# Response to Landslide Dam Failure Emergencies: Issues Resulting from the October 1999 Mount Adams Landslide and Dam-Break Flood in the Poerua River, Westland, New Zealand

J. S. Becker[1]; D. M. Johnston[2]; D. Paton[3]; G. T. Hancox[4]; T. R. Davies[5]; M. J. McSaveney[6]; and V. R. Manville[7]

**Abstract:** On October 6, 1999, a large rock avalanche from Mount Adams on the west coast (Westland) of the South Island, New Zealand, fell into the Poerua Valley. The landslide blocked the river valley, damming the Poerua River, and creating a large lake. The potential for overtopping and failure of the landslide dam presented a potential dam-break flood hazard that was assessed as posing a serious danger to Poerua Valley residents located downstream. The dam eventually failed 6 days after it was formed. Fortunately, the resulting flood was largely confined to the river channel and flood-plain areas, causing little damage and no deaths. The Poerua River landslide dam-break flood highlighted a range of issues that should be addressed in managing future landslide dam-break flood emergencies. This paper summarizes the key organizational, community, and response issues arising from a break-out flood such as this. Planning for the management of future landslide dam-break floods may help reduce loss of life from future events. Preparations could include setting aside more resources for assessing the hazard, and improved control and communications for managing the response. From an emergency management perspective, because of the remote and inaccessible location of landslide dam sites in steep mountain valleys on the west coast of New Zealand's South Island, it is important to ensure that the community has direct involvement in the readiness and response process.

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## Introduction

Landslide dam-break floods occur in many mountain regions. A number of factors contribute to the risk they pose; they occur infrequently, and local people usually do not expect them. The available warning time may be very short, and may limit the potential for evacuation. The peak discharge may be many times greater than any normal rainfall triggered flood, potentially placing "normally safe" infrastructure and lives at risk. High water levels in dam-break flood waves occur very quickly, and may carry more logs and debris than normal floods. It is therefore prudent to make warning systems, and the response to those systems, as effective as possible to ensure that vulnerable people and communities have some understanding of the risk and are prepared to respond quickly. These measures maximize the use of the available warning time to enable people to reach safety before the flood wave arrives.

The October 1999 Mount Adams rock avalanche and landslide dam-break flood on the Poerua River, Westland, New Zealand, highlighted a range of issues that should be addressed in managing future dam-break flood emergencies. This paper summarizes the key organizational, community, and response issues arising from that event. More detailed descriptions of the landslide and flood are published elsewhere (Hancox et al. 1999, 2000, 2005).

## Summary of the 1999 Poerua River Event and Response

On October 6, 1999 at 2:35 a.m., a rock avalanche with a volume of ~10–15 million $m^3$ fell from Mount Adams into the Poerua Valley in Westland on the west coast of the South Island, New Zealand (Fig. 1). The landslide blocked the narrow river gorge to a depth of about 120 m, damming the Poerua River and creating a lake that held, at most, 5–7 million $m^3$ of water (Fig. 2).

Local residents were awakened by the noise of the falling

[1]Social Scientist, Institute of Geological and Nuclear Sciences, P.O. Box 30368, Lower Hutt, New Zealand.

[2]Hazard Management Scientist, Institute of Geological and Nuclear Sciences, P.O. Box 30368, Lower Hutt, New Zealand.

[3]Associate Professor, School of Psychology, Univ. of Tasmania, Locked Bag 1342, Launceston, Tasmania 7250, Australia.

[4]Engineering Geologist, Institute of Geological and Nuclear Sciences, P.O. Box 30368, Lower Hutt, New Zealand.

[5]Associate Professor, Univ. of Canterbury, Private Bag 4800, Christchurch, New Zealand.

[6]Geomorphologist, Institute of Geological & Nuclear Sciences, P.O. Box 30368, Lower Hutt, New Zealand.

[7]Geoscientist, Institute of Geological & Nuclear Sciences, Private Bag 2000, Taupo, New Zealand.

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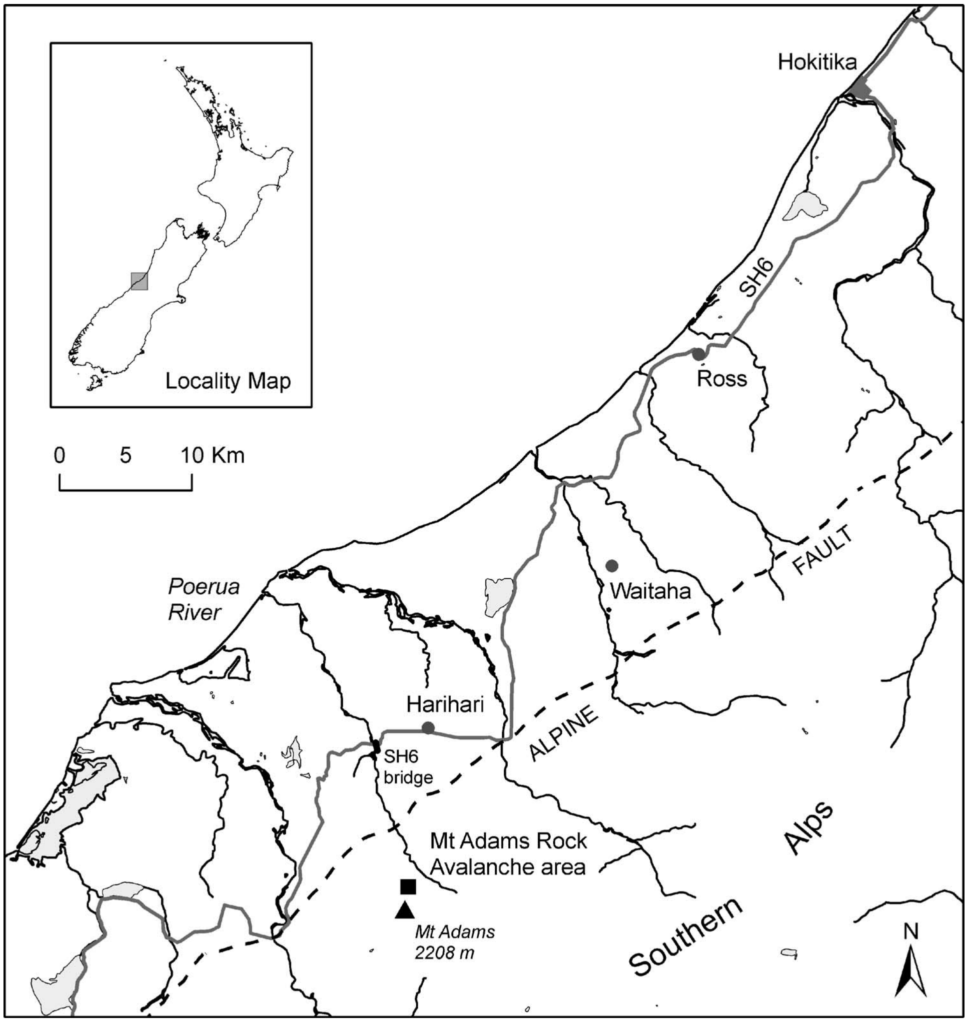


**Fig. 1.** Location of the Mount Adams rock avalanche, the Poerua River, and surrounding area

**Fig. 2.** Aerial view of Poerua landslide dam and lake on October 8, 1999. At this point, the lake is at its highest level (approximately 480 m), with an overflow channel established on the true left side of the dam and flowing into the Poerua River (Hancox et al. 2005).

rock. After dawn they noticed that flow in the river was reduced and contacted the West Coast Regional Council (WCRC), the police at Ross township, and the Westland District Council (WDC) in Hokitika (Hancox et al. 1999). The first calls from residents came in between 8 and 8:30 a.m. (Table 1, West Coast Regional Council 1999).

Following the initial contact by residents, a number of hours passed in which calls were made between the regional council, district council, local police, and Opus International Consultants (a consulting engineering firm) discussing the possibility of a newly formed dam and the current situation. Calls were also made to a helicopter company to arrange transport for a site visit (West Coast Regional Council 1999).

About 1:00 p.m., staff from the WCRC and WDC used a helicopter to inspect the inaccessible area affected by the rock fall—a narrow gorge 11 km upstream from the main road (State Highway 6) across the valley. They confirmed that a large landslide had dammed Poerua River and that a lake was forming. The situation was assessed as potentially dangerous and a strategy was formed by a group that included WDC emergency and civil defense staff, police, and two local residents. The strategy included (Westland District Council 1999):

- Monitoring of the dam every 4 h until water was within 10 m of the top of the dam after which the monitoring frequency would be increased.

**Table 1.** Timeline of Critical Events during the October 1999 Poerua Landslide Dam Response Period

| Date | Events |
|---|---|
| October 6 | |
| 2:35 a.m. | Initial rock avalanche occurs causing a landslide dam on the Poerua River. |
| 8–9 a.m. | Reduced flow noticed in Poerua River—WCRC, WDC, and Ross police alerted by residents. |
| 1 p.m. | Aerial inspection by WCRC and WDC staff confirms formation of landslide dam. |
| Afternoon | Residents warned by WDC and police. |
| 7:30 p.m. | Community meeting in Harihari. |
| October 7 | |
| 7:30 a.m. | Dam inspection—water level 15 m below dam crest, filling at 0.5 m/h. |
| Morning | WDC contacts GNS staff for expert advice; Lincoln University staff also contacted. |
| Morning | Dam inspection, rainfall filling lake faster. |
| 3 p.m. | WDC Civil Defense and police ask residents in Poerua Valley to move out overnight. |
| 7:30 p.m. | Public meeting in Harihari. |
| 8:00 p.m. | Dirty flow in Poerua River indicates dam overtopped. |
| October 8 | |
| 8–9 a.m. | Ground and helicopter inspection by WDC and GNS staff. Lake overflowing but continuing to rise. Position of landslide and dam accurately located. |
| Morning | Initial hazard assessment given to WDC and the police by GNS staff. |
| Morning | Residents in upper Poerua Valley are allowed to return to their homes. |
| Late morning | Second helicopter inspection by GNS and WDC staff. Oblique aerial photographs taken by GNS. |
| Early afternoon | Fixed-wing overflight by GNS and Lincoln University staff. Lake reaches maximum level. Meeting of GNS and Lincoln University staff to assess dam hazard and plan response measures. |
| Afternoon | GNS and Lincoln staff met with Mayor of Hokitika and WDC to advise hazard assessment. |
| Evening | Public meeting at Harihari. Results of investigations presented. |
| October 9–11 | |
| | Geomorphic mapping and assessment of dam-break flood hazard. |
| October 11 | |
| | Heavy rain on the West Coast. |
| October 12 | |
| 7:50 a.m. | Inundation of river flats in upper Poerua Valley indicates breaching of landslide dam. |
| Approximately 8:00 a.m. | Valley residents notified and self evacuate. |
| 8:11 a.m. | Civil Defense emergency declared. |
| 8:30–8:40 a.m. | River level peaks at SH6 bridge (2 m above normal flow). |
| 1:10 p.m. | Civil Defense emergency canceled after breach confirmed by WDC staff. |
| October 14 | |
| | Aerial and ground inspection of dam site by GNS and Lincoln staff. |

Note: WCRC=West Coast Regional Council; WDC=Westland District Council; and GNS=Institute of Geological and Nuclear Sciences.

- A manual quick-call "telephone tree" system was put in place to contact all residents in an emergency. After receiving a warning message from an official source, individuals at the top of the telephone tree were required to make a call to other individuals further down the list, and pass on the message. This was to continue until all listed residents had been informed of the emergency situation.
- Base operations would continue at a local resident's house until "events overtook" those involved in the response. In the event of being forced from this house, operations would be based at Harihari Fire Station.
- People occupying baches (small dwellings) at the Poerua River valley mouth would be asked to evacuate.
- The State Highway 6 (SH6) bridge would be used as a monitoring point and a watch kept on water levels at the bridge.
- The fire brigade would be used to close the State Highway and used to ensure that property was secure if necessary.
- The evacuation assembly point was located at the Harihari Hotel for the local community. Readiness planning needed to consider the duration of the period of evacuation and ensure that resources were made available accordingly.
- Peterson Road beside the Poerua River and the Department of Conservation (DOC) track access to the river would be closed.

A public meeting was held in Harihari at 7:30 p.m. the evening of October 6 to discuss evacuation plans and mitigation measures. Those present at the meeting included members of WDC, WCRC, local police, and residents of the Poerua Valley. It was surmised that as the lake was still filling and no rain was predicted, the lake did not pose an immediate threat to residents (Westland District Council 1999).

The following day (October 7), helicopter inspections of the dam were conducted from first light on a 4 h schedule. As the day progressed, it was found that rain was causing the lake to fill faster than anticipated. It was estimated that the lake was likely to overtop the dam that evening or the following morning. As a precaution, at 3:00 p.m. the WDC Civil Defense and Ross police asked at-risk Poerua Valley residents to voluntarily evacuate from their homes overnight (Hancox et al. 2000). The warning and request to evacuate were conducted primarily by telephone and reports of the evacuation indicated that this procedure went smoothly (Westland District Council 1999). A second public meeting was held in Harihari at 6:30 p.m. that night to discuss the events of the day and what was likely to happen overnight.

Earlier in the day WDC staff had also contacted the Institute of Geological & Nuclear Sciences (GNS) and Lincoln University for advice. GNS mobilized a field response (to the nearby town of Hokitika) as the dam began overtopping.

## Dam Overtops

The appearance of dirty water in the river indicated overtopping of the dam at approximately 8:00 p.m. on October 7, although the level of flow indicated that the dam still was intact.

On the morning of Friday October 8, two WDC staff members and a scientific advisor from GNS carried out a helicopter and ground inspection of the landslide dam and lake. Based on this inspection, the GNS scientific advisor gave the following hazard assessment and geotechnical advice to WDC and the police (from Hancox et al. 1999, 2000):

1. Because of its size, surficial armouring by large boulders, and the lack of erosion in the natural spillway channel, the landslide dam was considered to be *stable in the short-term*

*under present river flow*. Although channel erosion was unlikely with the existing river flow, the chances of the dam's long-term survival were considered to be very low. Geomorphic and historical evidence indicates that many landslide dams in West Coast rivers fail soon after formation.
2. Dam failure due to internal piping erosion was considered unlikely. Because of its size, the potential leakage path through the dam was very long and there was currently no evidence of leakage. Although there was a lot of coarse gravel and boulders in the natural spillway channel and dam, much of the slide debris was relatively fine (sand and silt-size) and would reduce seepage potential.
3. As the dam was considered unlikely to fail under the present flow, it was recommended to local authorities that valley residents could safely return to their homes.
4. There were still many uncertainties about the landslide dam and impounded lake. Mapping of the dam and lake would allow estimation of the lake volume and modeling of the size of the potential dam-break flood. Monitoring of lake-level changes, channel erosion, and seepage through the dam should be undertaken to further assess the dam-break hazard and determine appropriate mitigation and response measures.

As a result of the assessment which indicated that the dam was stable in the short term under present conditions, residents returned to their homes on the morning of October 8.

Following site inspections on the morning of October 8 and further investigation and analysis of the hazard by GNS and Lincoln University staff members, the scientific advisors presented their views on the long-term dam-break hazard and a response strategy at meetings held on the afternoon of October 8 with the Mayor of Hokitika and WDC staff. The main conclusions reached during these discussions were (Hancox et al. 1999):

1. Although the landslide dam survived overtopping and was considered stable in the short-term under existing low-flow conditions, it will inevitably fail, probably by channel erosion during a flood. This conclusion was based on two facts: First, most landslide dams fail within 1 year or less (Costa and Schuster 1988; Schuster, 2000). For example, smaller landslide dams formed in West Coast rivers after historical earthquakes have all failed within days or weeks of formation during floods or high normal flow (e.g., Buller River dams formed during 1929 and 1968 earthquakes, Hancox et al. 1997). Second, no landslide dams formed in large rivers on the West Coast in the central Southern Alps have survived to the present day (although recent work by Korup (2004) shows that this is in fact untrue).
2. Under the existing river flow, the dam-break flood hazard was considered to be low. Because of its size, the dam was thought unlikely to be breached without a significant increase in river flow, although there was a very small chance that weakening by piping and internal erosion might eventually occur. It was recommended that the dam should be watched for signs of seepage and erosion.
3. The dam-break hazard would be much higher during floods caused by moderate to heavy rainfall on the Poerua headwaters. It was not known how the Poerua dam would respond to higher lake level and increased spillway flow, but for response purposes it should be assumed that the dam would fail during high rainfall/flood conditions. The extent of the affected area would depend on the peak dam-break flow, which was estimated from an empirical formula (Costa and Schuster 1988) to be approximately 1,000–3,000 $m^3/s$ at the dam, depending on the (unknown) dam breach depth and duration. This compares with a mean annual flood in the Poerua River of 804 $m^3/s$ derived from 14 years of gauge records (McKerchar and Pearson 1989). Peak-flood flows ($Q_{max}$) can be better modeled once dam and lake volume estimates have been refined.
4. A range of monitoring measures should be implemented by the West Coast Regional Council, including: lake-level monitoring to detect any rise, or more significantly a rapid fall in lake level; and regular inspections of the dam and landslide area to check for seepage on the dam face, spillway erosion, or further falls of landslide debris which might block the natural spillway channel.
5. A system should be developed to warn residents of an impending flood and the need to evacuate affected parts of the valley. A paging system was to be investigated. The WDC and police should seek advice about forecast rainfall and the possibility of high river flows that could initiate a dam breach.
6. Until it was known how the dam would respond to higher river flow, it would be necessary for residents to evacuate from the Poerua Valley when heavy rain is forecast. The response of the dam to flooding could not be accurately predicted. It might survive one, two, or more floods, but it could be breached during the first significant flood and plans should be made for this possibility.
7. Geomorphic mapping of the landslide dam and lake would be undertaken to refine the size and volume estimates necessary for dam-break modeling. Because of the steep terrain this would be done from recent aerial photos and the 1:50,000 topographic map. Surveying of farmland was also suggested so that potential flood inundation paths could be modeled with greater accuracy.

After the discussions with the mayor and WDC, a public meeting arranged by WDC, police, and WCRC was held in Harihari at 7:30 p.m. to advise residents of the current situation and future hazard from the dam, and to present the conclusions (given earlier) from the earlier meeting. After considerable discussion among the residents, scientific advisors, and council staff members, these conclusions and recommendations were accepted by the meeting. To enable remote monitoring of lake level, the WCRC agreed to install a radio-linked water-level recorder on the lake as soon as practicable. Plans were also developed to manage the dam-break hazard and civil defense aspects aimed at protecting Poerua Valley residents from a dam-break flood. Until lake-level monitoring equipment was installed, the meeting agreed that the Poerua Valley area should be evacuated if rain were forecast (Hancox et al. 2005).

Over the following 2 days (October 9 and 10) monitoring of the dam continued. One resident heard rocks falling on October 10 and became concerned about dam failure. In response to this, WDC and WCRC organized a visit to view the dam but found no reason for additional concern (Westland District Council 1999).

## Dam Breaches

On Monday October 11, a heavy rainfall warning was issued with weather forecasts indicating that 80 mm of rain could occur on the West Coast. At this stage, no lake-level recorder had been installed due to poor weather conditions; so no early warning system was in place in case of dam breach. Visual monitoring from the SH6 bridge was the only provision for keeping a check on water-level changes (Hancox et al. 2000).

Because of the forecast of rain and the lack of recorders monitoring the lake level, a GNS scientific advisor recommended to WDC engineering and WRC staff that residents be evacuated overnight from the valley as a precaution. This message was relayed by telephone on the morning of October 11 and was confirmed in writing (e-mail) later in the afternoon of that day. The e-mail containing the evacuation message was not read by WDC or WRC until the following day after the dam had breached (Hancox et al. 2000).

Based on the heavy rainfall warning that was issued, WDC staff contacted police and a resident with a request to pass this information on to others. A WDC civil defense staff member monitored river levels from the SH6 road bridge downstream of all threatened dwellings during the afternoon of October 11 and throughout the night. Consideration was given by the WDC and police to evacuate the area on Monday evening, but given that no rain had fallen before dark, and monitoring was to be continued, this was not carried out. At least one household took it upon themselves to self-evacuate (Westland District Council 1999).

Some time before 8:00 a.m. on the morning of October 12, 1999, the landslide dam breached by overtopping and surface erosion. This was indicated by a rapid rise in river level across the river flats and farmland ~5 km up-valley from the SH6 bridge (Westland District Council 1999). A farmer observed the rise in river level and telephoned the police.

A phone call immediately went out from the WDC Civil Defense and police to evacuate the Poerua Valley, and the evacuation was carried out within 30 min. At 8:11 a.m. on October 12, 1999 a Civil Defense Emergency was declared. The water level at the SH6 bridge peaked at about 2 m above normal after 20–30 min, and then began to drop. The situation continued to be monitored and a helicopter was used to check that a number of coastal baches were evacuated and to check the state of the dam. The check confirmed that the dam had breached and the lake had partially (approximately three quarters) drained. With improving weather and falling water levels in the lake and river, the Civil Defense Emergency was cancelled at 1:10 p.m. (Hancox et al. 2000).

The peak flow of the flood was largely confined within the river channel and little damage resulted. Damage mainly occurred in the form of fences damaged and silt being deposited on pastures. A large quantity of material was eroded from the dam and deposited in the gorge and on the fan at the mouth of the gorge. This aggradation process is continuing to occur, affecting the riverbed and adjacent farmland, and may endanger the SH6 bridge in the future (Hancox et al. 2000, 2005).

## Warning the Community

There has been considerable research and discussion over the last two decades on warning systems for hazardous events and ways of managing them in order to deliver effective warnings to at-risk communities (Mileti and Sorensen 1990; Sorensen 2000; Handmer 2002). A number of basic decisions face emergency managers when confronted with risk information. These include:

- *Whether to warn*. In most events the probability of an impact is not well-defined and a decision on whether to warn the public has to be made. It is considered that when in doubt it is better to warn than to suffer adverse consequences as a result of not warning. People will tolerate false alarms if there is a valid scientific rationale for the warning and the lack of an event.
- *When to warn*. A warning should be issued sufficiently early to allow for appropriate action and its content geared to reflect the uncertainty and likelihood of the event. The warning can then be revised to take account of changing circumstances.
- *Who and where to warn*. Prior knowledge about the hazard and its impact on a particular geographical area will assist with decisions on who to warn. If in doubt, a larger spatial area should be warned to avoid having to react quickly if the impacts spread into unforeseen areas.
- *How to warn*. There is a need to specify the source of the warning, the channel of communication, message content, frequency with which the warning is given, and whether different audiences within the same geographical areas will require different warnings (Mileti and Sorensen 1990).

Five key pieces of information must be included when constructing a warning message: the nature of the hazard or risk, guidance, location, time, and source (Mileti and O'Brien 1992). The warning message must contain information about the impending hazard with sufficient simple detail that the public can understand the characteristics of the hazard that they need to protect themselves from. The message should include guidance about what they should do to maximize their safety. The warning message must describe the exact location that is at risk and address the "when" aspect of the required response. One or more of the important attributes required of warning messages (specificity, consistency, certainty, accuracy, clarity) is usually deficient or missing during such events. Specificity and certainty about the time and nature of the event are commonly missing. Table 2 summarizes the uncertainties that face emergency managers, scientists, and workers when faced with an event that may require a warning.

A number of the issues listed in Table 2 arose with respect to the Poerua crisis and the events that unfolded:

1. Issues arose with respect to the initial response of the local councils to the landslide-dam event on the morning of October 6. Some concern was felt by local residents in Poerua Valley regarding the delay that occurred from the time residents contacted the WDC, WRC, and police, to when key staff members became aware of the problem and acted. It was felt by some residents that a response of 2 1/2 h was too slow, and that prompter action was required. This illustrates two key readiness and response planning issues. The first concerns the important role played by local residents in raising the alarm. The fact that they are "on site" highlights the importance of incorporating the members of this group within the response planning process and training in a manner that facilitates their ability to provide the information required by other residents, users of warning information, and formal response agencies. The fact that this is an event characterized by sudden onset means that those local residents who first recognize a problem should be networked in a way that allows them to advise their neighbors of an impending or actual problem.
2. During the initial stages of the emergency, the response was coordinated from a local farmhouse at the head of the Poerua Valley. In essence, the farmhouse was operating as a temporary emergency operations center. Ideally, people who staff such centers should have a clear understanding of the problems related to an event and how they might change over time. They should also have a sound understanding of the roles of the various agencies involved, both in regard to their needs during the monitoring phase and in regard to their response activities. People who staff such centers will be

**Table 2.** Uncertainties of Warning Systems (Mileti and Sorensen 1990)

| | |
|---|---|
| Interpretation issues | • *Recognition of an event*. The variable abilities of people to recognize a threat may delay warnings and thus response time. |
| | • *Recognition of hazard*. |
| | • *Definition of magnitude*. Uncertainty of magnitude can lead to confusion over warning decisions and/or delayed (or premature) warnings and evacuation. |
| | • *Self-definition of role*. Uncertainty on the part of those who play key parts in the chain of communication can slow activation of the system because key players who are uncertain of their roles often do not convey risk in a timely manner. People are more likely to understand their roles in a warning system if plans exist and training occurs. |
| | • *Sorting of relevant information*. Sorting relevant from nonrelevant information is necessary when there is too much or bad information facing the decision-maker. |
| | • *Definition of authority*. Disputes may occur, information may not reach the right decision-maker, or decisions may be delayed or overlooked if no definition of authority has been decided prior to the event. |
| Communication issues | • *Whom to notify*. The communication process may not initiate, or may shut down or slow if it is not clear whom to notify, delaying public response. |
| | • *Ability to describe hazard*. If those who receive the warning cannot understand it, it compromises the usefulness of the message and the ability to warn. |
| | • *Physical ability to communicate*. Loss of technical ability to communicate creates uncertainty (or fails to initiate notification). |
| | • *Conflicting information*. Conflicting data or recommendations can lead to different conclusions about whether to issue a warning. Delays may occur in an attempt to clarify information or a bad decision may result if erroneous information is acted on. |
| Issues of perception | • *Adverse consequences*. Warning decisions are influenced by a decision maker's perception of the adverse consequences of action. |
| | • *Personal consequences*. Decision makers may fear that transmitting risk information for a threat that might not materialize could lead to personal consequences, such as loss of reputation, etc. |
| | • *Costs of protective actions*. Decision makers may be influenced by their perceptions of the dollar costs or losses that may stem from warning. |
| | • *Liability*. Warning decisions can be influenced by how organizations or the actors within them perceive liability. |
| | • *Feasibility*. Feasibility refers to the potential success of a warning in regard to successful public protection. |
| | • *Expectations*. Warning decisions can be influenced by the expectations or demands of persons outside the warning-system environment. |

responsible for coordinating information management and coordinating and/or monitoring the activities of the agencies and community groups involved (e.g., engineering, hydrology, police, fire, welfare, etc.). This will include deciding when the alarm is to be given, coordinating the response and evacuation, managing the evacuation, and acting in an intermediary capacity with agencies responsible for managing the period of evacuation, the recovery, and the return of families to their properties.

3. The agencies mobilized to respond had relatively limited professional contact under routine circumstances. Their collective and integrated response during this crisis highlights a need for developing integrated operating procedures (e.g., information sharing, problem definition, coordinated decision making) capable of allowing them to operate under unexpected and urgent circumstances.
4. Because of heavy rain predicted on October 11, the GNS science advisor recognized that there might be a dam-break hazard and in response recommended to WDC and WRC (by telephone and e-mail) that residents be evacuated from the Poerua Valley. Despite these organizations initially agreeing with this suggestion, somewhere along the line a breakdown in the decision-making process occurred and the recommendation to evacuate was not immediately put into action. This demonstrates that despite well-reasoned recommendations, human discretionary decision making still plays a large part in whether or not a warning is actually released.
5. While the telephone message recommending that evacuation take place was received before the dam had broken, the e-mail version of this message was only read by the WDC after the break had occurred. Other forms of communication in addition to e-mail (e.g., fax, or preferably a pager or mobile phone in the possession of the duty civil defense officer) would have assisted in wider dissemination of the information at an earlier stage.
6. Communication difficulties or misunderstandings between the scientific advisor and the WDC may have led to the two organizations favoring different options with regard to warning the public. For example, the telephone warning issued may not have been clear or precise enough, and therefore the council staff member may not have understood the significance of the warning to evacuate. This issue highlights the importance of developing liaison mechanisms between the action agencies and their advisors (and other technical information providers) to limit this risk and to ensure that decision-making procedures are in place to make as rational a decision as possible under the circumstances (see Point 3 above). Given the usual physical separation of the action agency and those likely to be affected immediately, the inclusion of local residents within this process is an issue worthy of additional consideration.
7. Only one person from the WDC received the initial telephone call and spoke with the scientific provider about the warning recommendation. A number of questions arise as a result of this situation including:
   - Were Council decision-making mechanisms for this hazard based on a comprehensive information needs/availability analysis?
   - Were there any organizational procedures in place for the initial contact person to consult or pass information on to others?
   - If there were procedures in place, did that person have adequate understanding of those procedures and the role of the information received within this process?
   - Was this person the appropriate person to make a decision about warning and evacuation based on the recommendations of the scientific provider? Given the limited time frame for response implicit within this type of event, attention may have to be given to issues concerned with the

delegation of authority under these circumstances.
- Was this person aware of all the information made available and discussions that had occurred previously, e.g., prior meetings where decisions had been made and consensus reached on issues regarding warning?
- Developing plans that outline warning procedures and having prior networks in place that involve other organizations and individuals, greatly assists in communication, following appropriate organizational procedures, and reduces the uncertainty involved in making decisions about warning the public.

8. Interviews with various organizations after the event have shown that there was also some confusion among these organizations with respect to roles and responsibilities, and whom to contact regarding certain issues. The WCRC, WDC, science providers, police, and community members all encountered these problems at one stage or another. For example, the police were uncertain who to contact regarding evacuation of the community, and in another instance the Fire Service contacted the WCRC instead of the WDC when following up about pagers and sirens. Some of these uncertainties over roles were already present within organizations and in the community, but in some cases misunderstandings evolved when intentions about responsibilities were not made clear during discussions. For example, actions were decided on during public and civil defense meetings, but in some cases it was not always made clear who was in charge of these actions.

Other issues may have had an influence on the events that unfolded during the Poerua River dam-break flood crisis, for example, perceptual issues (e.g., the fact that earlier evacuations had taken place but no actual event had occurred, etc.). However, these issues were unable to be assessed without in-depth study. Surveys or interviews of the people involved in the crisis would allow a focus on some of the personal aspects of decision making.

The issues experienced during the crisis are complicated in the present context as a consequence of the inaccessibility of the landslide-dam (hazard) site. The inaccessibility created difficulty in confirming the existence of a problem, in monitoring the progress of the potential hazard, and in anticipating its potential impact downstream. Consequently, it is worth considering how to involve the local community within the process of understanding and responding to the hazard. They are the group best placed both to provide the information required to formulate issues associated with deciding whether a warning is necessary, and if so, who, where, and how to warn (see above). The inclusion of members of this group is consistent with current conceptualizations of community resilience (Paton and Johnston 2001; Paton et al. 2005).

## Discussion

The formation and breaching of the Poerua landslide dam has drawn attention to the vulnerability of many communities on the West Coast of New Zealand's South Island to dam-break flood hazard. This was previously noted by Davies and Scott (1997) for the particular case of the Callery Gorge, and the hazard it presented to part of Franz Josef Glacier Township. Landslide damming occurs frequently on the geological time scale; yet there are few dam remnants in the West Coast area. Historical evidence shows that the majority of such dams fail quite quickly (most within days or weeks), and that flooding from this cause is to be expected in the future, particularly in association with the next earthquake on the Alpine Fault (Hancox et al. 2005).

The worst case scenario is a landslide dam caused by heavy rain on a saturated catchment at night. The dam may overtop before dawn, before anyone realizes that river flow is anomalously low. The debris-laden flood wave may reach dwellings where people are sleeping. An earthquake-generated landslide dam may possibly be less dangerous, as a large earthquake itself can be interpreted as a warning to all of the likelihood of a landslide, and provides the earliest possible warning. However, it may be a false alarm if the earthquake causes little landsliding. Further, the likelihood of an earthquake occurring during heavy rain is relatively low; so it is likely that an earthquake-generated landslide dam will overtop and fail after a longer time than a rainfall generated one, which may occur during high river flow and therefore overtop relatively soon. However, historical examples suggest that a rainfall-triggered landslide will in general be smaller on average than an earthquake-generated one, and therefore will overtop sooner and cause a smaller flood, as occurred in the Poerua Valley in August 1997, 2 years prior to the 1999 rock avalanche (Davies 2002; Optimx Risk Management Consulting Services 2002; Hancox et al. 2005).

Further planning for managing landslide dam-break floods in Westland may help reduce loss of life from such events in the future. Preparations could include improved control and communications for managing the response. One lesson that the Poerua dam-break incident highlighted was the need for reliable communication of geotechnical advice for hazard mitigation and for more effective liaison mechanisms between response agencies. For passing on important written messages during hazard events a fax or e-mail will suffice; however, a pager or mobile-phone contact may be more timely. It is also important that the sender obtains confirmation of receipt of a message (a standard civil defense procedure), possibly by a phone call within the critical time frame space.

Further technical studies, including monitoring the ongoing aggradation along the river valley and modeling of the Poerua dam break, will enhance understanding of the hazard and its effects. They will help to determine whether the Poerua incident was typical of what to expect under similar conditions for large rivers in Westland. If the Poerua dam had formed at night during a storm it could have overtopped and failed within a few hours, before authorities could act. In that scenario it is difficult to see what could be done to prevent a tragic outcome if the flood discharge were high enough to destroy dwellings. The destruction could occur before any official action could be taken; and survival would entirely be up to the actions of the inhabitants themselves.

Hazard mapping can identify the areas of greatest risk from dam-break flooding, and provide opportunity for appropriate mitigation measures to be considered. However, in most places the likelihood of a landslide dam-break flood is very small; so, only in obviously dangerous locations, such as downstream of the Callery Gorge at Franz Josef township, is it possible to advise of a sufficiently high event probability that precautions are practical. As noted by Davies and Scott (1997), in some cases the only effective precaution against a sudden flood without warning may be relocation of the threatened dwellings. This has in fact taken place at Franz Josef (Davies 2002; Optimx Risk Management Consulting Services 2002).

However, it appears that district councils are extremely reluctant to use their power to force relocation of previously authorized buildings. Councils can control new subdivisions and buildings in hazard zones, but not existing ones. As in the case of the extreme hazard zone on the south side of the Waiho River

(Callery River dam-break hazard; Davies 2002), some building owners refuse to move unless someone else pays, and since nobody wants to pay, the situation remains unresolved. Nonetheless, the WDC has put a lot of effort into civil defense planning, and they have full power to evacuate in an emergency.

From an emergency management perspective, the nature of dam-break floods on the West Coast of New Zealand's South Island suggests that there is merit in the greater direct involvement of the community in the readiness and response process. This is based on the premise that those living and working in areas likely to be affected have good local knowledge and they may be aware of conditions that could lead to the development of hazardous conditions. They are therefore also best-placed to issue warnings (and know to whom they should be directed). These factors make this group a particularly valuable emergency management resource. The more active involvement of members of this group in the event described in this paper could have reduced several of the response problems noted earlier. The adoption of this approach is consistent with contemporary ideas of developing community resilience, facilitating risk acceptance, and making the most effective use of available resources (Paton and Johnston 2001; Paton et al. 2005).

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