2.3.2 Permanent or Irreversible? 4
2.3.3 Functionally Irreversible 5
2.4 Is Some Infrastructure Functionally Irreversible? 5
2.5 Could NZ Hydro Schemes Be Functionally Irreversible? 6
2.6 Are There Degrees of Reversibility? 7
2.7 Renewable Energy Technologies Assessed in this Report 8
3.0 Methodology **9**
3.1 Introduction 9
3.2 Case Studies 9
3.3 Timeframes 9
3.3.1 Reversibility End Points 9
3.3.2 Restoration Treatments 9
3.4 Costs of Removal and Restoration 10
4.0 Hydro-electric Removal Case Histories **12**
4.1 Types of Hydro-electric Schemes 12
4.2 Operational Modes of Hydro Schemes 13
4.3 How Permanent are Dams? 13
4.4 Adverse Effects of Dams 15
4.5 US Case Studies in Hydro-electric Dam Removal 17
4.6 Lessons from Dam Removal Case Histories 19
4.7 Sediment Management 20
4.8 Summary and Conclusion 22
5.0 Reversibility of Hydro-electric Developments **24**
5.1 Timescale and Significance 24
5.2 Historical Costs of Removing Hydro Projects 25
5.3 Estimated Costs of Removing Hydro Developments 27
5.4 End of Life Scenarios 28
5.5 Summary of Hydro Reversibility 28
6.0 Reversibility of Geothermal Developments **29**
6.1 Timescale and Significance 29
6.2 Subsidence 30
6.3 Cultural Issues 31
6.4 Protection of Geothermal Features 32
6.5 Costs of Removing Geothermal Developments 32
6.6 End of Life Scenarios 33
6.7 Geothermal Summary 33
7.0 Reversibility of Wind Energy Developments **34**
7.1 Timescale and Significance 34
7.2 Estimated Costs of Removing Wind Farms 34
7.3 End of Life Scenarios 35
7.4 Summary of Wind Farm Reversibility 35
8.0 Risks and Bonds **36**
8.1 Risks 36
8.2 Bonds 37
9.0 Summary and Conclusions **38**
9.1 Findings 38
9.2 Wording of NPS 39

Table of Appendices

A – Proposed National Policy Statement on Renewable Electricity Generation

B – Restoration Treatments

C- Cost Estimates

D - Risk Matrix

Executive Summary

Purpose

The purpose of this report is to comment on reversibility of adverse effects of renewable generation technologies in relation to the proposed National Policy Statement (NPS) for Renewable Energy Generation, issued for comment by the New Zealand Ministry for the Environment in August 2008.

This is a private initiative of SPX Consultants Limited and has not been commissioned or funded by any external party.

Findings

The findings of this investigation and report are summarised in the tables below.

Summary of Findings

	Proposition	Finding
1	Hydro electric dams are permanent.	Hydro schemes are usually designed for a 100 year life and can last significantly longer. Storage hydro schemes have a life cycle which is governed by the rate at which sediment from the upstream catchment fills the reservoir.
2	Hydro-electric projects are functionally irreversible.	In New Zealand no dam or hydro–electric scheme is expected to be functionally irreversible, given the application of enough effort and time.
3	The adverse effects of hydro-electric generation are permanent or functionally irreversible.	Most adverse effects of hydro-electric projects are reversed within a few years of removing the structures. Sedimentation effects may last longer but generally are at their peak within a few years of dam removal and decline thereafter.
4	Removal and restoration of storage hydro-electric projects is an unreasonable burden for future generations.	Storage hydro schemes can be expensive to remove and restore; but this should not present a fundamental barrier. Where intergenerational equity issues are a concern, a bond can be required under s.108A of the Resource Management Act.
5	Renewable technologies have different degrees of reversibility.	Hydro-electricity, geothermal and onshore wind technologies have the same degree of reversibility: they are all completely reversible.
6	The adverse effects of geothermal power development are reversible.	Geothermal power production leads to permanent subsidence of land. This is not generally an environmental issue; but there is a need to address the risk of damage to infrastructure during the life of the project, and for a period of aftercare. Because these adverse effects can be made good it is considered that the adverse effects of geothermal power developments are reversible, even though subsidence is permanent.

In summary this report has found that, with the exception of some geothermal effects, all of the renewable technologies have the same degree of reversibility of adverse effects. Where the technologies differ is with respect to the ease of reversing adverse effects as summarised in the table below:

Summary – Ease of Reversing Adverse Effects of Renewable Electricity Technologies

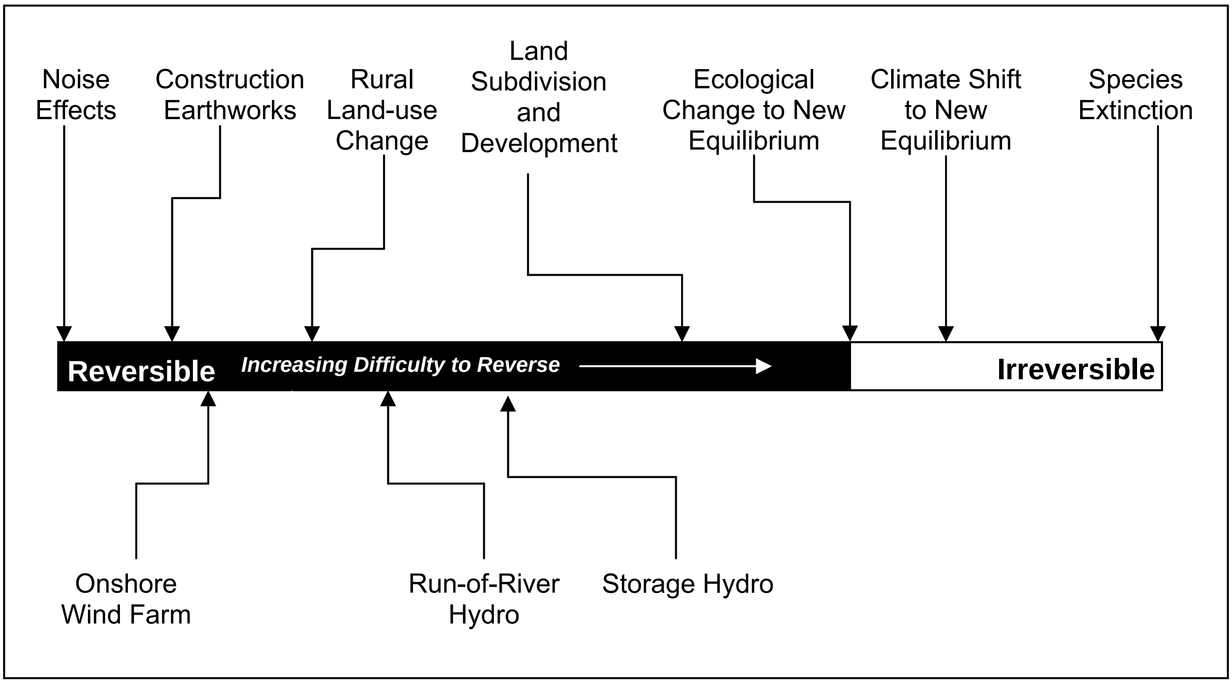
	Timeframe for Reversal of Significant Effects	Environmental Risk Following Removal	Typical Decommissioning and Restoration Costs as Proportion of Construction Cost (Note 1)
Onshore Wind Farm	Short	Low	4 - 8%
Geothermal	Short for local effects (Refer Note 2)	Low	10 - 20%
Run of River Hydro	Short to Moderate	Low	25 - 50%
Storage Hydro	Moderate	Medium (refer Note 3)	35 - 150%

Notes:

1. This table provides an indication of the relative costs of removing and restoring renewable energy projects derived on a comparable basis. Actual project costs should be determined on a case by case basis and, in some cases, may lie outside the ranges given.
2. Timeframe for reversal of geothermal steam-field related effects is moderate to long. Subsidence is not reversible.
3. Assumes that risk treatments will be implemented to manage hydro storage risks to not more than medium rating.

The relative ease of reversing adverse effects of onshore wind and hydro renewable energy technologies is illustrated in the following figure.

Relative Ease of Reversing Wind and Hydropower Renewable Energy Technologies



Wording of NPS

1. If it is accepted that reversibility is a valid concept to apply to renewable energy development approvals, then it is recommended that Policy 3 is reworded as:[1]

   When considering proposals to develop new renewable electricity generation activities, decision-makers must have particular regard to the ~~relative degree~~ <u>ease</u> of reversibility of the adverse environmental effects associated with <u>the</u> proposed generation <u>development</u> ~~technologies~~.

   The reasons for the proposed changes are summarised below.

	Proposed Change to Policy 3	Reason
1	Replace *degree* of reversibility with *ease* of reversibility.	All the current main renewable technologies have the same degree of reversibility, but differ in ease of reversibility.
2	Replace consideration of reversibility of adverse effects at a technology scale, with consideration of reversibility of adverse effects for the specific development.	Adverse effects will not only differ between technologies, but also between sites. While some broad conclusions can be drawn at a technology level, the ease of reversing adverse effects can differ markedly between projects of the same technology (eg hydroelectric schemes). It would be more accurate, and simpler, to consider the reversibility of adverse effects on a site-specific basis for a particular proposal.
3	Remove *relative*.	Removing redundant term improves clarity.

2. If it is intended to avoid collateral damage to geothermal energy developments from Policy 3, then it is recommended that the following definitions are added to the NPS:

   "Reversibility of adverse environmental effects" *in relation to the abstraction, use and disposal of geothermal fluids in geothermal development areas excludes subsidence, effects on geothermal resources and effects on surface geothermal features.*

   "Geothermal development areas" *are geothermal resources that are identified in a Regional Plan as being suitable for geothermal energy development.*

   The reasons for the proposed changes to the NPS definitions are:

	Proposed Change to Definitions in NPS	Reason
1	Define adverse effects in relation to the NPS.	Avoids capture of irreversible effects of geothermal energy developments by Policy 3.
2	Define geothermal development areas.	Limits the breadth of the reversibility-of-adverse- effects definition to only those geothermal resources identified by the regional council concerned as being suitable for development. This will encourage regional councils to classify geothermal resources for protection, and for development; thus clarifying the consenting regime.

[1] Additions <u>underlined</u>, removals marked with ~~strikethrough~~.

1.0 Introduction

1.1 Purpose

The purpose of this report is to contribute to informed discussion about the concept of reversibility, as applied to renewable electricity generation in the proposed *National Policy Statement for Renewable Energy Generation*, issued by the New Zealand Ministry for the Environment in August 2008.

This is a private initiative of SPX Consultants Limited and has not been commissioned or funded by any external party.

1.2 Copyright and Limitations

This report has been prepared by SPX Consultants for public use and may be used, abstracted from or quoted by any party, provided that the source is acknowledged. The report has been prepared solely for the purpose of informing public discussion about the proposed national policy; no liability is accepted for reliance on information contained in this report.

1.3 About the Author

The author of this report is Kevin Oldham. Kevin has a BE (Civil) (First Class Hons.) and ME (Civil) from the University of Canterbury. He is a member of the Institution of Professional Engineers New Zealand (IPENZ), member of the Institute of Directors, and is a co-convenor of the Climate Change Special Interest Group of the Resource Management Law Association (RMLA). Kevin has over 25 years of engineering and environmental experience in New Zealand and overseas, including:

- hydraulic engineering
- feasibility studies, design and construction of hydro-electric power projects
- environmental assessments and regulatory consenting of power projects, transmission lines and other energy developments
- bond assessments and peer review of landfill developments
- business management
- organisational strategic planning

Kevin has worked extensively in the consulting sector in New Zealand and is a director of SPX Consultants Limited, which was established in 2006.

2.0 Background

2.1 Resource Management Act

This section outlines how uncertainty and reversibility have been addressed in international treaties, and in New Zealand environmental law. The influence of uncertainty on the design of environmental policy in general is summarised in the following table.

Table 2.1 How Uncertainty Affects Environmental Policy Design[2]

Uncertain benefits and costs	There is uncertainty about underlying processes, economic impacts of environmental change and about possible technological responses. Costs and benefit functions tend to be nonlinear, and their shapes of the functions are often unknown particularly near the thresholds for change or 'tipping points'. Uncertainty favours 'hybrid' policies mixing multiple instruments.
Irreversibility	Damage is partially or completely irreversible. Irreversibility favours either stringent action now or waiting for more information, with no firm preference. How we predict and value catastrophe is important.
Very long time horizons	Potentially centuries versus typical business horizons of 20 or 25 years. This reduces the ability to predict outcomes and favours using lower discount rates.

The development of international treaties, and environmental law in New Zealand, reflects a growing recognition of these uncertainties. In 1987 the Brundtland report defined sustainability as: "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* Thus, serious and irreversible environmental changes should be avoided so as not to jeopardise human survival or the welfare of future generations.[3]

In 1991 the New Zealand Resource Management Act (RMA) adopted a similar principle in Section 5:

> *(2) In this Act, sustainable management means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while—*
> *Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
> *Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
> *Avoiding, remedying, or mitigating any adverse effects of activities on the environment.*

In 1992 Principle 15 of the Rio Declaration prepared by UNCED went another step:

> *In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall be not used as a reason for postponing cost-effective measures to prevent environmental degradation. (emphasis added).*

The RMA does not explicitly adopt the precautionary approach, but irreversibility arises in relation to a Minister's power to call in applications of national significance:

> *(2) …the Minister may have regard to any relevant factor including whether the proposal-*
> *Results or is likely to result in or contribute to significant or irreversible changes to the environment…* (emphasis added)

[2] Adapted from Guerin (2007). *Adaptive Governance and Evolving Solutions to Natural Resource Conflicts,* NZ Treasury Working Paper 07/03, 2007. The table was originally sourced from Pindyck, R. (2006). *Uncertainty in environmental economics.* NBER, Working Paper No. 12752.

[3] Cowell, R. (1996) Stretching the limits: environmental compensation, habitat creation and sustainable development, in *Transactions of the Institute of British Geographers,* 22, 3: 292-306.

The current New Zealand Coastal Policy Statement addresses irreversibility,[4] as do some regional freshwater policies.[5] The principle is also sometimes referenced by applicants and submitters, in relation to resource consent applications for developments.[6]

From the above, it can be seen that a thread connects irreversibility to intergenerational equity. Due to the threats posed by irreversible habitat loss, extinction and climate change, it can be expected that reversibility will become more important in future resource management decisions.

Section 3 of the RMA imports the related concept of permanency of effects into the definition of effect in Section 3 (emphasis added):

> *(3) Meaning of "effect"*
> *In this Act, unless the context otherwise requires, the term effect … includes—*
> *(a)Any positive or adverse effect; and*
> *(b)Any temporary or <u>permanent</u> effect; and*
> *(c)Any past, present, or future effect; and*
> *(d)Any cumulative effect which arises over time or in combination with other effects—*
> *regardless of the scale, intensity, duration, or frequency of the effect, and also includes—*
> *(e)Any potential effect of high probability; and*
> *(f)Any potential effect of low probability which has a high potential impact*.

Permanent does not have an identical meaning to *irreversible*. This distinction is important and is discussed further in Section 2.3.2.

2.2 NZ Government Policy on Renewable Energy

2.2.1 National Policy Statement

In August 2008, the New Zealand government released, for public comment, a proposed National Policy Statement for Renewable Electricity Generation. The national policy statement (NPS) is a statutory instrument under New Zealand's Resource Management Act 1991. A proposed national policy statement goes through a formal process of public comment to a Board of Inquiry. The Board of Inquiry then recommends to the Minister for the Environment any changes to the proposed NPS. Once a national policy statement is adopted, regional councils and local authorities must amend their planning policies and rules to give effect to the national policy statement. They must also give consideration to the NPS when making decisions on resource consent applications.[7]

Only one NPS was produced in the first decade after the Resource Management Act came into force[8], but there has been a growing realisation that essential national infrastructure has been at risk of delay, or refusal, due to local concerns. In 2007, a government strategy to increase the use of renewable energy was established in the *New Zealand Energy Strategy*

---

[4] Refer Policy 5.3.1 and Schedule 1, DoC (1994), *NZ Coastal Policy Statement*, NZ Department of Conservation. 1994. The concept of irreversibility has been retained in Policy 37 of the proposed NZ Coastal Policy Statement (DoC, 2008).
[5] For example refer Greater Wellington Regional Council, Regional Freshwater Plan. Policy 4.2.11 - Avoid, remedy, or mitigate the adverse effects of the use and development of water bodies by having regard to maintenance of biological and physical processes, habitat, diversity, fish movement and spawning, and prevention of irreversible adverse effects.
[6] For example refer Casey, M. (2008). *Legal Submissions on Behalf of Applicant in Reply. Central Plains Trust Applications and Notice of Requirement in regard to the Central Plains Water Enhancement Scheme.* September 2008. Also refer RFBS (2007) *Submission in opposition to applications by Central Plains Water for land use consents for the construction and use of pipelines, canals and other structures and works for the scheme***.** Royal Forest and Bird Protection Society of New Zealand Inc. (Central Office). January 2007. And Campbell, G. (2007). *Further Statement of Evidence on the Matter of Applications by WEL Networks to Establish 28 Wind Turbines near Te Uku*.
[7] Refer Resource Management Act s.55:Amendment to local authority documents, s.62: Incorporation into Regional Policy Statements, s.67:Regional Plans, s.75 District Plans, s.104: Consideration of resource consent applications, and s168A and s.171: Notices of Requirement
[8] The *New Zealand Coastal Policy Statement* prepared by the Department of Conservation and issued in May 1994. (Currently under review).

to 2050.[9] This strategy has led to central government preparing several NPS to enable electricity infrastructure.[10] The objective of this proposed NPS is to promote the development of renewable energy resources so as to meet the government's target of 90% renewable energy production by 2025. This report focuses on one aspect of the proposed NPS: Policy 3.

2.2.2 NPS Policy 3 - Reversibility of Adverse Effects

The proposed NPS for Renewable Electricity Generation Renewable is presented in Appendix A. Policy 3 requires that:

> *When considering proposals to develop new renewable electricity generation activities, decision-makers must have particular regard to the relative degree of reversibility of the adverse environmental effects associated with proposed generation technologies.*

The core focus of this paper is to explore whether there are degrees of reversibility of the adverse effects of renewable energy technologies. This will be explored in two parts:

- are the renewable energy facilities reversible (ie can they be removed and the land restored)?
- does removing the energy facility reverse the adverse effects?

2.2.3 Section 32 Analysis - Reversibility of Adverse Effects

Section 5.2.3.3 of the Section 32 analysis, which accompanied the release of the proposed NPS, makes the following statement:

> *Focusing decision-makers' attention on the relative reversibility of effects associated with particular generation technologies could prove prejudicial against those technologies with <u>functionally irreversible effects</u>, such as hydro-generation.*[11] (emphasis added)

The Section 32 report is only a statutory report on the NPS, and does not necessarily determine how the NPS should be interpreted. Nevertheless it provides context to the draft policy formulation and makes an important assertion: that hydro-generation has functionally irreversible effects. This assertion is important, as it appears to have influenced formulation of Policy 3. However, firstly it is essential to define the usage of these terms in this context.

2.3 Definitions

2.3.1 Reversible

Reversible means to return to a former state. In theory nothing in the natural world is completely reversible, as the natural state will have changed over the intervening time. However, in this report, a practical definition of reversibility is adopted: an adverse effect is considered to be reversed when a defined *end point* is reached. End points are discussed in Section 3.3.1.

2.3.2 Permanent or Irreversible?

Some authors contend that long lasting or permanent effects should be considered as irreversible.[12] That view is not supported in this report as *permanent and irreversible* do not

[9] *New Zealand Energy Strategy to 2050 – Powering Our Future*, Ministry of Economic Development, October 2007.
[10] The *National Policy Statement on Electricity Transmission* was gazetted on 13 March 2008.
[11] Section 32 analysis uses the words *functionally irreversibly effects* but this is assumed to be a typographic error and has been interpreted as *functionally irreversible effects*.
[12] For example refer Mchaina, D.M., Januszewski, S. & Hallam, R.L. (2000) *Development of an environmental impact and mitigation and assessment program for a tailings storage facility stability upgrade*, in Environmental Issues and Management of Waste in Energy and Mineral Production: Proceedings of the Sixth International Conference on Environmental Issues and Management of Waste in Energy and Mineral Production, Calgary: Taylor & Francis: 473 – 479.

have identical meanings. Irreversible means impossible to change back to the original state. Permanent refers to an expectation that change will not occur, or that something is intended to exist for an indefinite period.[13]

2.3.3 Functionally Irreversible

A way to understand what *functionally irreversible* means is to examine usage of the phrase in other contexts. The phrase is reasonably rare,[14] but in the predominant usage the word "functionally" is redundant: *functionally irreversible* means *irreversible*.[15] [16] [17]

However a more nuanced use of the phrase is contained in a notice concerned with threats to salmonids in the Columbia River estuary, issued in January 2008 in the US Federal Register[18]:

> *Identifying management actions that could reduce threats to salmon and steelhead as they rear in or migrate through the estuary is an important step toward improving conditions for salmonids during a critical stage in their life cycles. However, actual implementation of management actions is constrained by a variety of factors, such as technical, economic, and property rights considerations. In fact, in some cases it will be impossible to realize an action's full potential because its implementation is constrained by past societal decisions that are functionally irreversible. (emphasis added)*

This suggests an altogether different usage: *functionally irreversible* means reversible; but with societal consequences which are so onerous that reversal is very unlikely to occur. As such, *functionally irreversible* is a societal construct, not a physical or ecological factor. This latter usage is assumed to be the meaning intended in the Section 32 comment; as it is expected that the authors of the Section 32 document would be aware that dams are physically capable of being removed, and are assumed to be alluding to more subtle, societal factors.

2.4 Is Some Infrastructure Functionally Irreversible?

Could some physical infrastructure be *functionally irreversible,* if the adverse consequences for society, or the risks of attempting to reverse the effects, are too large? This seems a self-evident concept, but real-life examples in the New Zealand context are harder to find.

Looking overseas, could a society become so dependent on an infrastructure facility that it cannot be reversed? An example might be the North Sea defences that protect the Netherlands from flooding. However, the Netherlands is dependent on the functionality of the sea defences, and not on the sea wall structures themselves. The structures, and their attendant adverse effects, may indeed be reversible if, for instance, another structure was built to provide the required function. For instance a fixed sea wall - with adverse effects on an estuary - may be replaced by a moveable sea defence, which only operates when needed, and therefore has fewer adverse effects. Alternatively the sea defences could

---

[13] New Collins Concise English Dictionary, New Zealand Edition, Collins, Auckland, 1982

[14] For example the phrase appeared only 777 times on Google when searched on 17 October, 2008.

[15] For instance Silbergeld wrote in 1990 that that *clinical studies indicate that early exposure to lead causes functionally irreversible changes to the CNS* (central nervous system). Source: Silbergeld, E. K. (1990). *Toward the Twenty-First Century: Lessons from Lead and Lessons yet to be Learned.* Environmental Health Perspectives, Issue 86, June 1990.

[16] In 2007 Charles Vorosmarty stated that *the hydrology of the planet is under rapid and in many cases functionally irreversible change due the combined forces of climate variability, greenhouse warming*. Source: Vorosmarty, C.J. (2007). *The Science of Global Hydrology Lessons from New England.* Proceedings of North-eastern Section of Geological Society of America, 42nd Annual Meeting,, published in Abstracts with Programs, Vol 39, No.1,p33

[17] The futurist, Jamais Cascio, in an April 2008 blog posting, wrote that *the accumulation of non-linear drivers can lead to "tipping point" events causing functionally irreversible changes to geophysical systems (such as massive sea level increases).* Source:Cascio, J. *Feedback, Tipping Points and Hard Choices,* posted 29 April 2008 on the Institute for Environmental Ethics and Emerging Technologies web site, http:/ieet.org/index.php/IEET/more/2413/ . Accessed 12 October 2008.

[18] Vol 73, No1, 2 January 2008

become redundant, if the policy of sea defences was superseded by an alternative policy which placed less reliance on such structures.

Perhaps one of the least reversible human constructs is urban land subdivision and development. Increasing the density of people, and fragmenting land ownership, makes it is very difficult to reverse urbanisation, especially in a democratic society with private property rights. However such reversals of urban development do occur. In New Zealand some villages of housing owned by a single employer have been removed in recent decades,[19] and some gold mining towns have long since disappeared. In Germany, where the population is falling, parts of some towns are being deconstructed as the cost of maintaining the infrastructure is too high.[20] These examples demonstrate that urban land development is reversible.

Another example is the highway: surely transportation is the lifeblood of the economy and is functionally irreversible? That may be true for transportation, but the highways themselves are not irreversible. The most famous highway in pop culture is probably Route 66, which led from Chicago to California. However Route 66 has been superseded by the interstate highway I-40, and some stretches of roads that formed Route 66 have been abandoned completely. Many road-side business owners may have considered that Route 66 was functionally irreversible, but it no longer exists. The road transport functionality remains, but it has been catered for by different physical infrastructure.

Can dams be functionally irreversible? Communities can develop complex relationships and dependencies on dams. A dam may provide both power and irrigation water: for example the four dams on the lower Snake River (located in Washington State, north-west US), provide navigation access for river barges, irrigation water, and generate an annual average of 1022 MW of hydropower.[21] While environmental activists are pressing for removal of the dams to improve salmon fisheries,[22] the response from officials has centred on additional measures to mitigate adverse effects such as improved fish ladders.[23] It would be difficult, but not impossible, to remove those four dams, and certainly the activists do not consider them to be functionally irreversible.

2.5 Could NZ Hydro Schemes Be Functionally Irreversible?

The Section 32 analysis comments that hydro-generation has functionally irreversible effects. A question is: is this likely to be the case in New Zealand?

It is assumed that any decommissioning of a hydro-electric power scheme in New Zealand would be accompanied by increased generation from other renewable sources at an affordable cost.[24] Therefore the social benefits of the electricity generated have been disregarded for the purpose of this analysis.

There are few hydro schemes linked to irrigation in New Zealand; but a hydro scheme could become *functionally irreversible* if the community becomes dependent on other benefits that the hydro scheme brings. For instance development downstream of a hydro dam may

[19] For example Waipa Village which housed workers from the nearby Waipa Sawmill, south of Rotorua.
[20] Refer DW-World.DE, 3 Sept 2004. *Deconstructing Germany*, http://www.dw-world.de/dw/article/0,2144,1316056,00.html. Accessed 12 October 2008.
[21] Peak capacity is 3500 MW. BPA (2007). *The costs of breaching the four lower Snake River dams*, Fact Sheet, Bonneville Power Administration, March 2007
[22] For example refer *Save Our Wild Salmon* campaign at http://www.wildsalmon.org/actioncenter/
[23] Source: *Lower Snake River Juvenile Salmon Migration Feasibility Study - Final Report and EIA*, US Army Corps of Engineers, Feb 2002.
[24] Or by reduced demand through demand reduction at an affordable cost.

encroach onto the former flood plain. This may place the development at risk of flooding, if the dam is removed.

However, in New Zealand natural hazards are generally taken into account in planning documents which are reasonably well enforced. The nation is also lightly populated, and wealthy, by international standards. So it is difficult to conceive of examples where a particular New Zealand dam is likely to have functionally irreversible effects due to the dependence of downstream communities.

Another way in which a hydro-scheme could have functionally irreversible effects is if the effort, and timescale, of addressing the effects places an unreasonable burden on future generations. However mechanisms exist to provide for such funding, and are discussed further in Section 8 of this report. Accordingly, it is proposed that inter-generational equity issues do not make such facilities functionally irreversible.

In summary, it is concluded that removing some hydro facilities in New Zealand could be difficult from a societal perspective, but those difficulties can be successfully addressed, given enough effort and time. Therefore hydro-electric generation facilities, and associated dams, are unlikely to be functionally irreversible in New Zealand.

2.6 Are There Degrees of Reversibility?

Taken literally, there can be no such thing as a degree of reversibility of adverse effects: adverse effects are either reversible, or they are not.

However some adverse effects or energy developments are easier to reverse than others. For decision makers this is an important quality. They are also likely to be interested in scale of effects, timeframe and risk; but only for effects which are significant. It is therefore proposed that reversibility has four main attributes in this context (Table 2.2):

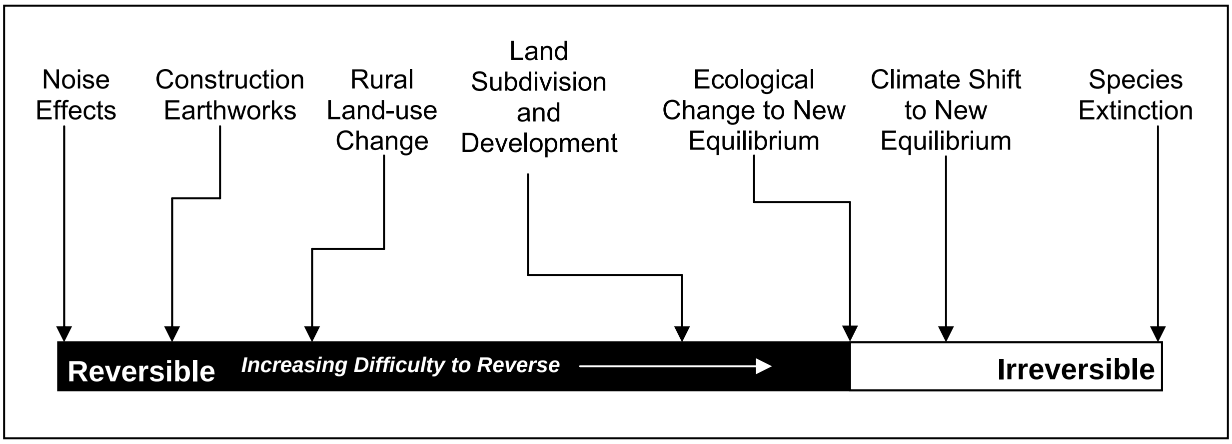
Table 2.2 Attributes of Infrastructure Effects Reversibility

Attribute	Comment
Significance	Includes dimensions such as scale, impact, and sensitivity of affected species and ecosystems.
Effort	Costs of reversing effects, including mitigations to address externalities, are a reasonable proxy for effort.
Risk[25]	Likelihood of failing to reverse adverse effects, or of creating new adverse effects.
Timeframe	Duration over which the removal process occurs, including any post removal management and time for significant effects to abate.

It is also proposed that an overall assessment of ease of reversibility can be made, based on the above attributes, to place activities on a continuum of ease of reversibility (Figure 2.1). The placements on Figure 2.1 involve a degree of judgment, and therefore have a subjective element; but despite these reservations, it is postulated that most people, given sufficient objective information, would be able to agree on the general order of activities in Figure 2.1.

[25] This is consistent with the standard AS/NZS4360:2004 defines risk from an organisational perspective as *the chance that something will happen that will have an impact upon its objectives.*

Figure 2.1 Reversibility of Effects[26]



2.7 Renewable Energy Technologies Assessed in this Report

This report concentrates on the three main renewable energy technologies currently being implemented in New Zealand:

- hydro-electricity
- geothermal
- onshore wind farms[27]

These three technologies have been selected due to their current predominance in New Zealand. Other renewable energy technologies such as offshore wind farms, solar, biomass, tidal, and wave power will undoubtedly play a role in the future New Zealand energy mix, and may be addressed in a future update of this report.

[26] Some ecological changes to a new equilibrium are reversible. Famously the peppered moth *Biston betularia* that was originally light coloured, but the population came to be dominated by a dark coloured mutant during the industrial revolution in England. With the cleaning up of air pollution the lighter form is now dominant again. Source: Roode, J. (2007) *Reclaiming the Pepper Moth for Science*, New Scientist, 8 Dec 2007. Other ecological changes to a new equilibrium have so far proven to be irreversible, such as the overfishing of cod on the Newfoundland Banks off Canada, which led to collapse of what was once considered to be the world's richest fishery. The cod population has never recovered despite closure of the fishery since 1992.

[27] Wind farms located on land, as opposed to offshore wind farms.

3.0 Methodology

3.1 Introduction

The research for this report consisted of three main components:

- evaluating case studies of renewable energy developments that have been removed
- considering timeframes for reversal of adverse effects of renewable developments
- estimating costs of removing and restoring renewable energy developments

The methodology is summarised below.

3.2 Case Studies

Research on case studies was primarily conducted by internet search, assisted by databases of scientific papers. Wherever possible the original source was located to verify the information. The research found a significant body of literature on dam removals, but little information on the removal of wind farms or geothermal plants.

3.3 Timeframes

3.3.1 Reversibility End Points

To define the timeframe for reversibility it is firstly necessary to define the end point: when it can be said the adverse effects have been reversed. It could be argued that some effects may never be completely reversed; that they will be detectable to future generations, even if of negligible environmental consequence. Consequently a range of end points was considered:

End Point 1 - Offsite adverse effects not more than minor
End Point 2 - Effects not generally obvious to casual ground-level observer
End Point 3 - No observable effects to specialist ground-level observer without specialist tools.
End Point 4 - No observable effects to specialist observer with specialist tools

This report focuses on the first end point – offsite environmental effects which includes ecological, and social effects. End Points 2 to 4 were discarded as they are anthropocentric and are of low relevance. Adverse economic effects were also considered as summarised in the following table.

Table 3.1 Adverse Economic Effects

Issue	Comment
Cost of providing alternative generation.	For onshore wind it is assumed that an economic alternative is available. This may, for instance, be to refurbish the wind farm with new wind turbines. For hydro and geothermal developments it is assumed that the life of the power station is such that other low cost generation (or demand reduction) technologies are available, at an affordable cost, by the time the project is decommissioned.
Cost of removal and restoration.	Likely costs, and possible funding mechanisms, are addressed in Sections 5 to 8 inclusive.

3.3.2 Restoration Treatments

It is also necessary to define the level of treatment that will be applied to reverse the effects. For this report the level of treatment selected is intended to represent what a reasonable, diligent and adequately funded, but not over-zealous, community would apply to achieve End Point 1. This would include:

- all above ground constructed facilities are removed
- scrap metal is recycled
- other scrap materials are disposed of off-site at a proper waste disposal facility
- concrete is crushed[28] and used as landscaping general fill on site
- below ground foundations are left in place and filled over
- tunnels are plugged (but not completely backfilled), and the portals are sealed, landscaped and planted
- above ground pipelines are removed
- embankments and dams are removed and the soil is used as general fill
- below ground pipelines and wells are sealed, cut off below ground level and left in place to decay
- electricity transmission lines and towers are removed; but tower foundations remain
- disturbed areas are topsoiled and planted in the vegetation cover before development.

End Point 1 does not include removal of foundations, tunnels, and underground pipes, as it is considered that the environmental effects of leaving such works would be not more than minor. This is a pragmatic choice, and some communities or authorities may prefer more complete removal. It is expected that such requirements, if generally prevalent, would affect removal of all the renewable technologies in a similar way, and would make little overall difference to their relative ease of reversibility.

This process of choosing the end point, and then considering the restoration treatments, has arrived at a similar conclusion to the Section 32 analysis, which accompanied the release of the proposed National Policy Statement:

> *The concept of reversibility is open to interpretation. For example, while it is possible to remove wind turbines at the end of their economic life, it is unlikely that the foundations and access roads would be removed.*[29]

Further comments on restoration treatments are provided in Appendix B.

3.4 Costs of Removal and Restoration

An objective of this methodology has been to quantify removal-and-restoration costs as a proportion of construction costs. This measure could then be applied across a range of project sizes to give a first order estimate of the costs involved. The analysis of costs, presented in Appendix C, inevitably involves a degree of judgement: accordingly the results should be regarded as being indicative of the relative costs of reversing renewable energy developments, rather than as an absolute cost that can be applied to a particular project.

As a check, information on the costs of removing hydro dams in the US was also compared against what it would cost now to build an equivalent sized hydro. A hydro-electric project cost model developed by the US Department of Energy[30] was used to estimate current US construction costs for those hydroelectric projects. The model is based on only one input variable, being the installed electricity generation capacity, so the estimated costs are

---

[28] Into particles not larger than say 50mm maximum dimension.

[29] Section 5.2.3.3 of *Proposed National Policy Statement for Renewable Electricity Generation – Evaluation under Section 32 of the Resource Management Act,* Ministry for the Environment, August 2008

[30] Model developed by Idaho National Laboratory of DoE from an analysis of several hundred hydropower projects of between 1MW and 1300MW capacity constructed in the US since 1940. Refer INEEL (2003), *Estimation of Economic Parameters of U.S. Hydropower Resources* , Idaho National Engineering and Environmental Laboratory, US Dept of Energy, June 2003. Cost estimates are for an undeveloped site. For use of a similar, but not identical cost model in New Zealand conditions refer to Gordon model *Hydro-Electric Potential in New Zealand*, Parsons Brinckerhoff Associates, February 2005.

indicative only. Historical demolition costs from the case studies were brought to the present day using a US Army Corps of Engineers cost index for dam construction.[31]

There is little information available in the published literature for the costs of demolition and removal of other types of energy developments. Demolition costs are, however, available for other types of development, from early papers in the then-emerging discipline of life cycle analysis. To provide an overall check on the methodology, a comparison was made to demolition and removal costs in the literature for facilities that are, in some ways, analogous to the renewable energy projects (Table 3.2).

Table 3.2 Costs of Demolition and Removal

Infrastructure	**Cost to Demolish and Remove as a Proportion of Construction Costs**	**Analogous to:**
Road Bridges [32]	4-8%	Dismantling Wind farm
60MW Coal Fired Power Station [33]	15%	Removal of Geothermal plant
Multi-storey Urban Buildings [34]	20%	Removal of Concrete Structures at Hydro Power Plant

While these studies used a range of different methodologies, the conclusions were comparable to the outputs of this study, which are reported in later sections of this report. This comparison is against a very small data set; but the similarities lend some confidence to the results of this study. Nevertheless areas of risk have been considered, and some potential critiques of the cost methodology are addressed in the table below.

Table 3.3 Critique of Cost Estimation Methodology

Issue	**Comment**
Not NZ Costs: Is it valid to apply costs from other countries?	Countries have different levels of costs but all developed countries share similar methods of heavy engineering construction. It is therefore considered valid to apply demolition and removal costs expressed as a percentage of construction costs, which removes the effects of local cost structures and currency effects.
Outdated: Won't historical information on project costs be outdated due to changes in construction methods?	More recent data is better, but heavy engineering is a mature industry with slow rates of change. While costs have risen, cost structures have not changed markedly. By expressing the costs of demolition and removal as a percentage of construction costs, the historical project information remains reasonably relevant.
Inflation: Won't historical information on demolition costs be outdated due to inflation?	Inflation is addressed by comparing with construction costs at that time, or by inflation adjusting historical demolition costs and comparing against current construction costs. Demolition uses similar equipment and techniques to construction. Accordingly historical demolition costs in the US have been updated to the present day using the USACE dam construction cost index.

Ideally the cost analysis would be founded on a deep pool of well-documented cost information. Unfortunately such information is not available, as few large dams have been removed, and most other renewable installations are only part way through their life cycles. These limitations should be borne in mind, but the cost estimates should be comparable as they have been derived on a similar basis for each technology.

---

[31] USACE (2008). Civil *Works Construction Cost Index System (CWCCISEM 1110-2-1304),* US Army Corps of Engineers, 31 March 2000, updated to 31 March 2008.
32 Frangopol, D. and Furuta, H. (2001). *Life-cycle Cost Analysis and Design of Civil Infrastructure Systems*, 2001.
[33] Wilson, T, and Norwoood J. (1991), *Power Plant Dismantling Cost Studies,* Transactions of the American Association of Cost Engineers, 1991
34 Kanda, J. and Satoh, I (1999). *Optimum Seismic Load Considering Multidamage Criteria.* in *Case studies in Optimal Design and Maintenance Planning Of Civil Infrastructure Systems* edited by Dan M. Frangopol, ASCE, 1999.

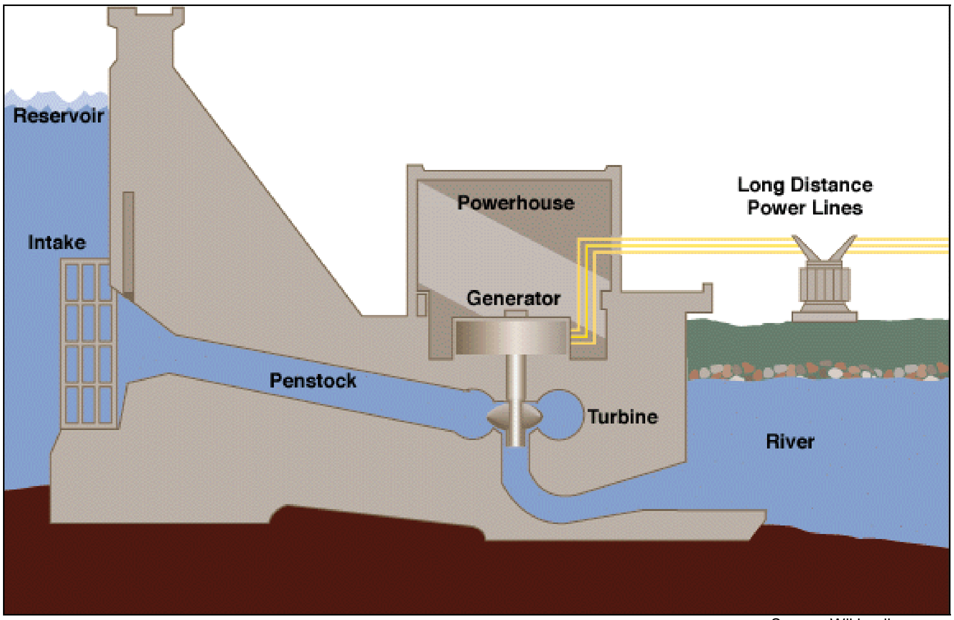
4.0 Hydro-electric Removal Case Histories

4.1 Types of Hydro-electric Schemes

Hydroelectric schemes can be usefully classified into two categories:

- storage hydro
- run of river hydro schemes

Figure 4.1 Storage Hydro Schematic



Source: Wikipedia

Storage hydro schemes (Figure 4.1) are the classic dam, blocking a river and forming a reservoir behind. The dam effectively concentrates, at a single location, all of the drop in river elevation over the stretch of river covered by the reservoir. The water passes at pressure through the powerhouse, where it is used to generate electricity. If the operator can vary the reservoir level, then the reservoir can be used to store water, holding it back to generate electricity at times when it the electricity is most valuable.

In contrast a run-of–river project typically has only a low weir and diverts water into a canal, winding at a slight grade along the flanks of a river, to a point where the water can be dropped down through turbines to generate electricity.[35] Run-of-river projects, such as the recently consented Wairau Hydro Scheme, do not regulate the river to the same degree as storage projects, and have become more actively promoted by power producers in recent years. For example in British Columbia, 43 independent power producers have filed for initial regulatory approvals to develop run-of-river power schemes, on over 400 rivers.[36]

Other types of hydro electric projects exist, and some schemes have elements of both the above types, but this remains a useful basic system of classification that will be employed in this report. This distinction between types of hydro scheme matters as the smaller dams in run-of-river hydroelectric projects generally retain much less sediment than storage dams, and sediment is a critical factor in dam removal.

[35] For a schematic of a run-of-river hydro refer http://www.hydromaxenergy.com/Green+Power/Run-of-River+Hydro+Power/Run-of-River+Hydro+Power.htm
[36] Source: Independent Power Producers Association of British Columbia, http://www.ippbc.com/EN/quick_facts_list/, accessed 5 October 2008.

4.2 Operational Modes of Hydro Schemes

A run-of-river project can only operate in one mode: run-of-river. Apart from a limited amount of storage in the canals, the outflow from a run-of-river hydro must be the same as the flow coming in from the river. That means that a run-of-river hydro is usually generating electricity for all the time that water is available.[37]

In contrast the operator of a hydro-electric plant with a storage reservoir has some choice; albeit sometimes constrained choices. *Live storage* is the amount of water stored between the minimum and maximum operating levels of the reservoir, under normal operating conditions. *Flow regulation* refers to the degree to which the reservoir is used to alter the natural flow regime in the river. Depending on the amount of live storage available, the operator may, in decreasing degree of flow regulation:

- store water from year to year
- store water from abundant flow seasons to low flow seasons
- store water from floods and release more in dryer periods times between floods
- reduce outflows during weekends, then use it during the week when electricity is more valuable
- reduce outflow during the night, then use the water during the day when electricity prices are higher
- release the same amount of water out as comes in (no flow regulation)

The financially optimal strategy depends on a range of factors, including the allowable reservoir range, reservoir level, present river flow, forecast river flow, expected releases from upstream dams, current electricity price, forecast electricity prices, grid transmission capacity, grid stability, and competitor behaviour. This is a complex issue and generation companies use sophisticated computer models to optimise their operations.

As the amount of storage available in a storage dam decreases, relative to average flows in the river, the operator's choices become more constrained. Some storage dams, with relatively small reservoirs, are so constrained that they are considered by their operators to effectively operate in a *run-of-river mode,* with little or no flow regulation.[38]

4.3 How Permanent are Dams?

When releasing the proposed National Policy Statement for Renewable Electricity Generation, the energy minister, David Parker, commented[39]:

> *Obviously, the effects of damming a river are far greater than erecting wind turbines. Large dams usually mean major permanent changes to water courses, with significant impacts on wildlife and ecosystems.* (emphasis added)

This statement reflects occasional statements in the scientific literature about "permanent" effects of dams and other hydrological works.[40] However those statements are implicitly predicated on the assumption that the dams concerned are permanent too. In the long run that is unlikely to be true: dams deteriorate over time, and are typically designed with an

[37] Some run-of-river projects have an off-line storage but such arrangements are rare.

[38] Examples of storage dams which effectively operate in run-of-river mode are Clyde and Roxburgh on the Clutha River, and Ohakuri on the Waikato River.

[39] Press release dated 13 August 2008. Refer http://www.beehive.govt.nz/release/major+step+towards+greener+energy+2025

[40] For example refer Kingsford, R.T. (2000). *Ecological Effects of Dams, Water Diversions, and River Management on Floodplain Wetlands in Australia*, Austral Ecology, Vol 25, Issue 2 , April 200 0, pp 109-127 , and Rossi, G. and Blivi, A. (1995), *The Consequences of Hydraulic Development in the Mono Valley, Togo-Benin*. Cashiers d'Outre-Mer, Vol 48, Issue 192, pp 435-452.

engineering life expectancy of 100 years. Some equipment such as steel-work, seals, and electrical controls, may not last this long and will need to be replaced or repaired, and some elements, such as concrete works, may last longer.

While some dams have been removed because of structural concerns, generally the useful life of a storage dam will be governed by the time it takes the reservoir to fill with sediment. The usual design standard for storage dam reservoir is a minimum of 100 years;[41] but the actual life depends on sediment inflows, which is governed by factors such as the geology and land use in the catchment. At current rates of sedimentation in the average reservoir life in China is 45 years; whereas in Europe it is 500 years.[42]

Operators can undertake a range of measures to slow the rate of sediment accumulations, mainly by increasing water velocities in the reservoir during floods to flush sediment out.[43] However such measures usually prolong the last stages in the life cycle of a storage hydropower project, rather than providing a reprieve.[44]

In New Zealand the Clyde dam and Roxburgh Dams have received heavy inflows of sediment from the Clutha River. Over 34 years, from 1958 until 1992, sediment accumulated in Lake Roxburgh, taking up 44% of the reservoir volume.[45] Sediment from the Clutha River is now accumulating in Lake Dunstan, behind the Clyde Dam, which has a much larger reservoir capacity. While these reservoirs, and other hydro facilities, will last for a long time yet, they will eventually fill with sediment.

The key question is: what happens at the end of the useful life of the storage-hydro reservoir? Initially the hydropower project could be operated in a similar mode to a run-of-river project. However, operating a storage hydro project in this mode passes abrasive sediment through the plant. This leads to sharp increases in wear on turbines, penstocks and gates;[46] and maintenance costs escalate rapidly.[47] Within a few decades it is likely that the hydropower plant would need to be completely refurbished, and substantially altered to extend its life. Alterations would not be simple, and would effectively involve reconsenting the project. The World Commission on Dams recommends that, where major physical changes to hydropower facilities are proposed, feasibility studies and environmental and social impact assessments should be undertaken.[48] Alternatively the dam could be decommissioned and removed.

Run-of-river hydro projects have to deal with sediment throughout the project life, and many run-of-river projects incorporate features to capture sediment and to return it to the river. Occasional desilting of canals may still be required, and components of run-of-river projects will need to be replaced over time. However, provided that the plant is maintained, there are no fundamental limits to the life of a run-of-river hydro-scheme, other than decay of the structures and equipment. In practice it is likely that a run-of-river project will undergo long periods of operation with routine maintenance, interspersed with major refits. The refits

[41] Morris, G. and Fan, J. (1998). *Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use*, McGraw Hill, 1998.
[42] Source: Table 1.1 of Palmieri et al (2003). Annual sedimentation loss provided by Palmieri et al inverted to give expected life. Refer Palmieri, A., Shah, F., and Dinar, A. (2003). *Reservoir Conservation Volume 1*. IBRD World Bank, June 2003.
[43] For Roxburgh example refer Roberts, K. and Foster, P. (2003). *Dealing with Sediment*, International Water Power and Dam Construction, October 2003. Tarbela – refer Palmieri, A., Shah, F., and Dinar, A. (2001). *Economics of Reservoir Sedimentation and Sustainable Management of Dams*. Journal of Environmental Management, 2001, 61, pp149-163
[44] Modelling of an improved flushing regime at rapidly filling reservoir of the 3,478MW Tarbela Dam on the Indus River in Pakistan found that the power generating capabilities would be preserved for an additional 10 years. Source: Palmieri, A., Shah, F., and Dinar, A. (2003). *Reservoir Conservation Volume 1*. IBRD World Bank, June 2003
[45] Roberts, K. and Foster, P. (2003). *Dealing with Sediment*, International Water Power and Dam Construction, October 2003.
[46] Vorob'ev, A (1982) *Flushing of Reservoirs as a Means of Increasing the Operating Efficiency of Hydroelectric Stations*. Translated from Gidroteckhnicheskoe Stroitel'atvo, No 9, pp14-16, Sept 1981.
[47] Morris, G.L. and Fan, J (1997). *Reservoir Sedimentation Handbook*, McGraw-Hill, 1997. p. 22.5
[48] WCD (2000). *Dams and Development - A New Framework*. The Report of the World Commission on Dams, Earthscan Publications Ltd, London. p.232.

could include rebuilding decaying concrete structures, relining canals and installing new turbines and gates.

The lack of fundamental limits to the life of run-of-river projects may provide an appearance of permanence but, in New Zealand, such projects must have resource consents, which have a finite life. Renewal of those consents often crystallises consideration by the owner, the regulatory authority, and affected parties as to whether the plant should continue in operation.[49] The most likely reasons for removal of such hydro schemes is as a result of societal change, rather than physical or economic factors; for instance if the standards for earthquake resistance change and it is uneconomic to improve the structures, or if society determines that electricity production by other means is preferable.

In summary, large dams have been in place for around 50 years or more, and have generally been designed and maintained in the expectation that they will last for at least another 50 years, and possibly much longer. Consent durations for hydro schemes can also be long: up to 35 years under the Resource Management Act. This all adds to an impression of permanence. However, while storage hydro dams have long lives, they eventually silt up, or decay, to the point where they have to be removed.

A question, examined below, is: are the adverse effects permanent, remaining after removal of the storage hydro dam?

4.4 Adverse Effects of Dams

The adverse effects of dams on river systems and aquatic ecology are well documented in the literature.[50] [51] Significant ecosystem impacts may arise when a dam is built because of changes to flow regimes, water temperature, sediment loads and connectivity (Figure 4.2).[52] Fragmentation of river ecosystems can also be a significant issue. [53] [54]

A key driver for removal of dams has been a desire to reduce ecosystem fragmentation, to help restore anadromous fisheries, such as salmon, which have crashed since the 1960's. The reasons for the population crashes are not fully understood; they are widely believed to be influenced by a combination of overfishing, reduction in access to spawning areas, and losses of fish passing through hydroelectric lakes.[55] Dam owners have retrofitted and improved fish-ladders; but many are still considered to be largely ineffective.[56]

Declines have been observed in New Zealand sport fisheries after dam construction, notably in the Waitaki River (Sockeye and Chinook Salmon) and Clutha River (Chinook Salmon).[57]

[49] In addition the Resource Management Act provides for conditions of consent to be reviewed, and consents usually include conditions of consent to enable review. But it is rare for such a review, during the term of a consent, to result in closure of a facility.

[50] For example refer Berkamp, G., McCartney, M., Dugan, P., McNeely, J., Acreman, M. (2000). *Dams, ecosystem functions and environmental restoration*, Thematic Review II.1 prepared as an input to the World Commission on Dams, Cape Town.

[51] Also refer Puckeridge J. T. et al (1998). *Flow Variability and the Ecology of Large Rivers*, Marine and Freshwater Research, Vol 49, Issue 1, 1998, pp55-72, and Power, M. E. et al (1996) *Dams and Downstream Aquatic Biodiversity: Potential Food Web Consequences of Hydrologic and Geomorphic Change*, Environmental Management, Vol 20, Issue 6, Nov 1996, pp887-895.

[50] Bednarek, A.T. (2001), *Undamming Rivers: A Review of the Ecological Impacts of Dam Removal,* Environmental Management Vol 27, No 6 , 2001, pp 803-814.

[53] Dynesius, M. And Nilsson, C. (1994), *Fragmentation and Flow Regulation of River Systems in the Northern Third of the World*, Science, Vol 26, Issue 5186, 1994, pp 753-762.

[54] WCD (2000) *Dams and Development - A New Framework*. The Report of the World Commission on Dams, Earthscan Publications Ltd, London.

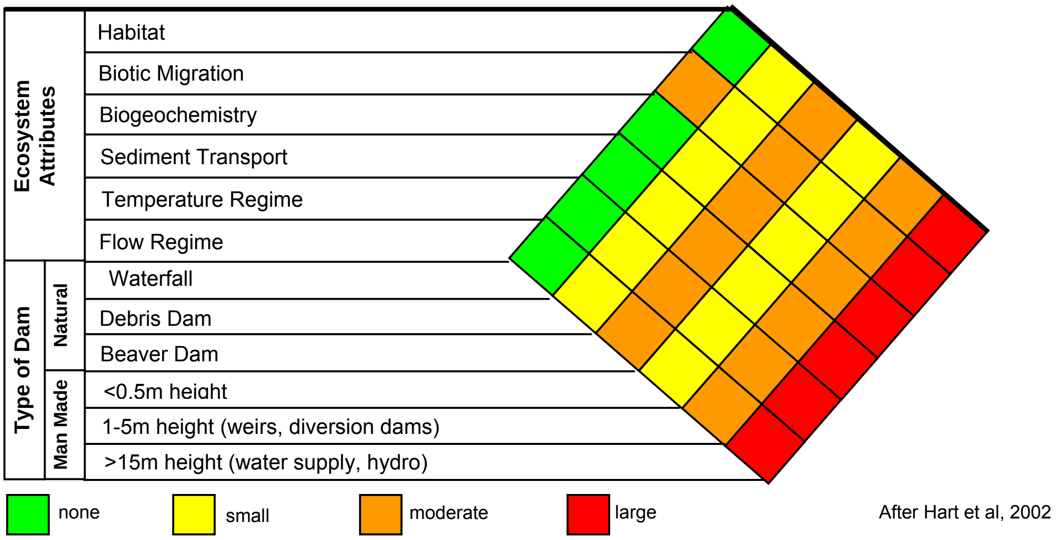
[55] Musick J. A. et al (2001). *Marine, Estuarine, and Diadromous Fish Stocks at Risk of Extinction in North America*, Fisheries Vol 25, No 11, 2001, pp6-30.

[56] Clay, C. M. (1995). *Design of Fishways and Other Fish Facilities*: Second Edition, CRC Press, 1994

[57] Young R, Smart, G, and Harding, J. *Impacts of Hydro-dams, Irrigation Schemes and River Control Works,* in Freshwaters of New Zealand, Chapter 37, New Zealand Hydrological Society , 2004

Like these sport fisheries, many of New Zealand's native fish species, including eels, require access to the sea for part of their *diadromous* life cycle[58] and may be affected by dams.

Figure 4.2 Relationships Between Ecosystem Attributes and Dam Type



In recent years greater attention has been paid in to the cultural values of Māori. Water is central to Māori cultural and personal identity: these values can be adversely affected by dams and diversions. Rivers and lakes carry ancestral connections, identity and wairua (spirit) for whanau, hapū and iwi, as reflected in tribal pepeha and personal mihi.[59] Cultural matters of concern to Māori include:

- the mauri and wairua of rivers[60]
- adverse effects on mahinga kai [61]
- protection of wāhi tapu and other taonga[62]
- recognition of special significance of particular water bodies

Flow regulation by storage dams changes the seasonal pattern of flows, the strength of the connection between the mountains and the sea, and the ability of a river to carry sediment and dilute contaminants. All these changes will affect the mauri or life-essence of a river.[63] Diversions, damming and abstracting water often sever the flow of water throughout the system and consequently sever the mauri of the river.[64]

Over the last few decades international pressures to remove existing dams has grown, led by environmental organisations,[65] and several US states now have active dam removal programmes.[66] Activists have been successful in pressing for removal of hydro dams that are near the end of their life cycle, especially those that isolate long stretches of river, lack effective fish ladders and produce little electricity. Dam removal has also attracted scientific interest and a growing body of scientific literature as discussed in the following sections.

---

[58] Diadromous fish travel between salt and fresh water. Of these anadromous fish live in the sea mostly, breed in fresh water (eg salmon) and catadromous fish live in fresh water, breed in sea (eg eels). Source: Carl E. Bonds, *Biology of Fishes*, 2nd ed. Saunders, 1996, pp. 599-605.

[59] *Pepeha*: Tribal saying; proverb. *Mihi*: Speech of greeting; acknowledgement.

[60] *Mauri:* the essential life force or principle; a metaphysical quality inherent in all things, both animate and inanimate.

[61] *Mahinga kai*: Interests in traditional food and other natural resources and the places where those resources are obtained.

[62] *Wāhi tapu*: sacred places; *Taonga*: Treasure, possessions, property

[63] Young R, Smart, G, and Harding, J. *Impacts of Hydro-dams, Irrigation Schemes and River Control Works,* in Freshwaters of New Zealand, Chapter 37, New Zealand Hydrological Society , 2004, p37.1

[64] MfE (1998). *Flow Guidelines for Instream Values,* Ministry for the Environment, May 1998 ,p.145,

[65] E.g.: American Rivers, Friends of the Earth, Tout Unlimited, Wild Salmon, and International River Network.

[66] E.g. Department of Natural Resources in Wisconsin, Michigan and Ohio.

4.5 US Case Studies in Hydro-electric Dam Removal

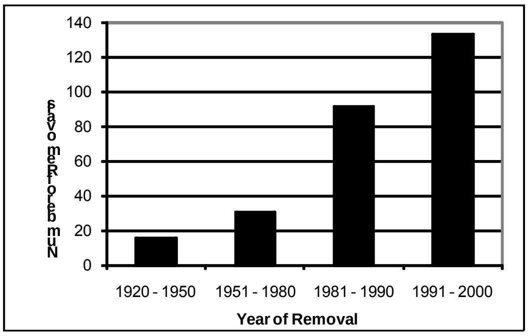
The United States has approximately 79,000 significant dams,[67] and has the most experience in removing them. Over the twentieth century 467 dams were completely or partially removed across the states[68]. The pace of removal has picked up over recent decades as a surge of dams have come up for relicensing on the 50 year cycle under Federal Energy Regulatory Commission (FERC) rules[69] (Table 4.1 and Figure 4.3).

Table 4.1 Dam Removals in the US

Year of Removal	Number Removed	Height* (m)
1920 - 1950	16	6.6
1951 - 1980	31	15.7
1981 - 1990	92	17.2
1991 - 2000	133	18.3

Height* = 95 percentile height for removed dams.[70]

Figure 4.3 US Dam Removals



New Zealand has fewer dams than the US; in May 1996 the Ministry of Commerce published a list of 402 significant dams over 3m high and 20,000 cubic metres capacity.[71] This represents an average of 100 significant dams per million population. In contrast that US has 260 significant dams per million population. While the criteria for dam significance criteria are not identical in the two countries, the density of significant dams appears to be much greater in the US than in New Zealand.

Many of the dams removed in the US to date are abandoned relics of industrialisation: the average age at removal is over 100 years, and most removed dams were less than 5m high.[72] In an analysis of 417 case studies Pohl found that environmental reasons were most commonly cited for dam removal (39%), followed closely by safety (34%).

As dams reach the end of their life, costs of maintenance can escalate and substantial reconstruction may be required. The Wisconsin Department of Natural Resources estimates that dam removal normally costs around a third of reconstruction,[73] but economic factors were only cited as being a primary reason for removal of 18% of dams in the Pohl study. Environmental reasons were most dominant in California where the active habitat restoration programmes such as the CalFed Bay Delta Program have removed a series of dams.[74]

An important early case history is removal of the Fort Edward dam in 1973 (Box 1), as it demonstrated the critical importance of sediment management.

---

[67] Dams in the NID meet one of three sets of criteria: 1) over 6 ft high and impounding over 50 acre ft of water (1.8m and 67,000 m3): or 2) over 25 ft high and impounding over 15 acre ft (7.5m and 20,000 cubic metres): or 3) pose a serious downstream hazard.

[68] *Dam Removal Success Stories: Restoring Rivers Through Selective Removal of Dams that Don't Make Sense*, American Rivers/Friends of the Earth/Trout Unlimited, 1999

[69] Doyle et al, (2000), *Dam Removal : Physical, Biological and Societal Considerations*, Proc. American Society of Civil Engineers Joint Conference on Resources Planning and Management, Minneapolis, July 30- August 2, 2000

[70] The 95 percentile height is given to provide an indication of the typical scale of larger dam removals.

[71] Ministry of Commerce (1996). *Safety Assurance for Large Dams – Proposed Statutory Requirements and Procedures*. In Crequer, D. (2003). *Living With Your Consents.* Proceedings of 2003 Symposium, New Zealand Society on Large Dams, August 2003.

[72] Poff, N. L. and Hart. D. (2002). *How Dams Vary and Why is Matters for the Emerging Science of Dam Removal*, Bioscience, Vol 52, No 9, Aug 2002, pp659-668

[73] *Dam Removal*, Wisconsin State Department of Natural Resources. http://www.dnr.stae.wi.us/org/water/wm/dsfm/Dams/removal.html accessed 3 October 2008

[74] Pohl reports that CalFed has partially or entirely funded at least nine major dam removals since 1994 to restore ecological health including the habitat of the protected Chinook salmon and steelhead trout. Source: Pohl, M. (2002). *Bringing Down Our Dams: Trends In American Dam Removal Rationales*, Journal of the American Water Resources Association, Vol 38, Issue 6, Dec 2002, pp 1511-1519

Box 1 – Fort Edward Dam Removal[75]

Fort Edward Dam was constructed in 1898 on the Hudson River in New York State for the purpose of supplying 2.8 MW of hydroelectricity generation. The dam was made of stone-filled timber crib, 10m high and 180m long with a total impoundment area of 79 ha. By the end of the 1960's the condition of the dam was poor, and studies indicated that repair or replacement of the dam would be uneconomical. Removal was agreed and was carried out in the summer of 1973, including removal of the estimated 2,500 cubic metres of sediment trapped behind the dam.

However, significant sediment problems arose, which closed all shipping in the downstream stretch of the Hudson River in 1974, clogged a marina and created a serious flood hazard for the town of Fort Edward.[76] Also significant water quality problems arose due to heavily contaminated with polychlorinated biphenyl (PCB) from heavy industry located upstream.[77] It was concluded that the dam removal was mishandled, and that poor analysis had led to a gross underestimate of the amount, and quality, of sediments behind the dam.

Since the Fort Edward experience, sediment management, and sediment quality, have been high on the agenda for all dam removal projects in the USA.

Information on case histories of hydro-electric removals in the US since 1973 is presented in Appendix C and is summarised in Table 4.1 below.

Table 4.1 Removal of Hydroelectric Projects in the United States - Selected Case Studies[78]

River	Dam	Height	Installed Capacity	Built	Removal Complete	Removal Cost
		(m)	(MW)			$USm
Historical						
Clearwater	Lewiston	14	10	1927	1973	0.6
Hudson	Fort Edwards	10	2.85	1898	1973	0.4
Willow	Mound	18	0.4	1924	1992	0.17
Clyde	Newport No 11	6	1.8	1957	1996	0.6
Pine	Stronach	5	2	1912	2003	0.8
Willow	Willow Falls	18	1	1925	1998	0.6
Kennebec	Edwards	7	3.5	1837	1999	3.0
Rappahannock	Embrey	7	6	1853	2004	10.0
Sturgeon	Sturgeon	16	0.8	1919	2007	2.0
Underway						
Sandy	Marmot & Little Sandy	14	22	1912	2009	17.1
Elwha	Elwha and Glines Canyon	33 & 65	28.1	1910 & 1926	2012	227
Planned						
White Salmon	Condit	38	14.7	1913	2009	17.5

[75] Sourced principally from American Rivers, http://www.americanrivers.org/site/PageServer?pagename=AMR_content_71a6, accessed 24 October 2008
[76] Source: American Rivers, Friends of the Earth and Trout Unlimited (1999) *Dam removal success stories: Restoring rivers through selective removal of dams that don't make sense.*
[77] Stanley, E. & Doyle, M. (2003) *Trading off: the ecological effects of Dam removal*, in Frontiers in Ecology and the Environment, 1:1: 15-22.
[78] Information compiled by author from a wide range of on-line sources in October 2008. Information was cross checked between references and, where possible, original sources were used. Excludes non-hydroelectric dams. This list may not be complete.

In addition there are advanced plans to remove the Matilija Dam, Ventura River, California. A 60m high mass concrete dam built in 1947 for water supply and flood control. Removal and restoration is currently proposed over 2 years, commencing in 2010 at estimated cost of$US145m.[79] These larger dam removals are being approached as an undertaking that is comparable to dam permitting and construction, including feasibility studies, environmental impact assessments, and community consultation.

4.6 Lessons from Dam Removal Case Histories

In the year 2000, the Aspen Institute, a Colorado-based environmental think tank, convened a dialogue group representing dam owners, users, and campaigners for dam removal. The dialogue group identified lessons from existing dam removals, grouped around 6 themes, and reported them in a book, *Dam Removal: A New Option for a New Century*.[80] The lessons agreed by the participants included:

- avoid over-engineering: allow natural physical and biological processes of the river and upland riparian environment to restore the site to the extent possible
- sometimes natural erosion can be the least costly method of sediment removal and may have the least impact on the river system.

Hart et al reported in 2002 that only around 20 dam removals were accompanied by published ecological studies, with a further 10 studies underway at that time.[81] The completed studies found rapid colonisation by migratory fish, which is often cited as evidence of restoration. It is widely assumed that the benefits of dam removal are substantial, relatively rapid and positive, but in some cases, dam removals have caused significant releases of toxins or nutrients, caused channel instability, or led to invasive populations[82]. These views were supported by Doyle et al in 2000 who concluded that, while anecdotal evidence or rapid positive benefits exists, there was, at that time, little hard ecological data available to support this view.[83] Hart et al concluded that many of the effects of dam are reversible, given a sufficient amount of time; but that effective river restoration will likely require that dam removal is coupled with other protection and restoration practices.

Box 2 – Proposed Condit Dam Removal

Figure 4.4 Condit Dam[84]

The Condit Dam is a 38m high mass concrete gravity dam and 14.7MW hydro-electric power plant built on the White Salmon River in Washington State in 1913 (Figure 4.4). The dam does not have a fish ladder and blocks fishery access to 22 km of chinook salmon spawning habitat and 53 km of steelhead trout habitat. In addition the reservoir covers 8 km of rapids on a river that is popular with whitewater enthusiasts and

[79] Collins: M. (2007), *Matilija Dam Removal OK'd,* Ventura County News, Sep 25, 2007
[80] Available on line from the Aspen Institute http://www.aspeninstitute.org/ and from Water Resources Center, an on-line clearing house on dam removal at the University of California, Berkley at http://www.lib.berkeley.edu/WRCA/damremoval/about.html
[81] Hart D. D. et al, *Dam Removal: Challenges and Opportunities for Ecological Research and River Restoration*, Bioscience, Vol 52, No 8, August 2002, pp 669-681.
[82] Conynngham et al (2006), *Engineering and Ecological Aspects of Dam Removal- An Overview*, Engineer Research Development Center, US Army Corps of Engineers, ERDC TN-EMRRP-SR-80, Sept 2006.
[83] Doyle et al, 2000, *Dam Removal : Physical, Biological and Societal Considerations*, Proc. American Society of Civil Engineers Joint Conference on Resources Planning and Management, Minneapolis, July 30- August 2, 2000.
[84] Photo Source: Wikipedia

is designated in parts as *wild and scenic.*[85]

The dam owner, PacifiCorp, agreed in 1999 to remove the dam by 2006. Removal was originally estimated to cost up to $US59 million but an innovative removal method, involving tunnelling under the dam to drain the reservoir, was agreed, at a cost capped at $17.15 million in 1999 dollars.[86] The timetable has been deferred several times due to delays on the part of the regulator, the Federal Energy Regulatory Commission, and legal action by adjacent local governments.

In 2005 the parties agreed that the dam could run for two more years to earn an additional $3.3million to cover the cost of additional regulatory requirements and studies.[87] The dam is now scheduled to be removed by October 2009.[88] Detailed cost estimates for removal, filed by the plant owner, are based on standard heavy engineering construction methods.[89]

A potential adverse effect that would not be reversible is the extinction of an endangered aquatic species. Where projects are contested to the Environment Court, or *called in* to a Board of Inquiry under the RMA, they receive thorough scrutiny in the approvals process. As approvals for any such dam would likely to be contested, it can be assumed that a dam would not proceed if there was a reasonable risk that it would contribute significantly to the decline of such an endangered species. On this basis it is not expected that future dams will have significant adverse effects on endangered aquatic species.

In summary:

- there is a dearth of long term studies on reversing the adverse effects of dams, in part because larger dams have only recently begun to be removed.
- the speed of recolonisation of the habitat by fish has surprised observers but, it is recognised that recovering the ecological health of the rivers depends on management of the whole watershed, not just removing dams.
- some adverse effects, such as increased water temperature and physical barriers to fish migration are reversed immediately when the dam is removed: others take some years to restore.
- sediment management is a significant issue in the first three to five years after a dam has been removed; but, with suitable sediment management, should recede in significance thereafter.
- dam removal activists have been quick to hail the success of dam removals; but, in the absence of long term studies, the scientific literature is more cautious.
- in the scientific literature there appear to be few, if any, suggestions that the adverse effects of dams are irreversible

4.7 Sediment Management

The American Society of Civil Engineers publication, *Guidelines for Retirement of Dams and Hydroelectric Facilities,* states that the primary concern of most, if not all dam removal cases is the fate of stored sediments in impoundments; and subsequent ecological and morphological effects when the sediment is released.[90]

Other studies have found that recovery times depend on factors such as the length of time sediment has been accumulating, the flow velocity, river gradient and techniques applied to

---

85 O'Keefe, T. (2005). *Opportunity to Support Condit Dam Removal***,** American Whitewater, http://www.americanwhitewater.org/content/Article_view_articleid_1427_display_full_. Posted Oct 19, 2005. Accessed 25 Oct 2008.
86 Becker, D. H. (2005), *The Challenge of Dam Removal: The History and Lessons of the Condit Dam Removal and Potential Threats from the 2005 Federal Power Act Amendments*, Environmental Law, Vol 36, p827.
87 Ibid. p.814
88 *Salmon Spawning Above White Salmon's Condit Dam First Time In 100 Years,* The Columbia Basin Fish and Wildlife Basin News Bulletin. http://www.cbbulletin.com/299084.aspx. Posted 10 October 2008. Accessed 25 October 2008.
89 Beck, R. W. (1998) , *Condit Hydroelectric Project Removal – Summary Report -Engineering Considerations*, May 1998
90 ASCE Task Committee on Guidelines for Retirement of Dams and Hydroelectric Facilities (1997). *Guidelines for Retirement of Dams and Hydroelectric Facilities,* American Society of Civil Engineers, New York.

stabilise or remove sediment[91]. In many cases the time taken for ecological recovery at a location has been just a few years, but in some case it may take decades for the pulse of accumulated sediment to move down the river.[92]

The ASCE Guidelines identify four approaches to sediment management:

- no action (leave sediment in place)
- sediment removal by natural river erosion processes
- removal of sediment
- stabilisation

The guidelines go on to comment that:

> *With partial or full retirement of a dam, river flows may erode sediment from the reservoir basin. If large volumes of sediment are released, the downstream river channel will be affected. Retirement of a dam, without a sediment management plan, could have the following adverse effects:*
>
> - *An increase in the sediment load in the downstream river can alter the river ecology established after the dam was constructed;*
> - *Fines that are deposited in the downstream reaches of the river can negatively affect spawning gravel;*
> - *Uncontrolled release of sediment can cause a sediment wave (or waves) to move down river over many years, increasing the elevation of the riverbed and altering tributary confluences;*
> - *An increased sediment load in the river can also increase the rivers potential to move in lateral directions; and*
> - *Increased riverbed elevations can increase flood potential and block water intakes.*

An approach discussed in the ASCE guidelines, and gaining acceptance, is to remove dams in stages over a number of years, to gradually release sediments. This method has been used for removal of two dams in Michigan (Box 3). Such staged removal is especially appropriate for concrete dams, where the consequences of overtopping should be small. Earth dams can fail catastrophically if overtopped; so it would be more challenging to safely remove an earth dam in stages.

In recent removals there has been a trend to use more natural processes to manage sediments. Examples include the Condit Dam and the Bull Run hydro scheme removals, both of which are due to be completed in 2009.[93] [94]

The ASCE task force concluded that, with proper analysis and care, reservoir sediment can be successfully managed in dam retirements[95]. While dam decommissioning practises have moved towards more natural methods of sediment management, this still remains as the dominant issue for most dam removals.

---

[91] Bednarek, A.T. (2001), *Undamming Rivers: A Review of the Ecological Impacts of Dam Removal,* Environmental Management Vol 27, No 6 , 2001, pp 803-814

[92] Doyle et al, 2000, *Dam Removal : Physical, Biological and Societal Considerations*, Proc. American Society of Civil Engineers Joint Conference on Resources Planning and Management, Minneapolis, July 30- August 2, 2000 , p.3

[93] Refer http://www.portlandgeneral.com/community_and_env/hydropower_and_fish/sandy/dam_removal.asp for removal progress and http://www.marmotdam.com/video1_files/marmot_overview.html for video summary or Marmot Dam removal.

[94] The decommissioning plan filed by Portland General Electric (PGE) states: *PGE will remove the minimal amount of sediment necessary to accomplish removal of Marmot Dam. ... .The sediments will be contoured to blend with the surrounding area and to prevent erosion into waterways. The sediments will be covered with topsoil if needed and revegetated*... Source: *Decommissioning Plan for the Bull Run Hydroelectric Project*, Filed by Portland General Electric Company with the Federal Energy Regulatory Commission Office of Hydropower Licensing, Washington, D.C. FERC Project No 477, Nov 2002

[95] ASCE Task Committee on Guidelines for Retirement of Dams and Hydroelectric Facilities (1997). *Guidelines for Retirement of Dams and Hydroelectric Facilities*. American Society of Civil Engineers. Publisher: ASCE, New York.

Box 3 –Staged Demolition of Two Michigan Dams

Stronach Dam

The 10m high Stronach Dam was built on the Pine River in Michigan in 1912, generating 2MW through an adjacent powerhouse. High sediment loads in the Pine River filled the 27 ha reservoir just 18 years later, in 1930. The hydro operated for another 23 years, but was retired in 1953.[96]

Figure 4.5 Sturgeon Dam before and after Removal [97]

The Stronach powerhouse was demolished in 1996. A series of stoplogs were inserted and progressively removed: one 150mm high stoplog per quarter, until the river was back down to its natural level by 2003. This gradual removal was aimed at reducing environmental effects downstream of the dam, by gradually releasing stored sediment back into the downstream river. Riprap was placed in some locations within the reservoir to prevent the accumulated sediment from eroding too quickly.

Sturgeon Dam

The 16m high Sturgeon concrete arch dam was built on the Sturgeon River, Michigan, in 1919 to supply 0.8MW of hydroelectric power (Fig 4.5). In 1998 the dam owner agreed to remove the dam, stating that it was no longer economic to operate.[98] The dam was progressively removed in three stages of 5m, 5m and the remainder, on the first, third and fifth years of the removal programme.[99] Removal commenced in 2003 and was completed in 2007[100] at a cost of approximately $2 million dollars.[101]

4.8 Summary and Conclusion

In summary:

- over 400 significant dams have been removed in the US alone
- dam removal appears to be technically feasible over a wide range of situations
- in most cases management of sediment accumulated in the reservoir will be the most challenging and costly issue to be addressed in dam removal

While the typical scale of dams removed to date is small, removal of some larger dams is planned. No technical limits to dam removal have been identified in the literature. This indicates that hydro-electric power developments are reversible from both engineering and

[96] Stronach case study largely drawn from Morris, G.L. and Fan, J (1997). *Reservoir Sedimentation Handbook*, McGraw-Hill, 1997. p17.15. Sturgeon case study drawn from Michigan Department of Natural Resources and

[97] Photo Source: DEQ (2007). *State of the Great Lakes Report: Restoring the Lakes.* Annual Report Prepared by the Office of the Great Lakes, Michigan Department of Environmental Quality, 2007.

[98] WEPC (1998). *10-K405 Filing*, SEC File 1-01245, Accession Number 107815-98-5. Wisconsin Electric Power Company, 1998.

[99] Emery, L. (Undated). *The Sturgeon River Project: A Case Study*, Office of Energy Projects, Federal Energy Regulatory Commission, Washington DC

[100] Source: Michigan Department of Natural Resources: http://www.michigan.gov/dnr/0,1607,7-153-10364_27415-80309--,00.html. Accessed 28 October 2008.

[101] DEQ (2007). *State of the Great Lakes Report: Restoring the Lakes.* Annual Report Prepared by the Office of the Great Lakes, Michigan Department of Environmental Quality, 2007.

ecological view points. The outstanding question is: are hydro-electric projects reversible from a societal perspective taking into account timeframes, risks and costs? These factors are explored in Sections 5 and 8 of this report.

5.0 Reversibility of Hydro-electric Developments

As stated by Palmieri et al: retiring a dam is a major environmental, engineering and socioeconomic undertaking.[102] This section considers timescale, significance and cost of dam removal. Risks are discussed in Section 8.

5.1 Timescale and Significance

The estimated typical timescales for adverse effects of hydroelectric schemes to abate are summarised below. For effects classified as minor significance, the timescale is the typical period over which active maintenance and management would be required; for effects classified as more-than-minor significance, this period encompasses the time required for effects to abate to minor significance.

Table 5.1 Estimated Typical Timescales for Adverse Effects to Abate Following Hydro Removal and Restoration

	Significance of Adverse Effects After Removal	Treatment	Run of River Hydro	Storage Hydro
Dam and Power Station	Minor	Remove dam, penstocks, powerhouse, and spillway, bury foundations, topsoil and plant, crush removed concrete and use for restorative fill.	Pasture – 2 yrs Native forest – 10 yrs	Pasture – 2 yrs Native forest – 10 yrs
Tunnels	Minor	Plug tunnels. Entrances: Seal off, cover over with soil and plant.	Pasture – 1 yr Native forest – 1 yr	Pasture – 1 yr Native forest – 1 yr
Reservoir	Minor (Run-of-river) Medium (storage hydro)	Remove and stabilise some sediments, allow most sediments to be removed by erosion processes over time.	1-3 yrs	10 – 50 yrs
Downstream Effects of Reservoir Sediment	Minor (Run-of-river) Medium to High (Storage Hydro)	Allow sediments to be gradually removed by natural erosion processes.	1-3 yrs	10- 50 yrs
Transmission lines	Minor	Remove surface structures, leave foundations.	Pasture – 1 yr Native forest – 5 yrs	Pasture – 1 yr Native forest – 5 yrs
Access roads and power canals	Minor	Remove embankments and culverts, fill cuttings, grade soil over side slopes, leave steep side cuts across slopes.	Pasture – 1 yr Native forest – 5 yrs	Pasture – 1 yr Native forest – 5 yrs

Note: The above significance assessments and timescales are indicative only. Individual projects should be assessed on a case by case basis and may lie outside the range given above.

A feature of the above table is that the significance of most effects is minor; most adverse effects can be expected to have substantially recovered - and will no longer require management - in 2 to 10 years. The exception is reservoirs and sediment management for storage hydro schemes, as it can take decades for sediment levels in the reservoir to

[102] Palmieri, A., Shah, F., and Dinar, A. (2001). *Economics of Reservoir Sedimentation and Sustainable Management of Dams*. Journal of Environmental Management, 2001, 61, pp149-163.

stabilise, and for sediment to pass through the downstream river system. Run-of-river hydro schemes store relatively small quantities of sediment; so adverse sediment effects should dissipate to background levels within a few years.

5.2 Historical Costs of Removing Hydro Projects

Cost data from historical and proposed dam removals is presented in Table 4.1. These costs have been brought forward to the present day using an inflation factor, and have been compared against the cost of building the same project using the methodology described in Section 3.4. The data (Appendix C) is summarised in the figures below.

Figure 5.1 Cost of Removal by Year

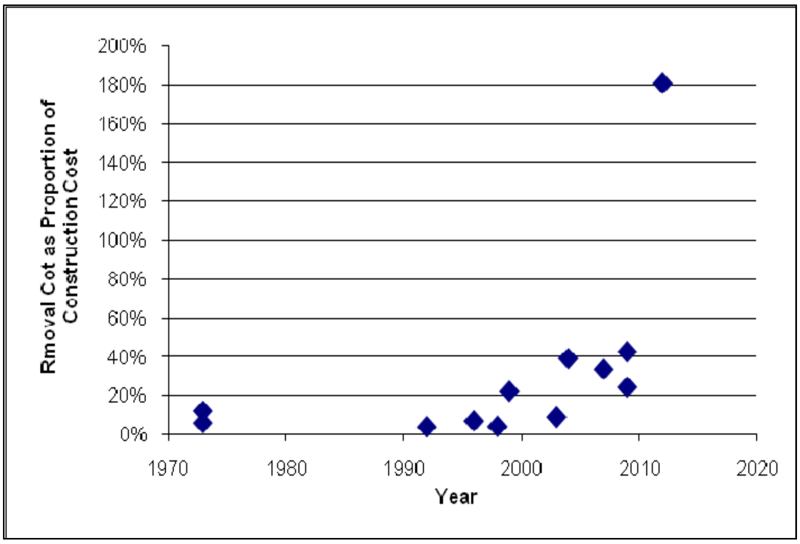
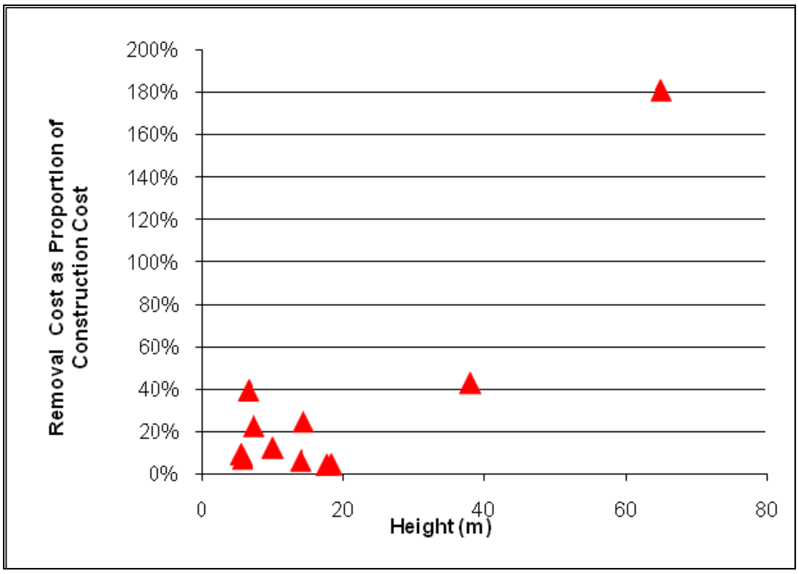


Figure 5.2 Cost of Removal by Dam Height



Prior to 1999, hydro-electric dam removal costs in the US, were remarkably inexpensive; typically less than 10% of the cost of building an equivalent hydro-electric scheme of the same electricity generation capacity. However, the 467 total number of dams removed last century is equivalent to less than 0.5% of the total stock of significant dams in the US[103]. So

[103] The actual percentage will be lower as not all of the 467 dams would have been classed as significant.

it is likely that these early removals represent the easiest dam removals; being those having lowest costs and high benefits. Since 1999 the cost of dam removals in the US has increased markedly, typically costing 20-40% of new construction costs, excluding the costs of any attendant fisheries rehabilitation. The proportion of significant hydro dam removals is still low, from a large stock of dams; so the removals from 1999 onwards are likely to represent the current lower bound of difficulty, and hence cost.

Removal of the Bull Run hydro scheme, which incorporates a 14m high dam, is underway, and is due for completion in 2009. Also removal of the 38m high Condit Dam, on the White Salmon River in Washington State, has been agreed with the owner; but the project has been long delayed, and faces legal challenges from local governments.

Based on current estimates, the Bull Run and Condit removals are expected to cost 24% and 43% of new construction costs respectively. This probably represents a lower bound for a hydro-electric project removal, as both projects have favourable conditions for sediment management. Also these projects are not completed, so final costs may be a little higher than current projections.

The largest hydro-dams currently planned for removal are the Elwha and Glines Canyon dams in Washington State. The Elwha removals have some unusual features; but, at 181% of the cost of replacement dams, this removal illustrates that decommissioning storage hydro-electric projects with significant sediment issues can be very expensive. The costs of this removal project have been treated in this report as an outlier: that is not considered as representative of typical removal costs. Some possible reasons why this dam removal has proven to be so expensive are discussed in Box 4.

Box 4 – Removal of Dams on the Elwha River

Figure 5.3 Glines Canyon Dam[104]

The 33m high Elwha and 65m high Glines Canyon storage dams produce a combined total of 28 MW of electricity, but they also isolate spawning areas in the headwaters of the Elwha River for several threatened fish species. These privately-owned dams were built in 1910 and 1926, predating formation of the Olympic National Park in which they are now located.

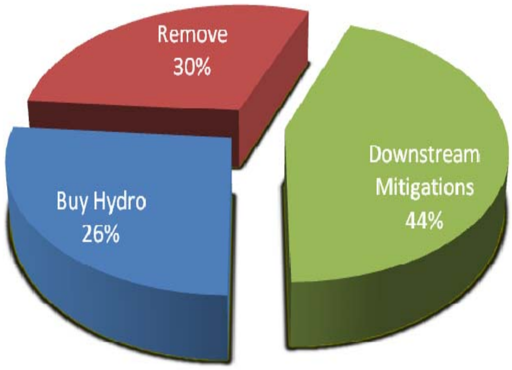
To place these dams in perspective, heights of the eight dams operated by Mighty River Power on the Waikato River range upwards from 34m; but only the 87m high Maraetai dam exceeds the height of the Glines Canyon dam.[105] However, in common with all dams removed in the US, the electrical power output of the Elwha dams is modest: the combined total of 28 MW from the two Elwha dams is just over half of the output of Waipapa, the smallest Waikato dam.

The US National Parks Service is proposing to spend a total of $308 million to purchase and remove both dams by 2012, and has already commenced construction of downstream mitigation works, in preparation for dam removal.[106] The first contracts are for improvements to water supplies to

[104] Photo source: Wikipedia. http://en.wikipedia.org/wiki/Glines_Canyon_Dam. Accessed 28 October 2008.
[105] Waikato dam heights from Might River Power website http://www.mightyriverpower.co.nz/Generation/PowerStations/HydroStations/Default.aspx, accessed 19 October 2008.
[106] Source: US National Park Service Press Release at http://www.nps.gov/olym/parknews/elwha-restoration-project-update.htm

downstream communities, which will be adversely affected by high sediment loads in the first few years after dam removal. In fact the cost of removing the dams and works to stabilise silt in the Elwha reservoirs represents a minority of the overall cost (Figure 5.4). Excluding purchase of the hydro schemes, the estimated cost of the Elwha removal project is 181% of cost of building equivalent new hydro-electric power plants.

Figure 5.4 Breakdown of Elwha Decommissioning Costs



Much of the Elwha project costs are for downstream mitigation works, such as building new water treatment plants to cater for elevated sediment loads and replacing septic tank systems in floodplains, which will now be inundated again. These mitigation works exceed the cost of removing the dams. A major factor is that the proposed sediment management method is to let the river erode the accumulated sediments over a relatively short period of time. Over the first three years following dam removal it is expected that high sediment loads will affect the quality of water supplies for downstream communities and industrial users. Sediment will also temporarily raise the river bed levels, requiring additional flood protection works[107].

This sediment management solution was chosen by the National Parks Service in 1995 because it was cheaper than dredging the reservoirs to remove the sediment. It is not clear why staged removal of the dams over a longer timetable was not evaluated (refer Box 3). The US National Parks Service has an aggressive policy of removing such dams from national parks[108] and the federal declaration of several species of fish present in the Elwha as threatened[109] may have precluded a slower, staged removal process.

5.3 Estimated Costs of Removing Hydro Developments

The costs and difficulties of removing large dams have not been previously been well considered by dam-builders; but more attention is starting to be given to these issues, as illustrated in the following passage from a report for the World Commission on Dams:

> *Most large dams in the world have not yet reached the end of their design life, and the issue of decommissioning is only now being perceived as a major issue. Most dams removed to date have been relatively small scale ..... although larger systems such as the breaching of the lower four dams on the Snake River in the northwest of the US is being considered as a viable alternative to restore salmon runs. What is evident from studies contemplating dam removal or even operating existing dams as a run-of-the-river for parts of the year, is that the potential impacts and costs are very substantial.*[110]

Costs of removing hydro electric projects have been estimated using the US Department of Energy INEEL cost model as described in Section 3. A cost breakdown is presented in Appendix C and is summarised in the following table.

[107] Source: p312 of *Elwha River Restoration Draft Sediment Management and Monitoring Plan*, Appendix B in *Elwha River Ecosystem Restoration Implementation Final Supplement to the Final Environmental Impact Statement*, US National Parks Service, July 2005.

[108] The US National Park Service had removed over 100 dams on NPS land by the turn of the century. Source: *The World's Water 200-2001*, Peter Gleick, Island Press, 2000

[109] Two Elwha fish species listed as threatened at http://www.elwhainfo.org/resource-management/biological-opinions (Bull Trout and Chinook Salmon). Bull Trout (Salvelinus confluentus) was federally listed as threatened in June 1998. Source: *Bull Trout Fact Sheet,* US Fish and Wildlife Service, http://www.fws.gov/oregonfwo/Species/Data/BullTrout. Accessed 9 October 2008.

[110] Goodwin, P. and Falte, M. (2000) *Managing for Unforeseen Consequences of Large Dam Operations, Report Prepared for Thematic Review* IV.5: Operation, Monitoring and Decommissioning of Dams , World Commission on Dams.

Table 5.2 Hydro Decommissioning and Restoration Costs

	Typical Removal and Restoration Costs as Proportion of Construction Cost
Run-of-river hydro	25-50%
Storage hydro	35-150%

The difference between the estimated costs of restoring the two types of hydro schemes is largely driven by sediment management issues. In addition the storage hydro estimate has a much larger contingency sum to allow for mitigation of downstream-community effects, and for situations where a more expensive sediment management solution is required.

5.4 End of Life Scenarios

End of life scenarios and case studies for hydropower projects have been discussed in Section 4. Hydropower facilities have a finite life, and at some stage need to be extensively refurbished or removed. At that stage a feasibility study should be undertaken and the option to remove the facility should be explored.

Removal of dams can have significant consequences for downstream and dependent communities. For these reasons the *World Commission on Dams* recommends that, like construction, dam removal should start with a feasibility study to select the overall best solution, considering economic, environmental, social and political factors.[111]

5.5 Summary of Hydro Reversibility

While a large number of dams have been removed in the United States, this has started from a very large base, in a country with a long history of industrialisation. The removals do not mean that all dams will be removed, or that no new dams are being built in the US, but it does signal a rebalancing of the relative weight given to electricity generation and environmental considerations. Dams removed in the US are typically around 100 years old; the removal of some dams recognises that not all resource decisions made a century ago are wise by modern standards. Fortunately the US experience shows that those decisions can be reversed. So far no insurmountable barriers to dam removal have been identified.

Run-of–river hydro-electric generation projects are relatively easy to remove and restore, and costs are moderate. Although these projects can have long lives, their adverse effects are not permanent and can be reversed, usually within a few years of removal.

Storage hydro schemes have a defined life cycle because they fill up with sediment. The cost of removing a storage hydro dam depends the sensitivity of the downstream environment and users, and whether time can be allowed to gradually remove the dam.

Removing large storage dams is a similar challenge to construction and needs to be approached in a like manner, identifying effects, consulting with affected parties and considering mitigation options. However, with appropriate planning, there are no technical reasons why storage hydro dams cannot be removed.

[111] WCD (2000) *Dams and Development - A New Framework*. The Report of the World Commission on Dams, Earthscan Publications Ltd, London. p.232.

6.0 Reversibility of Geothermal Developments

In this section consideration is given to timescale, significance and cost or removing and restoring geothermal energy developments. Risks are discussed in Section 8.

6.1 Timescale and Significance

The estimated typical timescales for the abatement of adverse effects on ecology and infrastructure are summarised below. Cultural issues are discussed in Section 6.3. For effects classified being of minor significance, the timescale is the typical period over which active management would be required; for effects classified as more-than-minor, this is the time required for effects to abate to minor significance. The exception is natural geothermal features which would not be managed; the timescale listed is a rough indication of how long it may take for some natural surface features in a geothermal field - such as hot springs, hot pools and geysers - to substantially recover.[112]

Table 6.1 Estimated Typical Timescales for Adverse Effects to Dissipate Following Removal and Restoration of Geothermal Power Plant

	Significance of Adverse Effects After Removal	**Treatment**	**Expected Timeframe Until Adverse Effects are Minor**
Subsidence	Medium	Make good adverse effects of subsidence on infrastructure.	Subsidence could continue for a number of decades.
Natural Geothermal Features	Medium	No treatment. Natural geothermal features are somewhat variable. Following cessation of abstraction some natural geothermal features may reform.	Recovery could range from decades up to several hundred years.
Thermal Tolerant vegetation	Medium	No treatment. Assemblages of thermal tolerant vegetation already cope with the variable nature of geothermal activity.	Dependant on timeframe for recovery of natural geothermal features.
Surface Structures	Minor	Remove surface structures, bury foundations, topsoil and plant	Pasture – 2 yrs Native forest – 10 yrs
Transmission lines	Minor	Remove surface structures, leave foundations due to remote access	Pasture – 1 yr Native forest – 5 yrs
Access roads	Minor	Remove embankments and culverts, fill cuttings, grade soil over side slopes, leave steep side cuts across slopes	Pasture – 1 yr Native forest – 5 yrs
Subsurface Raw Steam and Reinjection wells	Minor	Plug through depth, cut off near surface and leave to corrode.	Steel pipes will corrode over decades.
Steam pipelines	Minor	Remove including thrust blocks and foundations, topsoil and plant	Pasture – 1 yr Native forest – 5 yrs

Note: The above significance assessments and timescales are indicative only. Individual projects should be assessed on a case by case basis and may lie outside the range given above.

Most adverse effects will be substantially recovered within two to ten years following removal and restoration. The geothermal resource will be cooled through abstraction, and would normally be expected to gradually recover.[113] The relatively rapid recovery of Pohutu and

---

[112] Mock et all report that steam fields typically recover their heat within a timeframe of 10 times the production period. Source: Mock et al (1997). *Geothermal Energy from the Earth: Its Potential Impact as an Environmentally Sustainable Resource.* Annu. Rev. Energy Envion. 1997, 22:305-56

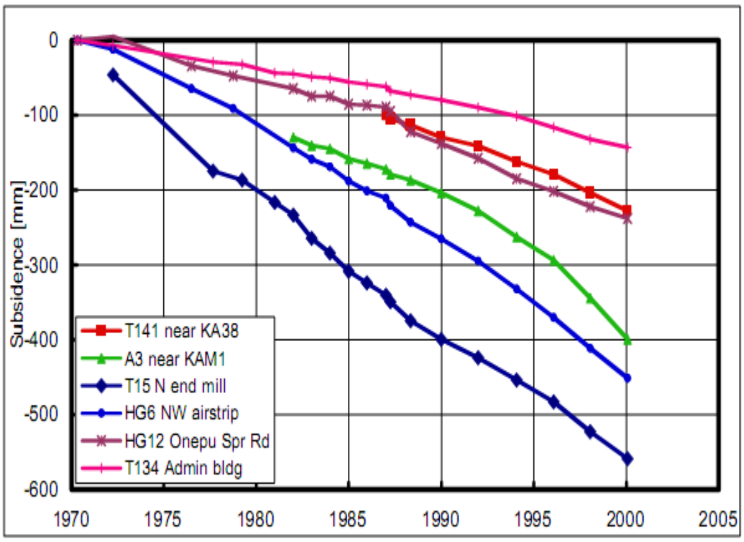
[113] Ibid

other geysers at Whakarewarewa in Rotorua, following closure of nearby steam bores in 1987-1988, shows that some recovery can occur, but that not all surface geothermal features return to their previous state.[114] This and other effects are discussed below.

6.2 Subsidence

When steam and hot fluids are released from the geothermal reservoir, pressure in the reservoir drops. This transfers more load from overlying soils onto the soil/rock structure within the reservoir, and the soil/rock materials slowly deform as a result. This process of creeping deformation leads to slow subsidence at the surface. For example subsidence at the Kawerau steam-field averages around 20mm per year (Figure 6.1), which is typical for geothermal fields around the world.[115]

Figure 6.1 Subsidence at Kawerau Steam-field[116]



Subsidence only becomes a problem if part of a rigid structure subsides more than the rest, if major pieces of machinery need to stay in precise alignment, or if a gravity system - such a drain or sewer - runs at a shallow grade across the subsidence bowl. At Kawerau it is reported that no significant problems have occurred, despite 600mm of subsidence at the pulp and paper mills which have a range of heavy machinery and structures.[117]

Some NZ geothermal fields have abnormally high rates of subsidence by global standards; for example there has been over 14 metres of subsidence at the Wairakei field, since abstraction of steam began in 1958. And at the Ohaaki geothermal field over 5 metres of subsidence is expected, which will eventually lead to inundation of the Te Ohaaki marae by waters of the adjacent Lake Ohakuri. Options to move the marae, and the associated urupa, have been considered.[118]

Reinjection

Subsidence can be reduced, but not eliminated, by reinjecting fluids back into the underlying formations.[119] Originally the Wairakei field operated on the basis of discharging spent geothermal fluids into the Waikato River; but some condensate is now reinjected. Increased rates of reinjection are proposed at the Wairakei field, and it is expected that reinjection of most, if not all, fluids will be the norm for new geothermal power plants. Subsidence is not

[114] Gordon, D. A (2005) Rotorua Geothermal Field Management Monitoring Update, June 2005
[115] Bloomer, A. (2005). *Kawerau Subsidence Interpretation*, Geothermal Engineering Ltd , April 2005.
[116] Ibid. Note that the sharp subsidence at the time of the Edgecombe earthquake has been removed from the plot.
[117] Ibid.
[118] TOMWP (2004). *Working Party Report*, Te Ohaaki Marae Working Party, September 2004.
[119] The reinjection wells need to be carefully sited to avoid quenching the field and to reduce the risk of short circuiting. Often the reinjection wells are located on the edge of the steam field, or in outlying areas, and may not be directly connected to the geothermal field.

reversible. Injecting water, even under considerable pressure will not raise the ground back again, due to irreversible pore collapse in the strata.[120]

Adverse Effects of Subsidence

It can be argued that subsidence is not an adverse effect in itself, as little or no damage occurs if land moves down uniformly. Differential settlement arises when one part of a rigid structure sinks more than other parts, causing cracks and, in severe cases, structural failure. Contact Energy reports that independent monitoring of residential properties in Taupo area has found that the buildings are not being damaged.[121] Should adverse effects arise due to subsidence, they can generally be mitigated by making good any damage. This approach has been taken by the Board of Inquiry to the Te Mihi consents, which recommended consent conditions to mitigate the adverse effects of subsidence.[122]

In some cases subsidence can lead to inundation of land, as at Ohaaki. From a social perspective such subsidence can generally (but not always) be made good by compensation, but some cultural effects may not be capable of redress in this manner.

Subsidence can be expected to continue for some time after the end of abstraction from the steamfield. This poses a potential aftercare issue.

6.3 Cultural Issues

Māori have a close relationship with geothermal areas, having lived there from the earliest days of settlement. Ngāwhā (boiling springs) were used for cooking, and waiariki (warm pools) were used for bathing, laundry and relaxation. The mud from some pools was found to have medicinal properties and vividly coloured clays such as kōkōwai (red ochre) were used as paints and dyes.[123]

The rights of Māori to geothermal energy, and thus to the development of geothermal energy, have been supported in the *Ngawha* and *Te Arawa Geothermal* reports of the Waitangi Tribunal.[124] Māori have retained ownership of land around many geothermal areas. So, irrespective of rights and ownership of the resource, Māori interests will have a pivotal role in development of most of the higher grade geothermal resources.

In the year 2000, the New Zealand Geothermal Association - which represents both Māori and non-Māori interests – identified the following cultural effects of energy production in a submission to government on proposed environmental indicators:[125]

> *The energy indicators for Māori should include the effects on traditional use, land use, land ownership, mauri of geothermal systems from geothermal use, the confiscation of land for energy production, and the effects on the use and mauri of geothermal features from the raising of water levels in hydro lakes.*

The submission went on to state that the following need to be considered:

---

[120] For example refer Bromley, J. (2008) in *EIC for Board Of Inquiry Te Mihi Geothermal Power Station Proposal* . Bromley stated in respect of the Wairakei steam-field that *the subsidence is mostly permanent. Rising pressures will not reinflate the ground surface to any significant degree*.
[121] Source: Contact Energy (undated). *Construction of the new Te Mihi geothermal power station. Information for interested parties.*
[122] Recommended Conditions in Appendix 2 of the *Final Report and Decision of the Board Of Inquiry in respect of the Te Mihi Geothermal Power Station Proposal*, July 2008
[123] Stewart., C. *Hot springs, mud pools and geysers*, Te Ara - the Encyclopedia of New Zealand, updated 5-Nov-2007 URL: http://www.TeAra.govt.nz/EarthSeaAndSky/HotSpringsAndGeothermalEnergy/HotSpringsMudPoolsAndGeysers/en
[124] Waitangi Tribunal (1999). *Radio Spectrum Management and Development Interim Report*. Waitangi Tribunal, 1999.
[125] NZGA (2000) *Submission to Ministry for the Environment on Environmental Performance Indicators Proposal for Indicators of the Environmental Effects of Energy,* June 2000 Draft.

- *the effects on kaitiakitanga of having reduced access to ancestral lands which are being used for electricity generation, and the effect of that use on urupa, waahi tapu, etc.*
- *the effects of hydro dams and geothermal power stations on geothermal features that are used for a variety of tradition uses and that are considered taonga*
- *the effects of land subsidence, the heating or cooling of ground, the formation of tomos*[126] *on land that is traditionally used by Maori*
- *the effects on the future aspirations of Maori from the taking of the geothermal resource (and land) by other parties from areas and geothermal resources that are under claim.*

Some of these concerns reflect historical events: when the Ōhaaki–Broadlands field was drilled, the Ōhaaki–Ngāwhā boiling pool declined. In addition, the Ōrākei Kōrako thermal area was flooded in 1961, when the Waikato River was dammed and Lake Ōhakuri was formed to generate hydroelectricity, drowning two hundred hot springs and 70 geysers.[127]

Māori are not only affected by geothermal development, but have also been active in developing geothermal resources. For instance the Mokai power station - commissioned in 2000 – was the first geothermal power station in New Zealand to be fully owned by a Maori trust (the Tuaropaki Trust).[128]

6.4 Protection of Geothermal Features

The Geological Society of New Zealand undertook an inventory of all New Zealand's geothermal fields, and prioritised sites. Five geothermal fields – White Island (Whakaari), Rotorua, Waimangu, Waiotapu and Ketetahi – were considered to be of international significance, and their complete preservation (including protection from further drilling) was recommended.[129]

Environment Waikato has proposed four categories of protection: 'development', 'limited development', 'research' and 'protected geothermal systems' in a variation to the Regional Plan. This has attracted submissions from both development and preservation interests. The Department of Conservation (DoC) supported the proposed categories, but raised concerns over a number of geothermal features and ecosystems that DoC considered were not provided with adequate protection.[130] In addition, a number of appeals from power companies sought to challenge the protection given to some features and systems. The appeals are still being resolved.

6.5 Costs of Removing Geothermal Developments

Costs of removing geothermal projects have been estimated using the methodology described in Section 3. For geothermal projects the cost estimate has been derived from a detailed breakdown of the costs of establishing the original Wairakei Geothermal energy project near Taupo presented in a 1970 paper by Smith and McKenzie.[131] It would be preferable to use a more recent cost breakdown but such information is rarely published for commercial reasons. The detailed cost breakdown is presented in Appendix C and summarised in the following table.

---

[126] *Tomo*: Caves or sinkholes.
[127] Stewart., C. *Hot springs, mud pools and geyser'*, Te Ara - the Encyclopedia of New Zealand, updated 5-Nov-2007 URL: http://www.TeAra.govt.nz/EarthSeaAndSky/HotSpringsAndGeothermalEnergy/HotSpringsMudPoolsAndGeysers/en .
[128] White. B. (undated). *An Update On Geothermal Energy In New Zealand*, New Zealand Geothermal Association.
[129] Stewart., C. *Hot springs, mud pools and geyser'*, Te Ara - the Encyclopedia of New Zealand, updated 5-Nov-2007 URL: http://www.TeAra.govt.nz/EarthSeaAndSky/HotSpringsAndGeothermalEnergy/HotSpringsMudPoolsAndGeysers/en .
[130] DoC (2007). *Annual Report for year ended 30 June 2007 - Protecting a range of natural heritage*. Department of Conservation, Wellington, 2007.
[131] Smith, J.H. and McKenzie, G.R. (1970). *Wairakei Power Station New Zealand, Economic Factors of Development and Operation,* presented at the UN Symposium in the Development and Utilisation of Geothermal Resources, Pisa, 1970. Published in Geothermics (1970) Special Issue 2.

Table 6.2 Geothermal Decommissioning and Restoration Costs

	Typical Decommissioning and Restoration Costs as Proportion of Construction Cost
Geothermal	10-20%

6.6 End of Life Scenarios

Wairakei geothermal power station at has operated since 1958, and is due to be retired in stages from 2011, with only a low pressure turbine operating from 2016 to 2026.[132] If the Wairakei station closes when the current resource consents expire in 2026, it will have operated for 68 years. Production from Wairakei will be replaced by production from Contact Energy's proposed Te Mihi power station, which will draw steam from the adjacent Te Mihi steamfield.

However geothermal power stations may not last so long if steam is extracted at a high rate. The Geysers Field in California suffered an annual 7-8% decline in power generation over the 1980's and one plant, PG&E Unit No 15, shut down in 1989, after only ten years operation.[133] Where steam resources decline more quickly than expected, the financial viability of the project may be jeopardised.

6.7 Geothermal Summary

The irreversibility of subsidence could put geothermal at a disadvantage compared to other renewable technologies. It could be argued that subsidence per se is not necessarily an adverse effect, and is therefore not subject to Policy 3. But this would most likely to be tested before the courts, which would add to uncertainties and delays. In addition geothermal power developments could have an impact on surface geothermal features for a relatively long time, which may give rise to debate about temporal aspects of reversibility.

It appears that, with the current wording of the NPS Policy 3, geothermal power developments may be caught as "collateral damage", to a policy which appears to have been prompted by disquiet about storage hydro proposals on New Zealand's major rivers. Assuming that the capture of geothermal developments is an unintentional consequence, it would be preferable for the NPS to pre-empt this issue, rather than leave it to the courts to resolve. A small change to the NPS to address these issues is proposed in Section 9.

The other physical effects of geothermal power projects are relatively simple, and quick, to remove and restore. The costs of removal are not high, but may become a burden on future generations, if not provided for by the geothermal plant owner before the resource declines.

Māori have long-standing relationships with geothermal resources, and have retained land ownership around many geothermal areas. That places Māori in a position of being affected by development of geothermal resources, but Māori are also taking the opportunity to have a direct role in renewable energy developments.

[132] Contact Energy (undated). *Construction of the new Te Mihi geothermal power station. Information for interested parties*

[133] A key issue at the Geyser field has been the loss of fluids from the geothermal system. In 1997 a 47 km pipeline was completed to bring treated effluent for injection back into the field to arrest the annual decline of 7-8% that had been experience to that point – Source: Mock et al (1997).

7.0 Reversibility of Wind Energy Developments

In this section consideration is given to timescale, significance and cost of removing onshore wind development. Risks are discussed in Section 8.

7.1 Timescale and Significance

The estimated typical timescales for adverse effects of wind farms to abate are summarised below. Timescale is the typical period over which active maintenance and management would be required.

Table 7.1 Estimated Typical Timescale for Adverse Effects to Dissipate Following Removal and Restoration of Wind Farm

	Significance	Treatment	Timescale
Surface Structures	Minor	Remove surface structures, bury foundations, topsoil and plant	Pasture – 2 yrs Native forest – 10 yrs
Transmission lines	Minor	Remove surface structures, leave foundations due to remote access	Pasture – nil Native forest – 5 yrs
Access roads	Minor	Remove embankments and culverts, fill cuttings, grade soil over side slopes, leave steep side cuts across slopes	Pasture – nil Native forest – 5 yrs

Note: The above significance assessments and timescales are indicative only. Individual projects should be assessed on a case by case basis and may lie outside the range given above.

The Irish Wind Energy Association recommends similar restoration treatments upon removal of a wind farm.[134] In the above assessment, all of the adverse effects are rated as minor. These effects are expected to have substantially recovered, and no longer require management, within 2 to10 years.

7.2 Estimated Costs of Removing Wind Farms

Costs of removing wind farms have been estimated using the methodology described in Section 3. For wind farms the cost estimate has been derived from a cost estimate for a 5MW wind farm published by the British Wind Energy Association.[135] It would be preferable to have a cost estimate for a larger wind farm; but cost estimates are rare on the public record for commercial reasons.

The cost of dismantling will be partly offset by the value of the recovered materials. The Irish Wind Energy Association comments that the turbine itself will often have a scrap value that will cover the costs of ground restoration.[136] That may well be correct; but there are other costs associated with removal and restoration, and it is estimated that there will be a small

---

[134] IWEA. *What Happens When a Wind Farm is Taken Down/ Decommissioned?,* Irish Wind Energy Association. http://www.iwea.com/index.cfm/page/planning_regulationsandadminis?#q78, accessed 13 October 2008

[135] BWEA (2007), *The Economics of Wind Energy*, British Wind Energy Association. http://wwww/bwea.co/ref/econ/html, accessed 3 October 2008

[136] IWEA. *What Happens When a Wind Farm is Taken Down/ Decommissioned?,* http://www.iwea.com/index.cfm/page/planning_regulationsandadminis?#q78, accessed 13 October 2008

net cost to remove and restore the site, especially if roads are removed and restored (Table 7.2).

Table 7.2 Onshore Wind Farm Decommissioning and Restoration Costs

	Typical Decommissioning and Restoration Costs as Proportion of Construction Cost
Onshore Wind Farm	4-8%

7.3 End of Life Scenarios

The turbines at a new wind farm would be expected to have life of around 15-25 years.[137] As turbines begin to fail more frequently towards the end of their life, the wind farm operator would need to decide whether to refurbish the turbines, reconstruct the wind farm, or close it.

Turbines could be operated until they fail, leading to a gradual abandonment of the wind farm. This is not unique to wind farms: similar scenarios apply to other renewable technologies, but the scrap value of masts and turbines mean that abandonment is unlikely.

It is possible that some wind farms will prove to be marginal for wind speed and turbine reliability, and consequently a private wind farm developer may go into receivership. While a receiver would probably keep the wind farm operating in the short term, turbines could be sold, leaving the masts behind; but again the masts have scrap value that would at least partly offset dismantling costs.

Well-sited wind farms are likely to be refurbished and reconstructed over time with more efficient plant.

7.4 Summary of Wind Farm Reversibility

Onshore wind farms are relatively simple, cheap and quick to remove and restore. Due to the scrap value and relatively low costs of removal, onshore wind farms are unlikely to pose a significant burden for future generations to bear.

[137] Source *Guidelines for Local Authorities: Wind Power*, NZ Energy Efficiency and Conservation Authority, 2004, p.12.

8.0 Risks and Bonds

8.1 Risks

Most elements of removing renewable energy projects have low risk, but three items with potentially higher risks are discussed below.[138]

Hazardous Waste Disposal

Demolition of power generation facilities will generate some hazardous waste. Recycling and disposal systems are now well established for most hazardous wastes found in power stations. Where practical, owners have already removed many hazardous materials, such as asbestos and PCB's. The quantities of hazardous materials should be small, found in specific equipment such as circuit breakers, and appropriate management of these items could manage the risk. Overall this risk is rated as being likely, but of minor magnitude.

Removal of Earth Dams

All of the notable dam failures over the last thirty years in New Zealand history have involved earth dams or earthen canal structures.[139] The Opuha Dam in South Canterbury, was overtopped and failed in 1997, following heavy rain during construction. Overtopping of any dam is undesirable and likely to cause damage, but overtopping an earth dam creates a risk of dam failure.

Overtopping may also occur during dam removal, and an earth dam is vulnerable if a major storm occurs in the upstream catchment during a critical phase. The risk may be increased if the dam is removed in stages, to control sediment releases downstream. Similar techniques to the construction phase can be used to manage the risk, so failure during earth dam removal is rated as of major consequence, but unlikely.

Sediment Management

Sediment management is recognised as an important issue - generally the most important issue.[140] However, even with a well managed sediment programme, there is a risk of an unanticipated adverse outcome, such as abnormally high levels of sediment discharge. For this reason unplanned sediment discharges from storage hydro removals are rated as a likely risk. Because the effects are likely to be temporary, the consequence is rated as moderate.

Risk Treatments

The above items are assessed as 'high' using the ERMA risk matrix in Appendix D.[141] Such a rating is unlikely to be socially acceptable, and additional risk treatments would be required to reduce the risks to an acceptable level. Such risk treatments could include:

- removal of hazardous wastes as a separate contract before general demolition
- explicit risk assessments and peer review of dam removal

---

[138] Refer Table 2.2 for definition of risk.
[139] Ruahihi (canal failure), Whaeo (canal head pond failure), Opuha dam (overtopping).
[140] ASCE Task Committee on Guidelines for Retirement of Dams and Hydroelectric Facilities (1997). *Guidelines for Retirement of Dams and Hydroelectric Facilities*. American Society of Civil Engineers. Publisher: ASCE, New York.
[141] ERMA (2004). *Decision Making : A Technical Guide to Identifying, Assessing and Evaluating Risks, Costs and Benefits* , NZ Environmental Risk Management Authority, March 2004.

- staged removal of dams combined with intensive monitoring to enable an adaptive management approach to sediment removal.

Such risk treatments should move the risks to a medium rating, which is acceptable.

Risk Summary

In summary there are risks of adverse environmental effects associated with removing all renewable energy projects. Removing storage hydro projects has intrinsically more risk than removing other renewable projects, and would require greater attention to risks. However the risks are manageable, and it is expected that risk assessment would be part of the feasibility studies undertaken prior to the removal of a storage hydro.

8.2 Bonds

Another risk with such long-lived facilities is that the facility owner will no longer be solvent when the time comes to remove the facility, and to restore the site. This has proven to be an issue with some old dams in the United States. Some commentators have observed that, given that storage dams have a finite useful life, intergenerational equity considerations require that adequate measures are taken to provide for retirement of the facility.[142] A possible mechanism is for consent conditions to require that a bond be provided under section 108A of the Resource Management Act.

The removal and restoration of renewable facilities such as storage hydro dams is conceptually similar to the closure and aftercare of a landfill. Bonds are already required of private landfill operators in New Zealand to meet the costs associated with an environmental incident, closure and aftercare. [143] [144] Bonds have also been required for renewable energy developments. An example is the $5m bond recommended by the Board of Inquiry for the Te Mihi geothermal project, in respect of monitoring of subsidence and remediation of subsidence-related damage.[145]

Financial instruments can take a variety of forms, and the optimum form may vary over the life of a project. The value of the bond would need to be determined on a project specific basis. Costs to remove and restore sites are difficult to predict at present due to the limited amount of practical experience, especially with decommissioning large storage dams.[146] To allow for changes in removal technologies, and other factors, it is recommended that the bond amount is reviewed regularly.[147]

The purpose of this discussion is not to suggest the widespread application of bonds to renewable energy projects, but to observe that, if intergenerational equity of remediation costs proves to be a regulatory concern, then the consent authority can address this by requiring a bond.

[142] Palmieri, A., Shah, F., and Dinar, A. (2001). *Economics of Reservoir Sedimentation and Sustainable Management of Dams*. Journal of Environmental Management, 2001, 61, pp149-163.
[143] For instance a bond for the Greenmount landfill was initially set at $2.1 million, rising to $12.6 million in 1994 dollars at a rate of $3 for each tonne of refuse deposited. Source: Manukau District Plan, Chapter 10, Waste Management.
[144] Guidance on this use, including examples of bond conditions, are available from the Ministry for the Environment . Refer MfE (2001). *Guide to Landfill Consent Conditions,* Ministry for the Environment, May 2001
[145] Recommended Condition 7 in Appendix 2 of the *Final Report and Decision of the Board Of Inquiry in respect of the Te Mihi Geothermal Power Station Proposal*, July 2008.
[146] WCD (2000) *Dams and Development - A New Framework*. The Report of the World Commission on Dams, Earthscan Publications Ltd, London. p.185.
[147] For example reviews could be on say a 10 yearly basis, with annual inflation indexing in the interim.

9.0 Summary and Conclusions

9.1 Findings

This report has examined a number of propositions in relation to the reversibility of renewable energy developments, as summarised in Table 9.1 below.

Table 9.1 Summary of Findings

	Proposition	Finding
1	Hydro electric dams are permanent.	Hydro schemes are usually designed for a 100 year life and can last significantly longer. Storage hydro schemes have a life cycle which is governed by the rate at which sediment from the upstream catchment fills the reservoir.
2	Hydro-electric projects are functionally irreversible.	In New Zealand no dam or hydro–electric scheme is expected to be functionally irreversible, given the application of enough effort and time.
3	The adverse effects of hydro-electric generation are permanent or functionally irreversible.	Most adverse effects of hydro-electric projects are reversed within a few years of removing the structures. Sedimentation effects may last longer but generally are at their peak within a few years of dam removal and decline thereafter.
4	Removal and restoration of storage hydro-electric projects is an unreasonable burden for future generations.	Storage hydro schemes can be expensive to remove and restore; but this should not present a fundamental barrier. Where intergenerational equity issues are a concern, a bond can be required under s.108A of the Resource Management Act.
5	Renewable technologies have different degrees of reversibility.	Hydro-electricity, geothermal and onshore wind technologies have the same degree of reversibility: they are all completely reversible.
6	The adverse effects of geothermal power development are reversible.	Geothermal power production leads to permanent subsidence of land. This is not generally an environmental issue; but there is a need to address the risk of damage to infrastructure during the life of the project, and for a period of aftercare. Because these adverse effects can be made good it is considered that the adverse effects of geothermal power developments are reversible, even though subsidence is permanent.

In summary this report has found that, with the exception of some geothermal effects, all of the renewable technologies have the same degree of reversibility of adverse effects. Where the technologies differ is with respect to the ease of reversing adverse effects (Table 9.2):

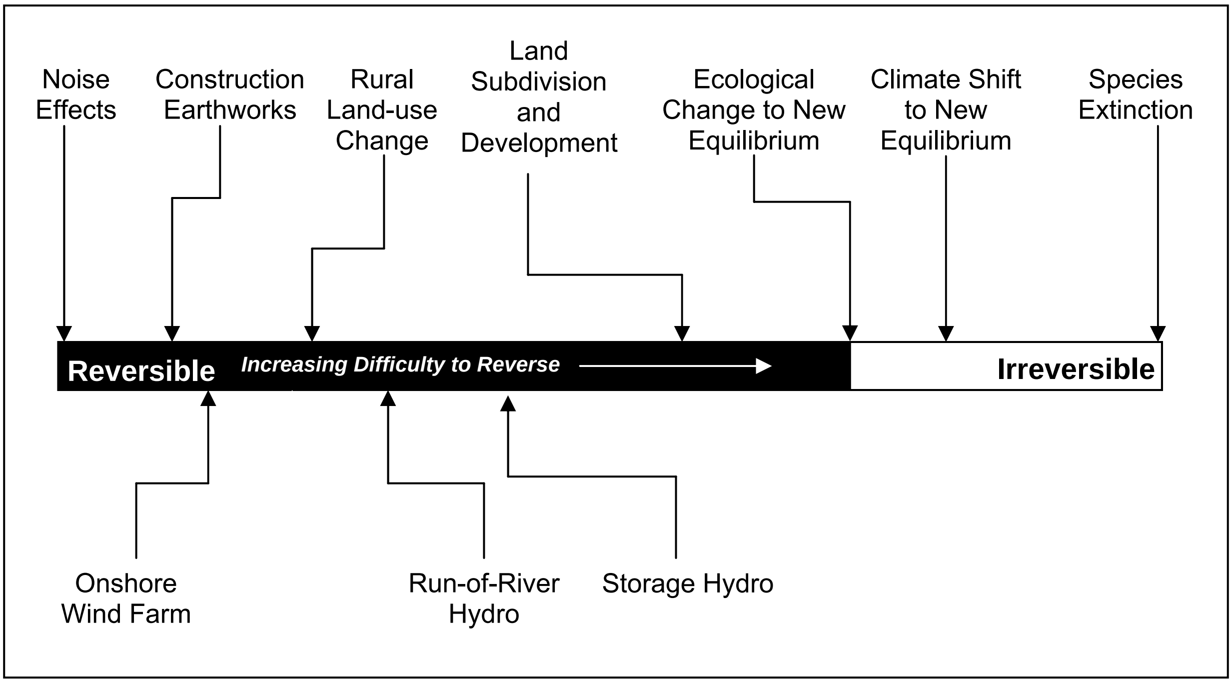
Table 9.2 Summary – Ease of Reversing Adverse Effects of Renewable Electricity Technologies

	Timeframe for Reversal of Significant Effects	**Environmental Risk Following Removal**	**Typical Decommissioning and Restoration Costs as Proportion of Construction Cost** (Note 1)
Onshore Wind Farm	Short	Low	4 - 8%
Geothermal	Short for local effects (Refer Note 2)	Low	10 - 20%
Run of River Hydro	Short to Moderate	Low	25 - 50%
Storage Hydro	Moderate	Medium (refer Note 3)	35 - 150%

Notes:
1. This table provides an indication of the relative costs of removing and restoring renewable energy projects derived on a comparable basis. Actual project costs should be determined on a case by case basis and, in some cases, may lie outside the ranges given.
2. Timeframe for reversal of geothermal steam-field related effects is moderate to long. Subsidence is not reversible.
3. Assumes that risk treatments will be implemented to manage hydro storage risks to not more than medium rating.

The relative ease of reversing adverse effects of onshore wind and hydro renewable energy technologies is illustrated in Figure 9.1.

Figure 9.1 Relative Ease of Reversing Wind and Hydropower Renewable Energy Technologies



9.2 Wording of NPS

1. If it is accepted that reversibility is a valid concept to apply to renewable energy development approvals, then it is recommended that Policy 3 is reworded as:[148]

   When considering proposals to develop new renewable electricity generation activities, decision-makers must have particular regard to the ~~relative degree~~ <u>ease</u> of reversibility of the adverse environmental effects associated with <u>the</u> proposed generation <u>development</u> ~~technologies~~.

   The reasons for the proposed changes are summarised below.

	Proposed Change to Policy 3	**Reason**
1	Replace *degree* of reversibility with *ease* of reversibility.	All the current main renewable technologies have the same degree of reversibility, but differ in ease of reversibility.
2	Replace consideration of reversibility of adverse effects at a technology scale, with consideration of reversibility of adverse effects for the specific development.	Adverse effects will not only differ between technologies, but also between sites. While some broad conclusions can be drawn at a technology level, the ease of reversing adverse effects can differ markedly between projects of the same technology (eg hydroelectric schemes). It would be more accurate, and simpler, to consider the reversibility of adverse effects on a site-specific basis for a particular proposal.
3	Remove *relative*.	Removing redundant term improves clarity.

[148] Additions <u>underlined</u>, removals marked with ~~strikethrough~~.

2. If it is intended to avoid collateral damage to geothermal energy developments from Policy 3, then it is recommended that the following definitions are added to the NPS:

"Reversibility of adverse environmental effects" *in relation to the abstraction, use and disposal of geothermal fluids in geothermal development areas excludes subsidence, effects on geothermal resources and effects on surface geothermal features.*

"Geothermal development areas" *are geothermal resources that are identified in a Regional Plan as being suitable for geothermal energy development.*

The reasons for the proposed changes to the NPS definitions are:

	Proposed Change to Definitions in NPS	**Reason**
1	Define adverse effects in relation to the NPS.	Avoids capture of irreversible effects of geothermal energy developments by Policy 3.
2	Define geothermal development areas.	Limits the breadth of the reversibility-of-adverse- effects definition to only those geothermal resources identified by the regional council concerned as being suitable for development. This will encourage regional councils to classify geothermal resources for protection, and for development; thus clarifying the consenting regime.

Appendix A

Proposed National Policy Statement for Renewable Energy Generation

Preamble

This national policy statement sets out an objective and policies to enable the sustainable management of renewable electricity generation under the Resource Management Act 1991 ('the Act').

New Zealand's energy demand has been growing steadily and is forecast to continue to grow. In October 2007 the government adopted the New Zealand Energy Strategy, which states that New Zealand must confront two major energy challenges as it meets growing energy demand. The first is to respond to the risks of climate change by reducing greenhouse gas emissions caused by the production and use of energy. The second is to deliver clean, secure, affordable energy while treating the environment responsibly.

The contribution of renewable electricity generation, regardless of scale, towards addressing the effects of climate change plays a vital role in the wellbeing of New Zealand, its people and the environment. In considering the risks and opportunities associated with various electricity futures, the government has determined that 90 per cent of electricity generated in New Zealand should be derived from renewable energy sources by 2025 (based on delivered electricity in an average hydrological year).

Development that increases renewable electricity generation capacity can, however, have environmental effects that span local, regional and national scales, often with adverse effects manifesting locally and positive effects manifesting nationally. In some instances the benefits of renewable electricity generation can compete with matters of national importance as set out in section 6 of the Act, and with matters to which decision-makers are required to have particular regard under section 7 of the Act. In particular, the natural resources from which electricity is generated can coincide with areas of significant natural character, significant amenity values, historic heritage, outstanding natural features and landscapes, significant indigenous vegetation and significant habitats of indigenous fauna. Adopting a nationally consistent approach to balancing the competing values associated with the development of New Zealand's renewable energy resources will provide greater certainty to decision-makers, applicants, and the wider community.

Title

This national policy statement may be cited as the National Policy Statement for Renewable Electricity Generation.

Commencement

This national policy statement comes into force on the day after which it is notified in the Gazette.

Matter of national significance

The matter of national significance to which this national policy statement applies is the need to develop, upgrade, maintain and operate renewable electricity generation activities throughout New Zealand.

Objective

To recognise the national significance of renewable electricity generation by promoting the development, upgrading, maintenance and operation of new and existing renewable electricity generation activities, such that 90 per cent of New Zealand's electricity will be generated from renewable sources by 2025 (based on delivered electricity in an average hydrological year).

Recognising the national significance of the benefits of renewable electricity generation activities

Policy 1

The benefits of renewable electricity generation activities, at any scale, are of national significance. Decision-makers must have particular regard to the national, regional and local benefits relevant to renewable electricity generation activities. These benefits may include, but are not limited to:

i. maintaining or increasing electricity generation capacity while avoiding, reducing or displacing greenhouse gas emissions

ii. maintaining or increasing security of electricity supply at local, regional and national levels by diversifying the type and/or location of electricity generation.

Acknowledging the practical constraints associated with the development, upgrading, maintenance and operation of new and existing renewable electricity generation activities

Policy 2

When considering measures to avoid, remedy or mitigate the adverse environmental effects of renewable electricity generation activities, consent authorities must have particular regard to the constraints imposed on achieving those measures by:

i. the nature and location of the renewable energy source

ii. logistical or technical practicalities associated with developing, operating or maintaining the proposed renewable electricity generation activity

iii. the nature and location of existing renewable electricity generation activities

iv. the location of existing structures and infrastructure including, but not limited to, roads, navigation and telecommunication structures and facilities, the local electricity distribution network, and the national grid.

Having regard to the relative reversibility of adverse effects associated with particular generation types

Policy 3

When considering proposals to develop new renewable electricity generation activities, decision-makers must have particular regard to the relative degree of reversibility of the adverse environmental effects associated with proposed generation technologies.

Enabling identification of renewable electricity generation possibilities

Policy 4

By 13 March 2012, local authorities are to notify, in accordance with Schedule 1 of the Act, a plan change, proposed plan or variation to introduce objectives, policies and, where appropriate, methods, into policy statements and plans to enable activities associated with:

the identification and assessment by generators of potential sites and energy sources for renewable electricity generation

research-scale investigation into emerging renewable electricity generation technologies and methods.

Supporting small and community-scale renewable electricity generation

Policy 5

By 13 March 2012, local authorities are to notify, in accordance with Schedule 1 of the Act, a plan change, proposed plan or variation to introduce objectives, policies and, where appropriate, methods, into policy statements and plans to enable activities associated with the development and operation of small and community-scale distributed renewable electricity generation.

Interpretation

In this national policy statement, unless the context otherwise requires:

"**Act**" means the Resource Management Act 1991.

"**Application**" means any application for resource consent or consents or application under section 127 of the Act. Applicant has the corresponding meaning.

"**Decision-makers**" means all persons exercising functions and powers under the Act.

"**Local electricity distribution network**" means the system of electricity conveyance that connects individual electricity users with the national grid and electricity generation facilities.

"**National grid**" means the assets used or owned by Transpower NZ Limited.

"**Renewable electricity generation**" means generation of electricity from solar, wind, hydro, geothermal, biomass, tidal, wave, or ocean currents resources.

"**Renewable electricity generation activities**" means the construction, operation and maintenance of structures associated with the generation of renewable electricity. This includes small and community-scale distributed renewable generation activities and the system of electricity conveyance required to convey electricity to the local electricity distribution network and/or the national grid.

"**Small and community-scale distributed renewable electricity generation**" means renewable electricity generation projects with an installed electricity generation capacity of less than four megawatts and excludes offshore wind, tidal and wave generation.

Explanatory note

This note is not part of the national policy statement but is intended to indicate its general effect.

This national policy statement comes into force on the day after which it is notified in the Gazette. It provides that renewable electricity generation is a matter of national significance under the Resource Management Act 1991.

This national policy statement is to be applied by all persons exercising powers and functions under the Act. The objective and policies are intended to guide applicants and decision-makers when making applications for resource consent, in making decisions on the notification and determination of resource consent applications, in drafting policy statements and plans that relate to renewable electricity generation activities, and when exercising other powers under the Act.

The national policy statement requires local authorities to give effect to its provisions in plans made under the Resource Management Act 1991 by initiating a plan change, proposed plan or variation by 13 March 2012.

Appendix B

Restoration Treatments

Roads

It is most likely that roads will remain. This is principally because they have utility beyond the project, but road removal has been considered to address situations where removal would be appropriate. Where road removal is undertaken, it has been assumed that road embankments and culverts will be removed and cuttings filled. Where roads sidle across steep slopes it has been assumed that the road base would and road furniture would be removed. Over time soil and debris would fall down from the slope above, gradually filling over the road bench.

Landscape

It is assumed that landscape restoration would consist of:

- placing excess fill to create a natural appearance to the landform (not necessarily to exactly recreate the landform prior to the project)
- re-topsoiling
- planting with vegetation to replace pre-development vegetation, or to match surrounding areas
- maintenance for approximately 5-10 years to control weeds.

Adequate quantities of topsoil are seldom conserved in construction projects: so it is likely that topsoil and subsoil applied for landscaping will be thin. This factor has been taken into account in the assessment.

Run-of-River Hydro Reservoir

It is assumed that no restoration of reservoir areas will be required for run-of-river projects; on the basis that the volume of sediment stored behind a run-of-river diversion weir is unlikely to be large, and that the area of the reservoir will be small.[149]

Storage Hydro Reservoir

Upon removal of a storage dam, a major objective is to manage the discharge of sediment accumulated in the reservoir, so that the downstream ecology does not suffer significant adverse effects. It is assumed that the sediment will be managed by a combination of:

- staged removal; that is removing the dam in layers over a number of years so as to release sediment more gradually[150]
- some, albeit limited, mechanical movement of sediment
- limited works within the reservoir where rates of erosion are excessive
- seeding and limited planting of the reservoir

Under this approach most, if not all, of the stored sediment will eventually pass down the river, as would have occurred if the dam had never been built. It is assumed that active monitoring and management of the reservoir sediment, and weed control will be required for 10 years after dam removal.[151]

---

[149] Poff et al (2002) report that in the US where the volume of accumulated sediment is similar to the average annual sediment load no special management measures are employed and the sediments are allowed to move downstream following dam removal.

[150] For example, at the Stronach Dam on the Pine river in Michigan the powerhouse was removed and stoplogs were inserted, with one 150mmm stoplog being removed each 3 months until the river was back down to its natural level. Source: Morris, G.L. and Fan, J. *Reservoir Sedimentation Handbook*, McGraw-Hill, 1997.

[151] In some cases management may be required for longer periods.

Appendix C

Cost Data and Estimates

US Case Histories in Hydropower Dam Removals

River	Dam	Height	Installed Capacity	Built	Removal Start	Removal Complete	Removal Cost	Date of Removal Cost	USACE Dam Cost Index in Year of Costing or Removal	USACE Dam Cost Index in 2008	Inflation Factor Since Removal	Removal Cost Inflated to 2008 using USACE Index	Estimated 2008 Construction Cost	Ratio Removal to Construct Cost	Notes
		(m)	(MW)				$USm						$USm		
Historical															
Clearwater	Lewiston	14	10	1927	1973	1973	0.6	1973	149	685	459%	2.9	47	6%	
Hudson	Fort Edwards	10	2.85	1898	1973	1973	0.4	1973	149	686	459%	2.0	17	12%	Cost excludes clean up of sediment problems after removal.
Willow	Mound	18	0.4	1924	1992	1992	0.17	1992	410	685	167%	0.3	7	4%	
Clyde	Newport No 11	6	1.8	1957	1996	1996	0.6	1996	460	685	149%	0.8	12	7%	
Pine	Stronach	5	2	1912	1996	2003	0.8	1996	460	685	149%	1.1	12	9%	
Willow	Willow Falls	18	1	1925	1998	1998	0.6	1998	479	685	143%	0.9	20	4%	
Kennebec	Edwards	7	3.5	1837	1999	1999	3.0	1999	488	685	140%	4.2	19	22%	Excludes $4.85m fish restoration programme.
Rappahannock	Embrey	7	6	1853	2004	2004	10.0	2004	567	685	121%	12.1	31	39%	
Sturgeon	Sturgeon	16	0.8	1919	2003	2007	2.0	2007	667	685	103%	2.1	6	34%	
Underway															
Sandy	Marmot & Little Sandy	14	22	1912	2007	2009	17.06	2002	519	685	132%	22.5	92	24%	Bull Run Hydro Scheme
Elwha	Elwha and Glines Canyon	65	28.1	1910 & 1926	2008	2012	227.0	2008	685	685	100%	227.0	126	181%	Excludes purchase of power plants.
Planned															
White Salmon	Condit	38	14.7	1913	2009	2009	17.5	1999	488	685	140%	27.8	65	43%	Includes for additional $3.3m agreed on 2005 for licencing costs.
Data															
Elwha	Glines Canyon	65	13.3	1926		2012							60		
Elwha	Elwha	33	14.8	1910		2012							66		

Notes

1 Project data compiled from a wide range of sources. In most case muliple sources of data were requierd for each project. Where possible original data sources were used.

2 Projects selected are largest US hydropower dam removal projects for which infomation is available in the litereature.

3 Construction cost estimated from *Estimation of Economic Parameters of U.S. Hydropower Resources* , Idaho National Engineering and Environmental Laboratory, US Dept of Energy, June 2003.

4 Dam construction cost index from USACE (2008). Civil Works Construction Cost Index System (CWCCIS), EM 1110-2-1304, US Army Corps of Engineers, 31 March 2000 (31 March 2008 udate)

Removal and Restoration of Hydro Facilities

INEEL Cost Model for Undeveloped Site		Storage Hydro				Run of River Hydro			
Site Information		Cost in Local Currency at Time of Construction	Cost of Item as Proportion of Total Construction Cost	Remove and Restore as Proportion of Initial Construction Cost for this Item	Remove and Restore as Proportion of Overall Initial Construction Cost	Cost in Local Currency at Time of Construction	Cost of Item as Proportion of Total Construction Cost	Remove and Restore as Proportion of Initial Construction Cost for this Item	Remove and Restore as Proportion of Overall Initial Construction Cost
Installed Capacity (MW)	30.000								
APR Finance Rate	5.0%								
Finance Period (yrs)	30								
Construction Year	2,008								
Development Costs									
Cost Escalation factor from 2002	15.97%								
Consents	$7,649,938	$7,649,938	6%	0.25	1.6%	$7,649,938	6%	0.10	0.6%
Construction Cost	$81,708,316	$81,708,316	68%	0.30	20.5%	$81,708,316	68%	0.40	27.3%
Fish & Wildlife Mitigation	$9,413,287	$9,413,287	8%	0.25	2.0%	$9,413,287	8%	0.05	0.4%
Recreation Mitigation	$7,539,839	$7,539,839	6%	0.02	0.1%	$7,539,839	6%	0.01	0.1%
Historical & Archaeological	$1,342,365	$1,342,365	1%	0.20	0.2%	$1,342,365	1%	0.20	0.2%
Water Quality Monitoring	$2,071,746	$2,071,746	2%	2.00	3.5%	$2,071,746	2%	0.25	0.4%
Fish Passage	$10,126,852	$10,126,852	8%	0.20	1.7%	$10,126,852	8%	0.05	0.4%
Reservoir Stabilisation	$0	Note 1		0.10	6.8%			-	0.0%
Reservoir Replanting and Weed Control	$0	Note 1		0.05	3.4%			-	0.0%
Downstream sediment mitigations		Note 1		0.10	6.8%			-	0.0%
Plant Construction Cost	$119,852,342	$119,852,342	100%		47%	$119,852,342	100%		29%
									say 10-30%
		Contingency		50%	23.3%	Contingency		25%	7.4%
				Total	70%				37%
					Say 35% - 150%				Say 25% -50%

Notes

1. Cost applied as a proportion of the construction cost line item
2. Base costing Spreadsheet from *Estimation of Economic Parameters of U.S. Hydropower Resources* *INEEL - June 2003*

Removal and Restoration of Geothermal Power Plant

	Construction activity	Reinstatement Activity	Cost in Local Currency at Time of Construction	Cost of Item as Proportion of Total Construction Cost	Reinstatement cost as Proportion of Initial Construction Cost for this Item	Reinstatement cost as Proportion of Overall Initial Construction Cost
Site Preparation	Clear land of vegetation	Replace topsoil and replant	393	1%	5.00	5.0%
Establishment	Set up construction site offices and services	Remove above ground services	1803	5%	0.02	0.1%
Power Stations Civil	Construct of concrete and steel	Remove above ground structures and bury foundations. Topsoil and plant.	4674	12%	0.10	1.2%
Power Stations M&E	Install plant	Net cost to remove plant and sell for scrap.	9859	25%	0.02	0.5%
Power Transmission	Install towers, switchyard, tansformers, conductors	Net cost to remove above ground elements, sell for scrap. Leave foundations.	2193	6%	0.02	0.1%
Cooling Water	Install pumps and pipes	Remove above ground elements for scrap. Fill over foundations.	1881	5%	0.05	0.2%
Steamfield wells	Install wells. Locate and properly plug wells fallen into disuse.	Mobilise drill rig, plug wells, cut off several metres below gorund and fill over.	7643	20%	0.10	2.0%
Steamfield pipes	Install pumps and pipes	Remove above ground elements for scrap. Fill over foundations.	7867	10%	0.05	0.5%
Steamfield Roads and other Civil	Install roads, drainage and other.	Remove above ground elements, embankments and culverts. (Topsoil and planting incl in site prep item).	2971	8%	0.25	1.9%
			39284	91%		11.5%
Contingency	25%					2.9%
Excludes village hot water scheme and land costs					**Total**	**14.4%**
					Say	**10 - 20%**

Notes :

1. Based on cost of original Wairakei development. Excludes village hot water scheme and land costs.
2. Costing source: Smith, J.H. and McKenzie, G.R. (1970). *Wairakei Power Station New Zealand, Economic Factors of Development and Operation,* presented at the UN Symposium in the Development and Utilisation of Geothermal Resources, Pisa, 1970. Published in Geothermics (1970) Special Issue 2.

Removal and Restoration of Onshore Wind Farm

	Construction activity	Reinstatement Activity	Cost in Local Currency at Time of Construction	Cost of Item as Proportion of Total Construction Cost	Reinstatement cost as Proportion of Initial Construction Cost for this Item	Reinstatement cost as Proportion of Overall Initial Construction Cost
Civil Works	Roads, access and platforms for turbines	Replace topsoil and replant	393	13%	0.25	3.3%
Turbines	Ship to site and erect	Net cost of turbine removal by crane and sale for reuse or scrap		64%	0.01	0.6%
Electrical Infrastructure at Site	Install cables, transformers, switchyard	Remove above ground services	1803	8%	0.02	0.2%
Grid Connection on Pylons	Install towers, switchyard, transformers, conductors	Net cost to remove above ground elements, sell for scrap. Leave foundations.	4674	6%	0.02	0.1%
Project Management	Management	Management	9859	1%	0.10	0.1%
Installation	Install wind turbines	Drop turbine towers to ground with explosives.	2193	1%	0.25	0.3%
Insurance, Legal , Bank Fees, Interest and Development Costs				7%	0.05	0.4%
			18922	100%		4.9%
Contingency	25%					1.2%
					Total	**6.1%**
					Say	**4 - 8%**

Notes
1. Costing source: BWEA (2007), The Economics of Wind Energy, British Wind Energy Association. http://wwww/bwea.co/ref/econ/html
2. © SPX Consultants limited, October 2008.

Elwha Decommissioning Costs

1. Costs at Feb 2008

Source: US National Park Service Press Release at http://www.nps.gov/olym/parknews/elwha-restoration-project-update.htm

Item	Cost $m	
Total Project	308	
Port Angeles Water Treatment	24.5	
Elwha Water Facilities	69.6	
Total WTP		94.1

Note: Only a partial breakdown of current costs is available.

2. Compare to 1996 EIS Costs

Source : Final EIS -Elwha River Ecosystem - Restoratation Implementation, USNPS, 1996

	A	B	C	B
Item	**Cost $m**	**Subtotal**	**Escalated C**	**Subtotal**
Escalation Multiplier	**1.00**		**2.72**	
Buy Hydro Scheme	29.8		81.1	
Subtotal - Buy Hydro		29.8		81.1
Decommission and remove hydro	28.15		76.6	
Sediment Monitoring	2.15		5.8	
Revegetation and Wildlife	3.2		8.7	
Subtotal - Project Works		33.5		91.1
Flood Protection	4.4		12.0	
Water Treatment Plants	33		89.8	
Fish Mgmt and Hatchery Expansions	6.9		18.8	
Tribal Works	0.7		1.9	
WTP O&M	4.9		13.3	
Subtotal - Downstream Communities		49.9		135.7
Total	**113.2**	**113.2**		**307.9**
Refer	Note 1		Note 2	

Notes

1. The WTP have escalated by multiplier of 2.85
2. Overall project has escalated by multiplier of 2.72 which is very similar.
3. In the absence of current detailed cost breakdown assume that the cost breakdown is similar to 1996. Refer columns C and D above

3. Summary

	$USM	%
Buy Hydro	81	26%
Remove	91	30%
Downstream Mitigations	136	44%
	308	

Appendix D

Risk Matrix

ERMA Risk Matrix

The following risk matrix is from *Decision Making : A Technical Guide to Identifying, Assessing and Evaluating Risks, Costs and Benefits* , NZ Environmental Risk Management Authority, March 2004.

	Magnitude of effect				
Likelihood	Minimal	Minor	Moderate	Major	Massive
Highly improbable	A	A	B	C	D
Improbable	A	B	C	D	E
Very unlikely	B	C	D	E	E
Unlikely	C	D	E	E	F
Likely	D	E	E	F	F
Very likely	E	E	F	F	F
Extremely likely	E	F	F	F	F

For this report the following descriptors have been adopted:

A. negligible
B. very low
C. low
D. medium
E. high
F. very high