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Field investigations at Waihi Landslide, Taupo 30 June & 1 July 2009

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1.0 INTRODUCTION

This GeoNet Landslide response to Waihi landslide was initiated because national news reported that Waihi Village had been evacuated, SH41 closed and a civil defence emergency had been declared by Taupo District Council, due to the threat of another large landslide at Waihi. Three historic landslides have occurred in the area, causing up to 150 deaths – two of these are well documented (Appendix A).

The GeoNet response team comprised: Dick Beetham, Chris Massey and Garth Archibald of GNS Science; and Charlotte Severne of NIWA.

1.1 Background to the response

The GeoNet landslide response team drove to Taupo on the morning of 30 June 2009 and attended a meeting held by Taupo District Council (TDC) along with MCDEM, Environment Waikato and OPUS (Land Transport NZ consultant for SH41).

The team were briefed by the various representatives. A brief summary as follows:

- The villagers of Waihi have self evacuated, SH41 has been closed, all residential property and the Braxmere Lodge have been evacuated;
- Landslide signs are anecdotal, with no quantifiable data at this stage;
- TDC representatives outlined potential data sources which could be used to establish a baseline (i.e. conditions prior to the earthquake swarm). These comprised: 1) change models using the 2006 LiDAR data, compared with the soon to be acquired LiDAR data (originally planned prior to these events). This new survey is due to be carried out in 2 weeks time; and 2) Re-survey of the OPUS survey pegs installed to monitor local displacements of a small slope adjacent to SH41, in an area of known historical instability;

The GeoNet landslide team were asked to carry out an aerial inspection of the area, via helicopter to identify any signs of “recent” landslide activity. The aerial inspection took place at 15:00 hours with Shamus Howard (TDC Controller).

2.0 RECONNAISSANCE ACTIVITIES

2.1 Aerial inspection (30 June 2009)

Approximately 1 hour was spent looking at key sites in and around the historical slip areas and around the village. This included inspections along the two main drainage lines, looking for signs of damming and inspections of the critical areas (potential source areas of future landslides), identified by Severne, (1989); Hegan et al., (2001); Hancox, (2002, 2006).

Findings from the aerial inspections include:

- No obvious signs of recent (over last few months) deep-seated landslide activity could be identified in the area.
- Several small and relatively shallow, and recent (2002 and more recent), landslides were identified. However, these were too small to be of significance with respect to a landslide failure affecting Waihi Village.
- Based on the aerial inspections GNS Science recommended that TDC to reinstate the OPUS monitoring sites along SH41, and install additional survey marks in and around the potentially critical failure areas based on both previous work (e.g. Hegan et al., 2002) and assessments made by the GeoNet landslide response team. This was approved by the local IWI and TDC and the team installed 11 of these on 1/06/09, assisted by a local surveyor (Russell Dick) working on the behalf of TDC. Future surveying of the network will be carried out by local surveyors acting on instruction from TDC. GNS Science will assist as required with the interpretation of the survey results.
- The team identified several boulders in and around the Waihi village. These were assumed to be rock-falls from the steep cliffs immediately behind the village. Locals confirmed that rock-falls do occur from the cliff, and that a tractor was used to clear rock-falls from the area. No recent rock-falls were reported.
- From a health and safety perspective the GeoNet team and TDC decided on the basis of the aerial inspection, that on-ground inspections could be carried out, taking into account the usual precautions required, when carrying out field work in these situations.

Charlotte Severne joined the GNS Science members of the response team in the evening (30/6/09). Charlotte briefed the team on background information relating to the area.

2.2 Field inspections (1 July 2009)

A meeting at 08:30am on 1/07/09 was held by TDC, where the points from the pervious days meeting were discussed and a plan made for the day's activities. The GeoNet response team was split into two groups and spent the entire day from about 11 a.m. installing monitoring pins and making on-ground surveys of Waihi Village, Hipaua geothermal area (the Steaming Cliffs) and the Waihi Fault escarpment.

At the end of the field day, about 6pm, a debriefing of the day's activities and findings was held at the TDC EMO. Following this the GeoNet landslide response team returned to their Wellington bases.

2.2.1 Charlotte Severne & Dick Beetham

2.2.1.1 Helicopter flyover of the Waimatai and Omoho Catchments

- The Omoho has small areas of flat unmoving water up-catchment which is the result of minor damming from slips and fallen trees. The whole catchment is littered with fallen trees, the result of wind and slippage.
- The Waimatai is less littered and has no evidence of slips, however, it is overgrown with established bush and regrowth and it was difficult to see flowing water over the full length of the stream. The headwaters collect a number of small springs over a large flat basin feature, with nothing untoward apparent.

- A helicopter pass of the gut between Tihia and Kakaramea was carried out hovering close to the ground over the expression of the Waihi Fault. No evidence of movement could be observed, however, it is considered unlikely that movement would have occurred given the small magnitude (M4) of the recent earthquakes.

2.2.1.2 Helicopter flyover of the Waihi Stream

- This area was flown over several times. The concrete weir appears to be undamaged. The stream itself has migrated to the south or closer to the village from its past course, although the flow is over a small delta and the stream will migrate from time to time. The taps in the village (their water supply is up at the weir at the top of the waterfall), were turned on and there was good pressure.

2.2.1.3 Foot inspection of the village

The team is aware that the villagers have made some observations and were clearly upset enough to move, so a careful assessment of their observations has been made.

- Lack of Bird life/noise – birds had returned not a great number in the village but many in the lake.
- Thinning of road width at entrance – no bulging or slippage could be observed in this area. There is evidence of past surficial movement but nothing from the bottom.
- Puia – there are ongoing changes to the hot springs. The Whakatara Bath was cooler than expected (no measurements taken but Charlotte reports having been burnt by it on several occasions). The Whakatara Stream was not moving at all, it looked as if it had been stagnant for longer than a week. Te Tuki Bath was not flowing (but the lake was down so it was not surprising as there is complex hydrology (but when the lake is down the truly mixed springs stop flowing). Charlotte was surprised to see the spring south of Chiefs House flowing furiously.

2.2.1.4 Foot inspection of the steaming ground and head-scarp

- The team was dropped off at several locations on the Hipaua geothermal area. Charlotte had spent several years taking measurements and sampling in this large area and she was surprised that the mid section of the steaming area, close to the fault head-scarp, had altered significantly. Boulders (the size of small cars) fall out of the Waihi Fault head-scarp regularly, are hydro-thermally altered were they land and then form part of the general slow moving landslide morphology below. The number of these was more than she remembered.
- Charlotte's earlier tracks were overgrown so access was difficult. Charlotte suggests a need to recalculate the amount of bare, steaming ground. She could see a number of changes (but was not alarmed by this, as it is to be expected).

2.2.1.5 The depression behind the scarp and the steaming cliffs

- About an hour was spent on the ground in this area looking for evidence of tension cracks or tomos, and no evidence of these were found. There is an area of steaming ground covered by fern, which should be a key priority area for further monitoring.

2.2.2 Chris Massey, Garth Archibald & Russell Dick

- On the 1 July 2009 the GeoNet landslide response team along with a local surveyor Russell Dick (Central Surveys, Taupo) installed 11 survey marks along the ridgeline (Figure 1). The marks comprised iron tubes 600 mm in length hammered into the ground surface. The marks were located in and around potential future landslide source areas (Severne, 1989; Hegan et al., 2001; Hancox, 2002, 2006), which if failure were to occur would have potential to impact parts of the village. The source area is defined as the location from where a landslide could initiate. Leica RTK GPS equipment was used to survey the marks. Access was via helicopter drop-off, with walking through the dense bush.
- The survey reference station comprised the LINZ 5th Order control mark DD9P, located at the intersection of two roads on the western side of Tokaanu.
- A second survey was carried out by OPUS on behalf of Land Transport NZ at a similar time to the GNS Science survey. The OPUS survey comprised re-survey of the historical marks located in a localised area adjacent to SH41. These are located in a known area of historic and recent creeping instability, which has affected the road in the past.

2.2.2.1 Survey limitations

As GPS equipment was being used (traditional theodolite based surveys would be extremely difficult due to vegetation cover), the marks had to be located in areas where adequate sky view was to be found i.e. in natural clearings with low vegetation cover. This means that the marks were not placed in the best geomorphic locations, from a landslide monitoring perspective. Although 11 marks were installed several of these are pairs and so a good spatial resolution was not achieved in the time frame available.

2.2.2.2 Site description

This description is based on field observations made during the survey. Significant geomorphic features associated with historic landslides and possibly active faulting are present in several areas along the ridgeline, in particular between the 1846 and 1910 landslide source areas, and north of the 1910 source area (Appendix A, Figure 1). Typical landslide features comprised: arcuate landslide scarps (which have not fully developed into landslides), some with > 2m of vertical offset; persistent linear tension cracks 10-100 m in length; grabens (small depressions linked to extensional or pulling apart movement); and sinkholes. A large, deep sinkhole was identified immediately upslope behind the 1910 landslide source area.

None of these features appeared fresh, and none of the vegetation observed appeared bent or deformed as a result of large deep-seated movements. Many of the scarps were fully vegetated. Some, however, did appear only partially vegetated and were assumed to be relatively recent (approximately 10 years old).

3.0 CONCLUSIONS FROM THE SITE INSPECTIONS

- The current reported damage in the village appears consistent with a ground shaking intensity of ~MM5, associated with a magnitude M4, localised shallow earthquakes.
- No evidence of recent (over the last few months) large-scale landslide activity could be identified.
- There is evidence to suggest that historical instability of the ridge-line in the area north of the 1910 landslide source area, and between the 1846 and 1910 source areas, has occurred. It is difficult to assess the age of these features, however none appeared recent (i.e. in the last two years).
- Based on historical precedent, previous studies and the results from these recent observations, there is still a significant risk to parts of Waihi village and Braxmere Lodge from large landslides originating from the steep cliff formed along the Waihi Fault scarp. In addition, other hazards affecting the village include rock falls from the steep cliffs immediately above the village; and reactivation of the large (and assumed to be actively-creeping) landslide currently affecting SH1 (This assumption will be tested when the initial survey results become available).

4.0 RECOMMENDATIONS

Based on the limited work carried out to date the following recommendations are made:

4.1 Long term

Given the past frequency of hazardous landsliding it is recommended that a comprehensive multi-disciplinary risk re-assessment is undertaken for Waihi village, the access road and the fishing lodge from the identified hazards, including: debris flows, rock falls, deep-seated landslide movement, landslide-induced tsunami and fault rupture along the Waihi Fault. This should be sufficiently robust to inform decisions on how to avoid or mitigate the risk.

4.2 Short term (next six months)

4.2.1 Community based monitoring

The Waihi community should continue to be vigilant and aware of potential landslide signs and their triggers. Landslide signs include reduced flows along drainage lines, tilting/deformed vegetation and deformation of SH1. Landslide triggers include: storm rainfalls (> 30 to 50 mm a day) and/or periods of prolonged rainfall (> 10~20 mm a day over multiple days or weeks, and earthquake induced ground-shaking typically associated with shallow earthquakes. Typically MM7 to MM8 (on the modified Mercalli scale, Appendix B and equivalent to a peak ground acceleration of ~ 0.2g) is required. This level of shaking usually requires localised, shallow earthquakes of magnitude ≥ 5.

4.2.2 Stream monitoring

It is recommended that the stream flows at the SH41 culverts for the Waimatai and Omoho Streams be monitored, as it is the damming and flow obstruction, which is common to both the 1846 and 1910 (although less obvious), landslides. NIWA can assist the TDC with the monitoring.

4.2.3 Ground deformation surveys

In the short term it is recommended that the survey marks installed are surveyed daily for three days to establish a baseline (using the local surveyors), including the OPUS marks.

It is recommended that additional survey marks be installed in other critical areas, which could not be accessed on 1/7/09. Localised vegetation clearance should be carried out to allow these additional marks to be properly located, and access routes should be cut between them. This work would best be carried out by the local surveyors, with guidance from GNS Science.

If no movement is identified from these surveys it is recommended that the survey frequency be decreased to weekly for a period of 3 to 4 weeks, and then if no movement is identified, the frequency should be further reduced to monthly, for a period of six months. Following a six month period the survey data should be reviewed by GNS Science and TDC, with any future monitoring carried out as part of systematic monitoring regime for the area, and based on the results of the risk assessment. Additional surveys of the network should be carried out following periods of intense rainfall, or ground shaking in response to earthquakes (Appendix B).

4.2.4 Geothermal monitoring

Geothermal monitoring of the area to assess changes in heat flow should be carried out. Cooling has been identified as a potential landslide trigger (Hegan et al., 2001).

4.2.5 Seismic monitoring

It is recommended that a temporary seismometer network be deployed in the area to record localised ground shaking intensities from any future earthquakes and to assess any topographic amplification effects.

4.2.6 Topographic and bathymetric data

It is recommended that the Lidar survey that is about to be undertaken include all of Waihi Village, including the foreshore. The Lidar survey should also include the Hipaua Geothermal field and the Waihi Fault scarp. (The planned survey may already cover these areas). Acquisition of shallow bathymetric data in Waihi Bay is also recommended to determine the extent of the 1910 landslide ingress into Lake Taupo and to provide data for tsunami modelling.

4.2.7 Remote sensing

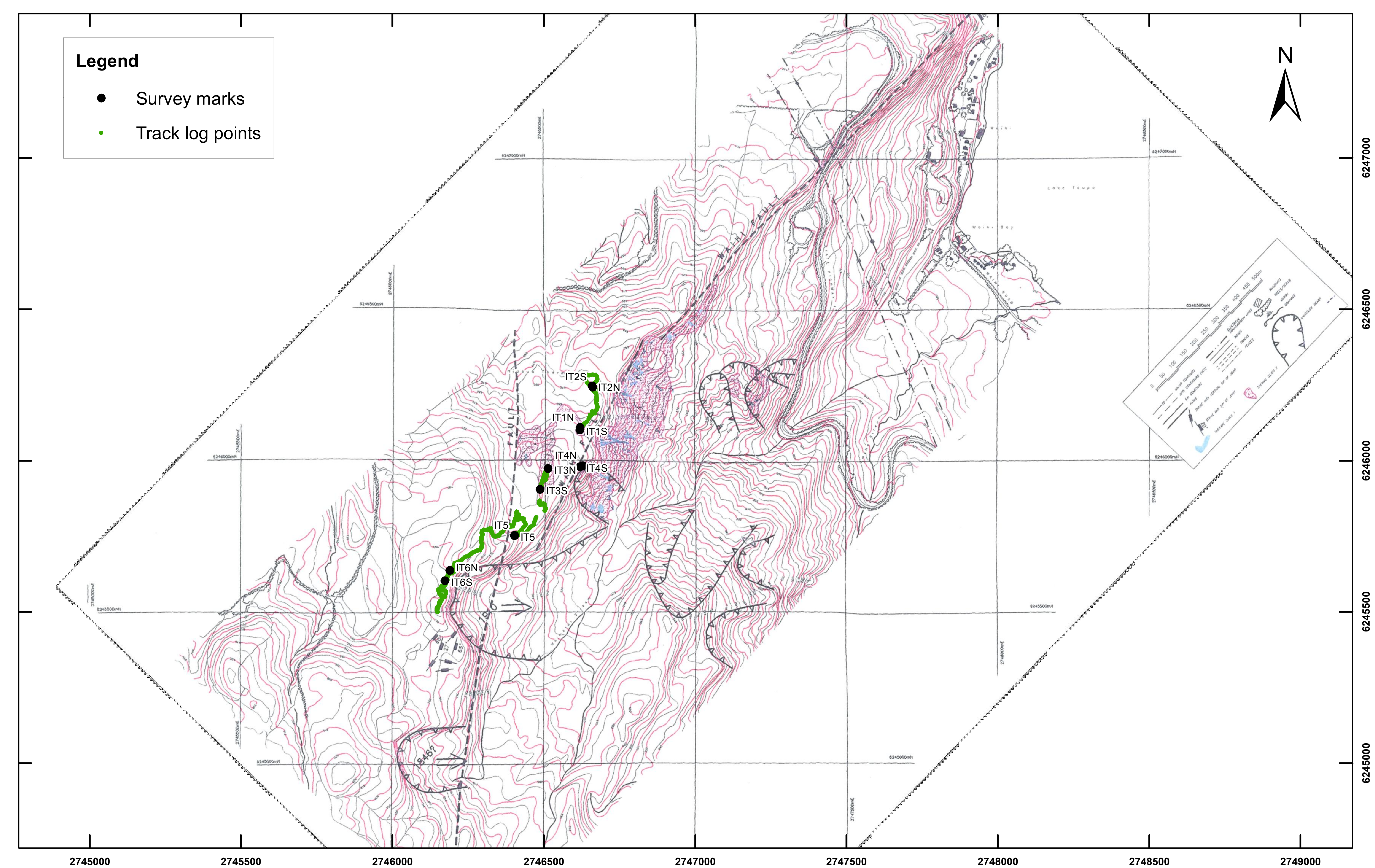
It is recommended that the acquisition and interpretation of two satellite-based radar images (from ALOS) dated 4 June 2009 and 22 June 2009 be undertaken to assess whether movement of the slopes at Waihi occurred during this time-frame.

5.0 ACKNOWLEDGEMENTS

The Landslide team would like to acknowledge: GeoNet for funding this work; TDC for their hospitality; support from our GNS Science colleagues Grant Dellow, Nick Perrin and Biljana Lukovic; and Terry Webb and Grant Dellow (GNS Science) for reviewing this report.

6.0 REFERENCES

Refer to the data summary in Appendix A



SCALE BAR: 0 250 500 1000 m

SCALE:

EXPLANATION:

Basemap taken from Severne C. 1999, The Tokaanu-Waihi Geothermal System
(A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy).
Track log points show the route taken on foot by the survey team.
Coordinates in terms of New Zealand Map Grid

DRW: BL

CHK: CM

APP: GD

GNS SCIENCE TE PŪ AO

WAIHI LANDSLIDE

LOCATION OF SURVEY POINTS
(Installed on 01-07-2009)

FIGURE 1

DWG DRAFT

REV: 0

SHEET: 1 of 1

REPORT:

DATE: July 2009

APPENDICES

APPENDIX A WAIHI LANDSLIDE, HIPAUA GEOTHERMAL AREA, LAKE TAUPO – DATA SUMMARY

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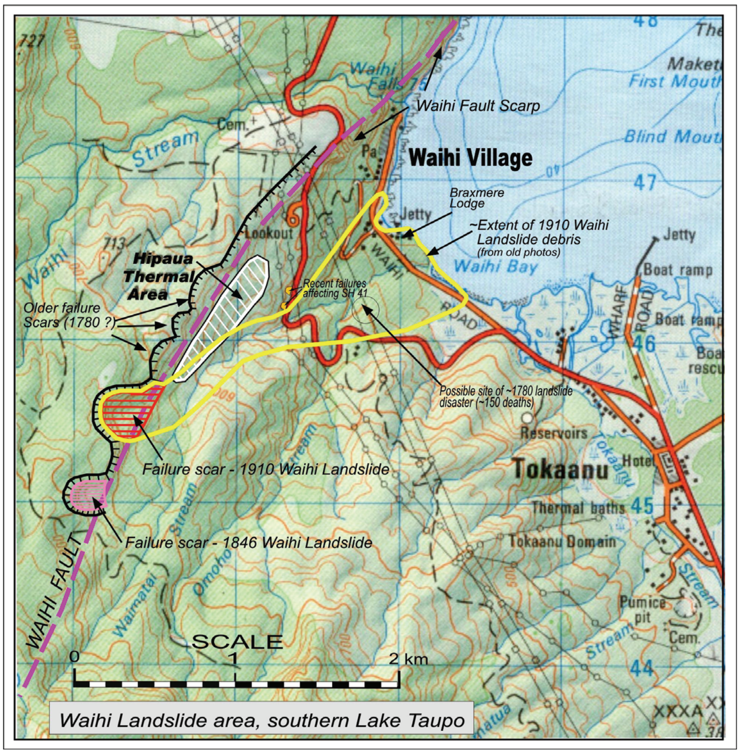


Figure 1 Map of Waihi Village area, southern Lake Taupo showing Waihi Landslide features.

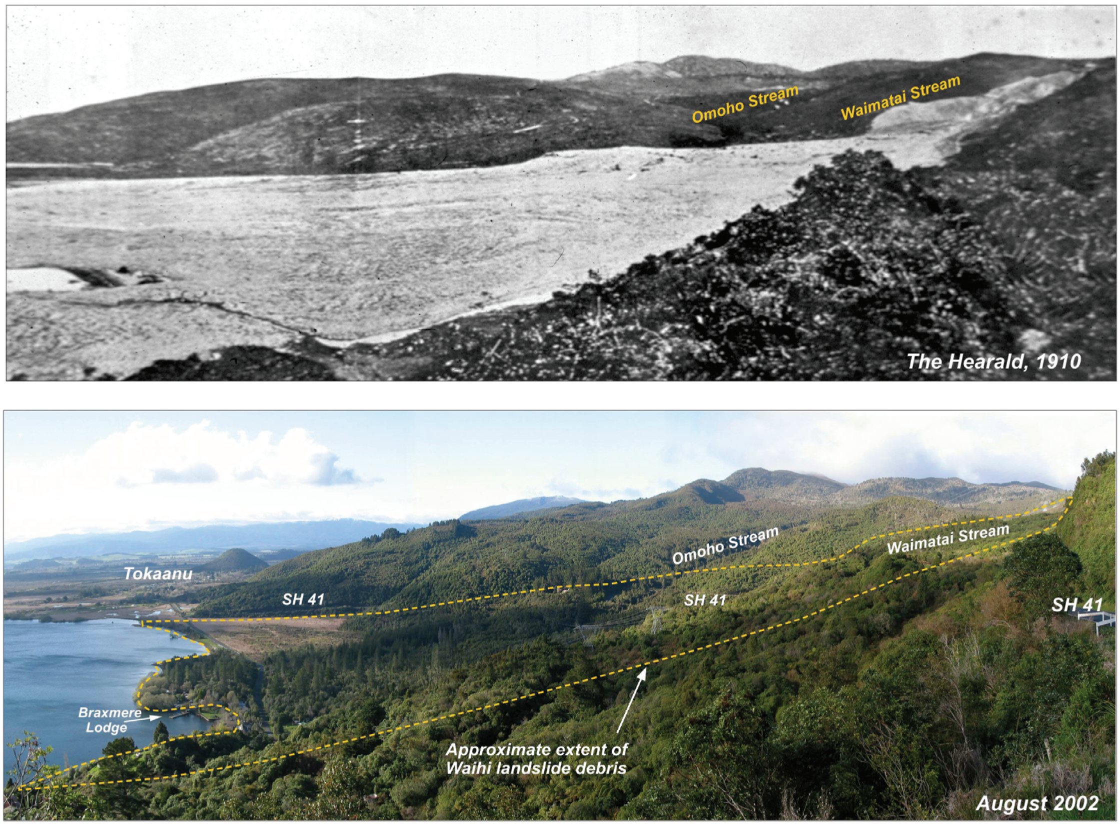
2. Summary

Several large landslides have occurred on the Waihi Fault scarp above the Hipaua thermal field at the southern end of Lake Taupo in the last c. 230 years which have transformed into very large debris flows in Waimatai Stream (see Figures 1 to 7). A well documented event occurred at night in May 1846 with the loss of 64 lives in Te Rapa (Little Waihi) village, including the chief Te Heu Heu (Figure 4). Another occurred on the morning of 20 March 1910 with the loss of only one life as people were alerted and escaped the massive debris torrent (Figures 2 and 3). There is also evidence of an earlier failure in about 1780, which apparently buried at pa at the mouth of nearby Omoho Stream with the loss of possibly 150 lives. The source area of the 1780 landslide is uncertain, but it could have been in the Waihi Fault Scarp just north of the 1910 failure scar, or possibly in Omoho Stream ~500-700 m upstream of SH 41 (Figure 6). Past failures on the steep fault scarp seem to have been related to ongoing tectonic and hydrothermal activity in the area, and also periods of heavy rainfall. The 1846 failures initially formed a small landslide dam in Waimatai Stream, and the main failure occurred when the dam breached during heavy rain. The 1910 landslide also originated of the Waihi Fault scarp about 300 m to the north of the 1846 failure area (Figures 2 and 3). The 1910 failure began with a loud noise and a cloud of steam or dust, and may have been triggered by a geothermal eruption. It was larger than the 1846 landslide (see source scars in Figure 5), and produced a debris flow of about 3 million m^3 which flowed 2 km to the southern shore of Lake Taupo (Figure 3), forming a wave about 3 m high.

Large failures of this type could occur again, affecting SH 41 over a length of about 300 m in the vicinity of the Waimatai Stream crossing, and possibly overwhelming the Braxmere fishing lodge on the shores of Lake Taupo, and some houses within Waihi Village, which are within the high landslide hazard zone. However, the main part of Waihi Village lies outside (north of) the inferred hazard zones for future large landslides from the Waihi Fault scarp (Figure 7).

A deep-seated failure of the slope immediately above the Waihi Hill slip area on SH 41 is considered to be likely in the future. Based on the historical failures, the estimated probability of a large, rapid debris flow at Waihi in the future was estimated to be 65% in 50 years and 13% in 10 years (Hegan et al., 2001). This equates to an annual probability of about 1%. However, such failures could occur at any time given the appropriate triggering conditions. Hegan et al. (2001) suggest a critical acceleration (for failure) of about 0.2 g for the existing slope. This corresponds to earthquake shaking of MM7 to MM8, which has an estimated return time of 45 to 210 years in the Taupo area. A prolonged period of very heavy rainfall could also bring about failure at any time. This suggests that the probability of another debris flow failure occurring at Waihi in the next 10-50 years is relatively high.

Figure 2 Photo of "The Great Waihi Landslide of 1910" *(Photo by W Beattie and Co.)*



Historical and recent photos of the site of the 1910 landslide at Waihi village.

Figure 3 Historical photo of the 1910 Waihi Landslide showing the 800 m wide debris lobe extending 2 km to the southern shore of Lake Taupo *(top)*, and a photo showing the same area in 2002 *(bottom).*

Figure 4 Watercolour sketch by Richard Taylor dated July 1846 showing: the course of the avalanche which, on 7 May 1846, destroyed Te Rapa Village *(at the south end of Lake Taupo c.500 m south of the present-day Waihi Village)*. The features shown and numbered on the sketch are: 1. Te Heuheu's house. 2. his son's house. 3. a swinging pole, still standing. 4. a waterfall of about 12 feet found since the destruction of the place. 5. The gorge of the valley stopped up by the land slip. 6. The land slip. 7. The stream of Abraham's torch[?]. 9. The trees in the lake. 10. Hot springs. 11. Te Rapa. *[Alexander Turnbull Library: Reference number: E-296-q-115-2]*.

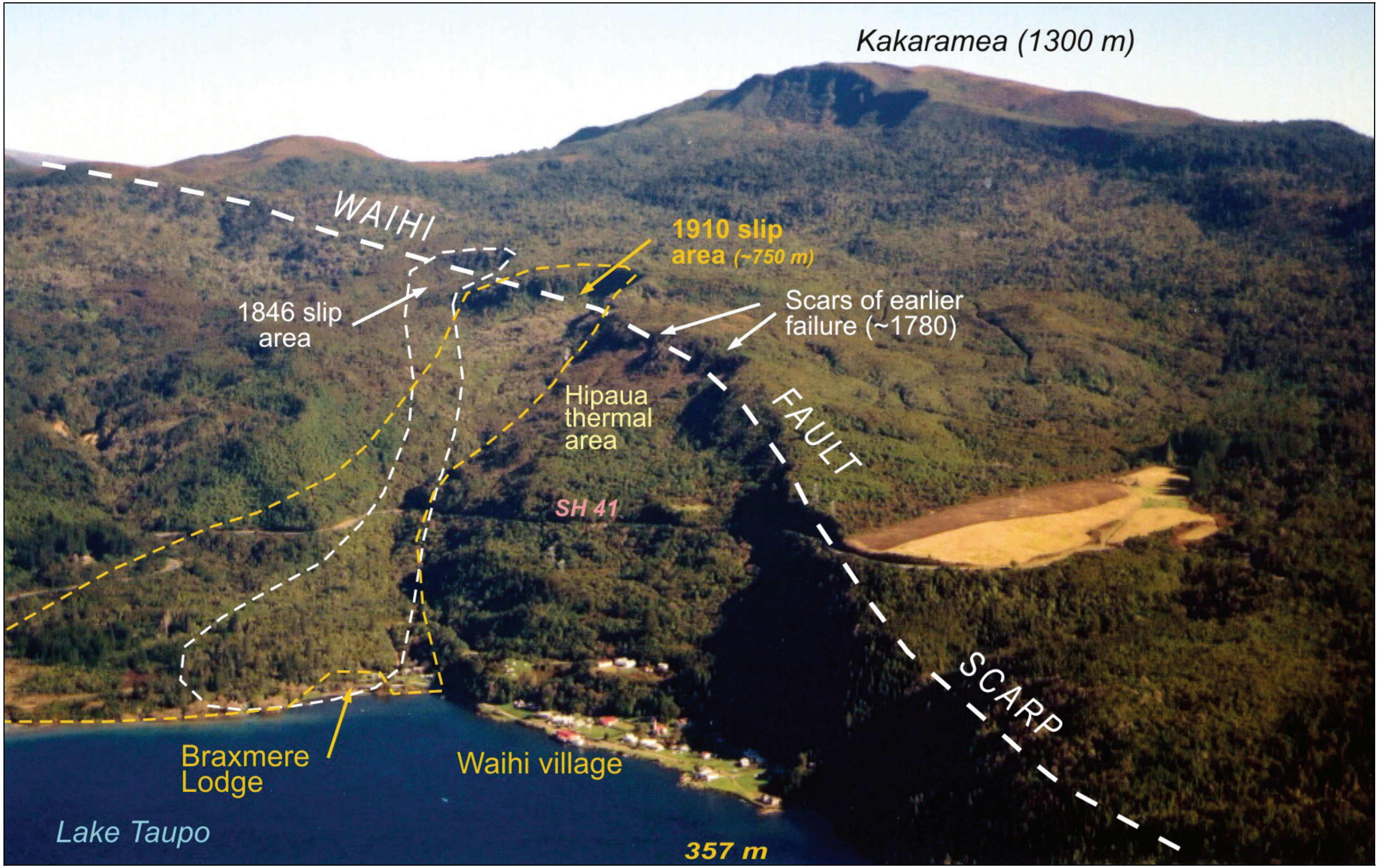


Figure 5 Aerial view of the Waihi Landslide area at the southern end of Lake Taupo showing the source area scars of three large historical landslides from the Waihi Fault scarp which have caused the loss of at least 65 lives, and the extent of the debris lobes at this site. State Highway 41, Braxmere Lodge, and a few houses at the southern end of Waihi Village (near to the lodge) are at considerable risk from future large landslides in this area.

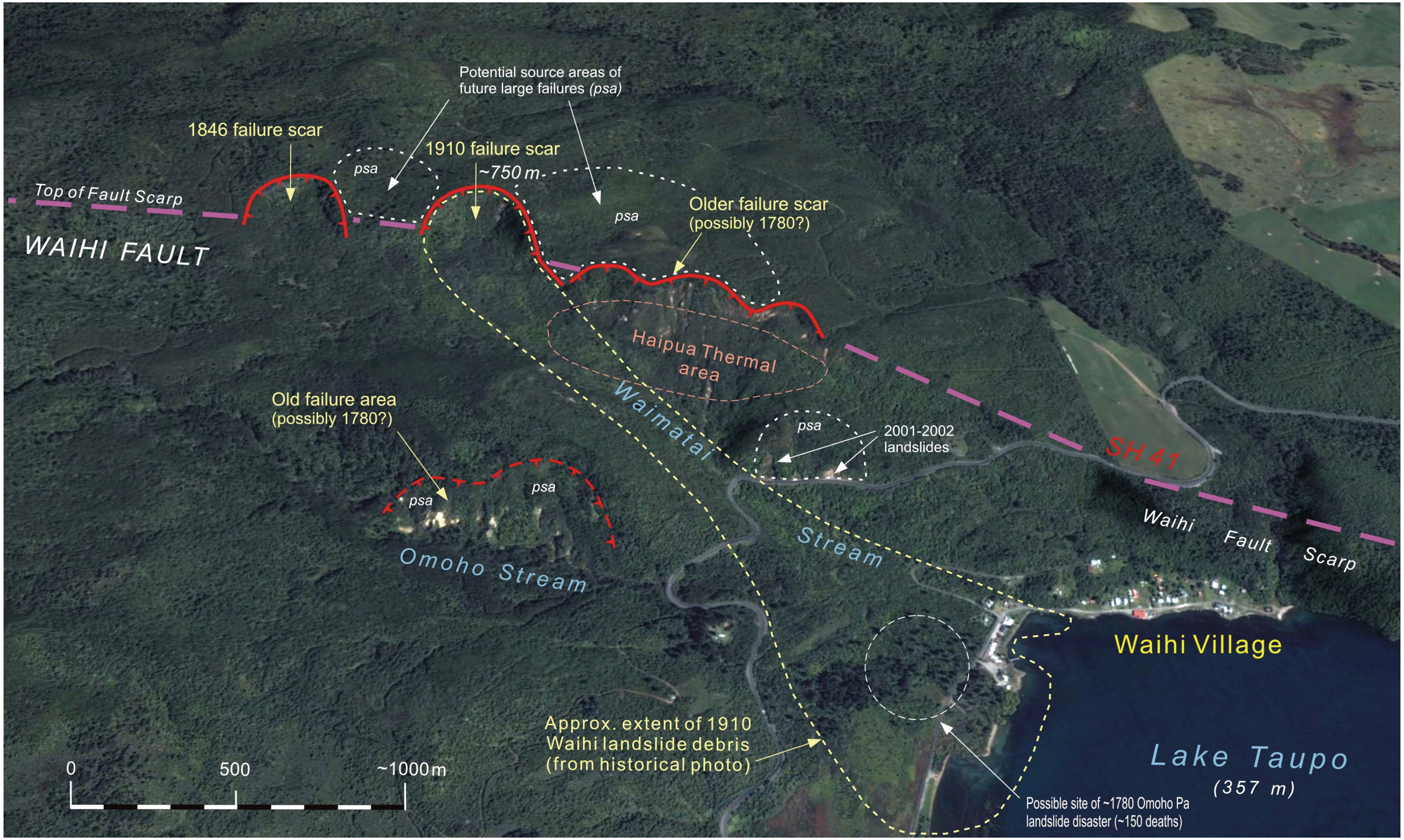


Figure 6 Annotated Google Earth Image (20 March 2007) showing the Waihi Landslide area above Waihi Village. The main features shown include the source areas of three historical failures (1780, 1846, and 1910), and the estimated extent of the 1910 landslide debris, based on a historical photo (Figure 3). The extent of the 1910 debris represents the highest landslide hazard and risk zone of a future large failure from the Waihi fault scarp immediately north (right) of the 1910 scar. Note that the main area of Waihi Village is located outside (north) of the hazard zone. Some potential source areas (psa) of future large landslides are also shown.

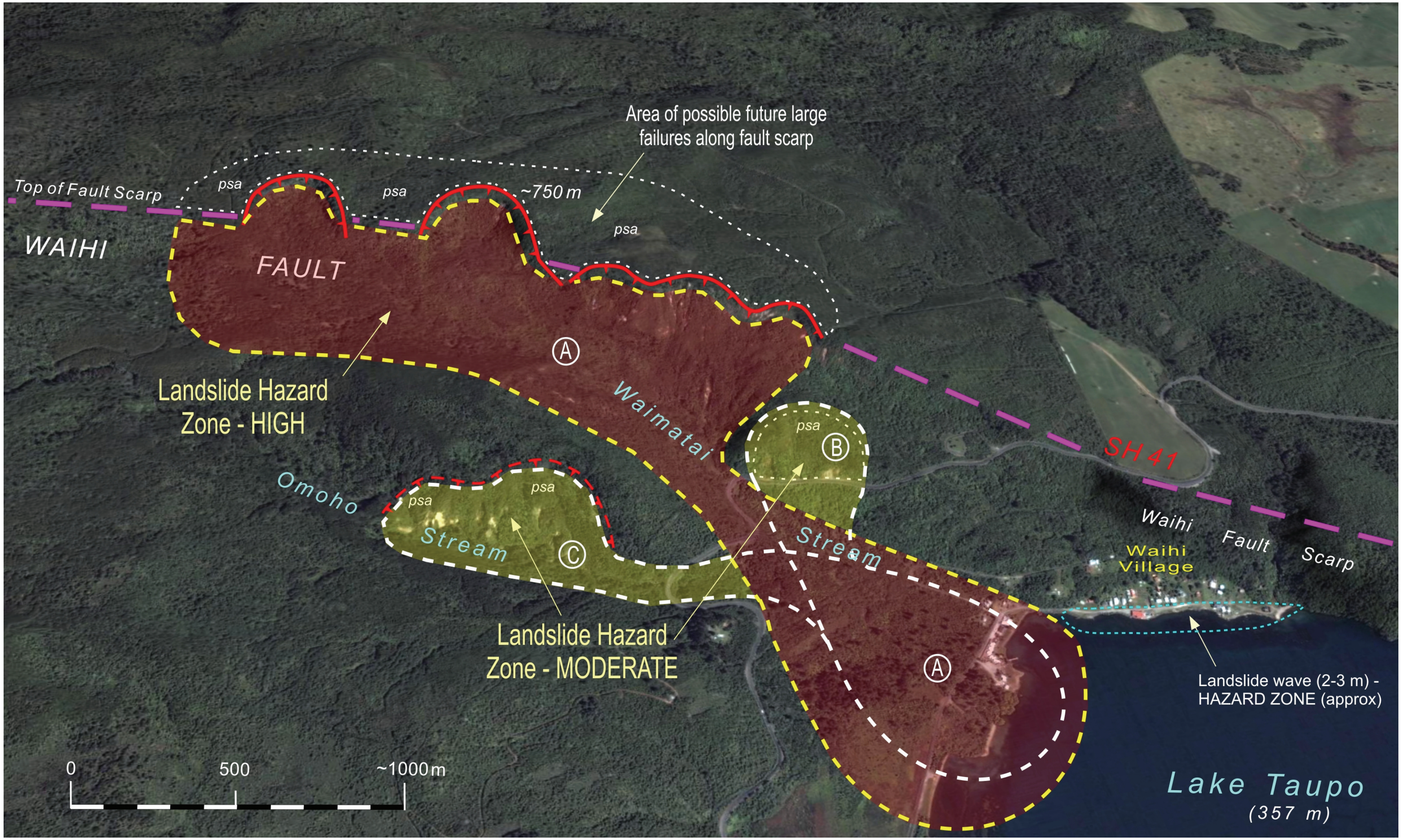


Figure 7 Annotated image showing landslide (debris flow/avalanche) hazard zones near Waihi Village determined from the existing literature (listed in Appendix A). The high (red) landslide hazard zone (A), consistent with the extent of the 1910 debris, presents the highest hazard from a future large landslide from the Waihi fault scarp. Areas of moderate landslide hazard (yellow) are inferred above the small landslides (2001-02) along SH 41 (B), and in Omoho Stream above SH 41 (C). The main part of Waihi Village is thought to be outside (north) of the landslide hazard zones, but parts of the village on the lake shore may be within the hazard zone of a landslide wave (~2-3 m high) which could be generated by a future large landslide from the Waihi Fault scarp (in zone A).

Photo featured in Figure 5 without annotations *(Photo by GT Hancox, 2002)*.

APPENDIX B LANDSLIDE AND ENVIRONMENTAL CRITERIA FOR NZ MODIFIED MERCALLI INTENSITY SCALE

Landslide and Environmental Criteria for N.Z. Modified Mercalli Intensity Scale[4]

MODIFIED MERCALLI (MM) INTENSITY SCALE – Landslide and Environmental Criteria	
MM 6	▪ Trees and bushes shake, or are heard to rustle. Loose material dislodged on some slopes, e.g. existing slides, talus and scree slope. ▪ A few very small (<10^3 m^3) soil and regolith slides and rock falls from steep banks and cuts. ▪ A few minor cases of liquefaction (sand boil) in highly susceptible alluvial and estuarine deposits.
MM 7	▪ Water made turbid by stirred up mud. ▪ Very small (<10^3 m^3) disrupted soil slides and falls of sand and gravel banks, and small rock falls from steep slopes and cuttings common. ▪ Fine cracking on some slopes and ridge crests. ▪ A few small to moderate landslides (10^3 –10^5 m^3), soil/rock falls on steep slopes (>30°) on coastal cliffs, gorges, road cuts/excavations etc. ▪ Small discontinuous areas of minor shallow sliding and mobilisation of scree slopes in places. Minor to widespread small failures in road cuts in more susceptible materials. ▪ A few instances of non-damaging liquefaction (small water and sand ejections) in alluvium.
MM 8	▪ Cracks appear on steep slopes and in wet ground. ▪ Significant landsliding likely in susceptible areas. ▪ Small to moderate (10^3-10^5 m^3) slides widespread; many rock and disrupted soil falls on steer slopes (terrace edges, gorges, cliffs, cuts etc). ▪ Significant areas of shallow regolith landsliding, and some reactivation of scree slopes. ▪ A few large (10^5-10^6 m^3) landslides from coastal cliffs, and possibly large to very large (>10^6 m^3) rock slides and avalanches from steep mountain slopes. ▪ Larger landslides in narrow valleys may form small temporary landslide-dammed lakes. ▪ Roads damaged and blocked by small to moderate failures of cuts and slumping of road-edge fills. ▪ Evidence of soil liquefaction common, with small sand boils and water ejections in alluvium, and localised lateral spreading (fissuring, sand and water ejections) and settlements along banks of rivers, lakes, and canals etc.
MM 9	▪ Landsliding widespread and damaging in susceptible terrain, particularly on slopes steeper than 20°. Cracking on flat and sloping ground. ▪ Extensive areas of shallow regolith failures and many rock falls and disrupted rock and soil slides on moderate and steep slopes (20°-35° or greater), cliffs, escarpments, gorges, and man-made cuts. ▪ Many small to large (10^3-10^6 m^3) failures of regolith and bedrock, and some very large landslides (10^6 m^3 or greater) on steep susceptible slopes. ▪ Very large failures on coastal cliffs and low-angle bedding planes in Tertiary rocks. Large rock/debris avalanches on steep mountain slopes in well-jointed greywacke and granitic rocks. Landslide-dammed lakes formed by large landslides in narrow valleys. ▪ Damage to road and rail infrastructure widespread with moderate to large failures of road cuts slumping of road-edge fills. Small to large cut slope failures and rock falls in open mines and quarries. ▪ Liquefaction effects widespread with numerous sand boils and water ejections on alluvial plains, and extensive, potentially damaging lateral spreading (fissuring and sand ejections) along banks of rivers, lakes, canals etc). Spreading and settlements of river stop banks likely.
MM 10	▪ Landsliding very widespread in susceptible terrain (3). ▪ Similar effects to MM9, but more intensive and severe, with very large rock masses displaced on steep mountain slopes and coastal cliffs. Landslide-dammed lakes formed. Many moderate to large failures of road and rail cuts and slumping of road-edge fills and embankments may cause great damage and closure of roads and railway lines. ▪ Liquefaction effects (as for MM9) widespread and severe. Lateral spreading and slumping may cause rents over large areas, causing extensive damage, particularly along river banks, and affecting bridges, wharfs, port facilities, and road and rail embankments on swampy, alluvial or estuarine areas.

NOTES:

(1) *"Some or 'a few' indicates that threshold for an effect or response has just been reached at that intensity. Effects below MM 6 generally insignificant in NZ.*

(2) *Intensity is principally a measure of damage. Environmental damage (response criteria) occurs mainly on susceptible slopes and in certain materials, hence the effects described above may not occur in all places, but can be used to reflect the average or predominant level of damage (or MM intensity) in a given area.*

(3) *Environmental response criteria have not been suggested for MM11 and MM12, as those levels of shaking have not been reported in New Zealand. However, earlier versions of the MM intensity scale suggest that environmental effects at MM11 and MM12 are similar to the new criteria proposed for MM9 and 10 above, but are possibly more widespread and severe.*

(4) *This appendix is based on Hancox et al. 1997, 2002.*

References:

Hancox, G. T., Perrin, N. D., and Dellow, G. D., 1997: Earthquake-induced landslides in New Zealand and implications for MM intensity and seismic hazard assessment. *GNS Client Report 43601B.*

Hancox, G.T., Perrin, N.D., and Dellow, G.D., 2002: Recent studies of historical earthquake-induced landsliding, ground damage, and MM intensity in New Zealand. *Bulletin of the New Zealand Society for Earthquake Engineering, 35(2)59-95.*

APPENDIX C WAIHI LANDSLIDE, HIPAUA GEOTHERMAL AREA, LAKE TAUPO – SIZE OF POTENTIAL TSUNAMI

The best available guide to the size of a future tsunami caused by a large landslide in this location appears to be the historical description of the tsunami that followed the 1910 landslide at Waihi, and of the probable tsunami following the 1846 landslide.

The NZ Historical Tsunami Database (Downes, 2009) suggests that when the 1910 landslide entered Lake Taupo it caused a surge of about 3m high in the near vicinity, which would have decreased in height with distance from the source, but was still about 1m high possibly as far away as Motutere, and caused a disturbance sufficient to dislodge canoes and boats from the shore around the lake. (See database extracts below).

The distance at which the tsunami had dropped in height to ~1m is uncertain as it is based on a newspaper account of children on the “opposite shore” having to be rescued after being washed away. The database speculates that this could possibly have taken place as far away as Motutere, but could also possibly be more local to Waihi.

Computer modelling of the 1910 event, and of future similar events, is made very difficult by the uncertainties regarding the parameters of the landslide at the point at which it enters the lake. It may however be possible to use modelling to judge the plausibility that a surge of ~3m above lake level in Waihi Bay / Tokaanu Bay would still be ~1m above lake level as far away as Motutere.

According to the database the 1846 landslide probably caused a tsunami which was interpreted at the time as the wake of a taniwha as it fled across the lake towards Motutere and on towards Waikato. (See database extracts below).

Some preliminary modelling suggests that the peak of the initial wave caused by a landslide at Waihi would likely propagate in a northeast direction across the lake, passing a few kilometres offshore of Motutere, before heading in the direction of Taupo. This is broadly consistent with the description of the Taniwha’s path and adds credence to the interpretation that what was interpreted as the wake from the Taniwha was indeed a tsunami. It seems likely that the amplitude of a tsunami wave would have to be at least a few tens of centimetres for the path of the wave to be visible to observers on the shore. This appears consistent with the description of boats and canoes being displaced from around the lake in 1910.

In the absence of other information it seems reasonable to make the assumption that the slow decay in wave amplitude implied by these accounts is correct and likely to be reproduced in future events.

Tsunami waves caused by landslides tend to have shorter periods than those caused by earthquakes, and this limits their ability to penetrate inland. On the other hand land may be developed much closer to water level around a lake than on the open coast.

Assuming that a surge of ~1m is sufficient to pose a threat to low-lying land this suggests that, with the current limited knowledge, there may be some cause for concern in low-lying areas as far away as Motutere on the southeast coast and Poukura Pa on the west coast.

Smaller waves than 1m can still cause difficult currents for swimmers and users of small boats. The account of canoes and boats being displaced by the 1910 tsunami around Lake Taupo suggests that this could again happen in future events. Small waves might also be a risk to people camping very close to the water because of the difficulty in exiting from a tent.

EXTRACTS FROM THE TSUNAMI DATABASE

1910

SOURCE EVENT SUMMARY

On March 10 1910 a large debris flow landslide fell from the 300m high Hipaua cliffs behind the Maori village of Little Waihi, destroying the village and killing more than 50 people. According to Cooper (2002), the cliffs are part of the Tokaanu-Waihi-Hipaua geothermal area and overlook the south western tip of Lake Taupo from the lower slopes of the Kakaramea volcano. The Hipaua cliff face has developed along the eroded south-eastern edge of the Waihi Fault scarp.

The cliffs are known to have fallen previously in 1846 9q.v.), when the village was destroyed, and many killed including a prominent Maori chief. At that time, another landslide 10 years earlier, i.e. in 1836, prior to organised European settlement was mentioned.

Further description of the landslide location and contributing factors (fault scarp and hydrothermal activity) in past and likely future landslides can be found in Cooper (2002).

PRIMARY DESCRIPTIVE ACCOUNTS

On March 20, hillside behind the Maori settlement of Waihi, a mile [1.6 km] west of Tokaanu, on the shores of Lake Taupo, began slipping, carrying whares, houses, and everything in its track 1.5 m [2.5 km] to the lake. The landslide spread out about 60 m into the lake in deep water. There was little warning, and one person was killed and others were injured by falling debris. As the hill continued to slide, people left the village. The landslide was only a short distance from the location of another major landslide in March 1846, when the village of Te Rapa was overwhelmed, and all the inhabitants were killed except three. Further particulars of the landslide at Waihi show that the person killed was knocked down by a big boulder, and as he rose and attempted to run away the body of the landslip overwhelmed him. As the landslide entering Lake Taupo, caused a surge that rose 10 ft (3 m), which then swept to the opposite shore [location unknown], where some children were playing. The children were swept off their feet, but were rescued by adults with some difficulty. All boats and canoes on the lake were washed away. The slip started a thousand feet [300m] above the lake level, a mile and a half [2.5 km] from the shore. Fissures 200 ft [60 m] deep were caused, and mud 30ft [10 m] deep covered the road from Tokaanu to Waihi. (Evening Post, 22 March 1910; also in other papers)

TSUNAMI IMPACT SUMMARY

As the large landslide March 10 1910 that fell from 300 m cliffs into Lake Taupo destroying Little Waihi village in its path, entered the lake, it caused a 3 m high surge. The surge then swept to the “opposite” shore where some children, swept off their feet, were rescued with some difficulty by adults. Canoes and boats were washed away. The height of the surge on the opposite shore and its location are unknown, possibly as far away as Motutere, possibly more local to the village, noting that the shoreline of the lake may have changed since 1910. The height of the surge needs to be at least 0.5 metre to have caused the children problems, but probably no more than 1-1.5 m, otherwise there would have been greater impact.

1846

PRIMARY DESCRIPTIVE ACCOUNTS

On May 7 1846, a large landslide fell from the thermal cliffs [Hipaua Cliffs] behind the village at Te Rapa, overwhelming it and burying it in 3 m of mud and rocks, killing 54 people. Following the landslide, it was reported that, "The natives say that afterwards the Taniwa fled across the lake to Motutere and thence to Waikato, whence he will go to the sea and perish there; they shall be no more troubled with him; they saw the splash of his tail as he crossed the lake." (New Zealand Spectator & Cook's Strait Guardian 1 July 1846).

TSUNAMI IMPACT SUMMARY

In 1846, on May 07, the Hipaua Cliffs behind the village of Te Rapa suddenly collapsed in a landslide that buried the village in mud reportedly to a depth of 3 m. Fifty four of the 56 people in the village were killed in the landslide, which flowed into the lake carrying trees with it.

The site was devastated again and many killed by a landslide from the same source in 1910 March 20 (q.v.). On that occasion, a tsunami occurred in the lake, the surges being large enough to cause problems for some children in the water on the opposite shore (Motutere?).

While no waves or surges are mentioned in the account of the 1846 event, a taniwa [taniwha] is, i.e. “The natives say that afterwards the Taniwa fled across the lake to Motutere and thence to Waikato, whence he will go to the sea and perish there; they shall be no more troubled with him; they saw the splash of his tail as lie crossed the lake” (New Zealand Spectator & Cook's Strait Guardian 1 July 1846). According to King et al. (2007), events involving large waves, storm surges and tsunamis were commonly explained as the work of taniwha in Maori traditional stories. In light of this, it is likely that the taniwha in the lake after the landslide in 1846 represents a tsunami.

The occurrence of a tsunami is given a validity of 3 (probable).

Interestingly, the account indicates another landslide 10 years before 1846, before organised European settlement.

REFERENCES

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