WAIHO RIVER FLOODING
RISK ASSESSMENT

For

MINISTRY OF CIVIL DEFENCE &
EMERGENCY MANAGEMENT

AUGUST 2002

PROJECT CONTROL

Consultant Details

Project Leader:	Adam Milligan	Phone:	04 471 2733
Project Team:		Fax:	04 471 2734
Organisation:	Optimx Limited	Postal Address:	P O Box 942, Wellington

Peer Reviewer Details

Reviewer:	David Elms	Phone:	03 364 2379
Position:	Director	Fax:	03 364 2758
Organisation:	Optimx Limited	Postal Address:	Department of Civil Engineering University of Canterbury Private Bag 4800, Christchurch

Client Details

Client:	Ministry of Civil Defence & Emergency Management	Postal Address:	PO Box 5010 Wellington
Client contact:	Richard O'Reilly	Phone:	04 473 7363

Project Details

Project:	Waiho River Flooding Risk Assessment	Project No.:	80295

Version	Status	File	Date	Approval signatory
1	Draft	80295 MCDEM Waiho River Risk Assessment Report - Version 1.doc	Aug 2002	David Elms
2	Final Draft	80295 MCDEM Waiho River Risk Assessment Report - Version 2.doc	Aug 2002	David Elms
3	Final	80295 MCDEM Waiho River Risk Assessment Report - FINAL.doc	Aug 2002	David Elms

This report has been prepared at the specific instructions of the Client. Only the Client is entitled to rely upon this report, and then only for the purpose stated. Optimx Limited accept no liability to anyone other than the Client in any way in relation to this report and the content of it and any direct or indirect effect this report my have. Optimx Limited does not contemplate anyone else relying on this report or that it will be used for any other purpose. Should anyone wish to discuss the content of this report with Optimx Limited, they are welcome to contact the project leader at the address stated above.

C:\lotus\notes\data\RSL_DMS.tmp\17-10 13-18-03 2656DC - MCDEM Waiho River Risk Assessment Report - FINAL.doc

Executive Summary

The bed of the Waiho River adjacent to the Franz Josef Glacier township is aggrading and is now higher than the surrounding ground level. The river is constrained to its present alignment by the flood defences constructed along this reach to protect the assets on the adjacent floodplain. At some point, a flood event will occur on the Waiho River that will breach the flood defences and inundate parts of the surrounding area.

Optimx has been engaged by the Ministry of Civil Defence & Emergency Management (MCDEM) to investigate the risk to life posed by flood events on the Waiho River to people in the Holiday Park area immediately to the south of the River adjacent to the SH6 bridge, and to assist in the evaluation of proposed risk reduction and response mechanisms.

The assessment considers the nature of the flood scenarios likely to occur on the Waiho River, the risk to assets and people in the Holiday Park area, and the effectiveness of the existing warning and response procedures.

Conclusions are drawn as to the likely risk to people in the Holiday Park area with the current systems in place, and recommendations made regarding areas where possible improvements in the warning and response systems may be achieved.

It should be noted that the estimated frequency of a breach of the right bank flood defences is similar to those on the left bank, that is, a 5 to 10-year return period. The risk to assets and people on the right bank has not been investigated in this report, but may warrant further investigation.

The principal conclusions are:

1. Flood hazards on the Waiho River can be grouped into two broad categories: “normal” rainfall related floods, and floods associated with landslide-dambreak events in the Callery Gorge.
2. The flood defences in the vicinity of the Holiday Park area are at high risk of failure in a flood event on the Waiho River.
3. The Holiday Park area is likely to be extensively damaged in a “normal” flood if the flood defences fail, and completely destroyed in a dambreak event regardless of the presence of the flood defences.
4. Any persons caught in the path of a flood through the Holiday Park area are likely to be killed in a “normal” flood, and extremely likely to be killed in a dambreak event.
5. The expected number of people that may be exposed to the flooding hazard in the Holiday Park area at any time is highly variable. It ranges from 20 to 26 during the day, up to 130 to 190 at night, depending on the time of year. The maximum number of people in the Holiday Park area is approximately 300, assuming every bed is full and all staff are on site.

6. The annual risk of fatalities in the Holiday Park area varies across the different types of floods and different numbers of people exposed to the hazard, but is generally in the order of 0.004 to 0.06 (i.e., 0.4% to 6%), if there is no warning or response system in place.
7. The existing warning and response plan has some limitations, but does reduce the risk of fatalities, primarily for "normal" floods and landslide-dambreak events that occur in fine weather. For landslide-dambreak events that occur during a storm, the existing warning and response plan is ineffective and does not significantly reduce the level of risk.
8. The annual risk of fatalities in the Holiday Park area varies across the different types of floods and different numbers of people exposed to the hazard, but is generally in the order of 0.002 to 0.02 (i.e., 0.2% to 2%), allowing for the existing warning and response systems.
9. The risk to life in the Holiday Park area is greatest for the "normal" flood events and the rainfall-triggered landslide-dambreak events. These events should therefore be the primary, but not exclusive, focus of any risk mitigation efforts.
10. Acceptable levels of societal risk for the likely numbers of fatalities in the Holiday Park area are in the order of 1 to 100,000 to 1 in 1,000,000 (0.000001 to 0.0001). These limits are substantially lower than the current level of risk, and are unlikely to be met through warning and response system improvements alone.
11. The only practical, long-term solution to reduce the risk of fatalities to an acceptable level appears to be through relocating the motel complexes with subsequent changes in the zoning of the Holiday Park area to prevent future redevelopment.
12. Regardless of what is done with the Holiday Park area, there will be an ongoing need to monitor the safety of the SH6 bridge during flood events on the Waiho River.

Possible areas for improvement in the existing warning and response procedures include:

1. Increase the robustness of the response procedures. For example:
   - Clearly identify the backup people for the Local CD Co-ordinator so there are always trained people available to assess the state of river.
   - Ensure that all of the people involved in evacuations (accommodation managers, staff, CD personnel, etc) are fully trained in their role, are aware of the role of others, and are clear on the channels and forms of communication to be used.
   - Trial the evacuation procedures (possibly around a table rather than a full trial evacuation) to more clearly identify the strengths and deficiencies of the existing response plan.
2. Investigate ways to reduce time required for evacuation (e.g., better coordination of the evacuation vehicles).
3. Investigate the feasibility and safety of the alternative evacuation option to the hills south of the motel complexes to possibly eliminate the need to evacuate people across the "at risk" SH6 bridge. If acceptably safe, investigate establishing a safe haven on hills to south of motel complexes to provide shelter to motel guests and staff.

4. Clearly state the need to immediately evacuate the motel complexes after an earthquake until the risk of a landslide-dambreak flood has been eliminated.
5. Investigate the feasibility of establishing a monitoring system for detecting changes in water levels in the Callery River to detect flow changes associated with a landslide dam.
6. Investigate the feasibility of establishing a local seismograph network to detect landslide activity in the surrounding valleys. This is technically feasible, as landslides have a different signature to earthquakes, but may not be economically viable.

Contents

1. Introduction

1.1 Purpose

The bed of the Waiho River adjacent to the Franz Josef Glacier township is aggrading and is now higher than the surrounding ground level. Since the 1940's, the bed level in the vicinity of the SH6 bridge has increased approximately 10 metres. The river is constrained to its present alignment by the flood defences constructed along this reach to protect the assets on the adjacent floodplain. At some point, a flood event will occur on the Waiho River that will breach the flood defences and inundate parts of the surrounding area.

Optimx has been engaged by the Ministry of Civil Defence & Emergency Management (MCDEM) to investigate the risk to life posed by flood events on the Waiho River to people in the Holiday Park area immediately to the south of the River adjacent to the SH6 bridge, and to assist in the evaluation of proposed risk reduction and response mechanisms. This report presents the results of the investigation carried out during August 2002.

The purpose of this study is to bring together the work that has been done in the past on the hazards associated with the Waiho River and develop a measure of the risk to life associated with these hazards. The assessment aims to:

1. assist utilities, local authorities, emergency services, and MCDEM in the preparation of their response plans for the Holiday Park area and adjacent area for flooding on the Waiho River,
2. provide an overview for government and other stakeholders of the risks associated with flooding on the Waiho River, to inform consideration of whether further measures might be appropriate, and if so which such measures would provide the most effective risk reduction.

1.2 Report Structure

The report is divided into the following sections:

Section 2	Outlines the rationale for, scope of, and background to the current project.
Section 3	Describes the general approach and methodology that has been followed for the study.
Section 4	Describes the different sources of flooding activity on the Waiho River, and assesses their expected probability of occurrence.
Section 5	Assesses the risk to the Holiday Park area from the flood scenarios presented in Section 4.
Section 6	Assesses the risk to people in the Holiday Park area.
Section 7	Assesses the effectiveness and reliability of the warning and response plans for the Holiday Park area, both current and planned.

Section 8	Summarises the findings of the project and determines the probability of different numbers of fatalities for flood events on the Waiho River.
Section 9	Discusses the acceptability of the risk to life on the Waiho River, and the implications for future work, both in further response planning and risk reduction.
Section 10	Presents the conclusions from the project.

1.3 Limitations

Optimx Limited has produced this report under contract to MCDEM. It is based on the contributions of many organisations and individuals, and the information and views expressed during meetings and visits. Optimx Limited is unable to vouch for the accuracy of that information, and is accordingly unable to warrant the information contained in this report.

Findings presented as a part of this project are for the sole use of MCDEM in evaluating the risk to life associated with flooding on the Waiho River. The findings are not intended for use by other parties, and may not contain sufficient information for the purposes of other parties or other uses. Our professional services are performed using a degree of care and skill normally exercised, under similar circumstances, by reputable consultants practicing in this field at this time. No other warranty, expressed or implied, is made as to the professional advice presented in this report.

2. Background

2.1 Rationale

The past four years has seen a great deal of effort put into investigating the natural hazards affecting the Franz Josef Glacier township and surrounding area. Examples of this work include McSaveney & Davies (1998), Gough, Johnston & McSaveney (1999), Hall (2000), Gough (2001), Davies & McSaveney (2000), and Davies (2002).

The two principal natural hazards affecting Franz Josef Glacier township are seismic activity on the Alpine Fault, which passes through the township, and flooding hazards associated with the Waiho-Callery river system. The risks to the township and surrounding area associated with rupture of the Alpine Fault are well known and understood, or as much as they can be given the uncertainties associated with high magnitude earthquake events. However, what is not well understood is the level of risk to the Franz Josef community associated with flooding on the Waiho-Callery river system. The Holiday Park area (refer §2.2) to the south of the Waiho River is of particular concern as it is immediately adjacent to the Waiho River flood defences and is below the bed level of the Waiho River at this location. Continuing aggradation of the Waiho River is contributing to an increase in the flooding hazard to this area.

The primary responsibility for managing rivers and reducing risks of the flood hazard to communities falls with local government, in this case, the West Coast Regional Council (WCRC) and Westland District Council (WDC). MCDEM typically has a role in advising and supporting local government to manage the flooding hazard. In the case of the Waiho River, MCDEM is involved with local and central government in identifying a solution to the flood risk, in particular reducing the risk to life.

MCDEM is currently working with WCRC, WDC, and the community to revise and improve their response plan for flooding on the Waiho River. In parallel with coordinating the response planning, MCDEM has commissioned this assessment of the risk to life in the Holiday Park area associated with the flooding hazard.

The risk assessment is based on the latest scientific knowledge of the behaviour of the Waiho-Callery river system, but also incorporates an assessment of the efficacy and reliability of the arrangements to protect assets and people, and of the warning and response measures currently in place or planned. The focus is on risks to people, rather than economic risks.

MCDEM hope to use the results of this assessment to:

1. assist in the development and co-ordination of response plans,
2. identify any areas that require further assessment, and
3. identify any areas of river management that require attention.

2.2 Holiday Park Area

The “Holiday Park area” is the name used to represent the area on the south side of the Waiho River adjacent to the SH6 bridge that is most at risk from flooding from the River, and that is the focus of this report. This area is indicated in Figure 2.1. The Holiday Park area includes two motel complexes, the Black Sheep Lodge and the Glacier Gateway Motel, and a private residence.

It is usual to refer to the “true left” and “true right” banks when talking about a river, with left and right referring to the sides of the river when facing downstream. This means that the Holiday Park area is situated on the true left bank of the Waiho River, a terminology that is adopted in this report.

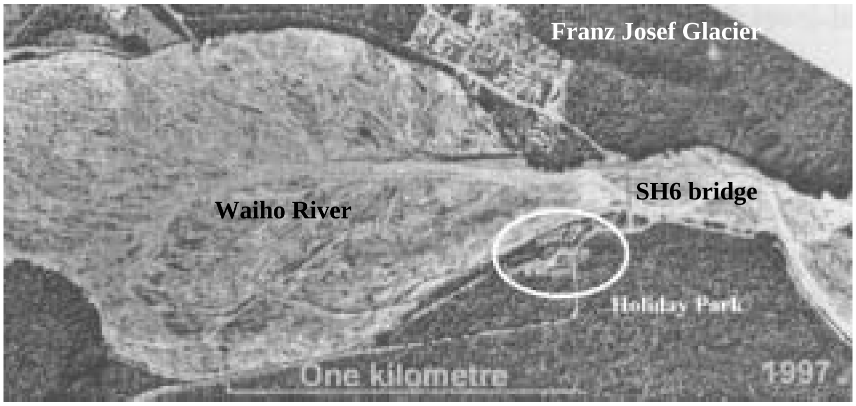

Figure 2.1: Holiday Park area on south side (true left bank) of the Waiho River. (original image from Davies & McSaveney, 2000)

2.3 The Waiho-Callery River System

The Waiho-Callery River system is shown schematically in Figure 2.2, with an aerial view of the catchment in Figure 2.3.

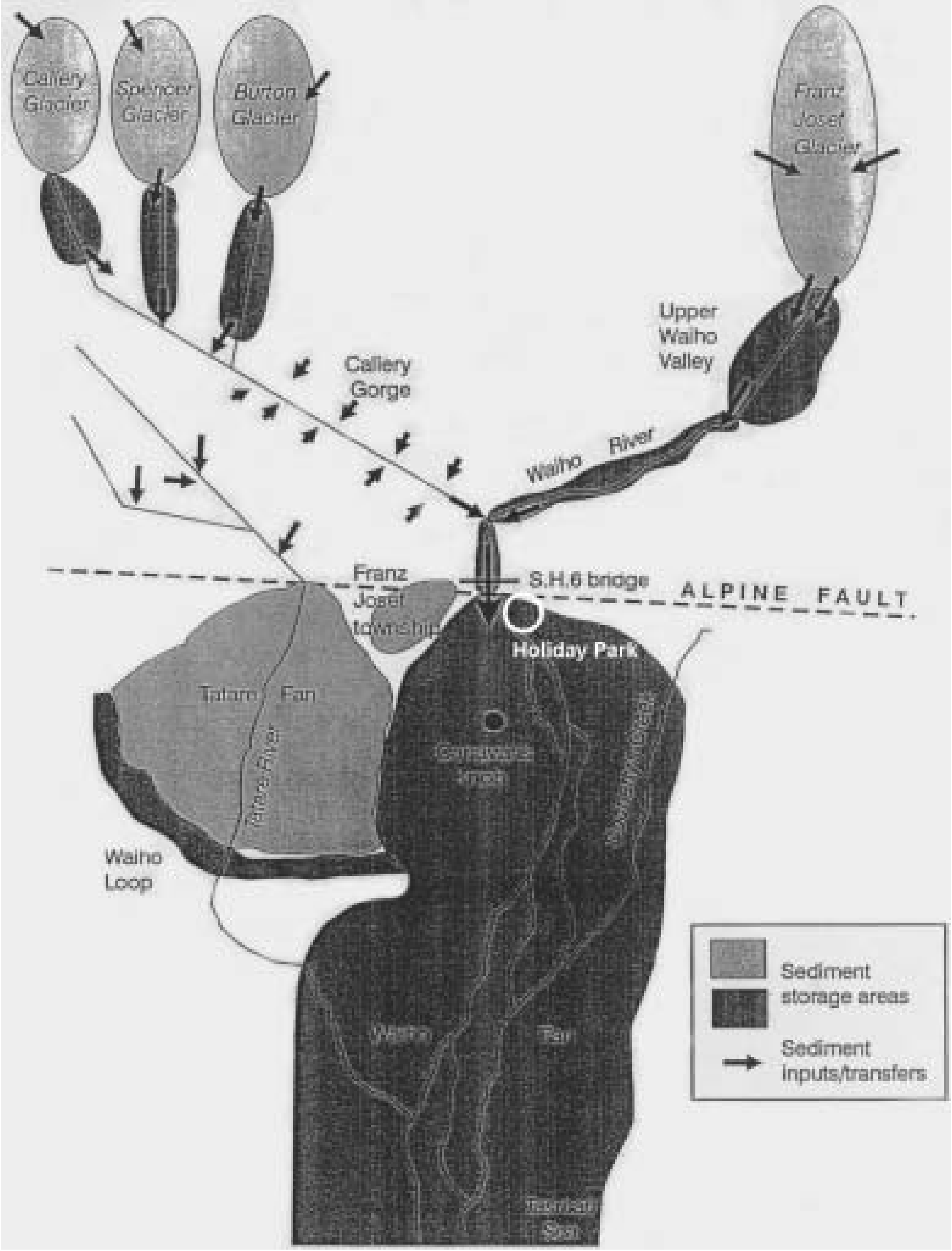

Figure 2.2: Waiho-Callery River system (natural behaviour), the location of the Holiday Park area is indicated by the white circle.
(original image from Gough, Johnston & McSaveney, 1999)

Figure 2.3: Aerial view of the Waiho-Callery River system (from the West) showing key features of the system (photo taken in mid 1980s, from Davies and McSaveney, 2000).

The Waiho-Callery River system is discussed in detail by McSaveney and Davies (1998) and Davies and McSaveney (2000). Relevant features of the system are listed below.

Overview

- The river system flows west from the Southern Alps' main divide to the Tasman Sea, a fall of approximately 2,500 metres over 30 kilometres.
- The system drains 170 km^2 of the Southern Alps, comprising the major catchments of the Callery and Waiho Rivers, together with the smaller catchments of the Tatare River and Docherty's Creek.
- Glaciers cover a significant part of the upper catchments.
- The bulk of the flood runoff comes directly from rainfall, with some contribution from the melting of snow and glacier ice – average annual precipitation in the upper headwaters is estimated to be at least 11,000 millimetres.
- In large storms, the total depth of rain falling on the upper catchment may be two to three times that recorded at the Franz Josef Glacier township. Much of the rain falling in the upper catchments enters glacial drainage systems such as that of the Franz Josef

Glacier.

- Intense storms are frequent in the area, with storms producing 200 millimetres of rain in 24 hours occurring once a year, 600 millimetres of rain in 72 hours once every 2-3 years.
- Approximately 2 million cubic metres of sediment are eroded from the Waiho-Callery catchment each year and either transported to the sea or deposited on the fan. Sediment is injected into the system at irregular intervals during storms and earthquakes, with large sediment pulses resulting from changes in subglacial drainage, or landslides or debris avalanches falling into steep tributaries such as the Callery River gorge.

Waiho Catchment

- The Waiho River catchment area is 77 km^2, 18% of which is covered by the Franz Josef Glacier and its tributaries.
- The bulk of the catchment (81%) delivers its water and sediment to the glacier and its internal drainage, with the remainder of the catchment delivering water and sediment directly to the river.
- Blockages or changes in the subglacial drainage system create brief floods that expel large pulses of sediment and broken ice into the upper Waiho valley. The sediment is stored in this valley and only transported to the lower valley at the transport capacity of the Waiho River.

Callery Catchment

- The Callery River catchment is the largest sub-catchment at 92 km^2, and is also about 18% covered by ice. This river contributes the greatest proportion of water and sediment to the Waiho River’s lower reaches.
- Approximately one-third of the catchment contributes water and sediment directly to the river, thus the glaciers have less of an effect on flows in the Callery River than in the Waiho.
- The 10 kilometre long Callery Gorge forms the lower reach of the catchment. This is a narrow, steep sided gorge, which has little sediment storage and is easily blocked by landslides from the gorge sides large enough to form a temporary dam.

Transfer Reach

- The transfer reach is the 700 metre section of the Waiho River between the Callery and Waiho River confluence and the SH6 bridge.
- The transfer reach is confined by high terraces formed by fault uplift on the north and the glacier access road on the south. Flood protection works have been constructed along both sides of this reach to prevent erosion of the banks.
- The transfer reach is currently aggrading, indicating that the sediment supply to the

reach is greater than its sediment transport capacity. An indication of the level of aggradation is provided by anecdotal evidence that people were able to commit suicide by jumping from the previous swing bridge over the Waiho River (immediately parallel to the current bridge). By comparison, the current Bailey bridge is higher than the swing bridge, but is only about two metres above the bed level.

Upper Fan

- The upper fan extends from the lower end of the transfer reach at the SH6 bridge through to the Waiho Loop.
- This reach is flanked by stopbanks on the true left (south) side from the bridge to downstream of Canavan's Knob, and on the true right (north) side by banks along the frontage of the heliport area, Franz Josef Glacier Hotel, and the oxidation ponds.
- The river channel changes its position frequently over this section of the fan. However, the true left stopbanks prevent the river from using the fan surface from the Holiday Park area to Docherty's Creek.
- Confinement of the river has contributed to an increase in aggradation over the past half century, to the point where the riverbed is now higher than surrounding ground level over most of the upper fan, and especially in the vicinity of the SH6 bridge and Holiday Park area.

Waiho Flats (Lower Fan)

- The Waiho Flats are the area of flat land between Canavan's Knob and the Tasman Sea.
- The Waiho River presently flows over the north eastern edge of the lower fan from the Waiho Loop through to the coast. The Waiho and Tatare Rivers converge downstream of the Waiho Loop.
- The level of the lower fan is essentially stable, with all sediment delivered to the fan being transported to the sea.

3. Risk Assessment Overview

3.1 Definition of Risk

Risk is often thought to be a vague concept, with different people interpreting the term in different ways. Thus, it is important to define very clearly what the term means in the context of the current investigation.

Risk may be considered as having three components: **consequence**, likelihood (**probability**), and the **context** of the situation under consideration. The level of risk increases as the consequence, or the likelihood, or both increase.

A **hazard** is a potential loss that can cause human, social, environmental, or economic harm. The term hazard is often used to refer to the consequence component of risk.

Risk must be considered in context. Examples of the context of risk include a cost-benefit context, and the context of the decision that is being made. Risk is intimately associated with decision – if there is no decision to be made, there is no point in trying to assess or manage risk. The decision context for MCDEM for the Waiho River was discussed in §2.1.

3.2 Approach

For the current project, the key outcomes of concern for the Waiho River are:

How likely are people in the Holiday Park area to be killed, when a flood happens?
and
How many people are likely to be killed in the Holiday Park area?

Previous work on the risk to life from lahar flows on Mount Ruapehu (Taig, 2002) focussed on whether anyone would die as a result of the lahars. A similar approach could be taken to the Waiho River. However, for the current study, the numbers of people at risk may be considerably larger than for Ruapehu, thus it is important to take a “societal risk” approach to the problem and explicitly consider the number of lives at risk.

The general approach adopted in the assessment is illustrated in Figure 3.1 below.

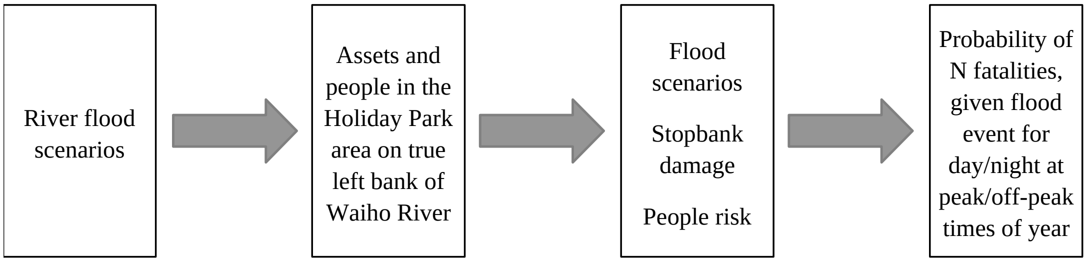

Figure 3.1: Methodology followed for the initial study.

The first step is to identify, understand, and characterise the different flood scenarios that can occur on the Waiho-Callery River system, including a comparison with historical records of flood events on the river. Important aspects of the floods that need to be considered are:

- How large the floods may be.
- How often floods of this size are expected to occur.
- How quickly the floods are likely to develop and reach the SH6 bridge and Holiday Park area.

Having considered the different types of floods that may be expected, the next step is to consider how these floods may affect the Holiday Park area and the operators and guests who are there at the time. The following issues need to be taken into account:

- How can the integrity of the flood defences be affected?
- How large does a flood need to be to overcome the stopbanks protecting the Holiday Park area?
- If the stopbanks are breached, what sort of flow can be expected through the Holiday Park area (e.g., depth, velocity)?
- How is this flow likely to affect people if they are in the Holiday Park area (i.e., how many people may be killed)?

The risk to people in the Holiday Park area is estimated in terms of the likelihood of there being N fatalities GIVEN that the flood has occurred AND the flood defences have failed. This risk is estimated in two stages: firstly, to estimate the risk given failure of the flood defences and no effective mitigation, and second, to reduce this risk by taking into account the estimated effectiveness and reliability of the current warning and response procedures.

3.3 Uncertainty

The behaviour of the Waiho River, as with any natural system, is highly uncertain. This is particularly true for the behaviour of the Callery catchment with its potential for landslides and subsequent dambreak floods. Wherever possible, the degree of uncertainty in the figures used in this assessment has been explicitly stated, and an attempt made to include this uncertainty in any further calculations. Where expert opinion has been used to estimate likelihood, this is clearly identified and the degree of belief in these opinions stated. Estimates of likelihood based on historical evidence or other evidence are also identified as such. An attempt is made to identify where uncertainty is material to the outcome of the assessment, and which aspects are more critical to the safety outcomes.

4. Flood Scenarios

The flood scenarios that have been considered in this assessment are shown in Figure 4.1 below.

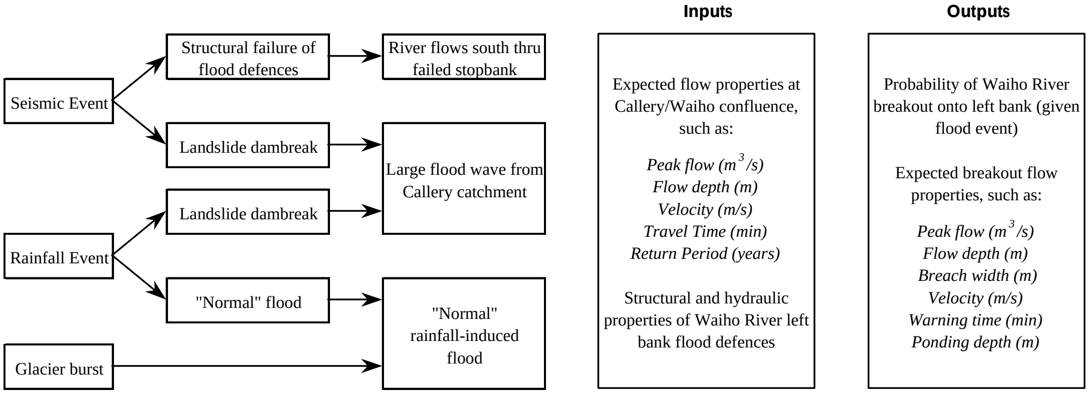

Figure 4.1: Waiho-Callery River flood scenarios.

4.1 Earthquake-induced Failure of the Flood Defences

The township of Franz Josef Glacier is situated directly on a major fault line, which passes through the forecourt of the petrol station in the town. Berryman (1998) estimated that there was a 16% chance of a fault rupture occurring within 10 years in the Franz Josef area (annual probability of approximately 1.6%). The anticipated earthquake is likely to cause widespread damage to the township, with numerous slips in the surrounding hills. It is likely that SH6 will be impassable in the vicinity of the bridge, either through failure of the bridge itself, or collapse of the 3 metre high scarps adjacent to the road to the north of the river. Structural failure of the flood defences is also likely, especially on the true left bank where the stopbanks are tall and narrow as a result of several height increases (to match the riverbed) in an area constrained by the presence of the state highway.

The seismically induced failure of the flood defences is a special case of the “normal” flood situation, because unless the river is in flood, the failure of the flood defences will not result in an increased risk to life. A 2-3 year return period flood on the Waiho is large enough to pose a substantial threat to life in the Holiday Park area. The effects of the flooding in this situation are the same as for the “normal” flood event with a 2-3 year return period.

The annual probability of fault rupture (0.016) multiplied by the annual probability of a 2-year or 3-year return period flood (0.5 or 0.33) gives an annual probability of flood hazard of **0.005 to 0.008**.

4.2 Landslide-dambreak Floods

The most catastrophic flood hazard associated with the Waiho-Callery River system is associated with landslides in the Callery Gorge. The gorge is narrow, steep-sided, and easily blocked by landslides from the gorge sides. Davies (2002) has estimated the peak flows and warning times for landslide-dambreak floods from several sites in the Callery Gorge, as listed in Table 4.1.

Table 4.1: Characteristics of floods from landslide dam failures in the Callery Gorge (from Davies, 2002).

Site	Dam Height	Peak flow	Warning Time *	
			Mean annual flow in Callery River	5-year Return Period flow in Callery River
	(m)	(m^3/s)	(hrs)	(hrs)
1	180	11,000 – 14,000	850	6
2	76	1,800 – 2,500	70	2
3	77	1,500 – 2,400	60	1.5
4	171	9,000 – 12,000	630	14
5	98	3,800 – 4,300	230	1

* The warning time is the time from when the landslide occurs for the lake to fill, the dam to fail, and the flood wave to travel from the dam site to the SH6 Bridge.

The two dominant triggers for such landslides are seismic events and rainfall (McSaveney & Davies, 1998). The annual probability of occurrence of a flood from the breach of either an earthquake or rainfall-triggered landslide in the Callery Gorge has been estimated by Davies (2002) and is listed in Table 4.2.

Table 4.2: Annual probability of occurrence of a flood from the breach of a landslide in the Callery Gorge (from Davies, 2002).

Landslide trigger	Annual probability of flood from landslide breach
Seismic	0.005 – 0.01
Aseismic (typically rainfall)	0.01 – 0.02

4.3 Glacier Burst Floods

Glacier outbursts result from the sudden release of blockages in the sub-glacial drainage systems. They are highly uncertain and unpredictable, but generally only affect the Waiho River, not the Callery, as the glaciers at the headwaters of the Callery are too small to produce significant outbursts.

Glacier bursts from the Franz Josef glacier release a large volume of sediment and ice into the Waiho River, and were especially frequent while the glacier was advancing. Outbursts with an estimated 10 to 20-year return period have deposited blocks of ice on the SH6 bridge[1] and on the Holiday Park stopbank[2] in the past. The glacier is now retreating and these events have become less frequent. The exact reasons are not clear, but a possible contributing factor is that the face of the glacier is now quite weak, with heavily fractured ice extending for some metres back from the face[3]. As a result, the glacier does not build up as much pressure, and the subsequent outbursts are substantially smaller and less frequent.

Glacier bursts are generally associated with heavy rainfall events, so a similar warning process is involved, and the resulting floods are very similar to “normal” flood events on the Waiho River. For this reason, glacier burst floods can be treated as a subset of “normal” rainfall-induced floods and do not need to be considered independently in this risk assessment[1,3].

4.4 “Normal” Floods

The West Coast of the South Island receives very large amounts of rainfall, with approximately 11,000 millimetres expected each year in the upper catchments of the Waiho-Callery River system. Rainfall-related “normal” flood events tend to develop quite quickly, due to the steep catchments, and the Waiho and Callery Rivers are fast moving and capable of transporting very large amounts of sediment along the river. The sound of boulders moving along the riverbed is audible during normal flows, but is particularly noticeable during flood events when they are moving faster and there are more of them, as is the sound of boulders hitting the bridge piers[1,4]. Local residents indicated that 2 to 3 days of heavy rain is generally required before they get concerned about the river flooding, but that once the river starts to rise, it generally does so quite quickly[4,5].

The degree of hazard associated with floods on the Waiho River is influenced as much by the amount of sediment brought down in a flood as it is by the amount of water. A minor aggradation event followed by a smallish flood may present as much, if not more of a hazard as an initial, larger flood. The flood defences on the Waiho are less effective with almost every flood as the bed continues to aggrade.

---

[1] Private communication, Mauri McSaveney, Geological and Nuclear Sciences, August 2002.

[2] Private communication, Chris Morris, Franz Josef Volunteer Fire Chief and Civil Defence Co-ordinator, August 2002

[3] Private communication, Tim Davies, Lincoln University, August 2002.

[4] Private communication, John Bainbridge, WDC, August 2002

[5] Private communication, Kevin & Linda Gibson, Glacier Gateway Motel, August 2002

Waiho River flood events with a 1 to 2-year return period are large enough to present a threat to the security of the flood defences, although the level of risk depends significantly on the channel the river decides to follow during an individual event. The best estimate by Mauri McSaveney and Tim Davies is that the stopbanks on the true left bank would be at risk of being breached approximately **once every 5 to 10-years** by a flood with a return period as short as 1 to 2-years.

The estimated 5 to 10-year return period for breaching of the flood defences agrees well with the historical average period between repairs of the flood defences, discussed in §5.2.2.

It should be noted that the estimated frequency of a breach of the right bank flood defences is similar to those on the left bank, that is, a 5 to 10-year return period. The risk to assets and people on the right bank has not been investigated in this report, but may warrant further investigation.

4.5 Summary: Probability of Flood Scenarios

The expected annual probability of the different flood scenarios is summarised in Table 4.3.

Table 4.3: Expected annual probability of Waiho River flood scenarios.

Flood Scenario		Annual probability of flood large enough to damage flood defences
"Normal" flood		0.1 – 0.2
Seismic failure of flood defences		0.005 – 0.008
Landslide-dambreak	Seismic	0.005 – 0.01
	Aseismic	0.01 – 0.02

5. Risk to the Holiday Park Area

5.1 Assets at Risk

The principal assets at risk in the Holiday Park area are the buildings associated with the two motel complexes operating from this location, namely:

- Black Sheep Lodge
- Glacier Gateway Motel

A private dwelling across SH6 from the Motel complexes is also at risk.

There are a number of private dwellings further west from the Holiday Park area and south of Canavan’s Knob. While these dwellings are at risk from floodwaters breaching the left bank flood defences, the floodwaters would have spread out significantly by the time they reached them. Thus, the risk to assets and to life in these private dwellings is significantly less than for the Holiday Park area and they are not considered in the current assessment.

5.2 Flood Defences

5.2.1 Description

There are two sections of flood defences on the true left bank that provide protection to the Holiday Park area – the raised glacier access road and rock groynes upstream of SH6 (Figure 5.1), and the Holiday Park stopbank (Figure 5.2).

Figure 5.1: Glacier Access Road and SH6 bridge.

The Glacier Access Road was raised due to aggradation of the river in 1988 and protected with rock riprap. The road was raised further in 1996 and 1998, and there is a current proposal to raise the road and the SH6 bridge a further 5 metres (McSaveney and Davies, 1998).

Figure 5.2: Holiday Park stopbank. The top floor of a building at the Glacier Gateway Motel is visible above the stopbank at the left (white), and the roofs of several of the motel units at the Black Sheep Lodge are visible near the middle of the picture.

The Holiday Park stopbank was first constructed in 1978, and the works were enlarged or repaired in 1980, 1991, 1996, and 1998 in response to continuing aggradation of the river (McSaveney and Davies, 1998). The bank is protected by continuous rock riprap immediately downstream of the SH6 bridge, and by stub groynes adjacent to the Holiday Park area, although there is no rock protection between the groynes.

5.2.2 History of Repairs to the Flood Defences

Table 5.1 provides a timeline of works associated with protection of SH6 at both the bridge site and further southwards towards Docherty Creek. This information has been provided by Grant Webby of Opus International Consultants Limited. The records of damage have been correlated with historical flood data.

Table 5.1: Timeline of events affecting protection works for SH6 and Glacier Access Road (from Grant Webby, Opus International Consultants Limited, based on historical records of repair works extracted from the Opus Greymouth office).

Year	Event Description	Comments
Pre 1970	Construction of Canavans stopbank	McSaveney and Davies (1998) indicate that Canavans stopbank was in place in 1965 although there had been earlier works constructed just upstream of Canavans Knob not long before 1948.
1979	Breakout of Waiho River south of Canavans Knob to Docherty Creek. Emergency repairs at Canavans Knob. Construction of Holiday Park stopbank	Flood event of 2 December may have caused breakout of Waiho
1982	Breakout of Waiho River south of Canavans Knob	Major flood event on 12 March which caused widespread damage to SH6 in South Westland
1984	Washout left bank upstream and down stream of bridge. Emergency works – bank rebuild	
1989	Replacement of SH6 bridge (suspension bridge raising)	
1990	Emergency works – bank rebuild Breakout of Waiho River south of Canavans Knob Left bank upstream and downstream washed out Reconstruction of Canavan's stopbank Raise stopbank and Glacier access road	Second largest flood event based on Whataroa flow record of 28 December, probably caused breakout of Waiho
1991	Construction of rock revetment on true right bank upstream of bridge Construction of spurs on true right bank upstream of bridge	
1994		Largest flood event based on Whataroa record occurred on 9 January

Year	Event Description	Comments
1995	Rebuild stopbank behind camping ground Failure of rock revetment on true right bank upstream of bridge Emergency works – rebuild stopbank Extension of stopbank behind camping ground	Third largest flood event based on Whataroa record occurred on 13 December and probably caused failure of rock revetment on true right bank upstream of bridge
1996	Waiho River Bridge – extension of Bailey Bridge by 30 metres Construction of rock revetment past church on right bank downstream of bridge	
1999	Build up of slippery face – Glacier access road	
2002	Destruction of spurs on true right bank upstream of bridge Breaching of true right abutment of bridge Emergency raising of Canavans stopbank Reinstatement of spurs on true right bank above bridge and bridge abutment	Major flood event 3 January caused destruction of rock spurs on true right bank upstream of bridge and breaching of bridge abutment

NOTE: Points that stand out in this timeline of events are:

- Canavans stopbank has been breached allowing the river to break out across SH6 on three occasions, in 1979, 1982 and 1990. The stopbank also came close to being breached in January 2002. This translates to an average breakout recurrence interval of about once every 7-10 years.
- The left bank upstream and downstream of the bridge has been breached on two occasions, in 1984 and 1990. The Holiday Park stopbank, which is an extension of this bank, required rebuilding in 1995. Reconstruction of the left bank in the vicinity or just downstream of the bridge has therefore been required on average about every 5 years, although not since 1995.
- Since their initial construction, bank protection works on the true right bank at the bridge have been destroyed on two occasions, in 1996 (revetment destroyed) and January this year (two rock spurs destroyed), or in other words, on average about once every 5 years.

The history of repairs to the left bank stopbanks being required approximately every 5 years agrees very well with the estimated 5 to 10-year return period for flows to breach these stopbanks discussed in §4.4.

5.3 Landslide-dambreak Floods

Landslide-dambreak events, whether earthquake- or rainfall-triggered, are easily capable of producing floods in the order of several thousands cumecs[6] (Davies, 2002). A flow of this size is likely to have a wave front some ten metres high when it exits the Callery Gorge[7] and cause extensive damage in the Franz Josef area. It is extremely unlikely that either the SH6 bridge across the Waiho River or the Holiday Park area would survive. Evacuation is the only useful, practical, or economical mitigation strategy for such an event.

5.4 Waiho River Breakout

A breakout by the Waiho River is possible through either the Glacier Access Road or the Holiday Park stopbank. Each of these banks is discussed below, based on McSaveney and Davies (1998), and personal communications with Mauri McSaveney of GNS and Tim Davies of Lincoln University.

The Waiho River is highly mobile through the transfer reach and upper fan, and at high flow rates tends to flow in a single channel, rather than as a braided river. This main channel changes position frequently, especially during storm events, and the likelihood of a breakout through either stopbank is highly dependent on the location and alignment of the main channel.

A breakout through the SH6 stopbank downstream of the Holiday Park area would not result in flow through the Holiday Park area, thus it is not considered in this assessment.

5.4.1 Glacier Access Road

A breakout through the Glacier Access Road above SH6 would result in water flowing parallel to the road until it entered the Holiday Park area at the corner of SH6. Much of the water would flow though the Holiday Park area and re-enter the bed of the Waiho at the downstream end of the Holiday Park stopbank. Some of the water could follow old river channels through the forest and eventually into Docherty’s Creek.

This bank is not heavily armoured, and the Callery-Waiho confluence can place a powerful river channel against this bank. A break out could occur by scour and erosion of the riverside face, especially between the groynes, or by overtopping and washout of the back face of the bank. The SH6 bridge works would tend to keep the flow out of the main Waiho riverbed, and anywhere from one- to two-thirds of the flow of the Waiho could be diverted into the breakout, depending on where the main channel of the river was at the time. The relatively high ground level (compared to the Holiday Park area) outside the stopbanks will tend to limit the proportion of river flow that will divert through the breach.

---

[6] 1 cumec = 1 cubic metre per second

[7] Private communication, Tim Davies, Lincoln University, August 2002.

5.4.2 Holiday Park Stopbank

Breakout through the Holiday Park stopbank would have a similar effect to the Glacier Access Road, although this breakout is potentially more likely as it is possible for the main Waiho River channel to divert almost at right angles from the right bank and flow directly at the Holiday Park stopbank, thus significantly increasing the risk of scour and failure of the bank. The bank is unprotected between the groynes and could not long withstand a direct attack.

The ground level in the Holiday Park area is approximately 1-3 metres below the riverbed behind the Holiday Park stopbank. It is therefore likely that a breakout would rapidly cut down through the riverbed and a large portion of the river flow would divert through the Holiday Park area. As for the Glacier Access Road, much of this flow would re-enter the Waiho, with some flowing through to Docherty's Creek.

5.4.3 Breakout Effect

A breach of either stopbank would result in a very large flow of water and gravel through the Holiday Park area. The flow is likely to be a few tens of metres wide, 1.5 to 2 metres deep, and flowing very rapidly. The direction of the flow is unpredictable, as it will depend on the location of the initial breakout and because the river will start depositing gravels as soon as it leaves the main channel, but it would be deep and fast enough to move cars, and possibly the cabins and motel units, depending on their foundation details.

After the floodwaters have receded, and assuming the river can be diverted back into the main channel, the Holiday Park area would be covered in a thick layer of gravels similar in nature to the existing riverbed. Any vehicles or buildings in the area are unlikely to be salvageable after the event, even assuming the gravels could be cleared to make rebuilding possible.

5.5 Summary: Probability of Damage to Holiday Park Area

The Holiday Park area will be extensively damaged, and is likely to be a complete loss, for any flood event that breaches or overtops the flood defences. It is extremely difficult to think of any situation in which flow through the Holiday Park area would result in little or no damage, especially for any landslide-dam break event. The likelihood of major damage to the Holiday Park area, given that a flood has occurred, is summarised in Table 5.2.

Table 5.2: Probability of major damage to the Holiday Park area, given that a flood event has occurred.

Flood Scenario	Probability of major damage to the Holiday Park area, given a flood event
Earthquake-triggered landslide-dambreak	0.9 – 1.0
Aseismic- triggered landslide-dambreak	0.9 – 1.0
“Normal” flood	0.8 – 1.0

6. Risk to People

6.1 Assumptions

This section outlines the approach taken to estimating the risk of fatalities in the Holiday Park area for a flood event on the Waiho River. The key assumptions made in this section are as follows:

- The risk to people is estimated based on damage to the Holiday Park area having occurred.
- The outcome is assessed as the likelihood of there being N fatalities, given that the Holiday Park area has been damaged.
- The assessment is carried out assuming that there is no warning or response mechanism in place.
- The number of people who may be exposed to the flooding hazard is estimated to give an indication of the potential scale of the incident.

6.2 Number of People Present

Estimates of the number of guests and staff present at each of the two Motel complexes at different times of the year has been obtained from the relevant operators. It is important to note that the number of people present in the complexes is highly seasonal, and varies greatly between day- and night-time. An estimate of the expected number of people, both guests and staff, at each Motel has been made for peak and off-peak seasons, as discussed in §6.2.1 and §6.2.2. The guests in these complexes are predominantly Europeans and Australians and, with the exception of 2-3% of guests, can all speak English reasonably well.

The assumptions made regarding the daily variation in visitor numbers are listed in Table 6.1

Table 6.1: Daily variation in Motel complex occupancy.

Time of day	Proportion of day	Proportion of guests on site	Proportion of staff on site
Day: 10:00 – 18:00	33%	5%	100%
Night: 18:00 – 10:00	67%	100%	70%

6.2.1 Glacier Gateway Motel

The Glacier Gateway Motel has a total of 23 units with 64 beds; units are generally only rented to a couple, so typically (approximately 80% of the time) there would be a maximum of 46 people on site. The first step, before estimating the expected number of guests and staff present (Table 6.2), is to estimate the expected total number of guests on the site.

The expected total number of guests on site is equal to 46*80% + 64*20%, which gives an expected total number of people of 49.6. In other words, at any point in time, the average maximum total occupancy (not allowing for seasonal variation) is **49.6** people. This number now needs to be modified by the assessment of seasonal occupancy levels and proportions of people on the site at different times of the day to develop an estimated number of people on the site on any day of the year. This is shown in Table 6.2. The peak and off-peak seasons have been approximated across both Motel complexes as Dec-May and Jun-Nov respectively.

Table 6.2: Expected number of people on site at the Glacier Gateway Motel.

Months of the year	% Occu-pancy	# Guests	# Staff	Expected numbers during Day		Expected numbers at Night	
				Guests	Staff	Guests	Staff
A	B	C	D	E	F	G	H
Nov – Mar	100%	49.6	8	2.5	8.0	49.6	5.6
Apr, Oct	75%	37.2	6	1.9	6.0	37.2	4.2
May	50%	24.8	3	1.2	3.0	24.8	2.1
Jun – Sep	25%	12.4	3	0.6	3.0	12.4	2.1

Expected Numbers:

Peak season	6 months (Dec-May)	2.2	6.8	43.4	4.8
		9.0		**48.2**	

Off-peak	6 months (Jun-Nov)	1.1	4.3	22.7	3.0
		5.5		**25.8**	

The calculation steps for the first line of figures (Nov – Mar) in Table 6.2 are as follows:

1. The expected number of guests (49.6) is multiplied by the % occupancy (B) to get the expected number of guests in residence for these months (C).
2. The number of staff on site to deal with these guests is estimated (D).
3. The expected number of guests (C) is multiplied by the proportion of guests expected to be on site (Table 6.1) to get the expected number of guests during the day (E) and night (F).
4. Step 3. is repeated for the expected number of staff on site during the day (G) and night (H).

The number of people expected on site during the peak and off-peak seasons is estimated using a weighted-average of the monthly figures derived in the first part of the table. For example, the expected number of guests on site during the day in the off-peak season is given by (2.5 + 1.9 + 0.6*4)/6 = 1.1.

6.2.2 Black Sheep Lodge

The Black Sheep Lodge consists of a variety of Motel accommodation units, a backpackers lodge, and a camping ground. The accommodation units are often rented at less than full capacity, and the camping ground usage is highly variable. As for the Glacier Gateway Motel, the first step, before estimating the expected number of guests and staff present (Table 6.4), is to estimate the expected total number of guests on the site (Table 6.3).

The expected number of guests per unit in Table 6.3 is calculated using a weighted-average of the total and typical occupancy levels. The calculations for Table 6.4 follow exactly the same process as those outlined for Table 6.2.

Table 6.3: Expected maximum number of guests at the Black Sheep Lodge.

Buildings			Total capacity	Typical occupancy (80% of the time)	Expected # Guests/ Unit	Total Expected # Guests
Type	#	Capacity				
Backpackers Lodge	1	115	115	115	115	115
Tourist Flats	3	5	15	2	2.6	7.8
Tourist Cottages	4	5.5	22	2	2.7	10.8
Motel Units	8	4	32	2	2.4	19.2
Camping Ground						
Campervans	5	4	20	2	2.4	12
Tents	2	2	4	2	2	4
			208		**Total**	**168.8**

Table 6.4: Expected number of people on site at the Black Sheep Lodge.

Months of the year	% Occu-pancy	# Guests	# Staff	Expected numbers during Day		Expected numbers at Night	
				Guests	Staff	Guests	Staff
Feb – May	100%	168.8	12	8.4	12.0	168.8	8.4
Jun – Nov	60%	101.3	10	5.1	10.0	101.3	7.0
Dec – Jan	35%	59.1	8	3.0	8.0	59.1	5.6

Expected Numbers:

Peak season	6 months (Dec-May)	6.6	10.7	132.2	7.5
		17.3		**139.7**	

Off-peak	6 months (Jun-Nov)	5.1	10.0	101.3	7.0
		15.1		**108.3**	

6.3 Summary: Probability of Fatalities and Number of People Exposed to Flooding Hazard

The expected nature of any flow through the Holiday Park area was described in §5. For either of the landslide-dambreak events, it is very unlikely that anyone caught in the path of this flow would survive such an event. The likelihood of fatalities for the dambreak flows has therefore been estimated as being in the range **0.8 to 0.9**.

The likelihood of a fatality for the "normal" floods is less certain than for the dambreak events, due to the flows being smaller and therefore less destructive. More important is that because the direction of the flow resulting from a breakout is highly uncertain, it is likely that there will be sections of the Holiday Park area that are not in the direct path of the flow. The flood is therefore only likely to pose a risk to some, not all of the people in the Holiday Park area. This will reduce the number of fatalities that may be expected from a flood event. The likelihood of fatalities for the "normal" floods has therefore been estimated as being in the range **0.4 to 0.8**, but affecting only **50%** of the people in the Holiday Park area at the time of the flood.

These probabilities are summarised in Table 6.5. Table 6.6 summarises the total number of people potentially exposed to each flood hazard (sum of values for Glacier Gateway Motel and Black Sheep Lodge from Table 6.2 and Table 6.4 respectively).

Table 6.5: Probability of fatalities, given damage to the Holiday Park area, and proportion of people in Holiday Park area exposed to flood hazard.

Flood Scenario	Probability of fatalities, given damage to the Holiday Park area	% of people in Holiday Park area exposed to flood hazard
Earthquake-triggered landslide-dambreak	0.8 – 0.9	100%
Aseismic- triggered landslide-dambreak	0.8 – 0.9	100%
"Normal" flood	0.4 – 0.8	50%

Table 6.6: Expected number of people exposed to the flood hazard at different times of day/year.

	Day	Night
Peak Season	26.3	187.9
Off-peak	20.5	134.0

7. Warning and Response Systems

7.1 Existing Warning Systems

7.1.1 "Normal" Floods

There are two aspects to providing warning of a potential flood on the Waiho River; the first is via rainfall forecasts, and the second is via monitoring of the river level itself.

Heavy rainfall warnings are issued by the MetService to the WDC office in Hokitika, and to the Department of Conservation office in Franz Josef. These forecasts are generally quite accurate for the Franz Josef area[8], at least for when heavy rainfall will occur, if not for the actual depth of rainfall. John Bainbridge, the WDC Civil Defence Officer, indicated that after receipt of a rainfall warning his first area of concern is the Waiho River and that he then maintains contact with the local CD Coordinator to check what is happening with the river.

Local residents indicated that, on the basis of past experience, they start to closely monitor the river after two days of heavy rain, especially if there is a third day forecast. Anything less than two days of rain and they will keep an eye on the river, but they are generally not concerned about the likelihood of significant flood flows.

A rainfall and river level monitoring station was established on the SH6 bridge in August 2001. This station transmits data back to the WCRC offices via automated telemetry where it is connected to their 24-hour monitored alarm system. From the WCRC, information from the recorder is disseminated to the WDC and back to Franz Josef. Records from this site indicate that the river level normally starts to rise approximately half an hour after the beginning of a storm event, a time period that was stated independently by several local residents. The alarm height on the water level recorder is approximately one metre below stopbank crest level. This alarm has not been triggered since the recorder was installed; yet during this time the bridge approach on the right bank has been lost twice, and the river nearly broke through the Holiday Park stopbank in January 2002 (downstream of the area currently occupied by the Motel complex buildings).

The telemetry equipment has been generally operational since it was installed a year ago. However, its reliability is questionable, as the modem is sensitive to lightning strikes, which have occurred several times in recent storms, and the alarm can be made inoperable by debris impact or high water velocities in the river[8]. The river level recorder can give an indication of early rises in water level, but is of limited use as a warning or monitoring device for high river levels, as the recorder has failed in all of the larger recent floods on the Waiho. The low reliability of the river monitoring system is reflected in the WDC (2002) *Franz Josef Response Plan and Operating Procedures*, which states: "the only really reliable form of monitoring of the Waiho River is by visual means which is carried out by local residents."

---

[8] Private communication, John Bainbridge, WDC, August 2002

The implications of these monitoring systems for the response plans for flooding on the Waiho River are discussed in §7.2.

7.1.2 Landslide-dambreak Floods

The nature of a landslide-dambreak flood is very different to a normal, rainfall-related flood on the Waiho River. The amount of warning that may be available is heavily dependent on the type of trigger (earthquake versus rainfall), time of day, and the type of weather when the landslide occurs, and is also influenced by the relatively inaccessible nature of the Callery Gorge.

Earthquake-triggered Landslide-dambreak

A rupture of the Alpine Fault is likely to result in numerous landslides in the Franz Josef area, including in the Callery Gorge. It is reasonable to assume that, following an earthquake in the area, there is an immediate danger of a landslide-dambreak flood. Thus, the earthquake itself forms an advance warning mechanism.

The amount of warning time from the occurrence of the landslide (assuming it is coincident with the earthquake) until failure of the resulting dam has been estimated by Davies (2002), as discussed in §4.2. This is highly dependent on the amount of rainfall and the flow in the Callery River at the time.

If the earthquake occurs at night, then it will be difficult and dangerous to inspect the Callery Gorge prior to daybreak in fine weather, and impossible in bad weather. In addition, it will be extremely difficult to observe any changes or discolouration in the flow in the Callery River. In fine weather the available warning time should be in the order of 60 hours or more, and there should not be any immediate danger. If it is raining heavily, then there may be as little as one hour prior to failure of the dam.

If the earthquake occurs during the day, and the weather is fine, then residents in Franz Josef may be able to hear the landslide and/or see a large dust cloud generated by the slide blow out of the Callery Gorge. The flow in the Callery River may also be discoloured, or cease entirely, thus providing further indications of a landslide dam. The gorge would also be easily inspected by helicopter, if one were available. Conversely, if it is raining then it may not be possible to observe any changes in flow, helicopter inspections would be difficult at best, and any dust cloud or noise may be obscured by the sound of the rain. Warning times are similar to those at night: 60 hours plus for fine weather, as low as one hour in heavy rain.

The different landslide indicators and indicative warning times are summarised in Table 7.1.

Rainfall-triggered Landslide-dambreak

If a landslide occurs in the Callery Gorge during a heavy rainfall event, then it is likely to fail quite rapidly with little or no warning, assuming the storm continues. It is unlikely that anyone would be able to hear the landslide, or see a dust cloud, if one was even generated during a storm. If the slide occurred during daylight it may be possible to observe a change in the behaviour of the Callery River, or to fly a helicopter in for a visual inspection if the rain is not too heavy. However, at night, neither of these actions is likely to be possible and almost no warning will be provided.

It is also possible for a landslide to occur with no obvious trigger, as was the case with the Mt Adams landslide. In this case, during daylight, it may be possible to hear the slide, and a dust cloud should be visible. The flow in the Callery may reduce or stop, and a visual inspection should be possible. At night, the slide may be heard, and dust and changes in the Callery River flow may be detectable. A helicopter inspection is probably not safe.

The different landslide indicators and indicative warning times are summarised in Table 7.1.

Table 7.1: Callery Gorge landslide indicators and indicative warning times.

Trigger	Time of day	Weather	Indicators					Warning time (hours from landslide occurrence)
			Sound	Dust	Flow in Callery River	Visual inspection of Gorge	Other	
Earthquake	Day	Fine	Y	Y	?	Y	Y	60+
		Rain	N	N	?	?	Y	1+
	Night	Fine	?	?	N	N	Y	60+
		Rain	N	N	N	N	Y	1+
Rainfall	Day		N	N	?	?	N	1+
	Night		N	N	N	N	N	1+
Other	Day		Y	Y	?	Y	N	60+
	Night		Y	?	N	N	N	60+

7.2 Existing Response Systems

The WDC has established a response plan for the Franz Josef Glacier township (WDC, 2002). The key people involved in a Civil Defence response to flooding on the Waiho River are:

1. WDC Civil Defence Controller (Hokitika)
2. Local Civil Defence Co-ordinator (Franz Josef)
3. Police (Whataroa, Ross)
4. Fire Brigade (Franz Josef)
5. Motel operators (Franz Josef)

The Response Plan is based on a combined response by all of the above parties, starting with the

Local Civil Defence Co-ordinator, and involving increasing numbers of people as the alert level increases. The alert levels and corresponding actions are listed in Table 7.2. In addition to the WDC Plan, the two Motel complexes on the south side of the river have developed their own plans setting out their actions corresponding to each of the Alert Levels.

Table 7.2: Franz Josef Glacier response plan Alerts Levels and corresponding actions for flooding on the Waiho River.

River Alert Levels	Basis for Alert	Key Actions
1	Heavy rain warning issued	Local CD Co-ordinator and DOC notified. Watch kept on river.
2	Dramatic change in river flows and/or level (e.g., direction of flow, increase in level)	CD Hokitika, Police, DOC notified.
3	Worsening forecast/continuous rain	Motel operators on south side of river notified – Guests to prepare to move out quickly if notified. Police, Fox Glacier Volunteer Fire Brigade, St Johns notified and on standby. Local transport and helicopters on standby. The Franz Josef Volunteer Fire Brigade is also notified, although they are not mentioned in the Response Plan document.
4	Bridge or river banks under worsening threat, failure likely. High level alarm activated from telemetry site.	No more bookings into Motels – guests sent north to Franz Josef Glacier Hall. Notify guests evacuation is imminent (to the Hall, the road south will be closed). Call in transport, local helicopters, Police (if not already on site), air force. Traffic control in place, Fox Glacier VFB on standby to close the road north. Franz Josef Glacier Hall is staffed.
5	Failure of bridge or banks imminent	If in evening, call to evacuate is to be made one hour minimum before dark (impossible to monitor condition of bridge or banks at night due to mist and rain). Close SH6 to the south.

The response plan was discussed with the following people:

- MCDEM South Island Emergency Management Advisor
- WDC CD Officer
- Local CD Co-ordinator
- Operators at the Black Sheep Lodge and Glacier Gateway Motel

A number of limitations of the current Response Plan emerged from these discussions:

1. Many of the key people are not resident in Franz Josef Glacier and so may not be available, or able to reach Franz Josef, when needed. For example, the Local CD Co-ordinator (and Franz Josef Fire Chief) is resident in Okarito, some 30 minutes drive away over roads that are often closed by slips in heavy rain. The Police are based in Whataroa and may also be unable to reach Franz Josef due to slips blocking SH6.
2. Communications in the area are heavily reliant on telephony, which may be unavailable after an earthquake. The landline crosses the Waiho River on the SH6 bridge and would be severed if the bridge or abutments failed. The cellular sites (Vodafone and Telecom 027) serving the area should remain operational in a flood, but service may be lost after an earthquake as they do not have backup power supplies. VHF hand-held radios are available to supplement telephony in an emergency – DOC has 5 radios, the Franz Josef Fire Brigade has a further 5, and the WDC has 9 radios available. Radios are given to the motel operators in the Holiday Park area when a Level 3 Alert is issued.
3. The success of the plan is heavily reliant on the Local CD Co-ordinator being available. At present, the backup positions are vacant, or filled by people who are shortly to leave the Franz Josef Glacier area. The Motel Operators were unaware of whom they would talk to if the Local Co-ordinator could not be contacted: “He’s always been available before.”
4. Until a declaration of Civil Defence Emergency is made by the Mayor of Westland District or the Local Co-ordinator, the NZ Police are the lead authority for a flooding situation. The Local Co-ordinator would support the Police and act in an advisory capacity. However, it was felt that the local Police are probably not sufficiently familiar with the river to be able to assess when it has reached the different Alert Levels, thus reinforcing the criticality of this individual’s involvement, as the Response Plan currently stands. In addition, no one in Franz Josef Glacier who was spoken to about the Response Plan mentioned the Police, either because they were unaware of their involvement, or are only used to dealing with the Local Co-ordinator.
5. Alert level 5 corresponds to failure of bridge or banks imminent. The motel operators both stated they believed it would take approximately 30 minutes to clear their sites from the time the order to evacuate is issued. The Local Co-ordinator believed that it would be prudent to allow an hour for this in case of traffic problems and other issues.

The order to evacuate should therefore be given well before failure of the banks or bridge is imminent to ensure a safe evacuation, especially when the evacuation route is over the bridge. It has been suggested that in a flood on the Waiho River, the motel guests may be safer remaining in their accommodation than crossing the bridge, especially if they are walking.

6. At the present time, there is no formal back up evacuation route if the bridge is impassable. For example, in January 2002, the right bank bridge approach was washed out when the river was still 2-3 metres below the crest of the flood defences on the left bank. Had the river changed course, or continued rising, and threatened the left bank defences, it would not have been possible to evacuate across the bridge. The bridge is also likely to be impassable after an earthquake.
7. Both motel operators stated they would take their guests up the hill into the bush to the south of the Holiday Park area if the bridge was out, but it was unclear if there was sufficient space for all of their guests to comfortably remain in this area under any shelter. At a Level 3 alert the Black Sheep Lodge sends 2 glacier guides up the hill to establish a temporary shelter, should it be required. Neither the WDC nor MCDEM were aware of this possible evacuation route. A potential problem is that people could be trapped on this hill if the river cut through the Holiday Park area. WDC are intending to investigate this option and to include it in the Response Plan, if this is deemed to be appropriate.
8. The Response Plan does not say anything about an immediate need to inspect the Callery Gorge (and the Tatare) for landslides after an earthquake, if weather conditions allow. If it is raining when the earthquake occurs, the Motel complexes on the south bank should be immediately evacuated, if possible, until the risk of a landslide-dambreak flood has been eliminated.

The WDC and MCDEM recognise that the existing response plan has some limitations, and are currently in the process of reviewing and updating the plan. They are paying particular attention to who is going to fill each of the critical response roles, and who the backups to these people are going to be, in order to make the response more robust.

The motel operators and Local CD Co-ordinator anticipate that it would take approximately 30 to 60 minutes to evacuate the motel complexes, from the time the order to evacuate is given.

The existing response plan should cope with “normal” floods on the Waiho, where there is sufficient time to get the relevant personnel on site, and to organise the evacuation. The high awareness of the hazard associated with the Waiho River means that the local residents are actively monitoring the river levels during heavy rainfall events, especially the operators of the Motels on the south side of the river. Coupled with the rainfall warnings from the MetService, it is unlikely that there would not be sufficient advance warning of flooding on the Waiho to evacuate the Motel Complexes.

For landslides that occur in dry weather, there should be sufficient time available for the landslide to be inspected and for any relevant areas of Franz Josef Glacier to be evacuated, provided the slide is observed in some way (e.g., sound, dust cloud, helicopter inspection). The greatest hazard is posed by landslides that occur during heavy rain, as their occurrence is unlikely to be noticed, even during the day. It is entirely possible that the first indication anyone in Franz Josef has of such an event will be the flood wave reaching the bridge, by which time it will be too late.

7.3 Summary: Probability of Failure of Warning and Response

The estimated probabilities of failure to provide a warning and of failing to respond as intended (within the available time) are summarised in Table 7.3. The overall probability of failure is given by:

$$P_{\text{failure, overall}} = 1 - (1 - P_{\text{failure, warn}}) \text{ x } (1-P_{\text{failure, respond}})$$

Table 7.3: Probability of warning and response failure, given a flood event on the Waiho River.

Flood Scenario			Probability of failure to WARN	Probability of failure to RESPOND	OVERALL probability of failure
“Normal” Flood			0.1	0.2	0.28
Landslide-dambreak:					
Earthquake	Day	Fine	0.1	0.3	0.37
		Rain	0.1	0.8	0.82
	Night	Fine	0.1	0.35	0.42
		Rain	0.1	0.85	0.87
Rainfall	Day		0.8	0.5	0.90
	Night		0.8	0.5	0.90
Other	Day		0.3	0.1	0.37
	Night		0.3	0.1	0.37

8. Summary: Risk to Life in the Holiday Park Area

The findings from this investigation, based on the WDC Response Plan in its current form, are presented in Table 8.1. For each flood scenario, Table 8.1 presents the following information (capital letters refer to the column numbering across the top of the table):

A & B. The minimum and maximum annual probability of a flood large enough to damage the flood defences (from Table 4.3).

C. The proportion of the day covered by day- or night-time.

D. The proportion of the year covered by the peak or off-peak season.

E. & F. The minimum and maximum probability of major damage to the Holiday Park area, GIVEN a flood event (from Table 5.2).

G. & H. The minimum and maximum probability of fatalities, GIVEN major damage to the Holiday Park area (from Table 6.5).

J. The minimum estimated probability of fatalities, with NO warning or response mechanisms in place (= A*C*D*E*G).

K. The maximum estimated probability of fatalities, with NO warning or response mechanisms in place (= B*C*D*F*H).

L. The estimated unreliability of the warning systems (from Table 7.3).

M. The estimated unreliability of the response/evacuation systems (from Table 7.3).

P. The overall unreliability of the warning and response systems (= 1 – [1 – L]*[1 – M.]).

Q. The minimum estimated probability of fatalities, WITH warning and response mechanisms in place (= J*P).

R. The maximum estimated probability of fatalities, WITH warning and response mechanisms in place (= K*P).

S. The number of people potentially exposed to each flood hazard (from Table 6.6).

T. The proportion of people in the Holiday park area exposed to the flood hazard (from Table 6.5).

U. The number of people at risk due to each flood scenario (= S*T).

Note that the results in columns J, K, Q, and R are rounded to one significant figure, rather than to a fixed number of decimal places.

The risk to life results in columns Q and R are dominated by the effects of the “normal” floods and the rainfall-triggered landslide-dambreak flood events, with the risk to life associated with these events generally an order of magnitude larger than for the other flood scenarios.

Table 8.1: Calculation of Risk to Life in the Holiday Park area.

Column Number					A	B	C	D	E	F	G	H	J	K	L	M	P	Q	R	S	T	U
Flood Scenario					Annual probability of flood large enough to damage flood defences		% of day	% of year	Prob of damage to Holiday Park area, GIVEN flood event		Prob of fatalities, GIVEN damage to Holiday Park area		Prob of fatalities, NO WARNING OR RESPONSE		Warning and Response			Prob of fatalities, WITH WARNING AND RESPONSE		Number of people exposed to flood hazard	% of people affected by flood waters	Number of people at risk, N
					Min	Max			Min	Max	Min	Max	Min	Max	Prob of failure to WARN	Prob of failure to RESPOND	OVERALL prob of failure	Min	Max			
"Normal" flood	Day			Peak	0.1	0.2	0.33	0.50	0.8	1	0.4	0.8	0.005	0.03	0.1	0.2	0.28	0.001	0.01	26.3	0.5	13.1
				Off-peak				0.50					0.01	0.03				0.001	0.01	20.5		10.3
	Night			Peak			0.67	0.50					0.01	0.05				0.003	0.01	187.9		93.9
				Off-peak				0.50					0.01	0.05				0.003	0.01	134.0		67.0
Seismic failure of flood defences	Day			Peak	0.003	0.008	0.33	0.50	0.8	1	0.4	0.8	0.0003	0.001	0.1	0.2	0.28	0.0001	0.0003	26.3	0.5	13.1
				Off-peak				0.50					0.000	0.001				0.0001	0.0003	20.5		10.3
	Night			Peak			0.67	0.50					0.001	0.002				0.0001	0.001	187.9		93.9
				Off-peak				0.50					0.001	0.002				0.0001	0.001	134.0		67.0
Landslide dambreak	Earthquake	Day	Fine	Peak	0.003	0.01	0.33	0.50	0.9	1	0.8	0.9	0.0006	0.002	0.1	0.3	0.37	0.0002	0.001	26.3	1	26.3
				Off-peak				0.50					0.0006	0.002				0.0002	0.001	20.5		20.5
			Rain	Peak				0.50					0.0006	0.002	0.1	0.8	0.82	0.0005	0.001	26.3		26.3
				Off-peak				0.50					0.0006	0.002				0.000	0.001	20.5		20.5
		Night	Fine	Peak			0.67	0.50					0.001	0.003	0.1	0.35	0.42	0.0005	0.001	187.9		187.9
				Off-peak				0.50					0.001	0.003				0.0005	0.001	134.0		134.0
			Rain	Peak				0.50					0.001	0.003	0.1	0.85	0.87	0.001	0.003	187.9		187.9
				Off-peak				0.50					0.001	0.003				0.001	0.003	134.0		134.0
	Rainfall	Day		Peak	0.01	0.02	0.33	0.50	0.9	1	0.8	0.9	0.001	0.003	0.8	0.5	0.90	0.001	0.003	26.3	1	26.3
				Off-peak				0.50					0.001	0.003				0.001	0.003	20.5		20.5
		Night		Peak			0.67	0.50					0.002	0.01	0.8	0.5	0.90	0.002	0.01	187.9		187.9
				Off-peak				0.50					0.002	0.01				0.002	0.01	134.0		134.0
	Other	Day		Peak	0.01	0.02	0.33	0.50	0.9	1	0.8	0.9	0.001	0.003	0.3	0.1	0.37	0.0004	0.001	26.3	1	26.3
				Off-peak				0.50					0.001	0.003				0.0004	0.001	20.5		20.5
		Night		Peak			0.67	0.50					0.002	0.006	0.3	0.1	0.37	0.001	0.002	187.9		187.9
				Off-peak				0.50					0.002	0.006				0.001	0.002	134.0		134.0

A summary of the probability of fatalities for each number of people at risk is presented in Table 8.2. These results have been found by adding the probabilities for each group of people numbers in column U of Table 8.1.

Table 8.2: Summary of Risk to Life in the Holiday Park area.

Number of people at risk	OVERALL RISK of fatalities, GIVEN flood event, NO WARNING OR RESPONSE		OVERALL RISK of fatalities, GIVEN flood event, WITH WARNING OR RESPONSE	
	Min	Max	Min	Max
10.3	0.006	0.03	0.002	0.008
13.1	0.006	0.03	0.002	0.008
20.5	0.004	0.009	0.002	0.006
26.3	0.004	0.009	0.002	0.006
67.0	0.01	0.06	0.003	0.02
93.9	0.01	0.06	0.003	0.02
134.0	0.007	0.02	0.005	0.01
187.9	0.007	0.02	0.005	0.01

9. Discussion

9.1 Acceptability of Risk

There are various measures of the acceptability of different societal risks, which can be used for different purposes. The societal risk criteria most applicable to the current investigation are those suggested by ANCOLD (1998), Finley and Fell (1997), Gillon (2000), and HSE (1992).

9.1.1 ANCOLD

One of the key design issues for large dams is the potential for failure during a flood event, both during construction and the operational life of the structure. ANCOLD have developed societal risk guidelines for dam failure involving the annual probability of failure and the number of fatalities. These guidelines are most clearly expressed as curves on an FN plot – a logarithmic plot of F, the annual probability of failure causing N or more fatalities, against N, the number of fatalities, as shown in Figure 9.1.

ANCOLD have suggested “objective” and “limit” levels of risk. The area below the objective line covers a region of broadly acceptable risk, which the majority of the community will accept. In contrast, the area above the limit line represents a region of unacceptable risks, where risks cannot be justified by any means. Between the two curves is what is known as the ALARP region, where risks are not necessarily accepted, but are tolerated and must be managed to be “as low as reasonably practicable”.

The results from the current investigation presented in Table 8.2 have been superimposed on to the ANCOLD societal risk chart, as reproduced in Figure 9.1. For each number of people at risk, the range of the probability of fatalities with and without the warning and response systems has been shown with the midpoint, and the minimum and maximum values. The results for the Waiho River are clearly in the unacceptable region of the chart, and a substantial reduction in both the number of fatalities and the probability of those fatalities is required to reduce the risk to acceptable levels.

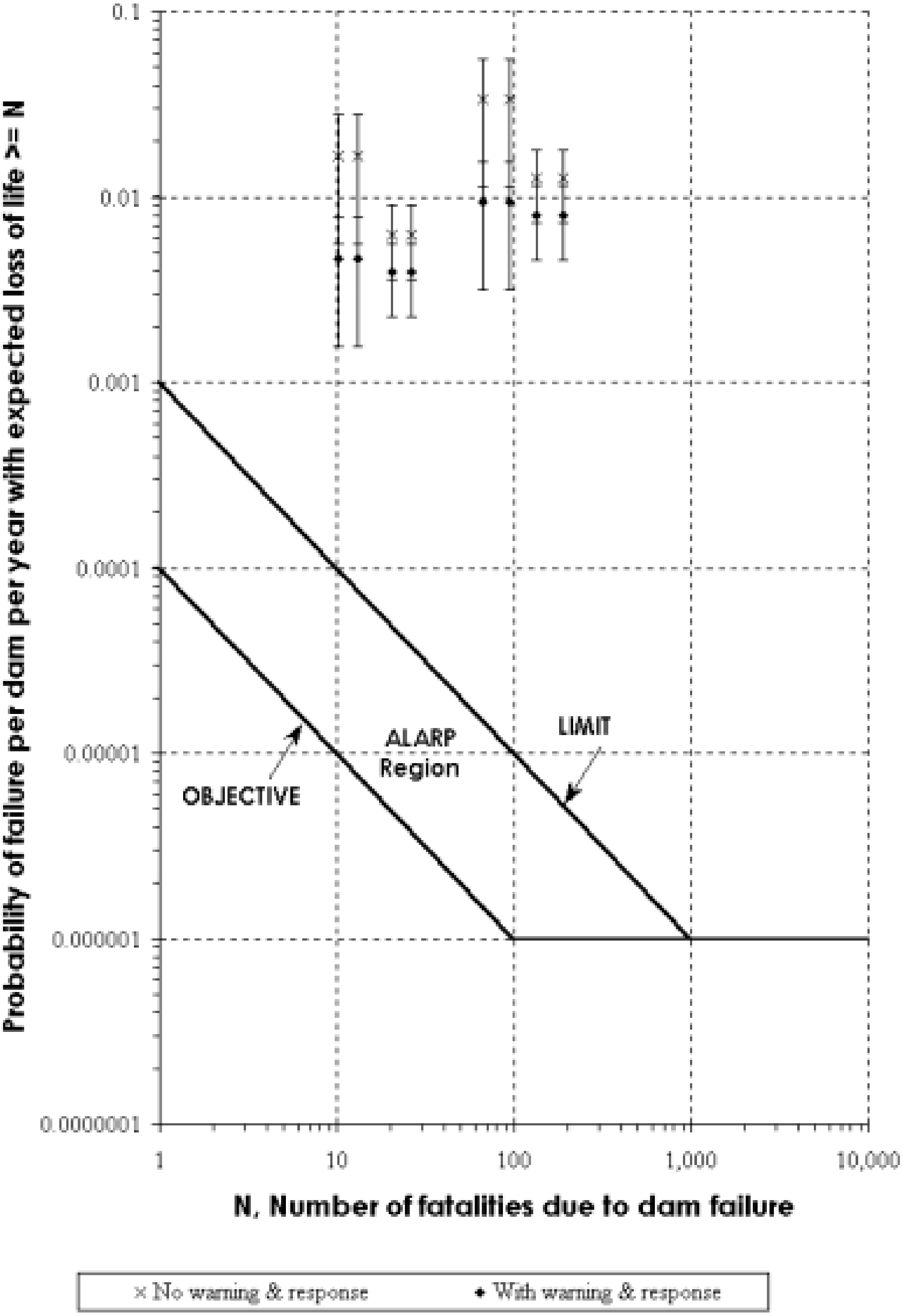

Figure 9.1: ANCOLD societal risk criteria (from ANCOLD, 1998).

9.1.2 Finley and Fell

Finley and Fell (1997) discuss the perception and acceptance of risk from landslides, including a review of acceptable risk criteria from other authors. Several observations and conclusions are of relevance to the Waiho River situation:

- The upper limit of acceptable risk **from a voluntary hazard** is an annual loss of life frequency of **1 in 1000** (0.001).
- For a risk to be perceived as low or very low, the annual loss of life frequency would need to be between **1 in 100,000** (0.00001) and **1 in 1,000,000** (0.000001), consistent with acceptable involuntary risks in other areas such as dams and petrochemical plants.
- Acceptable probabilities for loss of life from involuntary hazards decrease as the landslide situations become more dangerous.

9.1.3 Gillon

Gillon (2000) discusses the application of risk assessment to dam safety management. He comments that the safety of a dam must be assessed against current dam safety standards, although this process is complicated by two factors: the uncertainty in the risk assessment process is often large, and there are no widely accepted societal risk criteria.

Gillon proposes that an acceptable risk criteria for failures of constructed dams causing substantial loss of life (100 lives) is in the order of **1 in 100,000** (0.00001) to **1 in 1,000,000** (0.000001).

9.1.4 Health and Safety Executive

The HSE (1992) report on the tolerability of risk from nuclear power stations investigated a range of societal risk criteria. Some of the more relevant criteria include:

- The maximum level of risk to any member of the public from any industrial plant in any industry must be less than **1 in 10,000** (0.0001).
- At the time of construction, the risk of the Thames Barrier being overtopped by a freak tide had to be less than **1 in 1000** (0.001) per annum.
- Where there is little choice but to accept a major societal risk, its chance of occurrence should be **1 in 1000** (0.001) per annum or less, and if possible, less than 1 in 5000 (0.0002).

9.1.5 Application of Societal Risk Criteria to the Waiho River

The societal risk levels presented in §9.1.1 to §9.1.4 relate to a range of different industries and countries, and yet show a high level of agreement. Two key levels of risk acceptability are apparent: a frequency of 1 in 1000 for voluntary risks, or risks where there is little choice but to accept them, and a much lower frequency of 1 in 100,000 or less for major involuntary risks.

The distinction between voluntary and involuntary risks is important, especially in the current context. In general, people are willing to take on a significantly higher level of risk if the risk is voluntary. For example, a person may quite happily accept the risks associated with parachuting if they actively jump out of a plane. However, that same person is unlikely to accept the same level of risk if they are thrown out of the same plane wearing the same parachute from the same height. The actual level of risk, if one could be assessed, has probably not changed, but the level of risk acceptability is likely to be significantly lower in the latter situation.

For the Holiday Park area, the residents on the south side of the river may not have accepted the risk associated with flooding on the Waiho River, but the fact that they are still there means that they, actively or otherwise, are prepared to voluntarily tolerate this risk, at least in the short term. In contrast, for the guests in the two Motels, the risk associated with the river is involuntary. They are unlikely to recognise the degree of risk and, quite reasonably, would expect not to be put at risk in rented accommodation.

Flooding is a natural hazard and it could be argued that the societal risk criteria discussed here are not applicable because we are not looking at a designed dam or industry. However, while the floods may be a natural hazard, the degree of risk associated with the hazard is largely due to the actions of people. In the present situation, the location and design of the flood defences, the location and operation of the motel complexes, and the design and implementation of the warning and response plans, are all designed aspects of the river environment that affect the level of risk in some way. The societal risk criteria are therefore applicable to the Waiho River.

The societal risk criteria that are relevant to the Waiho River correspond to the involuntary risk associated with guests staying in the Holiday Park area, and are therefore at the lower level of the tolerable limits presented in §9.1.1 to §9.1.4. Applying this criteria means that the probability of fatalities associated with flooding on the Waiho River must be less that 1 in 100,000 to be considered acceptable.

The probabilities of fatalities listed in Table 8.2 are in the range 0.002 to 0.01 allowing for the current warning and response systems. These probabilities are significantly greater than the acceptable limit of 1 in 100,000. Even reducing the societal criteria to the lowest acceptable level of 0.001, the risk associated with the Waiho River remains unacceptable. This is demonstrated graphically in Figure 9.1.

The estimate of risk for the Waiho River involves a large degree of uncertainty. However, this uncertainty is unlikely to be more than a factor of two, that is, the probability of fatalities is unlikely to be less than 0.001 to 0.005. This is still equal to, or greater than, the maximum acceptable level of societal risk. It is therefore necessary to look at the options for reducing this risk, either through improved response mechanisms, or risk reduction.

9.2 Improving the Warning and Response Systems

Some of the limitations of the current response plan were discussed in §7.2. MCDEM and WDC are currently in the process of improving some of these limitations, including consideration of some of the following options:

1. Increase the robustness of the response procedures. Examples of possible improvements include:
    - Clearly identify the backup people for the Local CD Co-ordinator so there are always trained people available to assess the state of river.
    - Ensure that all of the people involved in evacuations (accommodation managers, staff, CD personnel, etc) are fully trained in their role, are aware of the role of others, and are clear on the channels and forms of communication to be used.
    - Trial the evacuation procedures (possibly around a table rather than a full trial evacuation) to more clearly identify the strengths and deficiencies of the existing response plan.
2. Investigate ways to reduce time required for evacuation (e.g., better coordination of the evacuation vehicles).
3. Investigate the feasibility and safety of the alternative evacuation option to the hills south of the motel complexes to possibly eliminate the need to evacuate people across the "at risk" SH6 bridge. If acceptably safe, investigate establishing a safe haven on hills to south of motel complexes to provide shelter to motel guests and staff.
4. Clearly state the need to immediately evacuate the motel complexes after an earthquake until the risk of a landslide-dambreak flood has been eliminated.
5. Investigate the feasibility of establishing a monitoring system for detecting changes in water levels in the Callery River to detect flow changes associated with a landslide dam. This would be a difficult system to put in place, given the remoteness of the Callery Gorge, and the problems already experienced with the monitoring systems on the SH6 bridge. It is unlikely that a system of sufficient reliability could be economically constructed and maintained.
6. Investigate the feasibility of establishing a local seismograph network to detect landslide activity in the surrounding valleys. This is technically feasible, as landslides have a different signature to earthquakes, but may not be economically viable.

There are many other improvements that can, and probably should, be made to the warning and response systems. However, it is important to realise that these improvements alone are unlikely to reduce the risks associated with the Waiho River to acceptable levels. The unreliability of the warning and response systems would need to be reduced from the current 0.3 – 0.9 to at least

0.0003 to 0.0009 to meet the acceptable societal risk criteria. This will be extremely difficult, if not impossible for the types of risks and responses being dealt with here, thus additional risk reduction measures are required.

9.3 Risk Reduction Options

There are a number of risk reduction options for the Waiho River. These are essentially "engineering" solutions, and have been discussed by McSaveney and Davies (1998), and Hall (2000). Broadly speaking, there are two possible approaches for reducing the risk associated with the Waiho River:

1. Increase the security of the flood defences against breaching by the river – this is a short-term option only, as the level of protection will decrease as the river continues to aggrade. This option only reduces the risk associated with "normal" floods, and will not impact on the level of risk for any dambreak or seismic events.
2. Relocate the motel complexes in order to eliminate the risk. Ideally, this would need to be accompanied by zoning changes in the District Plan to ensure the area was not subsequently developed in the future. This is the only viable long-term solution that will reduce the flooding risk to acceptable levels. Changes may also be required to the alignments of SH6 and the stopbanks in this area.

Eliminating or reducing the risk to the motel complexes (e.g., through property purchase) will not eliminate the need to monitor and manage the risk to life associated with people using the SH6 bridge. Fortunately, the simple solution of closing the bridge during flood events will manage this risk, but it means that river monitoring systems will still be required. This has not been explicitly considered in the current study, but will clearly need to be considered in any future developments in the response plans for the area.

10. Conclusions

1. Flood hazards on the Waiho River can be grouped into two broad categories: "normal" rainfall related floods, and floods associated with landslide-dambreak events in the Callery Gorge.
2. The flood defences in the vicinity of the Holiday Park area are at high risk of failure in a flood event on the Waiho River.
3. The Holiday Park area is likely to be extensively damaged in a "normal" flood if the flood defences fail, and completely destroyed in a dambreak event regardless of the presence of the flood defences.
4. Any persons caught in the path of a flood through the Holiday Park area are likely to be killed in a "normal" flood, and extremely likely to be killed in a dambreak event.
5. The expected number of people that may be exposed to the flooding hazard in the Holiday Park area at any time is highly variable. It ranges from 20 to 26 during the day, up to 130 to 190 at night, depending on the time of year. The maximum number of people in the Holiday Park area is approximately 300, assuming every bed is full and all staff are on site.
6. The annual risk of fatalities in the Holiday Park area varies across the different types of floods and different numbers of people exposed to the hazard, but is generally in the order of 0.004 to 0.06, if there is no warning or response system in place.
7. The existing warning and response plan has some limitations, but does reduce the risk of fatalities, primarily for "normal" floods and landslide-dambreak events that occur in fine weather. For landslide-dambreak events that occur during a storm, the existing warning and response plan is ineffective and does not significantly reduce the level of risk.
8. The annual risk of fatalities in the Holiday Park area varies across the different types of floods and different numbers of people exposed to the hazard, but is generally in the order of 0.002 to 0.02, allowing for the existing warning and response systems.
9. The risk to life in the Holiday Park area is greatest for the "normal" flood events and the rainfall-triggered landslide-dambreak events. These events should therefore be the primary, but not exclusive, focus of any risk mitigation efforts.
10. Acceptable levels of societal risk for the likely numbers of fatalities in the Holiday Park area are in the order of 1 to 100,000 to 1 in 1,000,000 (0.000001 to 0.0001). These limits are substantially lower than the current level of risk, and are unlikely to be met through warning and response system improvements alone.
11. The only practical, long-term solution to reduce the risk of fatalities to an acceptable level appears to be through relocating the motel complexes with subsequent changes in the zoning of the Holiday Park area to prevent future redevelopment.
12. Regardless of what is done with the Holiday Park area, there will be an ongoing need to monitor the safety of the SH6 bridge during flood events on the Waiho River.

References

ANCOLD (1998), *ANCOLD Guidelines on Risk Assessment*. Position paper for revised criteria for acceptable risk to life. Australian National Committee On Large Dams (ANCOLD) Working Group on Risk Assessment.

Berryman, K. (1998), Appendix 2 – probability estimates for rupture of the central section of the Alpine Fault. *In* McSaveney, M.J., & Davies, T.R. (1998), Natural hazard assessment for the township of Franz Josef Glacier and its environs. *Client Report 43714B.10*, Institute of Geological and Nuclear Sciences Limited, Lower Hutt, 43-48.

Davies, T.R. (2002), Landslide-dambreak floods at Franz Josef Glacier township, Westland, New Zealand: a risk assessment. *Journal of Hydrology (New Zealand)*, **41**(1), 1-17.

Davies, T.R., & McSaveney, M.J. (2000), Anthropogenic fanhead aggradation, Waiho River, Westland, New Zealand. *Proceedings of Gravel-bed Rivers 2000*, 27 August – 2 September 2000, Christchurch, New Zealand. Mosley, M.P. (Ed), pp. 531-553.

Finley, P.J., & Fell, R. (1997), Landslides: risk perception and acceptance. *Canadian Geotechnical Journal*, **34**, 169-188.

Gillon, M.D. (2000), Current trends in assessing dam safety. *Proceedings of Technical Groups*, IPENZ, NZ Society On Large Dams, Wellington, New Zealand, 25-36

Gough, J. (2001), *Changes in Understanding, Awareness and Preparedness for Natural Hazard Risk (Franz Josef Glacier Village)*, 13p.

Gough, J., Johnston, D., & McSaveney, M.J. (1999), *Community Response to Natural Hazard Risk at Franz Josef Glacier*. Institute of Geological and Nuclear Sciences science report 99/10, Institute of Geological and Nuclear Sciences Limited, Lower Hutt, 44p.

Hall, R.J. (2000), *Evaluation of Options for the Management of the Waiho River Aggradation Threats*. Civil & Environmental Consulting Ltd., Timaru, New Zealand, 29p.

Health and Safety Executive (1992), The tolerability of risk from nuclear power stations (1992 Ed), HMSO London, ISBN 0 11 883982 9.

McSaveney, M.J., & Davies, T.R. (1998), Natural hazard assessment for the township of Franz Josef Glacier and its environs. *Client Report 43714B.10*, Institute of Geological and Nuclear Sciences Limited, Lower Hutt, 65p.

Taig, T. (2002), *Ruapehu Lahar Residual Risk Assessment, a Report Produced for the Ministry of Civil Defence & Emergency Management, New Zealand*. TTAC Limited, 92p. (plus Appendices).

Westland District Council (2002), *Franz Josef Response Plan and Operating Procedures*, 62p.