Appendices 1 – 8

Appendix 1	Ruapehu Crater Lake Lahar Residual Risk Assessment – Lahar Flow Calculations
Appendix 2(a)	Tranz Rail Ruapehu Lahar Hazard
Appendix 2(b)	Ruapehu Lahar Residual Risk Assessment – discussion with John Skilton
Appendix 3	Ruapehu Lahar Residual Risk Assessment – discussion with Transit
Appendix 4	Ruapehu Lahar Residual Risk Assessment – discussion with Genesis Power
Appendix 5	Ruapehu Lahar Residual Risk Assessment – discussion with John Larking, Transpower
Appendix 6	Ruapehu Lahar Residual Risk Assessment – technical meeting
Appendix 7	Ruapehu Lahar Residual Risk Assessment – telephone discussion with Vetti Bala, Genesis Power
Appendix 8	Ruapehu Lahar Residual Risk Assessment – discussion with Ruapehu District Council/Police

Appendix 1

Ruapehu Crater Lake Lahar Residual Risk Assessment - Lahar Flow Calculations

Ministry of Civil Defence and Emergency Management

Prepared By M G Webby and D J Forster

Reviewed By C J Roberts

Opus International Consultants Limited
Environmental
Level 9, Majestic Centre
100 Willis Street, PO Box 12-003
Wellington, New Zealand

Telephone: +64 4 471 7000
Facsimile: +64 4 499 3699

Date: June 2002
Reference: 39F521.J0
Status:
g:\projects\3\39g\39g521.j0 mocd ruapehu risk study inputs\lahar report.doc

Approved for issue to Client ....

Contents

Introduction

Lahar flow calculations were required as an input to a Ruapehu Crater Lake lahar residual risk assessment being carried out for the Ministry of Civil Defence and Emergency Management. This brief note outlines the basis for these calculations.

Assumptions

The lahar flow calculations extended some earlier work reported in Hancox *et al* (1997) and Hancox *et al* (1998) which used a computational hydraulic modelling approach to estimate lahar depths and flows at key sites down the Whangaehu River. The Whangaehu River forms the primary path for any future lahar likely to result from a future breach of the tephra barrier across the Crater Lake outlet.

The previous studies assumed a worst case scenario of barrier failure occurring when the lake level was coincident with the barrier crest. The present study considered a range of lake levels at which a piping failure of the barrier was assumed to occur. A piping failure of the tephra barrier would ultimately result in collapse of the dam crest above the "pipe" and an overtopping type failure breach.

The previous studies assumed initial estimates of the Crater Lake area and volume at various elevations. These were updated in the April 1999 Department of Conservation report "Environmental and risk assessment for mitigation of the hazard from Ruapehu Crater Lake" (Department of Conservation, 1999). The present study used this most recent lake area and volume data for estimating Crater Lake outpour volumes resulting from a barrier failure.

The previous studies assumed that the lava lip on which the tephra barrier across the Crater Lake outlet is founded was unmodified by the 1995-96 eruption sequence with an elevation of RL 2530 m. Recent evidence suggests that the lava lip could have been eroded over a short width (H Keys, Department of Conservation, pers. comm.). For the present study, various sensitivity tests were carried out assuming that the lava lip had been eroded by up to 1 m (to a level of RL 2529 m) over a 30 m width.

The previous studies assumed a maximum breach bottom width of 60 m with 1:1 side slopes and breach development times between 15 and 45 minutes based on evidence from historical failures of manmade earthfill dams. These assumptions were retained for the present study. However in the sensitivity tests for the lower lip level, the assumed shape of the modified lip acted as a constraint on the breach size.

The water volume released from the Crater Lake by an outlet barrier failure would entrain sediment as it flowed down the Whangaehu Gorge and become transformed into a sediment-water mixture known as a lahar. The bulking of the original water volume into the sediment-water volume has a large influence on the magnitude of the lahar. It is reasonable to assume that the lahar has achieved its maximum bulked volume at the end of the Whangaehu Gorge where the river channel breaks out onto the Whangaehu fan, a geomorphological feature formed by historic lahar events. The previous study by Hancox *et al* (1998) assumed a bulking factor of 3.33 (corresponding to a sediment concentration by volume of 70%) based on field evidence from lahar events during the 1995-1996 eruption sequence. Subsequent calculations for the Department of Conservation considered higher bulking factors at the end of the gorge of 4 and 5 (corresponding to sediment concentrations of 75% and 80% respectively). The same range of bulking factors was considered in the present study.

The slope of the Whangaehu River reduces as it crosses the fan and then turns southward parallel to Desert Road. Any lahar travelling down the river will start to drop sediment in response to the reducing bed slope so that the sediment concentration (and hence bulking factor) will reduce with distance for the end of the gorge. The previous study by Hancox et al (1998) assumed an attenuation relationship for sediment concentration based on field evidence from lahar events during the 1995-1996 eruption sequence. However recent work by the Scientific Advisory Panel advising the Minister of Conservation on the Ruapehu Crater Lake Lahar hazard has indicated that the attenuation relationship for sediment concentration may be less severe based on data from similar sized historic lahar events on the Mt St Helens volcano in Washington State, USA. The present study assumed this new attenuation relationship as outlined in Table 1.

Table 1 Sediment concentration values for lahar simulation modelling

Site	Distance from Crater Lake (km)	Sediment concentration		
		Lower bound	Likely maximum	Upper bound
End of Whangaehu gorge	8.8	70% (BF* 3.33)	75% (BF 4)	80% (BF 5)
End of Whangaehu Fan	15.6	65%	70%	75%
SH49 at Tangiwai	38.1	50%	55%	60%
NIWA hydrological recorder at Karioi	54	41%	46%	51%

* BF refers to bulking factor

Methodology

The hydraulic modelling of lahars is fraught with difficulty principally because of the complex field mechanics behaviour of such flows during the various phases of development from an initial water flow into a mudflow and then back into a hyperconcentrated stream flow. Hancox *et al* (1998) identify some of the areas of uncertainty associated with modelling such events. Annex A includes a summary paper prepared as background material for the Scientific Advisory Panel providing advice to the Minister of Conservation on the Ruapehu Crater Lake lahar hazard. The provides a comprehensive discussion of the rheology, fluid mechanics and hydraulic modelling of lahar flows which extends considerably the discussion of these matters by Hancox et al (1998). The paper concludes that using the one-dimensional shallow water wave equations incorporating a single energy dissipation parameter (equivalent to a Mannings n channel roughness coefficient for turbulent water flows) seems to give acceptable results for hazard assessment purposes. This was the method adopted by Hancox *et al* (1997 and 1998) in their studies.

In the previous studies of Hancox *et al* (1997 and 1998), a simple Crater Lake model was constructed to calculate the breach outflow hydrograph for an outlet barrier failure. The appropriate bulking factor was then applied to this outflow hydrograph and the bulked hydrograph routed down the Whangaehu River using a model, solving the shallow water wave equations. The global model was calibrated to match various observations from the 1953 lahar event and then used as an analogue for simulating future lahar events generated by a failure of the Crater Lake outlet barrier. Flow hydrographs predicted by the global model were then routed through local models which incorporated the local river channel geometry at key sites of interest along the river. These local models translated flow into depth so that the lahar hazard could be quantified at these sites.

The same approach was used in the present study with the updated assumptions as outlined previously. Eight different Crater Lake model cases were analysed as outlined in Table 1.

Table 1 Scenarios for future Crater Lake outlet barrier failure

Case no	Crater rim level	Lake level at failure (RL m)	Max depth on rim (m)	Breach dev rate	Breach dev time (mins)
D1	pre 95	2536.5	6.5	fast	15
D2	pre 95	2536.5	6.5	slow	45
D3	pre 95	2534	4	fast	15
D4	pre 95	2534	4	slow	45
D5	before pre 95	2536.5	7.5	fast	15
D6	before pre 95	2536.5	7.5	slow	45
D7	before pre 95	2533	4	fast	15
D8	before pre 95	2533	4	slow	45

The range of possible bulking factors for the outflow volume released from the Crater Lake gave a total of 24 possible scenarios for the global model of the Whangaehu River. However only a selected number of the lahar hydrographs for these 24 scenarios were routed downstream using the global model. Peak discharges at key sites of interest were interpolated from the results of these flow simulations for the other scenarios. The relevant

flood hydrographs were then run through the local models for these key sites to establish a peak depth/discharge relationship. These relationships could than be used to assess the hazard posed by each scenario.
The results of all the flow simulations are summarised in various spreadsheets included in Annex B.

Estimates of uncertainty are given for the estimates of peak discharge and depth at each of the key sites along the Whangaehu River. These are based on judgement, the results of sensitivity tests with the various models and, in the case of the peak depths, the observation that obstructions in the river (such as bridge piers) tend to cause a large bow wave to rise up above the general flow surface during the passage of a lahar event.

References

Department of Conservation (1999). "Environmental and risk assessment for mitigation of the hazard from Ruapehu Crater Lake". Assessment of environmental effects, prepared for the Minister of Conservation, April 1999.

Hancox, G T, Nairn I A, Otway P M, Webby, G, Perrin, N D and Keys J R (1997). Stability Assessment of Mt Ruapehu Crater Rim following the 1995-1996 Eruptions. Institute of Geological and Nuclear Sciences, Client Report 43605B, prepared for Department of Conservation, Turangi, June 1997.

Hancox, G T, Otway P M and Webby, M G (1998). Possible Effects of a Lahar caused by a Future Collapse of the Tephra Barrier formed at the Mt Ruapehu Carter Lake Outlet by the 1995-1996 Eruptions. Institute of Geological and Nuclear Sciences, Client Report 43711B, prepared for Department of Conservation, Turangi, September 1998.

Annex A

Rheology, Fluid Mechanics and Hydraulic Modelling of Debris Flows and Mudflows

Introduction

The following discussion of the rheology, fluid mechanics and hydraulic modelling of lahar flows has been prepared as an addendum to earlier discussions in Hancox *et al* (1997) and Hancox *et al* (1998). It summarises additional information collated from the literature since these two reports were produced.

Rheological and Fluid Mechanics Behaviour of Hyperconcentrated Stream Flows, Debris Flows and Mudflows

Table 1 of Hancox *et al* (1998) lists a number of areas of uncertainty regarding the hydraulic modelling of lahar flows. One additional area of uncertainty not specifically included in this table (but related to some of the factors listed) is the rheological behaviour of the sediment-water mixture forming the lahar material. This behaviour is a function of sediment concentration, sediment type and grain size distribution (Pierson and Scott, 1985; Takahashi, 1991; Wan and Wang, 1994; Coussot, 1997). The rheological behaviour may be either Newtonian (exhibiting a linear relationship between applied shear stress and shear rate) as in ordinary water flows or non-Newtonian (exhibiting a non-linear relationship between applied shear stress and shear rate including a finite yield strength). The rheological characteristics of a sediment-water mixture influence the fluid mechanics behaviour of the mixture, i.e. whether it flows with a laminar motion or a turbulent motion (albeit with the turbulence suppressed by the apparent viscosity of the mixture).

Sediment-water mixtures with negligible amounts of clay and silt and sediment concentrations in the hyperconcentrated streamflow range of 20-60% by volume (corresponding to total volume to original water volume or bulking factor ratios of 1.25-2.5) appear to exhibit Newtonian fluid behaviour (Pierson and Scott, 1985) of the turbulent type. Sand and gravel particles suspended in such mixtures are able to settle out although fall velocities will be reduced. The fluid and granular phases of these mixtures act independently of each other during motion so that the mixtures are termed non-homogeneous.

With increasing proportions of clay and silt sized particles in a sediment-water mixture, electrochemical attraction forces between sediment particles become significant (Pierson and Scott, 1985; Wan and Wang, 1994; Coussot; 1997). This is reflected by the sediment-water mixture exhibiting a finite yield strength, the magnitude of which is dependent on the clay type of the clay fraction and the overall grain size distribution of the sediment material. Sediment-water mixtures comprised mainly of silt develop a yield strength with a volume concentration in the range 30-35% while clay-rich mixtures develop a yield strength with a volume concentration of 10% or less.

The rheological behaviour of sediment-water mixtures with finite yield strength has often been described by a linear two parameter Bingham plastic model but there is evidence to suggest that a non-linear three parameter Herschel-Bulkley model is more appropriate (Coussot, 1997). With the latter model, the apparent viscosity of the flowing mixture decreases with increasing shear rate.

A flowing sediment-water mixture becomes a debris flow (gravel content > 50%) or mudflow slurry (gravel content < 50%) when the shear strength of the static mixture is sufficient to support gravel size particles and course and fine grain particles are unable to settle out. The mixture flows as a homogenous plastic material (with the consistency of wet concrete) in which the fluid is no longer the transporting agent but the pore fluid in a saturated granular matrix. Debris flows and mudflows typically have a sediment concentration by volume greater than 60% (corresponding to a total volume to original water volume or bulking factor ratio of greater than 2.5).

Debris flows and mudflows with a finite yield strength generally tend to flow with a laminar motion although, if the flow depth is large enough, they become turbulent (Coussot, 1997). The turbulent behaviour may be confined to the head of a debris flow or mudflow while other parts exhibit laminar flow behaviour. Turbulent debris flows and mudflows may also exhibit roll wave behaviour, which is indicative of flow instability.

Coussot (1997) has postulated a generalised conceptual rheological classification of sediment-water mixtures based on the compilation of an extensive database of experimental data. This classification is presented as a phase diagram which defines different regions of mixture behaviour depending on the total solid volume concentration and the ratio of the fine fraction (< 0.04 mm) to the total solid volume.

Hydraulic Modelling of Debris Flow, Mudflow and Lahar Events

The hydraulic behaviour of hyperconcentrated streamflows and debris flows is not well understood (Pierson and Scott, 1995) and there is no uniformity in the theoretical treatment of both types of flow as evidenced by the diversity of approaches presented by Takahashi (1991), Wan and Wang (1994) and Coussot (1997). Furthermore the transition between a debris flow and a hyperconcentrated streamflow is not adequately understood either and there is certainly no comprehensive theoretical model available that attempts to represent, firstly, the transition from a water flow to a debris flow as sediment is entrained and, secondly, the reverse transition from a debris flow to a hyperconcentrated streamflow as sediment detainment occurs with distance from the source (Pareschi, 1996). Various models have been developed to describe the flow behaviour of the separate distinct phases of a flowing sediment-water mixture.

A range of theoretical models have been utilised in the past to simulate the flow behaviour of debris flows and avalanches. These include non-Newtonian Coulomb-viscous, Bingham viscoplastic, Herschel-Bulkley viscoplastic, generalised viscoplastic and dilatant fluid models (Pierson and Scott, 1985) and Newtonian laminar and turbulent models (Hunt, 1994). The major disadvantage of the non-Newtonian models is that they require an *a priori* knowledge of the rheological characteristics of the debris flow material. These characteristics may very well change with distance from the source.

Hyperconcentrated streamflows have generally been modelled using a Newtonian turbulent flow model (Takahashi, 1991). Takahashi shows that the frictional resistance of debris flows and mudflows asymptotically approaches that of a turbulent water flow when the ratio of the flow depth to the mean particle diameter d is large ($h / d > 100$).

Because of the range of flow behaviour exhibited by flowing sediment-water mixtures (including lahar events) and the uncertainty regarding the rheological characteristics of the mixture, recent modelling of such flow events has tended to favour a simplified approach using the one-dimensional St Venant or shallow water wave equations (based on a turbulent flow model) for the purposes of hazard assessment. The advantage of this approach is that it only requires estimation of a single parameter, an energy dissipation parameter equivalent to the Manning's n channel roughness coefficient for turbulent water flows. This parameter acts as a catch-all parameter to describe the energy dissipation and rheological characteristics of a flowing sediment-water mixture.

For example, Costa (1997) of the US Geological Survey used the US National Weather Service DAMBRK model to reproduce field-documented flow depths of historic and prehistoric lahars from Mount Rainer, Washington and Mount Hood, Oregon, USA. The key result of interest from these simulations for further lahar hazard assessments was a plot of energy dissipation parameter (n) values as a function of hydraulic radius (equivalent to flow depth in a wide rectangular channel). This plot also included back- calculated n values from field data for lahar events in 1982 from the Mount St Helens area of Washington, USA. For hydraulic flow depths less than 10 m, the energy dissipation parameter plot shows n values similar to Manning's roughness coefficient values for turbulent water flows. Following the analysis of historic and prehistoric lahar events, Costa (1997) used the DAMBRK model to simulate a hypothetical lahar event down the East Fork Hood River off Mount Hood, Oregon and then carry out a hazard assessment for this event. He concluded that it appeared feasible to use the DAMBRK model (and hence other similar models such as MIKE11) to undertake lahar hazard assessments in many situations where input flows hydrographs and energy dissipation parameters could be reasonably estimated.

Jin and Fread (1999) of the US National Weather Service used a related one-dimensional flood routing model FLDWAV to simulate a number of historic debris flow and mudflow events. They compared three alternative techniques for representing the energy dissipation and frictional resistance of these flow events; a non-Newtonian Bingham type viscoplastic technique, a granular sliding model technique and the combined energy dissipation parameter technique as used by Costa (1997). They found that the latter technique was the most robust of the three techniques and the best option to use if data on the rheological characteristics of the flow material is not available. They suggested that the energy dissipation parameter n is a function of the discharge with a small value (0.03-0.06) for low flows and a large value (0.08-0.16) for near peak or peak flows.

Takahashi (1991) used a one-dimensional flood routing model with a variable energy dissipation parameter to satisfactorily simulate the mudflow down the Stava River in Italy in 1985 caused by the failure of a mine tailings dam. The energy dissipation parameter n values he obtained were again similar to typical Manning's channel roughness coefficient values for turbulent water flows in a river,

Caruso and Pareschi (1993) also found that the energy dissipation parameter approach gave acceptable results from a simulation of the runout flow for the 1975 lahar event in the Whangaehu River off Mount Ruapehu using a one-dimensional flood routing model. The value of the energy dissipation parameter n they obtained was similar to that for turbulent water flows in a river.

Conclusions

Because of the range of flow behaviour exhibited by debris flows and mudflows and the uncertainty regarding the rheological characteristics of the debris material, it is necessary to rely on simplified flood routing methods for undertaking hazard assessments of such events.

For modelling lahar and other debris flow events, the one-dimensional shallow water wave equations incorporating a single energy dissipation parameter (equivalent to a Manning's n channel roughness coefficient for turbulent water flows) appear to give acceptable results for hazard assessment purposes.

The lahar simulation modelling undertaken by Hancox *et al* (1997 and 1998) to assess the hazard posed by a lahar event resulting from a collapse of the Ruapehu Crater Lake outlet barrier is consistent with this suggested approach. In this case the simplified routing model developed for the hazard assessment used the 1953 and 1975 lahar events as analogue events with the energy dissipation parameter adjusted so that model predictions for these events closely matched various field observations (lahar travel times and flow depths at specific sites). The calibrated model was then used to make predictions about peak lahar discharges and depths at different locations resulting from a Crater Lake outlet barrier collapse.

References

Caruso, P and Pareschi, M T (1993) "Estimation of lahar and lahar runout flow hydrograph on natural bed". *Environmental Geology*, Vol. 22, pp 141-152.

Costa, J E (1997): "Hydraulic Modelling for Lahar Hazards at Cascades Volcanoes". *Environmental and Engineering Geoscience*, Vol. 3, No. 1, pp 21-30

Coussot, P (1997). *Mudflow Rheology and Dynamics*. International Association for Hydraulic Research Monograph, Balkema, Rotterdam, 225 p.

Hancox, G T, Nairn I A, Otway P M, Webby, G, Perrin, N D and Keys J R (1997). Stability Assessment of Mt Ruapehu Crater Rim following the 1995-1996 Eruptions. Institute of Geological and Nuclear Sciences, Client Report 43605B, prepared for Department of Conservation, Turangi, June 1997.

Hancox, G T, Otway P M and Webby, M G (1998). Possible Effects of a Lahar caused by a Future Collapse of the Tephra Barrier formed at the Mt Ruapehu Carter Lake Outlet by the 1995-1996 Eruptions. Institute of Geological and Nuclear Sciences, Client Report 43711B, prepared for Department of Conservation, Turangi, September 1998.

Hunt, B (1994). "Newtonian fluid mechanics treatment of debris flows an avalanches". *Journal of Hydraulic Engineering*, ASCE, Vol. 120, No. 12, December 1994, pp 1350-1363.

Jin, M and Fread, D L (1999). "1D Modelling of Mud / Debris Unsteady Flows". *Journal of Hydraulic Engineering*, ASCE, Vol. 125, No. 8, August 1999, pp 827-834.

Pareschi, M T (1996). "Physical modelling of eruptive phenomena: lahars". In *Monitoring and Mitigation of Volcano Hazards*. Ed. R Scarpa and R I Tilling, Springer-Verlag, Berlin, pp 463-489.

Pierson, T C and Scott, K M (1985). "Downstream dilution of a lahar: transition from debris flow to hyperconcentrated streamflows". *Water Resources Research*, Vol. 21, No. 10, October 1985, pp 1511-1524..

Takahashi, T (1991). *Debris Flow*. International Association for Hydraulic Research Monograph, Balkema, Rotterdam, 165 p.

Wan, Z and Wang, Z (1994). *Hyperconcentrated flow*. International Association for Hydraulic Research Monograph, Balkema, Rotterdam, 290 p.

Annex B
Summary of Flow Simulation Results

Summary of Ruapehu Crater Lake Lahar Simulations g:\projects\3\39g\39g521.jo MOCD Risk Study\flow data summary.xls

Assumptions
1 crater lake area based on most recent data in Figure a of Appendix 6 of AEE document prepared by DOC April 1999
2 below pre-1995 level assumed to be a maximum of 1 m below RL 2530 m over a 30 m width

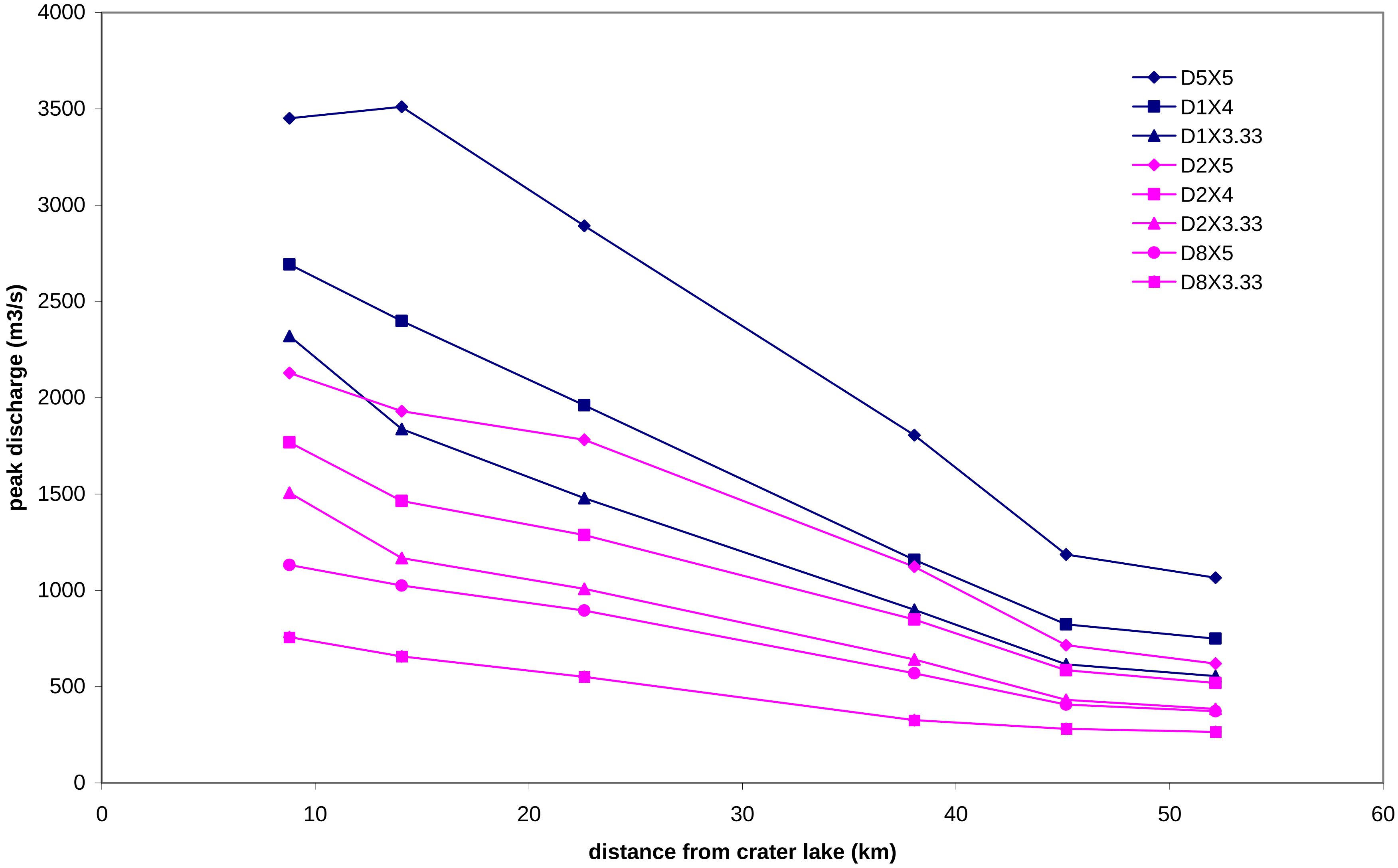
Refer tree diagram of crater pour scenarios on pg 3 Ruapehu lahar residual risk assessment, TTAC ref N19, note of meeting 29 May 2002

Rim Level	Lake level at failure (RL m)	Max depth on rim (m)	Breach dev rate	Breach dev time (mins)	Scenario Title	Peak flow (m3/s) crater lake
pre-95	2536.5	6.5	fast	15	D1	837
pre-95	2536.5	6.5	slow	45	D2	470
pre-95	2534	4	fast	15	D3	442
pre-95	2534	4	slow	45	D4	254
below pre-95	2536.5	7.5	fast	15	D5	882
below pre-95	2536.5	7.5	slow	45	D6	545
below pre-95	2533	4	fast	15	D7	349
below pre-95	2533	4	slow	45	D8	233

Ranking scenarios in descending order of peak crater lake outflow
Then applying bulking factors to peak crater lake outflows as initial estimate only of gorge outflows
And reranking scenarios in descending order of bulked outflows

Rim Level	Lake level at failure (RL m)	Max depth on rim (m)	Breach dev rate	Breach dev time (mins)	Scenario Title	Peak flow (m3/s) crater lake	BF value	INITIAL ES Peak flow bulked
below pre-95	2536.5	6.5	fast	15	D5	882	5	4410
pre-95	2536.5	6.5	fast	15	D1	837	5	4185
below pre-95	2536.5	6.5	fast	15	D5	882	4	3528
pre-95	2536.5	6.5	fast	15	D1	837	4	3348
below pre-95	2536.5	6.5	fast	15	D5	882	3.33	2940
pre-95	2536.5	6.5	fast	15	D1	837	3.33	2790
below pre-95	2536.5	6.5	slow	45	D6	545	5	2725
pre-95	2536.5	6.5	slow	45	D2	470	5	2350
pre-95	2534	4	fast	15	D3	442	5	2210
below pre-95	2536.5	6.5	slow	45	D6	545	4	2180
pre-95	2536.5	6.5	slow	45	D2	470	4	1880
below pre-95	2536.5	6.5	slow	45	D6	545	3.33	1817
pre-95	2534	4	fast	15	D3	442	4	1768
below pre-95	2533	4	fast	15	D7	349	5	1745
pre-95	2536.5	6.5	slow	45	D2	470	3.33	1567
pre-95	2534	4	fast	15	D3	442	3.33	1473
below pre-95	2533	4	fast	15	D7	349	4	1396
pre-95	2534	4	slow	45	D4	254	5	1270
below pre-95	2533	4	slow	45	D8	233	5	1165
below pre-95	2533	4	fast	15	D7	349	3.33	1163
pre-95	2534	4	slow	45	D4	254	4	1016
below pre-95	2533	4	slow	45	D8	233	4	932
pre-95	2534	4	slow	45	D4	254	3.33	847
below pre-95	2533	4	slow	45	D8	233	3.33	777

Note shaded scenarios to be simulated through downstream gorge and river channel



4000
3500
3000
2500
2000
1500
1000
500
0
peak discharge (m3/s)
0
10
20
30
40
50
60
distance from crater lake (km)
D5X5
D1X4
D1X3.33
D2X5
D2X4
D2X3.33
D8X5
D8X3.33

Summary of Ruapehu Crater Lake Lahar Simulations

g:\projects\3\39g\39g521.jo MOCD Risk Study\flow data summary.xls

Assumptions

1 crater lake area based on most recent data in Figure a of Appendix 6 of AEE document prepared by DOC April 1999

2 below pre-1995 level assumed to be a maximum of 1 m below RL 2530 m over a 30 m width

Refer tree diagram of crater pour scenarios on pg 3 Ruapehu lahar residual risk assessment, TTAC ref N19, note of meeting 29 May 2002

							INITIAL ESTIMATE ONLY	
Rim Level	**Lake level at failure (RL m)**	**Max depth on rim (m)**	**Breach dev rate**	**Breach dev time (mins)**	**Scenario Title**	**Peak flow crater lake (m3/s)**	**Peak flow (m3/s) BF value**	**bulked**
below pre-95	2536.5	6.5	fast	15	D5	882	5	4410
pre-95	2536.5	6.5	fast	15	D1	837	5	4185
below pre-95	2536.5	6.5	fast	15	D5	882	4	3528
pre-95	2536.5	6.5	fast	15	D1	837	4	3348
below pre-95	2536.5	6.5	fast	15	D5	882	3.33	2940
pre-95	2536.5	6.5	fast	15	D1	837	3.33	2790
below pre-95	2536.5	6.5	slow	45	D6	545	5	2725
pre-95	2536.5	6.5	slow	45	D2	470	5	2350
pre-95	2534	4	fast	15	D3	442	5	2210
below pre-95	2536.5	6.5	slow	45	D6	545	4	2180
pre-95	2536.5	6.5	slow	45	D2	470	4	1880
below pre-95	2536.5	6.5	slow	45	D6	545	3.33	1817
pre-95	2534	4	fast	15	D3	442	4	1768
below pre-95	2533	4	fast	15	D7	349	5	1745
pre-95	2536.5	6.5	slow	45	D2	470	3.33	1567
pre-95	2534	4	fast	15	D3	442	3.33	1473
below pre-95	2533	4	fast	15	D7	349	4	1396
pre-95	2534	4	slow	45	D4	254	5	1270
below pre-95	2533	4	slow	45	D8	233	5	1165
below pre-95	2533	4	fast	15	D7	349	3.33	1163
pre-95	2534	4	slow	45	D4	254	4	1016
below pre-95	2533	4	slow	45	D8	233	4	932
pre-95	2534	4	slow	45	D4	254	3.33	847
below pre-95	2533	4	slow	45	D8	233	3.33	777

FROM FLOW SIMULATIONS

	Peak flow	**(m3/s)**					
	gorge outlet bulked flow	***Site F pylons***	***Wah aqueduct***	***Tangiwai***	***Strachans Br***	***Marae Br***	
GNS Site ref	*Site D*	*Site F*	*Site G*	*Site I*	*Site J*	*Site L*	
MIKE11 ref	*GORGE 8.79*	*DESERT 0.05*	*DESERT 10.592*	*DESERT 26.05*	*DESERT 33.15*	*DESERT 40.15*	
fast	3451	1755	2892	1805	1186	1065	
fast	*3290*	*1637*	*2695*	*1668*	*1109*	*998*	*interpolated (fast)*
fast	*2821*	*1294*	*2118*	*1268*	*885*	*803*	*interpolated (fast)*
fast	2692	1200	1960	1158	823	749	
fast	*2420*	*994*	*1608*	*969*	*671*	*606*	*interpolated (fast)*
fast	2320	919	1479	899	615	554	
slow							
slow	2128	965	1781	1122	715	619	
fast							
slow	1998	881	1602	1023	668	583	*interpolated (slow)*
slow	1769	732	1286	849	585	519	
slow	1716	702	1230	807	554	492	*interpolated (slow)*
fast							
fast							
slow	1506	584	1007	641	431	384	
fast							
fast							
slow	1230	531	924	588	413	375	*interpolated (slow)*
slow	1132	512	895	569	406	372	
fast							
slow	988	442	763	476	358	331	*interpolated (slow)*
slow	907	402	688	423	331	308	*interpolated (slow)*
slow	825	362	612	370	304	284	*interpolated (slow)*
slow	757	329	550	326	281	265	

	Peak flow	(m3/s)				
	gorge outlet	***end of fan***	***Wah aqueduct***	***Tangiwai***	***Strachans Br***	***Marae Br***
	bulked flow					
	Site D		*Site G*	*Site I*	*Site J*	*Site L*
	GORGE 8.79	*DESERT 2.05*	*DESERT 10.592*	*DESERT 26.05*	*DESERT 33.15*	*DESERT 40.15*
distance (km)	8.79	14.05	22.59	38.05	45.15	52.15
D5X5	3451	3510	2892	1805	1186	1065
	2692	2399	1960	1158	823	749
	2320	1837	1479	899	615	554
	2128	1930	1781	1122	715	619
	1769	1464	1286	849	585	519
	1506	1167	1007	641	431	384
	1132	1024	895	569	406	372
	757	657	550	326	281	265

Summary of Ruapehu Crater Lake Lahar Simulations g:\projects\3\39g\39g521.jo MOCD Risk Study\flow data summary.xls

Assumptions

1 crater lake area based on most recent data in Figure a of Appendix 6 of AEE document prepared by DOC April 1999

2 below pre-1995 level assumed to be a maximum of 1 m below RL 2530 m over a 30 m width

Refer tree diagram of crater pour scenarios on pg 3 Ruapehu lahar residual risk assessment, TTAC ref N19, note of meeting 29 May 2002

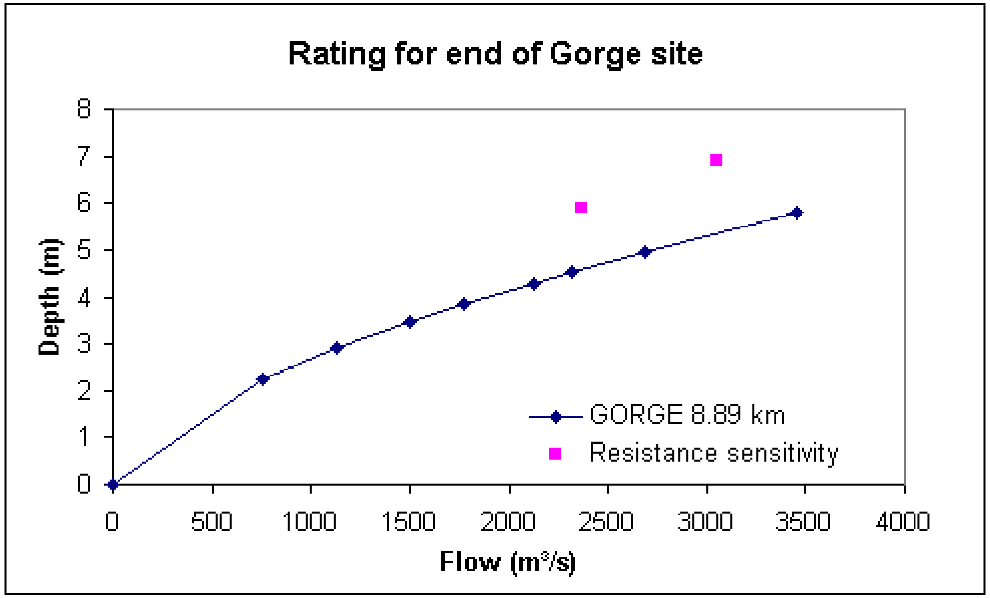
INITIAL ESTIMATE ONLY FROM FLOW SIMULATIONS

Scenario		Peak flow		Time of arrival	(mins)					
Title	**BF value**	**bulked**		***gorge outlet***	***Site F pylons***	***Wah aqueduct***	***Tangiwai***	***Strachans Br***	***Marae Br***	
		(m3/s)		***bulked flow***						
			GNS Site ref	*Site D*	*Site F*	*Site G*	*Site I*	*Site J*	*Site L*	
			MIKE11 ref	*GORGE 6.88*	*DESERT 0.05*	*DESERT 10.592*	*DESERT 26.05*	*DESERT 33.15*	*DESERT 40.15*	
D5	5	4410		19	39	57	92	109	128	
D1	5	4185		19	40	58	94	112	132	*interpolated*
D5	4	3528		21	41	63	100	121	142	*interpolated*
D1	4	3348		21	42	64	102	123	145	
D5	3.33	2940		22	43	67	108	130	154	*interpolated*

D1	3.33	2790	22	44	68	110	133	157	
D6	5	2725	23	45	69	111	133	157	*interpolated*
D2	5	2350	27	52	76	114	136	159	
D3	5	2210	28	53	77	117	140	163	*interpolated*
D6	4	2180	28	53	78	118	141	164	*interpolated*
D2	4	1880	29	55	81	125	149	173	
D6	3.33	1817	29	55	82	127	151	176	*interpolated*
D3	4	1768	29	56	83	128	153	178	*interpolated*
D7	5	1745	29	56	83	128	154	179	*interpolated*
D2	3.33	1567	30	57	86	133	160	186	
D3	3.33	1473	31	58	87	135	162	188	*interpolated*
D7	4	1396	31	59	88	136	163	189	*interpolated*
D4	5	1270	32	61	90	138	165	192	*interpolated*
D8	5	1165	33	62	91	140	167	194	
D7	3.33	1163	33	62	91	140	167	194	*interpolated*
D4	4	1016	35	65	95	149	178	206	*interpolated*
D8	4	932	35	67	97	154	184	213	*interpolated*
D4	3.33	847	36	69	99	159	190	219	*interpolated*
D8	3.33	777	37	71	101	163	195	225	

End of Gorge GORGE 8.89 km

Flow scenario	Peak flow (m^3/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	3451	1235.8		5.8
D1X4	2692	1234.97		4.97
D1X333	2320	1234.52		4.52
D2X5	2128	1234.29		4.29
D2X4	1769	1233.84		3.84
D2X333	1506	1233.46		3.46
D8X5	1132	1232.92		2.92
D8X333	757	1232.26		2.26
	0			0
D5X5	3053	1236.9		6.9
D1X4	2371	1235.9		5.9



Uncertainty estimates

depth +30%
-10%

discharge +10%
-10%

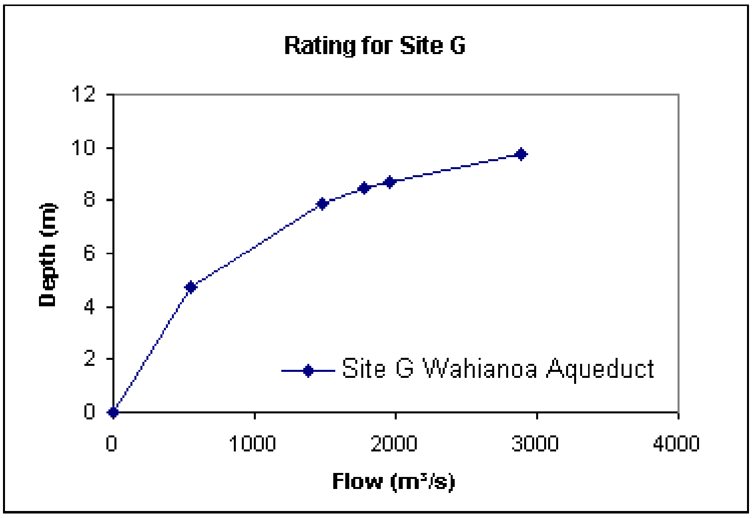
These flow depths are based on the GNS measured section at this site in Hancox et al (1998)

Wahianoa Aqueduct WHANGAEHU 22.68 km				
Flow scenario	Peak flow (m^3/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	2892	915.463	905.74	9.723
D1X4	1960	914.408	905.74	8.668
D2X5	1781	914.182	905.74	8.442
D1X333	1479	913.585	905.74	7.845
D8X333	550	910.465	905.74	4.725
	0			0

Uncertainty estimates

depth +20%
-10%

discharge +10%
-10%

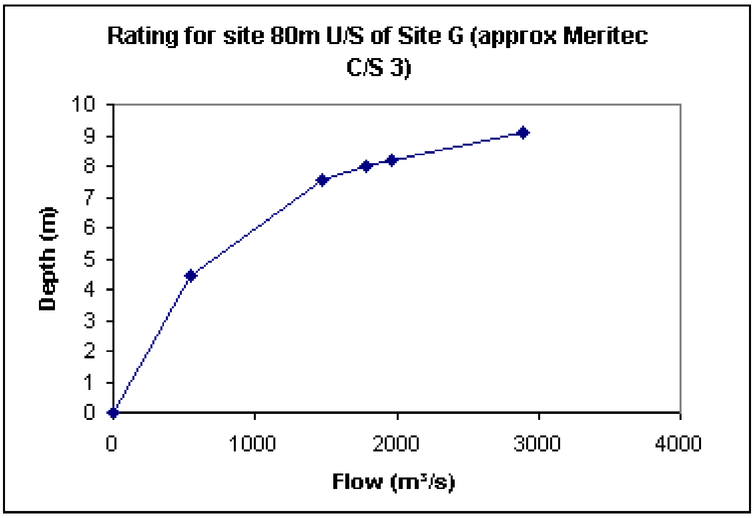


80m U/S of Site G				
Flow scenario	Peak flow (m^3/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	2892	916.817	907.69	9.127
D1X4	1960	915.866	907.69	8.176
D2X5	1781	915.682	907.69	7.992
D1X333	1479	915.233	907.69	7.543
D8X333	550	912.166	907.69	4.476
	0			0

Uncertainty estimates

depth +20%
-10%

discharge +10%
-10%

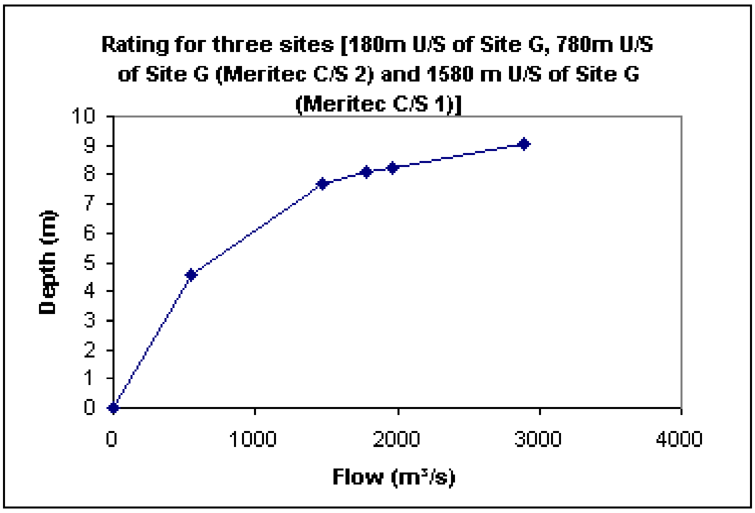


180 U/S of Site G				
Flow scenario	Peak flow (m^3/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	2892	918.285	909.22	9.065
D1X4	1960	917.442	909.22	8.222
D2X5	1781	917.289	909.22	8.069
D1X333	1479	916.936	909.22	7.716
D8X333	550	913.752	909.22	4.532
	0			0

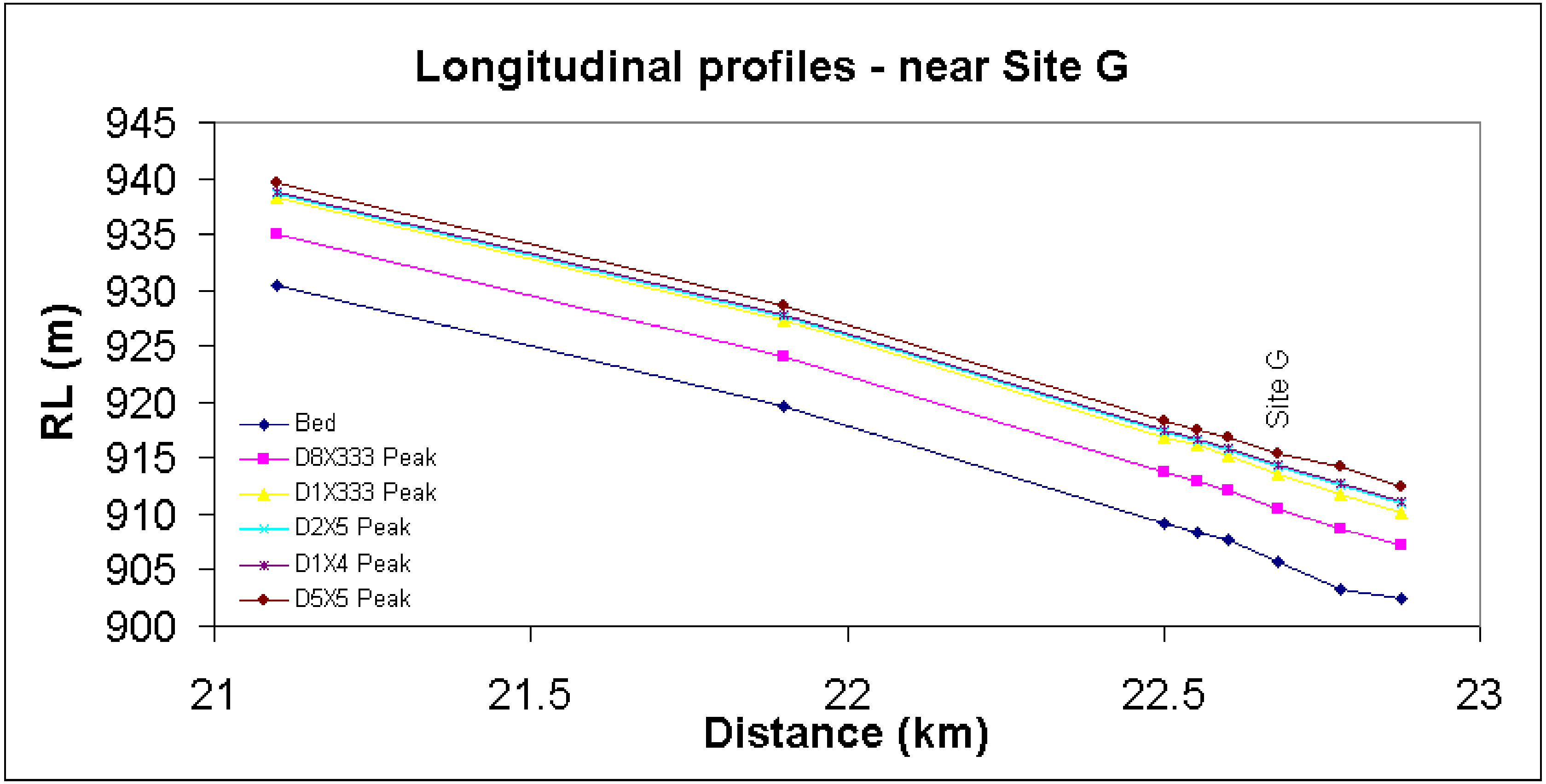
Uncertainty estimates

depth +20%
-10%

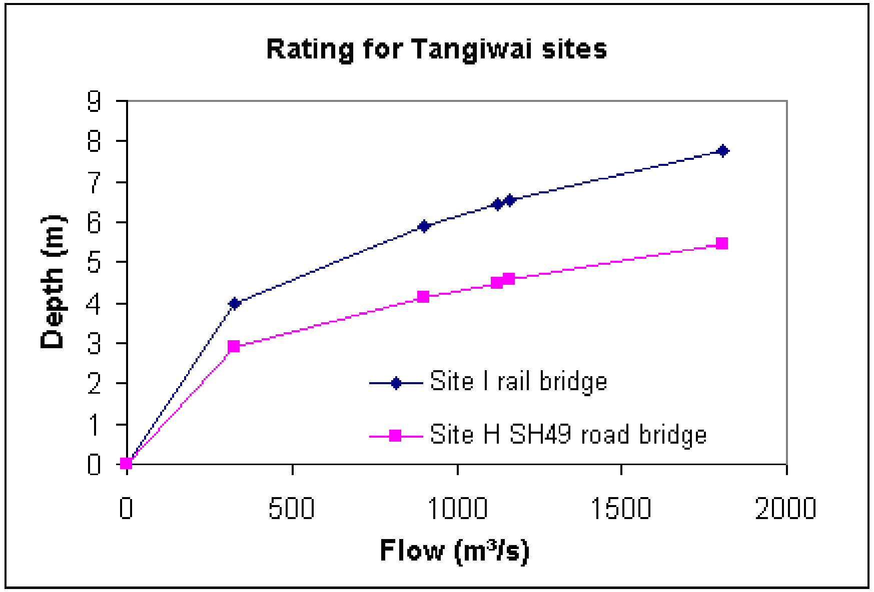
discharge +10%
-10%



Data source	Distance	Bed level	Peak level (m)			
	(km)	(m)	D8X333	D1X333	D2X5	D1X4
Meritec C/S 1	21.1	930.51	935.042	938.226	938.579	938.7
Meritec C/S 2	21.9	919.59	924.122	927.306	927.659	927.8
Opus TPD invest dwg	22.5	909.22	913.752	916.936	917.289	917.4
Opus TPD invest dwg	22.553	908.3	912.97	916.133	916.51	916.6
Opus TPD invest dwg	22.603	907.69	912.166	915.233	915.682	915.8
Opus TPD invest dwg	22.68	905.74	910.465	913.585	914.182	914.4
Opus TPD invest dwg	22.778	903.31	908.67	911.777	912.564	912.
Opus TPD invest dwg	22.874	902.39	907.169	910.153	910.916	911.1



Rail bridge WHANGAEHU 26.1 km				
Flow scenario	Peak flow (m^3/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	1805	682.787	675	7.787
D1X4	1158	681.523	675	6.523
D2X5	1122	681.43	675	6.43
D1X333	899	680.907	675	5.907
D8X333	326	679.003	675	4.003
	0			0



SH49 bridge WHANGAEHU 26.42 km				
Flow scenario	Peak flow (m^3/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	1805	677.129	671.65	5.479
D1X4	1158	676.21	671.65	4.56
D2X5	1122	676.142	671.65	4.492
D1X333	899	675.774	671.65	4.124
D8X333	326	674.558	671.65	2.908
	0			0

Uncertainty estimates

depth	+20%
	-10%
discharge	+10%
	-10%

SH1 Waikato Stream

Flow scenario	Bund scenario	Peak flow ex Whang (m³/s)	Duration of flow (mins)	Peak depth (m)	Time of arrival (mins)
D5X5	bund failure	110	35	1.15	57
D5X5	no bund failure	30	8	0.18	100
D1X4		0			
D2X5		0			
D1X333		0			
D8X333		0			

Uncertainty estimates

depth	+20%	Note this assumes a worst case of overtopping of the bund due to either wave reflection from expanding flow past the bund
	-10%	or superelevation effects of flow round the upstream bend resulting in a small breach of the bund down to original ground level.
		This would only occur in the case of flow scenario D5X5.
discharge	+10%	A maximum breach width of 3 times the bund height above original ground level (4.5 m) was assumed.
		It would result in an approximately triangular shaped overflow hydrograph with a peak of about 110 m3/s and a duration of 0.55 hours corresponding
	-20%	to a total volume of about 110,000 m3.

flow in north branch only						flow in north and south branches						flow in south branch only		
Peak flow at SH1 (m³/s)	Peak level (m)	Bed level (m)	Peak depth (m)	Time arrival l (mins)	Peak flow Tong Riv (m³/s)	Peak flow at SH1sth (m³/s)	Peak flow at SH1nth (m³/s)	Peak level (m)	Minimum road level (m)	Peak depth (m)	Time of arrival (mins)	Peak flow at SH1	Peak level (m³/s)	Minimum road level (m)
71	1045.65	1042.96	2.69	57	51	not yet calculated								
3.2	1043.6	1042.96	0.64	90								63	1054	1052.85
												1.75	1053.03	1052.85

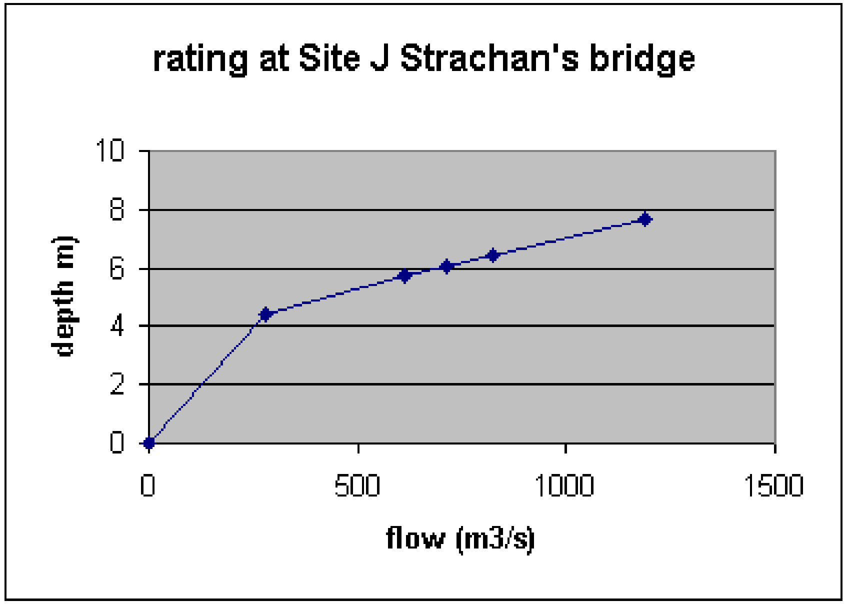
Site J Strachan's Bridge

Flow scenario	Peak flow (m³/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	1186	637.64	630	7.64
D1X4	823	636.47	630	6.47
D2X5	715	636.08	630	6.08
D1X333	615	635.72	630	5.72
D8X333	281	634.39	630	4.39

Uncertainty estimates

depth	+20%	
	-10%	
discharge	+10%	
	-10%	

height of bridge soffit above bed level 5.3-5.8 m
refer Fig 26 of GNS report Hancox et al (1998)



Site L Marae bridge

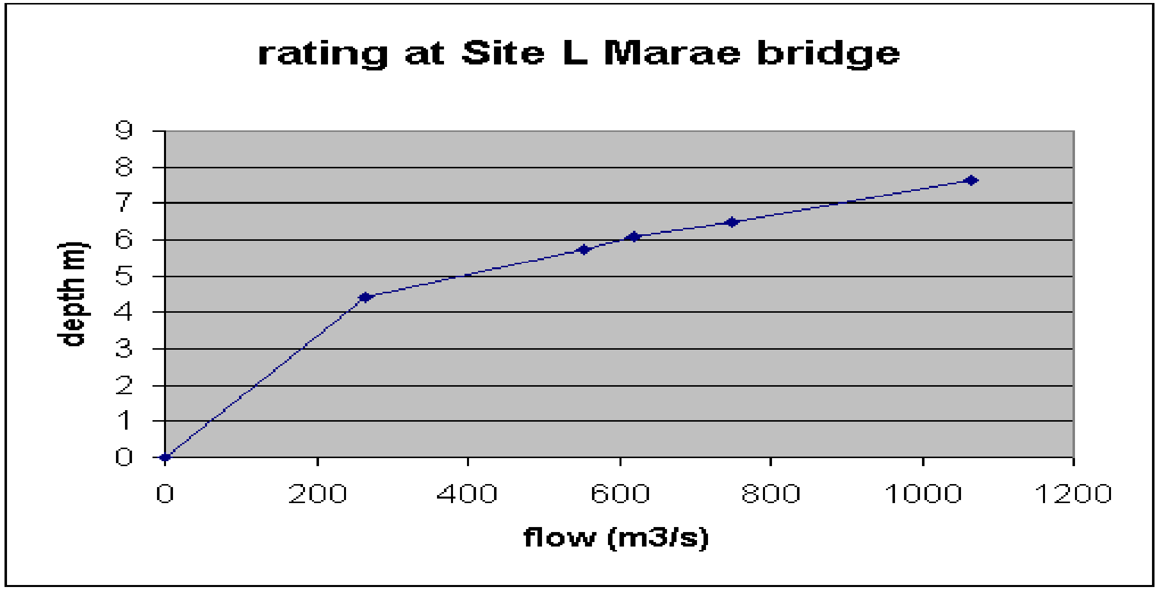
Flow scenario	Peak flow (m³/s)	Peak level (m)	Bed level (m)	Peak depth (m)
D5X5	1065	593.58	585	8.58
D1X4	749	590.92	585	5.92
D2X5	619	590.13	585	5.13
D1X333	554	589.84	585	4.84
D8X333	265	588.23	585	3.23
	0			0

Uncertainty estimates

depth	+20%
	-10%
discharge	+10%
	-10%

height of bridge soffit above bed level 7 m

refer Fig 28 of GNS report Hancox et al (1998)



Appendix 2(a) - Tranz Rail Ruapehu Lahar Hazard

Note of discussion between Walter Rushbrook and Tony Taig, 28 May 2002

Tony explained the background and approach being taken to the MCDEM Residual Risk Assessment. The key aim was to understand what various parties' response plans needed to achieve, and with what reliability, to ensure residual risks were adequately controlled. Walter explained his background (civil engineering, recently moved from a field to an track and structures asset management role); he was able to provide an overview of the bridge and the protection arrangements, but not familiar with some of the operational details relevant to the latter stages of the risk assessment.
This note covers:

- the risk to the bridge asset
- economic consequences of damage to the bridge
- arrangements to stop trains in the event of a lahar, and
- risk factors if trains were to attempt to cross while the bridge was damaged (note – this is based on Tony's initial guesses not on information provided by Walter, but is included here to facilitate corroboration or otherwise by Tranz Rail).

1 Risk to the Bridge

Key measures taken to improve the integrity of the bridge following the 1953 disaster were to use fewer piers with longer spans between them (2 main spans on new bridge), and to found the piers far deeper below the bed of the river (approx 6 metres). The inspection arrangements for the bridge involve:

(a) a rigorous full inspection every eight years (last one was in 1999)

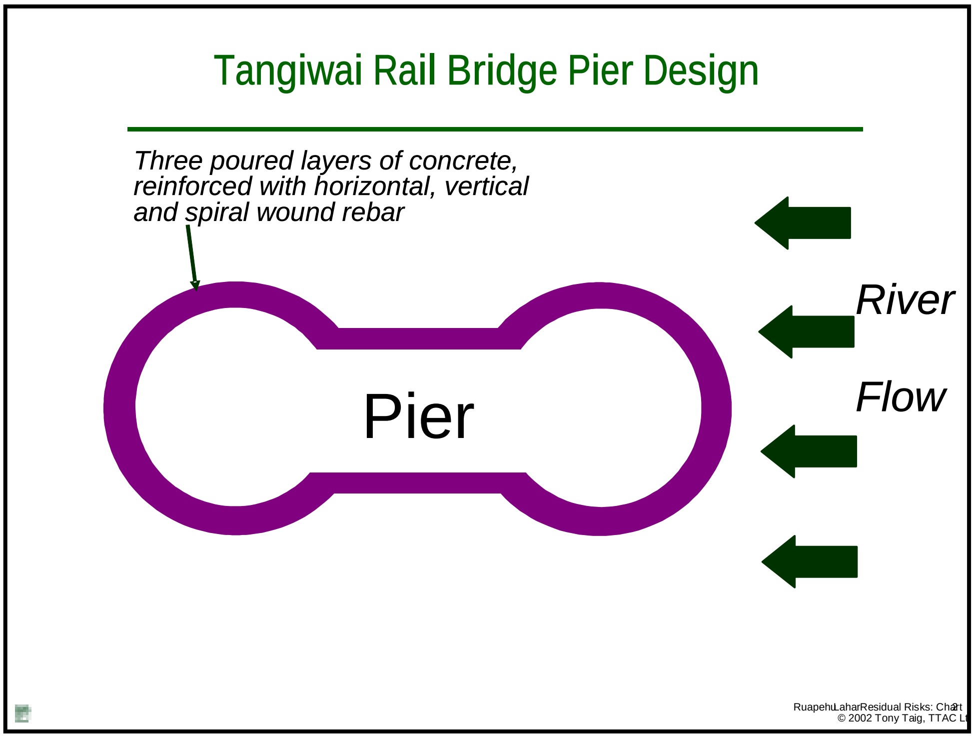
(b) an annual general inspection

© twice weekly track inspections.

In addition, track gangs regularly pass over the bridge and would note any track-related problems. Finally, 40-50 trains per day pass over the bridge, providing opportunities for drivers to report (via the standard procedure) any track problems or unusual observations.
We discussed possible failure mechanisms of the bridge as follows:

1 Scour (as in the 1953 disaster) – there is a very low possibility of bridge failure due to scour. The existing bridge built after the 1953 event has very deep piers, which would survive several metres of scour. The most recent full inspection reported no observable scour around the foundations.

2 Other damage to piers – it would be possible in principle for a very large boulder to cause significant structural damage to a pier. Walter had recently been involved in replacement of a bridge of very similar design built in the same era, and the pier structure had been immensely strong (see schematic diagram for pier design and construction). Given the likelihood of even more particular attention having been paid to the Tangiwai bridge in the wake of the 1953 disaster, Walter felt that while cosmetic damage associated with (for example) a very large boulder impact could not be ruled out, significant structural damage to the bridge via this route was unlikely.



3 Failure of spans – assessments have suggested that the bridge would have some capacity to survive direct lahar loading onto the span members. Clearly there is a possibility that there could be damage to the spans and track if the level of the lahar comes above the soffit of the bridge.

4 Embankments – the first possible issue here was of erosion of either bank by a lahar, leading to collapse of track support. The second possibility was that a lahar might actually flow up onto the track if it overtopped the upstream, eastern embankment. These possibilities would require a site visit were they to be assessed in any detail. Walter noted that the arrangements for prevention of access of trains to the bridge would extend for a considerable distance in either direction, so would provide equivalent protection for the embankments either side of the bridge itself.

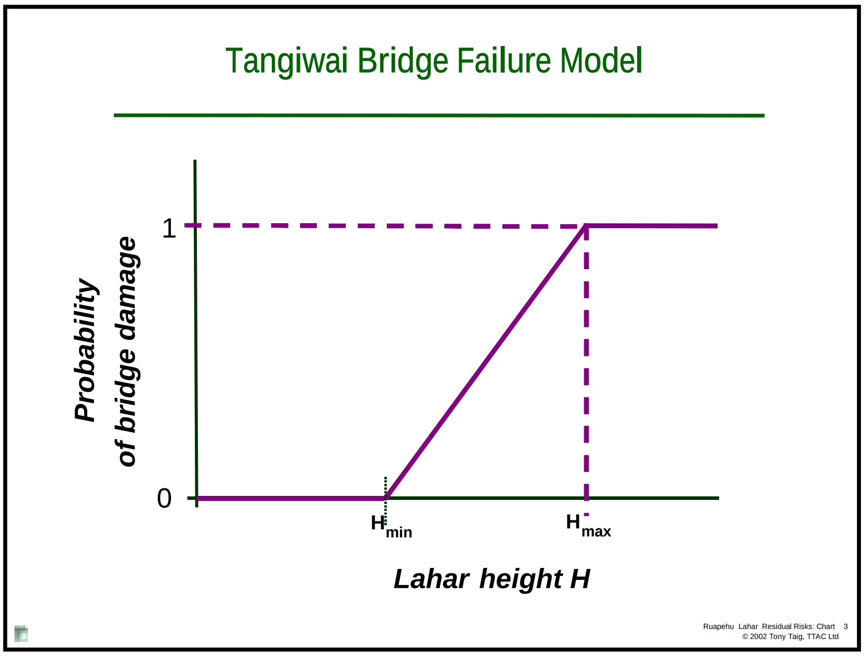
5 Structural failures within design loads because of poor design and/or construction – Walter was extremely confident there would not be any unrevealed failure mechanisms lurking in the current bridge, given the inspection arrangements and comments in 2 above on design and construction.

In summary, overtopping of the bridge was considered the principal failure mechanism of concern. We noted the possibility of significant "*bow wave*" effects on impact of the lahar with the bridge, and Walter produced a photo showing the scale of such a wave produced when a lahar passed the Site K lahar warning gauge. Tony proposed a very simple model for assessment of the likelihood of bridge failure for a lahar of a given height, based on:

- high confidence the bridge would survive a repetition of the 1953 lahar
- high confidence the track would sustain severe damage in a lahar whose height (of the bulk of the lahar, not the bow wave), reached the soffit of the bridge.

This was represented in a simple damage probability/lahar height relationship as shown in the figure below where H_{min} is the height of the 1953 lahar, and H_{max} the height necessary for the bulk flow of the lahar to reach the span members.

Note: This analysis has been discussed and confirmed by Tranz Rail in discussion between John Greenfield (TRL Structures Engineer) and Rudolph Kotze (Technical Director, Holmes Consulting Group)



2 Economic Implications of Bridge Damage

Tranz Rail have 1700 bridges around New Zealand, many of which are susceptible to natural hazards risks. They therefore have standard procedures in place to deal with bridge damage, the main elements of which are:

- stocks of "*standard*" temporary bridge elements held around the country
- arrangements to procure use of large cranes and heavy plant they do not own, and
- pre-planned template designs and procedures for rapid erection of temporary bridges.

There had been relatively recent experience of a "*worst case*" loss of a bridge very similar to that at Tangiwai, in the derailment at Ngaruawahia in 1998. The situation there had been exacerbated by:

- a train accident in which parts of the train were badly damaged and wedged in among parts of the bridge
- the difficulty of work on site (higher piers/more spans), and
- the absence of alternative routes for Tranz Rail traffic around the damage site.

It had taken about two weeks to put in place a temporary bridge and restore traffic. The situation for restoration at Tangiwai would be less bad, because of the easier access to the bridge. Business interruption costs would be lessened by the availability of an alternative route from Taumaranui to Marton (taking a long way round to the west – not all traffic would be able to travel on this altenative route due to rolling stock restrictions on some tunnels and bridges).
The approximate costs involved were estimated as:

(a) $0.5 million for immediate works to rectify site damage and put in place a temporary bridge

(b) $2 million for the replacement of the two 36m long truss spans with steel through plate girders. The cost of replacing the entire bridge will cost about $3.5 million, and

(c) $? for business interruption (a good proportion of the value of 4-5 days traffic, plus whatever longer-term losses of revenue might be associated with adverse reactions by customers to a lahar damage incident).

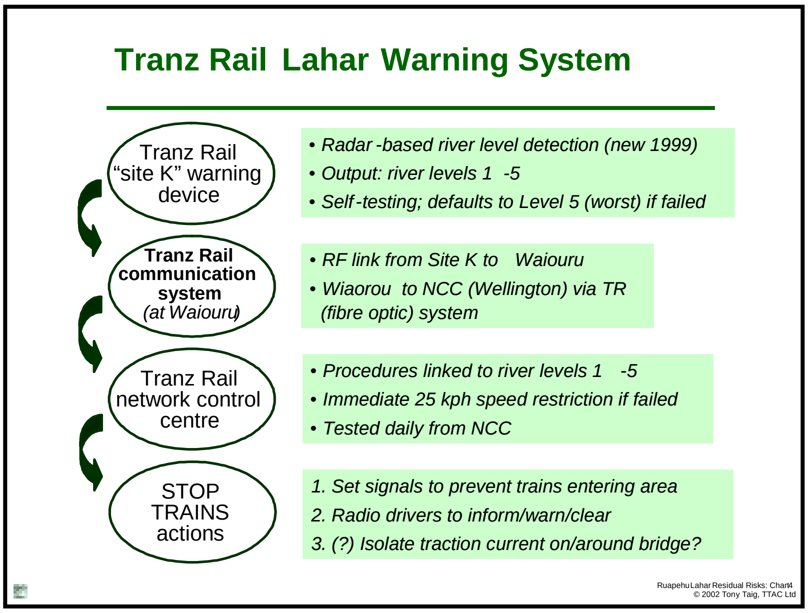
3 Arrangements to Stop Trains

It was recognised that some plausible lahar scenarios could involve damage to the bridge sufficient to derail trains. High reliability is therefore required for systems to prevent trains getting onto the bridge if it is damaged. Tranz Rail's system is based on provision of a warning by their own lahar warning system, installed 11km upstream of the Tangiwai Bridge, followed by action from the Network Control Centre to clear trains out of the bridge area and stop trains from approaching it. We noted that the new ERLAWS system should be capable of providing a significantly earlier warning than the Tranz Rail system, and that the Tranz Rail procedures involved will probably be reviewed once ERLAWS is functioning. The key elements of the Tranz Rail system are shown in the figure. Important aspects of the system include:

1 The Site K warning device: The original device relied on rising water levels in the river to complete a circuit between detector probes at various heights up the tower on which the device is situated. This was unreliable because the tower could silt up, with both false positive and false negative alarm possibilities. The system was therefore replaced in 1999 with the new radar-based system, which bounces a pulse from an arm off the top of the tower down to the river surface, and times the return of the pulse to the probe. This monitoring system is linked to a "*good modern practice*" control system which includes self-test facilities, and provides a continuous broadcast of the river level (categorised from level 1 for the lowest to level 5 for the highest) via an RF link to the Tranz Rail communications system at Waiouru. We did not have access to the details of the design (these were available if required via John Skilton), but Walter was confident that the monitoring equipment was a) highly reliably, and b) would provide an indication if in a failed condition.

2 Communication of alarm to NCC: This takes place in two stages, first via an RF link to Waiouru, and then via the Tranz Rail telecommunications system to the Network Control Centre (currently in Wellington; will be moving to Auckland in the medium term). The RF link is probably the weak link in the whole of this chain (see below).

3 Procedures driven from the NCC: Tranz Rail procedures for action in response to each of the possible levels 1-5 indicated by the warning system are contained in their Working Timetable for the relevant section of their route (copy supplied). Each level is accompanied by an audible alarm in the NCC, which is a permanently manned facility with several fully trained controllers present at all times.



The system is tested daily from the NCC (after completing our discussion Walter took me to the NCC, where an additional test was carried out for my benefit). The controller in NCC is seated in front of a train diagram showing the location of all trains on the route, and it is a very straightforward matter to initiate a test. The test returns a default "*FAILED*" indication until all steps are successfully completed. The controller advised us that test failures used to be a relatively frequent (approx weekly) event, but that work on the reliability of the system had improved this significantly. Failures were now approximately a monthly occurrence, with the RF link generally being the problem.

4 **Stopping trains approaching the bridge**: For a Level 5 alarm, the instructions for the Controller are to:

(a) immediately set the signals controlling access to the bridge to STOP in both directions

(b) notify appropriate management and emergency services personnel

© notify all train crews currently using the route or approaching the area via train radio, and

(d) record all changes and actions taken.

These procedures are to be maintained for a period of two hours after the flood level falls to ensure that any hazard at the bridge has passed before they are relaxed.

Tony recalled reading of provisions to cut off the traction current on the bridge and its approaches, but no such arrangements were described in the Working Timetable (it is possible there are other local working procedures and arrangements in place).
In considering how this system might fail, the most plausible weak link appears to be the RF link from Site K to Waiouru. This is because:

- the monitor/probe is reliable, self-testing, and reports itself failed when not working properly
- Tranz Rail telecommunications links (other than the RF links down to Waiouru) are generally reliable
- the NCC is reliably manned by well trained staff who receive an audible alarm signal when the river level changes and know exactly what to do if that happens
- the arrangements for stopping trains from the NCC should be very reliable; signal setting on its own should provide a high degree of protection, but the back-up of radio contact with train crews should also be very reliable (trains do not operate unless their radios are working).

4 Risk Factors for Trains Approaching Bridge

Were the above arrangements to fail and a train to pass over the bridge in its damaged state, then the casualties would depend on the:

1 likelihood of the driver stopping the train in time having received a warning by other means, eg noticing noise of lahar, or someone running up the track. (assumed probability zero for initial risk assessment)

2 likelihood of the train derailing and leaving the bridge (assumed probability 1 for initial risk assessment – note implications for the degree of damage implicit in the bridge failure model in Section 1 of this note above)

3 number of people on the train. My first thoughts for the initial risk assessment are to use: 1 person for 90% of trains (freight), 100 people for 8% of trains (typical passenger train occupancy) 200 people for 2% of trains (high passenger train occupancy) (advice from Tranz Rail on actual likely numbers would be much appreciated).

4 proportion of people on the train killed (assumed 100% for initial risk assessment – 50% might be a better estimate based eg on the Tangiwai disaster experience)

Tony Taig
TTAC Limited, 28 May 2002

Appendix 2(b) - Ruapehu Lahar Residual Risk Assessment

Note for the Record – Discussion with John Skilton, Tranz Rail, 4 June 2002
I telephoned John at the suggestion of Walter Rushbrook to clarify how the Tranz Rail lahar alarm system worked, and in particular what status it would display in Wellington if the RF linked failed between the monitoring site in the Whangaehu River and the Tranz Rail communication system at Waiouru. We had a useful discussion also of the relative reliability of various elements of the Tranz Rail warning and response system, and of its likely overall reliability. This note extends and updates my earlier note of a meeting with Walter Rushbrook on 26 May.

Monitoring of RF Link Status

The system at Wellington is continuously polling the monitoring station in the Whangaehu River (approx every five seconds). If the system is unable to confirm a level indication from the monitor for any reason (including RF link failure) then the Wellington system status moves immediately to "We cannot rely on the alarm". A pop-up screen will then appear in the control room to warn the network controller (there is also an audible alarm). The Controller will then carry out a test of the system, as witnessed by me on 26 May. If this fails, then speed restrictions will immediately be introduced in line with the Tranz Rail procedures.
At the time of writing my earlier note I was uncertain whether the Wellington system would know about it if the RF link were failed. It is clear from my discussion with John that the Wellington system WOULD know, unless the whole system was in a failed state.

System Reliability

A rough estimate of the probability of failure of the warning system on demand can be made by looking at the frequency and duration of occasions on which the alarm system is in the "*We cannot rely on the alarm*" state. John's view was that this unavailability added up to no more than a few hours unavailability per year.
We then talked through the overall warning and response system reliability. The system is not designed to high integrity standards (eg SIL, the international signalling integrity level) but has performed very reliably to date. John agreed with my assessment that the reliability of response once the alarm was raised (based on the Controller actuating signals, and communicating by radio with train crews, whose trains do not operate unless the train radio is working) was high in comparison with the reliability of Tranz Rail receiving the alarm in the first place.
As regards a reasonable estimate of system unreliability, we agreed that there were a variety of plausible occasional failure mechanisms, and that the overall sustainable reliability (probability of failure on demand for the system to provide a timely alarm in Wellington) was probably of the order of 0.01 to 0.001 (ie 1% to 0.1% chance of failure).
At these levels, John agreed that it was very desirable to back up the warning system, which was the weakest link in their risk mitigation arrangements, with warnings available from other sources. We noted the ERLAWS system now becoming available, and I undertook to flag up the importance of making sure that a call to Tranz Rail to confirm that the lahar is coming should be an early priority for those responding to the lahar.

Tony Taig
6 June 2002

Appendix 3 - Ruapehu Lahar Residual Risk Assessment

Note for Record – discussion with Transit, 30 May 2002
Those present: John Jones (Transit), Jim Begg & Richard O'Reilly (MCDEM), Tony Taig (TTAC).

Introduction

The meeting was held to discuss Transit's actions in relation to potential lahars, and the MCDEM risk assessment currently under way. Tony explained the approach being taken to the risk assessment:

1. Characterising possible water pour scenarios from the crater.
2. Characterising resulting lahar flows down the mountain (further calculations of flow rates, heights and volumes for a spectrum of lahar scenarios were being commissioned from Opus consultants).
3. Assessing the likelihood of damage to assets.
4. Assessing safety and economic risk, with and without effective emergency response plans.

The particular aim was to help asset managers and government develop a shared appreciation of the lahar hazard and what everybody is doing about it, and to establish requirements and priorities to help those planning the emergency response. John then explained Transit's risk and arrangements to mitigate it. Notes of the discussion are grouped under the headings of:

- risk to road assets
- prevention of risk to people
- consequences
- summary/next steps.

1 Risk to Road Assets

SH1 (Waikato Stream): If the bund were to be overtopped then a fairly modest flow of lahar material down the Waikato Stream could overtop SH1 either at the culvert or the shallow bridge over the stream. The purpose of the bund was to prevent such flows, so the risk was considered small. Transit was nevertheless planning to prevent traffic access as a precautionary measure.
SH1 (Waihianoa Aqueduct): There was considered to be a small but non-negligible risk of flows down the Whangaehu valley spilling over onto SH1. Again, the risk was considered small but merited precautionary measures to close SH1 to traffic.
For SH1 generally, any lahar damage to the road would be expected to be relatively straightforward to repair, within tolerable financial risk limits, and public safety was Transit's primary concern.

SH49 (Tangiwai Road Bridge): Although the bridge had been rebuilt following the 1953 lahar to a much stronger design, the risk from the impending lahar is considered medium-high. We discussed the model Tony had proposed for the Tranz Rail bridge:

- probability of failure = 0 for lahar heights up to that of the 1953 lahar
- probability of failure = 1 for lahar heights reaching the bridge members
- straight line connecting these two points for probability of failure for intermediate lahar heights.

John felt this was a reasonable rough model for application to the road bridge. Damage to the bridge would have significant economic as well as safety implications. Transit had good recent information on the likely cost of replacement ($1.8-2 million), and estimated a timescale of 18-24 months for replacement. Consequential losses for motorists during that period would be slight, however, as a) traffic is relatively light, b) alternative routes are largely available, and c) a temporary replacement bridge should be able to be constructed relatively quickly at moderate cost. Transit's principal concern was for public safety in the event of bridge damage.

2 Prevention of Risk to People

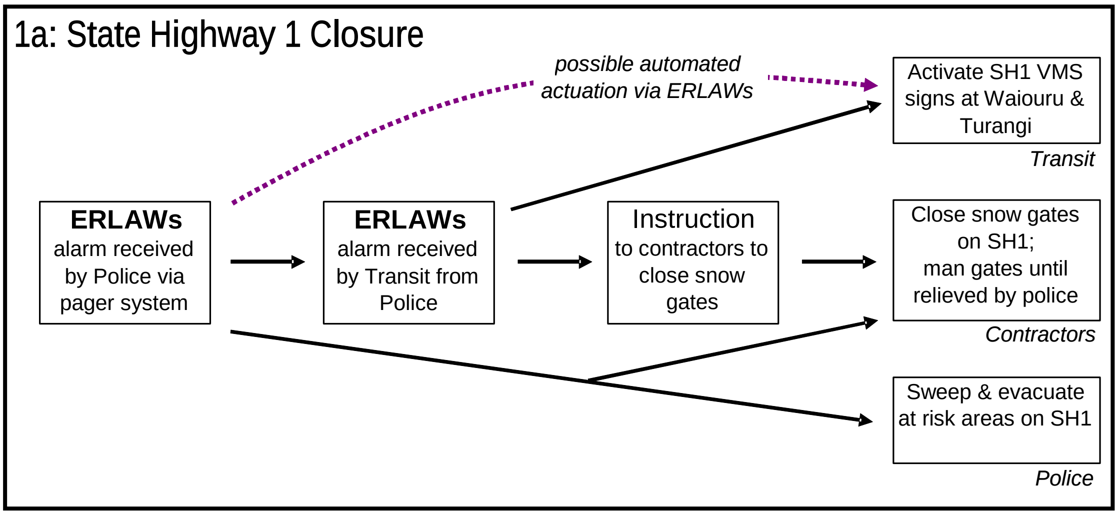
There are in principle two sources of risk to people in road vehicles:
(a) people would be in the path of the lahar as it came through, or
(b) that they would subsequently drive into/onto lahar-damaged road.

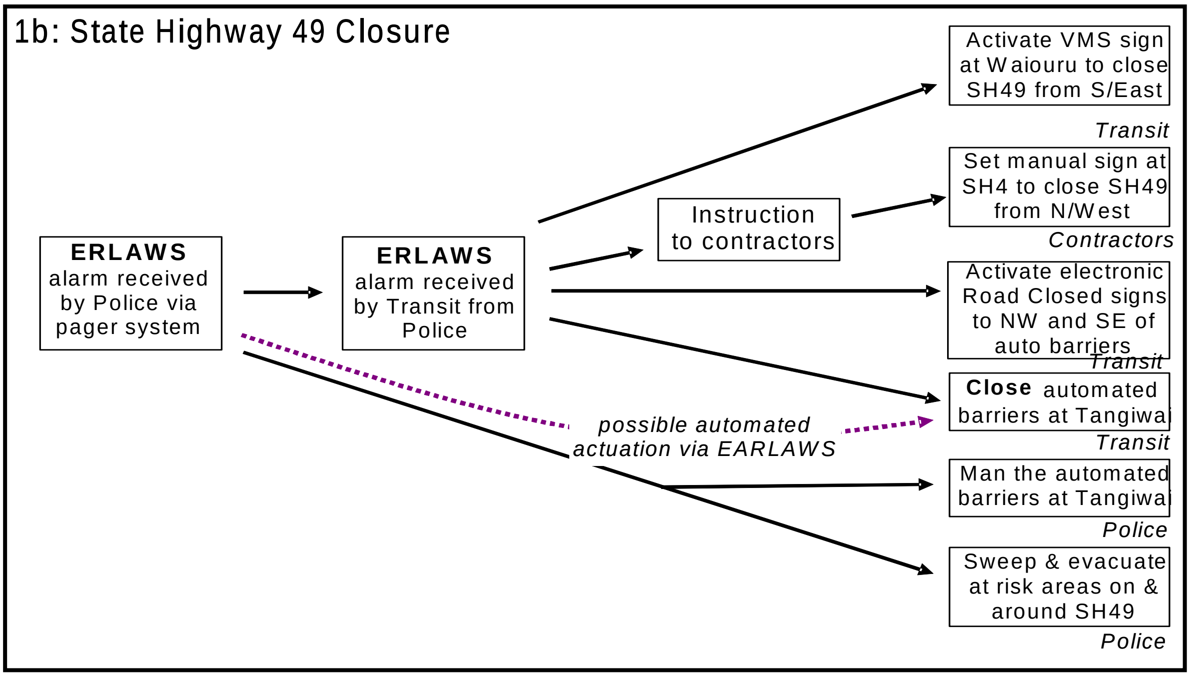
Transit are planning to prevent access to the at-risk roads, while making sure people in the at-risk areas are able to escape them. It will be up to the emergency services to ensure that anyone parked or otherwise in the at risk areas is evacuated.

SH1: Transit had considered the use of automated barriers to be activated on receipt of an ERLAWS alarm, but given the relatively low risk had decided to use existing means to close the Desert Road and prevent access to the at-risk areas. On receipt of an ERLAWS alarm, they would:

- set the Variable Message Signs (VMSs) at Waiouru and Turangi to read "Road closed – severe flood" or similar
- instruct their contractors to close the snow gates at either end of the Desert Road, and remain in situ to supervise the gates until relieved by the police or other authorities.

SH49: Given the relatively high risk to the Tangiwai road bridge, Transit were planning, in addition to using VMS indications of road closure, to install automated barriers on either side of the bridge, which would be actuated on receipt of the ERLAWS alarm. John provided copies of related drawings. Transit are currently engaged in procuring the equipment for the barriers, and Tony suggested that they include the issue of reliability (including under the severe environmental conditions encountered in the Ruapehu area) in the procurement discussions. The diagrams below summarise the arrangements for SH1 and SH49 respectively:





3 Consequences of Protection Failure

If the protective arrangements for people work then the consequences will be limited to economic and other road closure impacts. The main elements of cost involved for Transit are likely to be:

- costs of mitigation measures: about $40,000 had been spent to date on assessment and design of the SH49 barriers, and a further $150,000 was the likely cost of procuring and installing the equipment (not including automated linkages to ERLAWS)
- costs of replacing the Tangiwai bridge: about $1.8-2 million
- consequential social and economic costs of road closure: relatively modest.

If the protective arrangements for people fail then the safety risk factors in qualitative terms would be as follows.

SH1:

(a) People trapped in the path of the lahar: key risk factors are:

- levels of camping/overnight parking/long-term stopping close to the road (low),
- risk of lahar reaching the road (relatively low),
- reliability of sweep and evacuation of road and surrounding areas within lahar travel time to SH1 (may be difficult), and
- risk of harm if people/vehicles trapped in the path of a lahar (almost certain).

(b) People driving into road sections damaged by lahar: key risk factors are:

- effectiveness of road closure (John would check on past experience of driver behaviour at the snow gates but thought they were very effective)
- chance that drivers would be able to see/avoid damaged road sections (? moderate – John and Jim struggled to recollect a small handful of incidents in the past several decades in which carriageway damage had led to serious accidents – data could be checked with LTSA as to frequency of such incidents; frequency of serious carriageway damage might be available via Transit)
- likelihood of harm if drive over damaged road surface (more likely if over damaged bridge; less likely if over eg damaged carriageway in culvert)
- reliability of closing the road within the time taken for the lahar to reach it (John could check on typical timescales for contractors responding to Transit requests and closing the road)

SH49:

(a) People trapped in the path of the lahar: key risk factors are:

- levels of camping/overnight parking/long-term stopping close to the road (relatively frequent at Tangiwai memorial, next to toilets)
- risk of lahar reaching the road (relatively high)
- reliability of sweep and evacuation of road & surrounding areas within lahar travel time to SH1 (more time available than for SH1)
- risk of harm if people/vehicles trapped in the path of a lahar (almost certain).

(b) People driving into road sections damaged by lahar: key risk factors are:

- chance that drivers would be able to see/avoid damaged road sections (depends on lighting/visibility – Tangiwai bridge is easy to see from N/W but only becomes visible very close to bridge when approaching from S/E)
- likelihood of harm if drive over damaged road surface (more likely for Tangiwai bridge than for SH1 areas)
- reliability of closing the road within the time taken for the lahar to reach it (should be much higher than for SH1 given automated barriers and extra time available).

4 Summary/Next Steps

In summary, the road hazards on SH1 are considered moderate to low, and precautionary arrangements are based around existing road closure systems. The hazard on SH49 is potentially higher, so new automated road closure barriers are being installed.
Emergency planners should be aware of the particularly high importance of carrying out an effective "*sweep*" and evacuation of the Tangiwai area, particularly in view of the regular use made of the memorial area for overnight stops. Getting uniformed personnel (police or army) to the road blocks on SH49 and SH1 would also be important priorities, both to prevent drivers trying to bypass or get through the barriers, and to provide added reliability of getting the barriers closed.

Actions:

1 Tony would produce and circulate a note of the discussion to confirm understanding of the above points and provide an agreed basis for the risk assessment.

2 MCDEM would ensure the results of the new lahar flow, height and timing calculations were made available to Transit in a timely way (asap once available, hopefully early in the week commencing 17 June), and likewise the findings of the risk assessment.

3 John would:
- check up on Transit experience with the snow barriers on SH1 (how long it takes to get them operated; what driver behaviours are experienced)
- see whether any information is readily to hand on how often serious carriageway damage is sustained on major roads (if this is available, Tony will then check on corresponding accident stats with LTSA)
- liaise with colleagues involved in procurement and installation of the barriers to see what kind of reliability was likely to be achievable.

Tony Taig
5 June 2002

Appendix 4 - Ruapehu Lahar Residual Risk Assessment

Note for the Record – discussion with Genesis Power Ltd, Friday 31 May 2002

Present:	Jarrod Bowler	Genesis
	Denis Drinkrow	Genesis
	Tony Taig	TTAC Ltd

Introduction

The meeting was held to discuss issues related to lahars in the Tongariro river catchment in the context of the current MCDEM residual risk assessment.
I explained the background to the MCDEM risk assessment. The aim is to help asset managers and government develop a shared appreciation of the lahar hazard and what everybody is doing about it, and to establish requirements and priorities to help those planning the emergency response.
The approach being taken to the risk assessment involves:

1 characterising possible water pour scenarios from the crater

2 characterising resulting lahar flows down the mountain (further calculations of flow rates, heights and volumes for a spectrum of lahar scenarios were being commissioned from Opus consultants, which would include estimates of flows over the bund and into the Waikato stream catchment for a range of different crater pours and bulking factors)

3 assessing the likelihood of damage to assets, and

4 assessing safety and economic risk, with and without effective emergency response plans.

Genesis provided me with an overview of power generation on the Tongariro River, and we then discussed issues in relation to lahars and Genesis' assets. The discussion notes below group the issues discussed under four main headings:

1 Risk to power generation assets

2 Genesis' planned responses to lahars

3 Safety impacts of Genesis' responses, and

4 ERLAWS equipment and roles & responsibilities.

1 Risk to Power Generation Assets

We discussed these first in the context of lahars travelling down the Whangaehu valley, then in relation to lahar material entering the Tongariro catchment.
Whangaehu Valley lahars

The principal assets at risk are:

- ***Wahianoa aqueduct***: The aqueduct comprises a large buried concrete pipe which passes under the Whangaehu River, and is protected by a concrete shield. The 1995 eruption lahars, which were small in comparison to anticipated tephra dam failure lahars, had scoured out the Whangaehu bed to expose this shield. In the anticipated tephra dam failure lahar, Genesis' view is that the aqueduct is at very high risk. Even if lahar material does not travel through to Lake Moawhango (see below), Genesis estimate that it would take about six months to survey, clean out and repair the aqueduct. The average flow collected via the aqueduct is about 3.4 cumecs (m^3 per second), which would be lost for generation at Rangipo, Tokaanu and all stations on the Waikato river.

- ***Lake Moawhango***: there is at present no valve or barrier between the Whangaehu River crossing and Lake Moawhango, which means it would not be possible to isolate the lake from contamination if the aqueduct were penetrated by a lahar. Although the lake would provide a good "*settling tank*" for lahar sediment material, a) lahar sediments could do extensive damage to the outflow and control equipment, and b) Rangipo power station is very sensitive to chemical contamination (pH and conductivity are critical parameters; both would be affected significantly if appreciable volumes of crater lake water entered Lake Moawhango via a lahar). The worst case is that the supply of an average of 13.6 cumecs of water from the lake to Rangipo might be cut off for several months while the lake was drained and flushed, and associated equipment repaired.

- ***Rangipo Power Station***: was severely damaged in the 1995-96 lahars by the abrasive action of lahar sedimentary material. It was out of service for many months, and cost some $7 million to repair. The inflow to the power station, and the outflow from Lake Moawhango, are both closely monitored, and the flow from lake to power station via the Moawhango tunnel can quickly and reliably be stopped. The control station at Tokaanu is permanently manned by highly trained personnel, so the risk of contamination entering the power station via this source is very low.

The economic impacts of asset damage are dominated by the lost revenue due to lost water flows for generation at Rangipo, Tokaanu, and the Waikato river stations. The lost generation is probably not big enough significantly to perturb the New Zealand electricity market, though that risk would be more significant for the Lake Moawhango event. Approximate figures are shown in the table below.

Parameter	**Waihianoa Aqueduct**	**Lake Moawhango**	**Units**
Time to repair	180	180	days
Lost water flow to Rangipo	3	10	m3/sec
Generation per cumec (Genesis)	4	4	MW/cumec
Generation per cumec (Mighty River)	4.5	4.5	MW/cumec
Approx value of one MW-hour of electicity	40	40	$ NZ
Total lost generation	110160	367200	MW-hours
Approx lost revenue (Genesis + Mighty River)	4	15	$ millions

Tongariro Catchment

The principal assets at risk here are:

- ***Rangipo Power Station***: (see above). If lahar material enters the head pond for the power station, then the only way to avoid serious damage to the power station is to close the intake, and flush any lahar material out through the head pond sluices before commencing generation at Rangipo. In practice, if any lahar material settles in the head pond then major asset damage is very likely. The only way to avoid this is to flush the lahar material through as it arrives. To do this, the sluices need to be opened and the water level in the head pond must be very low, so that incoming flows pass straight through and out.

- ***Poutu Canal and Lake Rotoaira***: The lake is of great cultural importance to local iwi, and Genesis has accepted an obligation to protect the quality of water entering it via the Poutu canal. Preventing ingress of lahar material to the canal (and hence the lake) is thus a top priority for Genesis. This operation will become mandatory once resource consents become operational for the scheme. (**Note**: resource consents have been granted, however, they have been appealed to the Environment Court. The appeals won't affect this operation.)

- ***Tokaanu Power Station***: In principle the power station could be at risk via contamination of Lake Rotoaira. In practice, because a) the risk of contamination of the lake is so slight and b) the lake would provide substantial settling and dilution, there is no significant risk to Tokaanu.

Rangipo Power Station - Economic Implications of Damage		
Time to restore power station to service	180	days
Lost generation capacity (average)	60	MW
Total lost generation	259200	MW-hours
Total lost revenue (Genesis only)	10	$ millions
Total restoration cost (damage as 1995)	7	$ millions
TOTAL loss to Genesis	**17**	**$ millions**

The principal asset at risk is thus Rangipo Power Station if contaminated water was allowed to enter the Rangipo Station. Approximate economic values associated with serious damage to the power station are summarised in the table above. Some perturbation of the New Zealand electricity market might again be an issue here.

2 Genesis Planned Response to Lahar Risks

Genesis' arrangements for protecting their assets are designed against a spectrum of potential volcanic hazards, including volcanic eruptions and type 1 (eruption) lahars, as well as the anticipated tephra dam collapse lahar into the Whangaehu valley.

In the Whangaehu valley, there is not a great deal Genesis feel they can do to protect the Wahianoa Aqueduct from lahars on the scale anticipated for the tephra dam collapse event. They are, though, considering installing an isolation system for Lake Moawhango, to permit the flow of water from the aqueduct to the lake to be stopped in the Mangaio tunnel (between the Whangaehu River crossing and the Lake). Decision making in this area is relatively straightforward, with the costs of investment being balanced against the value of protecting the Lake Moawhango asset.

As regards the Tongariro catchment, Genesis' first asset at risk is Rangipo Power Station. To protect the power station, as mentioned above, it is necessary to be able to let any lahar material entering the head pond be carried straight through the sluices as it would have done naturally if the dam was not in place. A necessary precursor to this is to drain down the head pond by 4 metres, which is potentially hazardous to people further down the Tongariro River if done suddenly. The strategy therefore is to drain down the head pond gradually, as soon as ERLAWS detects a lahar, so as to minimise the water remaining in the head pond if/when lahar material is detected flowing towards it.

Lahar material could enter the head pond either via overspill of a Whangaehu valley lahar into the Tongariro catchment (over the bund built by DoC specifically to prevent such an eventuality), or via a type 1 eruption lahar direct into the Tongariro catchment (such as the 1975 lahar which came down the Mangatoetoenui stream). Genesis provided me with a copy of their operational response procedure for dealing with lahars via either source. The main elements are:

on detection of a lahar by ERLAWS (assumed to be into the Whangaehu valley), Genesis will:

- cease diversion of water from the Wahianoa Aqueduct to Lake Moawhango
- shut down Rangipo power station
- close the Moawhango and Waihohonu Tunnels to prevent lahar material entering the Rangipo head pond via these sources, and
- open sluice gates out of the Rangipo head pond to drain down the pond 4 metres in a controlled manner (this would take about 40 minutes).

Genesis has its own lahar sensors high up the Waikato and Mangatoetoenui Streams, to provide considerable warning of any lahar material approaching the Tongariro River and Rangipo head pond. If either of these is triggered, Genesis will (in addition to all the measures above for Whangaehu valley lahars):

- open the sluice gates at Rangipo dam to the maximum extent possible to allow the lahar to pass through, and
- close the Poutu intake to prevent any contaminated material being diverted into Lake Rotoaira.

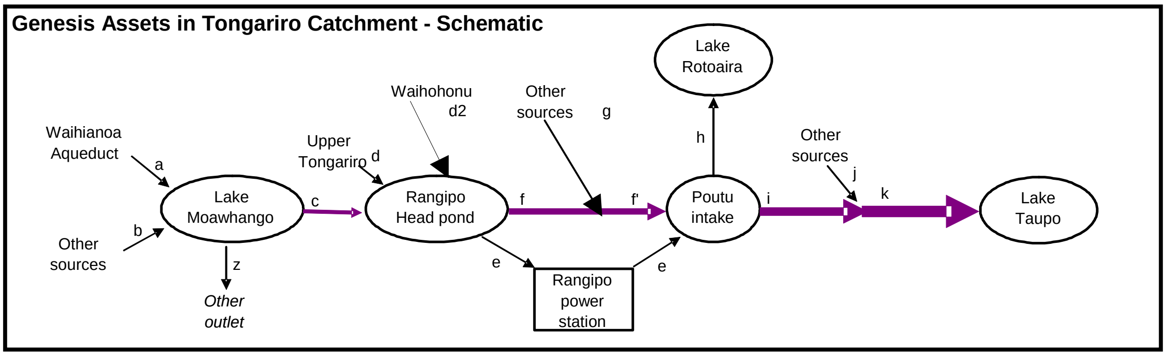
Genesis recognises the potential hazard to people in the lower Tongariro River associated with sudden changes to the flow below the Poutu intake. The issues here are discussed in the following section.

3 Safety Impacts of Genesis' Responses to Lahars

Genesis have given considerable attention to the likely effects of their lahar risk management strategy on water flows in the lower Tongariro river, which is heavily used for leisure activities (rafting in the stretch below the Poutu intake, and fishing further down in the Turangi area). This is the only part of the river where people are normally at risk.

Genesis recognises their responsibility to advise other people of their strategy, and to provide timely warning of any sudden changes in flows. They are not constrained to require permission from anybody before changing flow in the lower Tongariro River. They are, though, seriously concerned at the absence of any current plan for warning and evacuating people from the lower reaches of the Tongariro river, in the event of sudden increases in flow (for whatever cause). Devising and implementing such a plan is outside their responsibility or powers to act (it lies with Taupo DC and Police).

A schematic of the Tongariro river and relevant Genesis assets is shown in the figure below, which shows typical "*dry conditions*" flows (typical of the 90%+ of the time that the river is not "*fresh*" in rain or storms).



The potential risks to people in the lower river of Genesis' actions to alter flows are greatest when the river is at normal levels (ie NOT in wet weather, when the river is "*fresh*" or in flood). This is because a) there are far fewer people out on the river in fresh conditions (fishing is no good and rafting too dangerous), and b) such conditions prevail for only perhaps 5-10% of the time. Typical flow rates at the lettered points in the figure above under such "*normal*" conditions are shown in the panel.

Site	Normal Flow (m^3/sec)
a	3
b	10
c	13
d	7
d2	10
e	30
f	0.6
f'	5
g	4.4
h	19
i	16
j	11
k	27

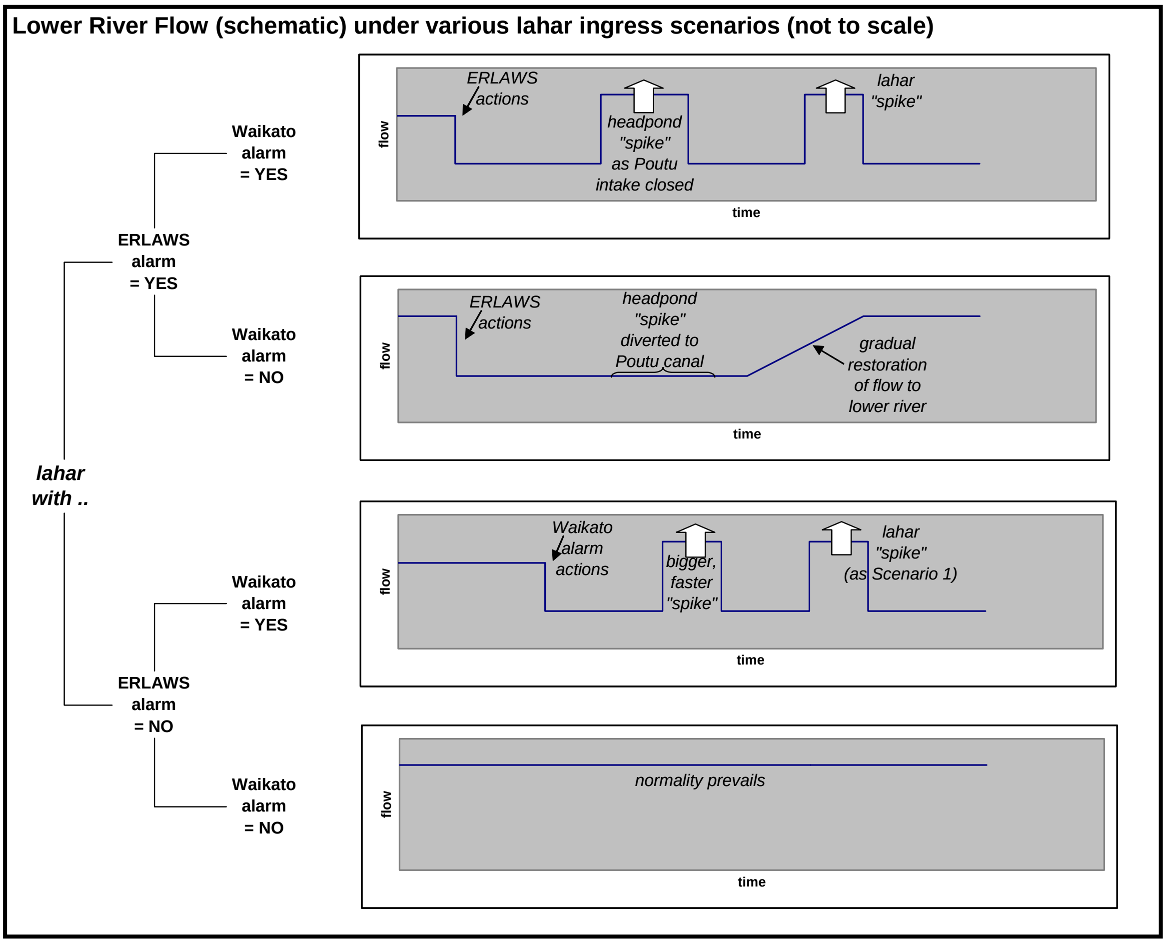
The effect of the Genesis response is immediately to decrease flows in the lower Tongariro River, because of the reduced flow (site e in the figure above) out of the Rangipo power station. Some time later, flow into the Poutu intake will surge up as the head pond contents reach the intake and are diverted into the canal. In the absence of an alarm from the Waikato or Mangatoetoenui Streams, Genesis would gradually manage the lower river flow back up to its normal level. This needs to be done carefully; too sudden an increase in flow would put people in the lower river at risk.

If lahar material gets into the Waikato or Mangatoetoenui Streams, then the situation changes significantly. The rapid opening of the head pond sluices will put a larger "*spike*" of any remaining head pond waters into the river. More significantly, the closing off of the Poutu canal will result in the "*spike*" created by the initial opening of the sluice gates being transferred to the lower river (note there will be no flow in the canal at this point unless the river is in flood). The actual flow pattern in the lower river will depend on which combination of ERLAWS and Waikato/ Mangatoetoenui alarms are received and acted on, and the timings of flows to Poutu of the lahar material and of the "*spikes*" of water released from the head pond.

Genesis have modelled the flows and timings and will supply me with the documentation once certain commercially sensitive items have been removed. The event tree below shows in schematic the sorts of flow patterns in the lower river which would follow from different lahar flows, giving rise to different ERLAWS/ Waikato alarm combinations:

As the figure illustrates, there are three possible sources of sudden increases in flow in the lower river under these "*dry/normal*" conditions:

1 Poorly managed restoration of flow following an ERLAWS response in which no lahar material enters the Tongariro,



2 An increase (approx 40 cumecs) corresponding to the draining down of the Rangipo head pond, when the Poutu intake is closed on receipt of a Waikato alarm, and

3 A sudden increase in flow corresponding to lahar material travelling downstream (**Note** – the distances and travel times to the lower river are long, so the volume of lahar material involved would probably be limited to the volume of water contained in the lahar; solids would be largely deposited in the river en route unless the river is in flood at the time of the lahar).

Of these three scenarios, the first would involve failure of Genesis' well planned and rehearsed management action, so is probably quite unlikely (but the trigger event of the ERLAWS alarm is virtually certain to occur given a lahar).
The second two scenarios each involve virtual certainty of a sudden surge of flow in the lower river, but are contingent on the detection of lahar material in the Tongariro catchment (scenario 2) and the actual entry of lahar material to the Tongariro River (scenario 3). Both these contingencies are, hopefully, quite unlikely. Scenario 2 is the more likely to arise because only a fraction of alarms on the Waikato or Mangatoetoenui streams will actually lead to lahar material entering the Tongariro River.
Scenario 3 probably has the less certain consequences to predict, as Scenario 2 can to some extent be managed by gradual closure of the Poutu intake to make the rise in lower river flow more gradual, whereas the lahar is unpredictable and not manageable in its timing. The volume of lahar material entering the river would, though, need to be significant in order to produce an equivalent 40 cumecs surge in flow in the lower river, as entrained solid material in the lahar would be mostly deposited along the earlier reaches of the Tongariro (eg if the bulking factor of the lahar material entering the river was 3, the lahar flow into the river necessary to produce a 40 cumec surge in the lower river

would be about 120 cumecs; again, this is dependent on whether or not the river is in flood at the time of the lahar).

4 ERLAWS Equipment, Roles and Responsibilities

Genesis showed me around their control room and the room where the DoC server and pager system is situated, and provided me with a copy of their MoU with DoC on the installation, maintenance and operation of ERLAWS. Principal elements of the system and delineation of DoC and Genesis responsibilities are shown in the schematic.

Genesis emphasised that their role is limited to providing supporting infrastructure for ERLAWS (in particular the microwave link from the Tukino hut down to Tokaanu Power Station, and the room where the DoC equipment is situated), and that they have no role in the civil defence emergency response.

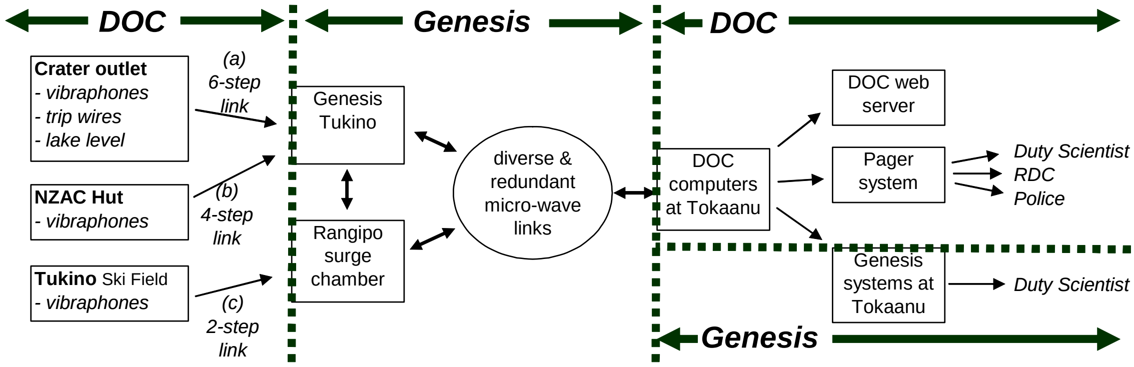
The first element of the ERLAWS system for which Genesis is responsible is the communications link from the Tukino radio building across to Tokaanu. This is provided via a Nokia microwave network. In the MoU with DoC, Genesis accept responsibility for fixing failures in this network as soon as possible at their expense, but also advise (and DoC accepts) that 100% reliability is not achievable. Until recently the microwave link has involved a single channel system, but Genesis are currently upgrading the system to provide dual channels and significant redundancy and diversity (in terms of equipment and locations) to improve reliability of transmission of alarms down to Tokaanu.

It was clear from the discussion that Genesis would not be able to assume any significant role in emergency response, as the duty operator in the control room will have a lot to do to manage Genesis' response. That response needs to be very well managed, with the operator's full attention, in order to avoid creating safety, environmental and economic risks downstream.

*[**NOTE** – while I recognise the points made by Genesis, it is clear in the MoU with DoC (para 12) that Genesis WILL telephone a DoC duty person on receipt of an ERLAWS alarm at Tokaanu to confirm that the alarm has been received. This is in my view a vitally important element of the emergency response, and mitigates against the not insignificant risk of DoC equipment failure somewhere between entry of signals to Tokaanu power station, and exit of pager alarms from Tokaanu. There is a "nightmare scenario" in which Genesis are busy responding to an ERLAWS alarm of which the rest of the world is oblivious. This 'phone call from Genesis is the only way to avoid that risk, and should thus in my view occupy a high priority in Genesis' lahar response procedures (which make no mention of this action at present).*

There is also a significant potential issue of false alarms from ERLAWS. Any alarm equipment has to strike a balance between the probability of missing a true alarm, and of providing false alarms (the lower the likelihood of missing an alarm, the higher the likelihood of false alarms). Arrangements for qualifying ERLAWS alarms before triggering the full response programme are therefore an important issue for DoC. I am not going to be considering reliability of individual elements of ERLAWS in detail, but it seems very plausible to me that a good percentage of false alarms could be cleared up via a simple 'phone call from DoC to Genesis at Tokaanu. There is no mention in the Genesis/DoC MoU of Genesis responding to such inquiries from DoC; it seems to me that the arrangements for qualifying alarms received by DoC might also usefully figure in the MoU.]

Figure 3. ERLAWS System at Ruapehu/Tokaanu - Key Responsibilities



Steps in links from monitoring equipment

step:	1	2	3	4	5	6
(a)	AFM transmit	radio link 1 channel	dome repeater	radio link 1 channel	Taiping repeater	radio link 2 channel
(b)	AFM transmit	radio link 1 channel	Taiping repeater	radio link 2 channel		
(c)	AFM transmit	radio link 1 channel				

5 Summary

1 The risk to power generation assets from lahars is very considerable. The expected minimum loss of generation associated with the tephra dam collapse lahar (via penetration of the Wahianoa Aqueduct) is worth several $ millions. This loss would be shared by Genesis and Mighty River Power but is probably not large enough significantly to perturb the New Zealand electricity market. The losses if Lake Moawhango or Rangipo Power Station are reached by lahar material are potentially an order of magnitude higher again, and might produce some market perturbations.

2 Genesis are spending large amounts of time, effort and money (above the $ million level) to mitigate lahar risks, including:

- installation and maintenance of their own lahar warning systems
- installation and maintenance of high integrity elements of the ERLAWS system
- consideration of additional automated isolation systems for Lake Moawhango, and
- assessment and planning of their own emergency responses, and liaison with parties at risk from, or involved in dealing with the impacts of, those responses.

3 Genesis' planned response actions to lahars produce a safety risk for people using the lower Tongariro River, in particular if lahar material is detected entering the Tongariro catchment. Genesis recognise their responsibility to advise others of this risk and assist in responding to it, but do not have the authority or capability to manage such response. They require no permissions or authorities from other parties to make sudden changes to flows in the lower Tongariro River.

4 Genesis' role in ERLAWS is limited to provision of a part of the communications infrastructure from the mountain to Tokaanu, and to allowing DoC use of a room at the power station for their equipment. Genesis' procedures for lahar response do not currently include specific instructions for telephoning DoC as per their MoU with DoC (para 12). Genesis' procedures and the MoU do not include arrangements for DoC to check with Genesis to qualify the status of alarms received by DoC or others via the pager system.

Tony Taig
6 June 2002

Appendix 5 - Ruapehu Lahar Residual Risk Assessment

Note for the record – discussion with John Larking, Transpower, 4 June 2002
The meeting was held to discuss risk to Transpower's pylons and transmission lines in the context of the residual risk assessment of Mt Ruapehu lahars being carried out by MCDEM. I explained the background to the MCDEM risk assessment. The aim is to help asset managers and government develop a shared appreciation of the lahar hazard and what everybody is doing about it, and to establish requirements and priorities to help those planning the emergency response. The approach being taken to the risk assessment involves:

- characterising possible water pour scenarios from the crater
- characterising resulting lahar flows down the mountain (further calculations of flow rates, heights and volumes for a spectrum of lahar scenarios were being commissioned from Opus consultants for a wider range of plausible lahars than that considered by Transpower/Meritec to date)
- assessing the likelihood of damage to assets, and
- assessing safety and economic risk, with and without effective emergency response plans.

Key points raised in the discussion were:

1 John noted the wider spectrum of lahars being considered in the MCDEM study and would get Meritec to reconsider their conclusions in the light of any new calculations. He felt the conclusion that only one of the three transmission lines was potentially at risk from lahars was fairly robust.

2 Meritec HAD done fresh surveys and cross-sectional measurements in the course of their work, and John pointed me towards these in the Meritec report to inform any new calculations of lahar flows.

3 Transpower have contingency plans in place via their contractor Electrix for rapid replacement of one or more pylons and restoration of transmission lines. Local supplies are held of the only scarce, specialist conductor material needed.

4 Estimates of scale of economic costs for Transpower would be:
   - $50,000 for assessment & mitigation work to date
   - $50-80,000 per pylon asset restoration costs
   - $? revenue loss if transmission were interrupted (John will try and get a rough idea of the revenue implications from Wellington colleagues).

5 The three transmission lines between the Whangaehu valley and SH1 are not the only means of transmission from the south to the north of the North Island, and electricity flow is by no means always from south to north. At high load times in the Auckland region there is often a high S-N flow through these lines because of the economics of using cheaper base-load hydro power from southern stations rather than firing up Huntly and Otahuhu fossil stations. Key mitigators of the risk of interruption of such transmission are a) the availability of Huntly and Otahuhu (at some hours notice), b) the availability of alternative transmission routes (albeit of lower capacity) to the west and the east of the area, and c) the low risk of transmission interruption for all three lines in question.

6 Next steps:
   - Transpower had no plans for further asset protection work at this stage but would reconsider this view in the light of new lahar flow calculations emerging from the risk assessment.
   - Tony would provide a note of the discussion.
   - John would attempt to find out what loads are carried through the three transmission lines, for what proportion of the time.

Tony Taig
6 June 2002

Appendix 6 - Ruapehu Lahar Residual Risk Assessment

Note for the Record – Technical Meeting at MCD&EM, Thursday 20 June 2002

Present:	Mike O'Leary	MO	MCDEM,
	Graham Hancox	GH	GNS
	Harry Keys	HK	DOC
	Grant Webby	GW	Opus
	Tony Taig	TT	TTAC Ltd
	Adam Milligan	AM	Optimx Limited

Introduction

The meeting followed on from the review meeting earlier in the day. The purpose of the technical meeting was to resolve any issues that arose during the review meeting. The items identified by the review meeting for discussion during the technical meeting were:

1 How do the levels from the latest modelling relate to the levels from previous work included in the 1998 GNS report? What do these levels mean for the security of the assets along the Whangaehu valley and the risk to people in the event of a lahar?

2 How likely is it that a lahar will overtop the bund?

3 What effect will overtopping of the bund have on its performance, and what flow is likely to reach SH1 if the bund is overtopped? Will this flow get to the bridge, the culvert, or both, and will it be large enough to damage SH1?

4 How critical is the uncertainty related to the level of SH1 at the aqueduct? Is any additional work required to resolve this uncertainty?

5 Are there any assets downstream of the Marae Bridge that should be identified and included in the current risk assessment?

6 After all of the revised results are taken into account, what is the likelihood of one or more fatalities for each site considered in the study?

7 How does this likelihood compare to the risk from other situations – eg, eruption lahars, earthquakes on the Wellington fault, flood hazards? Are these appropriate comparisons?

8 What level of reliability can reasonably be expected from ERLAWS and the associated response plans? How does this affect the likelihood of fatalities from a lahar.

1 Flow Depths and Freeboard at the Bund, Risk to SH1 at the Waikato Stream Crossing

The crest of the bund at Site D (H_B) is at 7.1m above the streambed. Based on the results of the latest modelling by GW and the earlier results published in the 1998 GNS report, the following table of flow depths was prepared to determine how the current and previous flow depths compare.

Lahar Scenario	Flow depth (m)		Freeboard		Probability of		
	H	H + 30%	H_B - H	H_B - (H+30%)	Lahar scenario	Bund failure given overtopping	Bund failure given lahar
D1x5	5.6	7.3	1.5	-0.2	0.04	0.1	0.004
D1x4	5.0	6.5	2.1	+0.6	0.10	0	
D1x3.3	4.5	5.9	2.6	+1.2	0.06	0	
D5x5	5.8	7.5	1.3	-0.4	0.04	0.3	0.012
D5x4	5.1	6.6	2.0	+0.5	0.10	0	
D5x3.3	4.6	6.0	2.5	+1.1	0.06	0	
<u>OLD:</u>							
D1x5	5.5		1.6				
D1x3.3	4.0		2.6				

The group agreed that there was good agreement between the previous results and those from the latest set of modelling. However, the question of how the overtopping would affect the bund, and how large the flow would be at SH1, and how likely damage to the bund actually is still needed to be answered.

1.1 Frequency of bund overtopping

An event tree was used to estimate the likelihood of flows large enough to overtop the bund. The five key input probabilities to the event tree were agreed to have the values indicated in yellow in the table below:

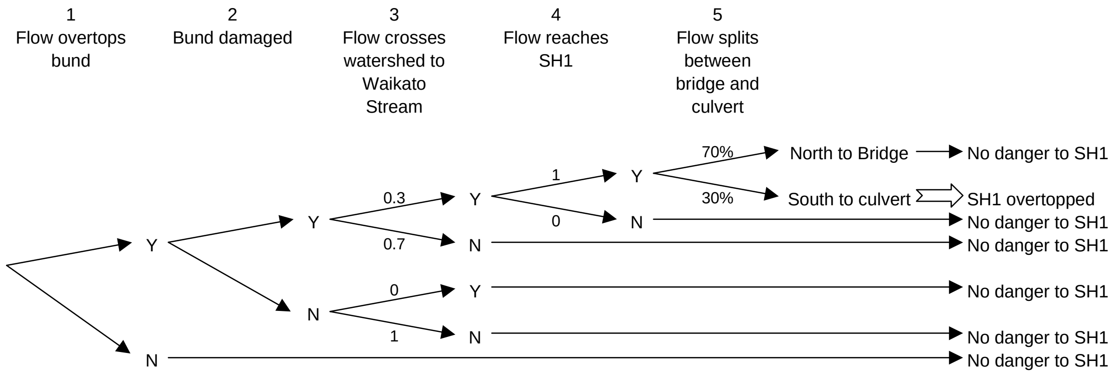
P(pre-1995 rim geometry)	0.5
P(1m max below pre-1995 rim geometry)	0.5
P(dam fails with lake at top of dam)	0.8
P(dam fails with lake part way up dam)	0.2
P(fast breach development, 15 min)	0.5
P(slow breach development, 45 min)	0.5
P(Bulking Factor = 5)	0.2
P(Bulking Factor = 4)	0.5
P(Bulking Factor = 3.3)	0.3

The resulting probabilities of the relevant D1 and D5 failure scenarios are indicated in the previous table.

1.2 Damage to SH1 at Sites A (bridge) and E (culvert)

The D1x5 and D5x5 scenarios overtop the bund by 0.2m and 0.4m respectively, but only if the maximum uncertainty is applied to the flow depth. No other flow scenarios overtop the bund. Grant Webby estimated the probability of failure of the bund for these two scenarios to be 0.1 and 0.3 respectively.

GW advised that the peak flows over the bund for D5x5 are approximately 30m^3/s if no erosion occurs, rising to 110m^3/s for total loss of the bund (the peak for D1x5 is approximately 100m^3/s). By the time these flows reach SH1, they will have attenuated to 2-3m^3/s and 60-70m^3/s respectively. A discussion about the flow from the bund to SH1 made it clear that the situation is more complex than Grant had considered in his modelling, and that additional detail should be considered to better estimate the likelihood and size of any flow at SH1. An event tree approach was used, as outlined below:



P_{flow} :
P_1(D1x5)=0.04
P_1(D5x5)=0.04

P_{damage} :
P_2(D1x5)=0.1
P_2(D5x5)=0.3

Flow to SH1 for D1x5, bund damaged	100m^3/s	30m^3/s	20m^3/s	14m^3/s	Bridge
				6m^3/s	Culvert
Flow to SH1 for D5x5, bund damaged	110m^3/s	40m^3/s	30m^3/s	21m^3/s	Bridge
				9m^3/s	Culvert

GW estimated that any flow larger than approximately $1m^3/s$ reaching the culvert would result in overtopping of SH1, with approximately 70m of SH1 affected.

HK noted that it would be very easy and inexpensive to construct a small bund to direct lahar flows to the bridge rather than the (subject to a more thorough site survey to establish the best way to reduce the uncertainty as to the possibility of flow over the culvert). This would then eliminate any risk to traffic on SH1. He estimated that this would take approximately one day with a bulldozer. GW noted that if a bund were to be constructed, it would need to be built to appropriate standards to ensure its performance in a lahar event. General consensus was that this would be an easier and cheaper alternative to increasing the height of the bund at Site D.

2 Flow Depths and Freeboard at Site G, Wahianoa Aqueduct

2.1 SH1

The critical assets of concern relating to lahar depth are the Transpower pylons (H_P=5 to 8m) and SH1 (H_{SH1}=13m at Aqueduct).

Lahar Scenario	Flow depth (m)		Freeboard	
	H	**H + 20%**	**H_{SH1} - H**	**H_{SH1} - (H+30%)**
D1x5	9.5	11.4		< 1.6
D1x4	8.7	10.4		< 2.6
D1x3.3	7.9	9.4		< 3.6
D5x5	9.7	11.7		< 1.3
D5x4	8.9	10.6		< 2.4
D5x3.3	8.1	9.7		< 3.3
OLD: D1x5				
D1x3.3	7.9			

SH1 is lower to the south of the aqueduct, but the level of this section of road is unknown. The current best estimate is that SH1 drops to approximately 10m above the riverbed. At this level, the road would be in significant danger of being overtopped, with the associated danger to traffic on SH1.

It was observed that no lahar deposits in the past 6,000 years have extended as far as the SH1 site. The floodplain at this point is very wide, which reduces the effects of superelevation and waves (outside of the main channel), thus further reducing the danger to SH1.

It was agreed that the level of SH1 at the lowest point is critical to completing this aspect of the risk assessment, and that a GPS survey of SH1 and the adjacent floodplain should be undertaken to eliminate this uncertainty. Transit will need to be involved in this process.

The best estimate for SH1 is that it is a Medium to High risk.

A possible solution to eliminate the danger to SH1 would be to construct a low bund parallel to the road. The crest level and overall size of the bund will need to be confirmed after the survey has been undertaken.

2.2 Wahianoa Aqueduct

The top of the aqueduct was exposed during the 1995 lahar events, and Genesis have assumed that any lahar larger than this will damage the aqueduct. HK is not convinced of this argument, as the 1995 lahars were a series of smaller events, that have a different effect on the riverbed that a single large lahar. The dam break lahar will probably be larger than those of 1995, but will a single event of significantly shorter duration. HK thinks it may cause less damage than the 1995 event.

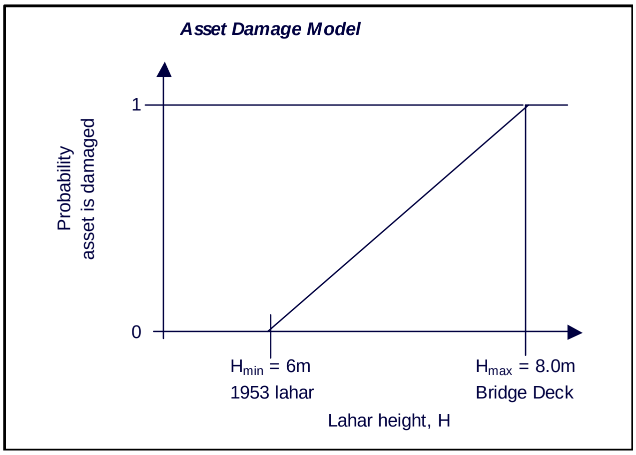
After some discussion it was agreed that Genesis is the appropriate party to be making decisions regarding the safety or otherwise of the aqueduct. After the report is finalised, it will be distributed to the utility providers, including Genesis, for their consideration and response.

3 Flow Depths and Freeboard at Site I, Tangiwai Rail Bridge

H_{SOFFIT} = 8.0m (minimum level, up to 8.6m at high end)
$H_{TRUE\ RIGHT\ BANK}$ = 9.7m (protecting Transpower substation

Lahar Scenario	Flow depth (m)		Freeboard	
	H	H + 20%	H_{SOFFIT} – (H+30%)	H_{TRB} - (H+30%)
D1x5	7.5	9.0	-1.0	+0.7
D1x4	6.5	7.8	+0.2	+1.9
D1x3.3	5.9	7.1	+0.9	+2.6
D5x5	7.8	9.3	-1.3	+0.4
D5x4	6.7	8.1	-0.1	+1.6
D5x3.3	6.1	7.3	+0.7	+2.4
OLD: D1x5				
D1x3.3	5.8	7.1		

The general consensus was that the Tangiwai Rail Bridge has always been considered at high risk from lahars, and that the current work has merely confirmed this. Tranpower should be made aware of the expected lahar depths in comparison to the height of the right bank as this protects the Transpower substation beside the bridge. The probability of damage to the Tangiwai Rail Bridge is to be estimated using the following figure:



4 Flow depths and freeboard at Site H, Tangiwai Road Bridge

H_{SOFFIT} = 6.2m (minimum level)

Lahar Scenario	Flow depth (m)		Freeboard
	H	H + 20%	H_{SOFFIT} – (H+30%)
D1x5	5.3	6.3	-0.1
D1x4	4.6	5.5	+0.7
D1x3.3	4.1	4.9	+1.3
D5x5	5.5	6.6	-0.4
D5x4	4.7	5.7	+0.5
D5x3.3	4.2	5.1	+1.1
OLD: D1x5			
D1x3.3	4.0	5.0	+1.2

As for the Tangiwai Rail Bridge, the road bridge has always been considered at high risk from lahars, and that the current work has merely confirmed this.

5 Flow Depths and Freeboard at Site J, Strachan's Bridge

This bridge is low enough that it was inundated by the previously estimated flows. The current study is using larger flows, thus the bridge will be even more at risk and does not need to be considered in any detail.

6 Flow Depths and Freeboard at Site L, Marae Bridge

H_{SOFFIT} = 7.3m (minimum level)

Lahar Scenario	Flow depth (m)		Freeboard
	H	H + 20%	H_{SOFFIT} – (H+30%)
D1x5			
D1x4	5.9	7.1	+0.2
D1x3.3	4.8	5.8	+1.5
D5x5	9.6	10.3	-3.0
D5x4			
D5x3.3			
OLD: D1x5			
D1x3.3	5.0-5.9		+1.1

The Marae Bridge is at risk during a lahar event, although the group agreed that the probability of damage for this bridge is probably slightly lower than for the Tangiwai Bridges.

7 Downstream Assets

The Colliers Bridge is downstream of the Marae Bridge and was destroyed in the 1953 lahar event. It was then reinstated with a much higher bridge with a single concrete pier and, in HK's opinion is not in any danger of damage from the expected lahar event. The Wanganui and Ruapehu District Councils are the most affected by lahars in the Whangaehu valley, and are also the most active. GW commented that the Councils have identified three or four locations where the road adjacent to the Whangaehu River is at risk from lahar flows. It was agreed that the best approach is to provide the councils with information on the revised, larger lahar events and they can manage their assets as appropriate.

8 Tangiwai Memorial

The Tangiwai Memorial is at risk of damage from most of the 24 flow scenarios down the Whangaehu Valley. The issue at this site is not the level of damage, but the likelihood of fatalities at the site. TT has assessed this using an event tree approach as follows:

		Proportion of year	Proportion of time occupied	Daytime	
Memorial	DAY	0.3 Summer	x 0.2 – 0.6	x 2/3	≈ 0.1 0.2 }
		0.7 Rest of year	x 0.05 – 0.2	x ½	≈ 0.07 }
	NIGHT	0.03 – 0.3 (Propn of nights)	x 2/3 (Non winter)	x 2/3 (Hours of day per stop)	≈ 0.01 – 0.1

The group agreed that these were reasonable assumptions to make at the present time. MO noted that it is very likely that once the crater lake gets above a critical level the Memorial will be closed to all visitors to eliminate this risk.

9 Probabilities of Asset Damage and Fatalities - Summary

The likelihood of asset damage was revised following the review of the lahar levels at each asset site. The estimates of the probability of one or more fatalities given asset damage were also revised in light of the expected performance of the assets, and the proposed warning and response systems. The probabilities agreed by the group are summarised in the following table (**Note** – the response failure probabilities were considered without access to the tables of response times incorporated in the main body of the report, and were superseded in the risk assessment by the considerations described in Section 8 of the main report).

Asset	Prob of asset damage	Prob of 1 or more fatal accidents GIVEN asset damage (pre ERLAWS)	Overall P of 1 or more fatal accidents (pre ERLAWS)	P of ERLAWS technical unreliability	P of failure of response	Residual risk pre further mitigation (approx)
SH1 Aqueduct	0.1-0.3	$(0.3\text{-}1)_{occup}$ x $(0.1\text{-}0.3)_{fatal}$	0.1	0.1	0.5	0.05
Tangiwai Rail Bridge	0.2-0.5	0.005-0.01	0.005	0.1	$< 10^{-4}$	0.0005 #
Tangiwai Memorial Day	1	0.06-0.2 +	0.2	0.1	0.05	0.03 } 0.1
Tangiwai Memorial Night		0.01-0.1	0.1		0.5	0.06 }
Tangiwai SH49	0.2-0.5	0.1-0.5	0.25	0.1	0.05	0.025
SH1 Waikato Stream	0.005-0.01	$(0.4\text{-}0.7)_{occup}$ x $(0.2\text{-}0.5)_{fatal}$	0.004	0.1	0.5	0.002
Tongariro River (ERLAWS alarm response)		0.005-0.03				
Tongariro River (Waikato alarm response)		0.03-0.3				

Approx 20% chance of a passenger train involving 50 to 200 people involved.

TT observed that the most significant hazards in the Tongariro River are a function of the Genesis response to the lahar alarms (refer Section 1). As such, they do not need to be considered further in this study, as the hazards can be managed by Genesis in how they respond to the alarms.

10 Deliverables

The following actions were assigned to these individuals to be completed subsequent to the meeting:

GW A note explaining the basis of the hydraulic modelling and the key assumptions made in this work. This note should also explain the basis of the uncertainties in the flow data and lahar heights included in GW's results spreadsheet.

AM Work with TT to complete the residual risk assessment model.

TT Complete the report covering the residual risk assessment.

Adam Milligan
Tony Taig
1 July 2002

Appendix 7 - Ruapehu Lahar Residual Risk Assessment

Note for the record – telephone discussion between Tony Taig & Vetti Bala, Genesis Power Ltd, Friday14 June 2002

Vetti is Genesis' communication engineer at Tokaanu, where he has taken the lead in devising the new communications systems Genesis has installed to improve monitoring and operation of its generation facilities in and around the Tongariro catchment. I spoke to him at the suggestion of Jarrod Bowler, as being the Genesis person with the best knowledge of communications issues associated with getting ERLAWS messages from the monitoring sites on the mountain out to the wider community beyond Tokaanu. Our conversation covered:

- Genesis' part of the ERLAWS communication network, from Tukino Hut down to Tokaanu power station
- telecommunications reliability from Tokaanu outwards into the New Zealand telecommunications network, and
- communication from ERLAWS monitoring sites to the Tukino Hut (DOC system)

1 Tukino Hut to Tokaanu (Genesis' system)

Genesis have invested considerably in recent years in improving the telecommunications links between their operational facilities in and around the Tongariro catchment, and Tokaanu power station. This is entirely for operational and commercial reasons, not related to ERLAWS. The ERLAWS system has been able to take advantage of some of this investment, by using the Genesis network to carry ERLAWS messages between Tukino Hut and Tokaanu power station.

The Genesis system is based on Nokia microwave links, which are very reliable. Nokia estimate availability for a single link system of 99.9%. It was worthwhile Genesis investing to achieve higher reliability than this would have conferred (recognising there are several steps of links and equipment between the Tukino Hut and Tokaanu). The system has dual redundancy for each step in the communications chain, with a significant degree of diversity being provided by the availability of three signal routes:

1 Tukino	*μ-wave link*	Rangipo surge chamber or Rangipo dam	*μ-wave link*	Wairehu or Pihanga	*fibre optic link (from Wairehu)* *μ-wave link (from Pihanga)*	Tokaanu power station
2 Tukino	*μ-wave link*	Rangipo surge chamber or Rangipo dam	*μ-wave link*	Wairehu or Pihanga	*fibre optic link (from Wairehu)* *μ-wave link (from Pihanga)*	Tokaanu power station
3 Tukino	*μ-wave link*	Rangipo surge chamber or Rangipo dam	*μ-wave link*	Wairehu or Pihanga	*fibre optic link (from Wairehu)* *μ-wave link (from Pihanga)*	Tokaanu power station

The Nokia links from Tukino to Tokaanu power station will have two different paths. In case of failure of one path the other one will look after the connectivity. These paths are Tukino/Rangipo Dam/ Pihanga/Tokaanu power station or Tukino/Rangipo surge chamber/Wairehu/Tokaanu power station. Wairehu to Tokaanu power station is the only fibre optic link, all the others are microwave links.

Given the high degree of diversity built into an already very reliable microwave based system, Genesis anticipate, and are currently achieving (**Note** – the microwave link is not installed in the Tukino yet;

Genesis are hoping to commission the dual path link by end of this year), effectively 100% availability of communications between Tukino Hut and Tokaanu. From the ERLAWS viewpoint, I suggested that for all practical purposes the unreliability of the communications link from Tukino Hut to Tokaanu Power Station could effectively be ignored, as it was almost certainly more reliable than the other associated communication links. Vetti agreed with this assessment.

2 Tokaanu to Rest of World (Telecom Network)

Vetti considered the Telecom network connection to Tokaanu was very reliable. But the Telecom network relied on a single route from Tokaanu to the rest of the world, via the Turangi exchange, and was thus vulnerable to single point failures. In his 6 years at Tokaanu there had been two such failures, one last year and one a few years ago, which had cut off the normal Telecom links to and from Tokaanu for a few hours each. The implied unavailability of telecommunications to and from Tokaanu to the rest of the world is thus about: 2 x few hours (say 10 hours) unavailability, per 6 x 365 x 24 (say 50,000 hours) which works out as about 2 per 10,000 hours unavailable (availability of 99.98%). This was already high, but Vetti noted that following these Telecom failures Genesis had installed their own link to a sister power station in the Napier region to provide supplementary reliability of communications between Tokaanu and the rest of the world.

Vetti understood that the ERLAWS telephone lines in and out of Tokaanu power station were not linked into this Genesis system. If DoC sought further reliability for this stage in the chain it would be possible in principle to route those DoC lines via the Genesis system. In practice, though, I pointed out the existence of the MoU between DoC and Genesis under which Genesis already undertook to telephone DoC whenever they received an ERLAWS alarm at Tokaanu. We agreed that this manual back-up to the Telecom links from DoC equipment at Tokaanu to the outside world (which ***would*** gain the benefit of the added reliability of Genesis' telecommunications links) was likely to provide a good remedy for any unreliability of the Telecom lines in and out of ERLAWS.

3 ERLAWS Monitoring Sites to Tukino Hut (DoC System)

Vetti was broadly familiar with the DoC system, but does not have detailed knowledge of all the associated equipment and its reliability. I asked his views on what would be a reasonable reliability to aspire to for UHF radio links working in the mountain environment. Vetti considered that a very good quality individual UHF link would be rather more than an order of magnitude less reliable than the individual microwave links used by Genesis between Tukino Hut and Tokaanu. The ERLAWS communications from monitoring sites to Tukino were currently performing well below this level (perhaps with 85-90% availability over the past few months of commissioning of the DoC system). But Vetti recognised that the system was still in its teething stages, and felt there was considerable scope for reliability to improve. (Please note that the reliability of the Site 3 has been, since it was commissioned, in the order of upper 99%. We will need to ignore the site 1 and 2 for the moment, as Genesis Power is yet to commission the microwave links from Tukino.) He would expect the maximum likely availability for an individual UHF link to be around 98%, but noted that if the actual figure were critical then the manufacturers of the ERLAWS system should be able to supply reliability data for their equipment, for a given environment and pattern of use.

I noted that there were three UHF links between Site 1 and Tukino Hut, and various items of equipment required to function in addition to those links in order for the ERLAWS function to be achieved. We agreed that for Site 1, the assumption of 98% unavailability for each UHF link and 100% availability for all monitors, AFM and other equipment would give an upper bound availability for "*delivering the whole ERLAWS function*" of about 94%. I noted Vetti's point that, based on current commissioning stage performance of ERLAWS communications equipment, there was still a good way to go before achieving such a level of performance.

Tony Taig
16 June 2002

Appendix 8 - Ruapehu Lahar Residual Risk Assessment

Note for the record – discussion with Ruapehu District Council/Police, 31 May 2002
Present: Barbara Dempsey (RDC Customer Services Manager), Rob Glennie (RDC Emergency Management Co-ordinator), Michael Craig (Okahune Police), Tony Taig (TTAC Ltd).

Introduction and Background

Tony explained the background to the MCDEM residual risk assessment. The aim was to help emergency planners, utilities and government develop a shared appreciation of the lahar risks, and to establish requirements and priorities to help those planning the emergency response. Tony explained the approach being taken to the risk assessment which involved four main steps:

1 characterising possible water pour scenarios from the crater
2 characterising resulting lahar flows down the mountain (further calculations of flow rates, heights and volumes for a spectrum of lahar scenarios were being commissioned from Opus consultants)
3 assessing the likelihood of damage to assets, and
4 assessing safety and economic risk, with and without effective emergency response plans.

Barbara explained the Ruapehu District Council (RDC) background and approach to the emergency plan. Although the council had opposed the policy of letting the lahar happen and relying on warning and response to ensure safety, it recognised its own responsibilities for planning and implementation of appropriate response measures, now that the policy was in place. Successful response was seen as critical for the social and economic well-being of the whole district.

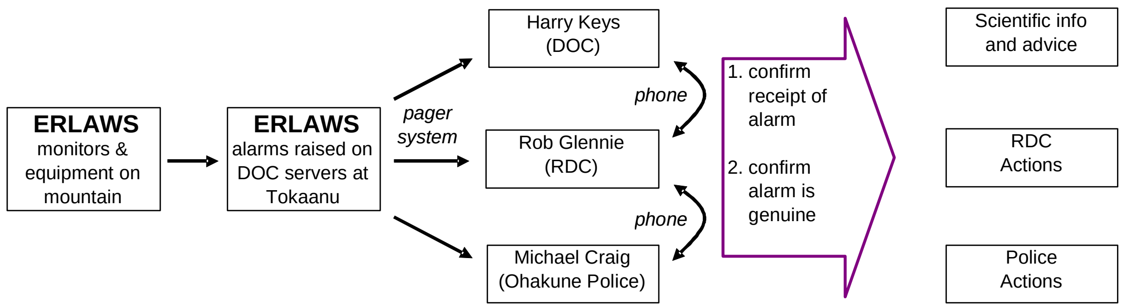
The current draft plan represented a "*best endeavours using local resources*" first stab. The council recognised that something significantly more needed to be done, and that it would not be possible to achieve a high reliability plan given the very limited scale and capability of local resources (eg an entirely voluntary fire-fighting force). A project manager had been appointed who was now working to develop a more detailed and comprehensive plan, and see through its implementation and testing.
The council were in discussion with DoC and MCDEM with a view to clarifying in advance the circumstances in which a civil emergency would be declared, and securing appropriate resources to help strengthen their plan. Their clear view is that government policy has placed a very substantial burden of risk management responsibility on them. The beneficiaries of their actions and investment would largely be people and utility customers from outside the Ruapehu District.

RDC and the police warmly welcomed the risk assessment, and wished it had been available a lot earlier. They were keen to cooperate, and we had a valuable discussion of how the response to the lahar would work. The main points raised are grouped here under the headings of "*Initiating the Response*", "*Implementing the Response*" and "*Risk Assessment Approach*", followed by a summary of key points.

Initiating the Response

The response plan all hinges on receipt of the ERLAWS alarm via the DoC pager system. The main steps and people involved are illustrated in Figure 1 below:

Figure 1. ERLAWs and RDC/Police Plan Initiation



RDC and the police had a number of fairly obvious key concerns associated with making sure the warning of the lahar got through to them, in particular:

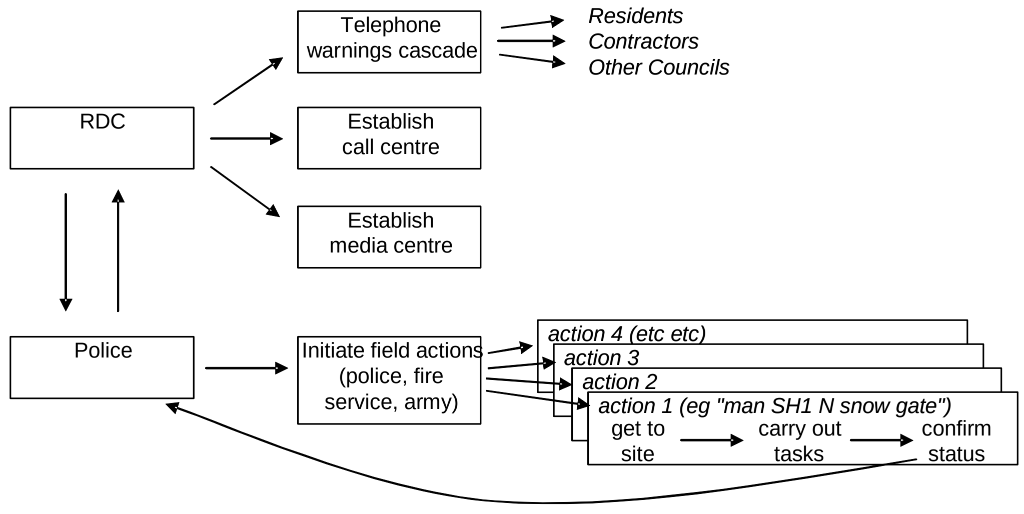
1 Everything hinges on ERLAWS – how reliable will the WHOLE system be? (ie including computers, pagers, telecom links). Hopefully the current teething problems can be resolved and confidence can then be developed.
2 Dependence on two key individuals (Rob and Michael) for initiation of the plan (with the best will in the world, pager batteries may go flat during the night, people have to take showers, etc etc)
3 Ability to communicate with each other to confirm receipt of alarms, and that the lahar is genuine (though once the lake level is high Rob and Michael would not wait to confirm this with Harry before initiating follow-up action).

Tony emphasised the impossibility of achieving ultra-high reliability of response without significant attention to diversity and redundancy of communications channels, response personnel etc. Hopefully the emergency response would be providing "*top up*" safety assurance over and above that already provided by the actions of DoC and utilities to limit people's access to at-risk locations. The risk assessment should shed light on how reliable the response needs to be, and will also make clear what it is reasonable to expect for a given level of resources.

Implementing the Response

The broad scheme of arrangements is illustrated in Figure 2.

Figure 2. RDC and Police Responses



Several important issues were raised and discussed, in particular:

1 There would be no realistic chance of assembling an emergency response team at a central location (unless a team were maintained ready on a 24 hour basis once the lake reached a certain level, which seems unlikely). The entire scheme therefore rests on the ability to be able to communicate remotely; telecoms reliability would be critical.
2 How far should RDC go in actions to protect against the possibility of risk, particularly where those actions could put emergency services personnel at risk? For example,
   - to what extent should RDC be planning to get personnel up onto the mountain to prevent access to and evacuate at risk areas?
   - when is a telephone call sufficient and when do emergency services personnel need to visit and secure a site in person?
   - how far down the Whangaehu valley should precautionary measures be extended?
   - what actions are required to complement or supplement the arrangements utilities are already making?
   -
3 The list of actions to be taken, the details of tasks to be carried out under each action, who will be doing it, and the order in which parties will be called out by the police (and by RDC) need to be firmly established, agreed and rehearsed in advance.

4 What should be the list of top priority tasks for the "*field actions*" initiated by the police? It seems fairly clear that the most at risk areas are likely to be:

- State Highway 1 (Waihianoa aqueduct and Waikato Stream crossings)
- Tangiwai (rail and road bridges; campers at Memorial parking lot)
- roads and bridges downstream of Tangiwai (Strachan's Bridge, Marae Bridge etc – but ? how far does the response need to go up the mountain/down the valley?).

Multiple personnel may be required at each location, for the purposes of a) preventing access and b) carrying out a "sweep" and evacuation of at risk areas. Even this short list of high priorities could quickly exhaust available personnel.

5 There are major implications for resources, morale and responsiveness of regular testing of the plan and of possible false alarms. The plan was going to involve a lot of people, many of them volunteers, who would have to give up a lot of time to training and preparedness. There would be major implications and costs involved in triggering the plan; false alarms would be expensive and demotivating. A balance would need to be struck between the risk of triggering a false alarm, and the risk of missing a true alarm through excessive checking and assurance that an alarm was genuine.

We discussed other issues such as the requirement to have a helicopter available to carry out a search of the mountain and/or SH1, but this question probably resolves itself given the length of time it would take to mobilise a helicopter in comparison with lahar travel times.

Risk Assessment Approach

Tony's general approach would aim to estimate consequences and risks thereof both with and without effective emergency response. The likelihood of successful response for a given lahar scenario would then be estimated by comparing the time available for lahar travel to a given site with the total time required for successful response at that site (that time to include reasonable allowance for each step of the warning and response chains).

In addition to using the risk assessment to help prioritise and establish requirements for emergency response actions, RDC and the police were very interested in the Upper Mountain part of the risk model and in the risks associated with lahars other than the tephra dam collapse scenario. These were seen as providing important context for response planning – for example, it would be much easier to make decisions about sending emergency services personnel into high risk locations in order to alert and evacuate people up on the mountain if we knew a) how likely people were to be there, and b) what sort of risks were already being tolerated for the type 1 eruption lahars which occur every five to ten years on the mountain.

Summary

RDC and the police are taking their responsibilities for response to a civil emergency associated with lahars very seriously, but recognise their limited resources and capability available to provide an effective response.
Tony would incorporate the issues discussed into the risk assessment, and would aim to make it as helpful as possible for the emergency response planners, in particular by:

- providing clear guidance on priority at-risk areas for targeting responses
- identifying likely critical path or weak link issues for warning and response, and
- making clear what level of reliability can reasonably be expected for a given level of resources and capability.

Tony Taig
June 2002