The Hazard of Lahars to the Tongariro Power Development, New Zealand

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SUMMARY The Tongariro hydro-electric scheme intercepts a number of rivers which drain two active volcanoes and diverts them into rivers and natural lakes renowned for trout fishing. One of the active volcanoes, Ruapehu, is subject to unpredictable eruptions of its crater lake, during which lahars or volcanic mudflows are generated in several of the main valleys. As the chemical waters from the crater lake are toxic to fish, a lahar protection system was installed to prevent the spread of volcanic contamination into waters normally unaffected by these eruptions. This system also prevents volcanic debris from silting the power scheme waterways and reservoirs.

The lahar protection system was designed to cope with eruptions of the size that occurred in 1969, but proved to be inadequate for the 1975 eruption which was several times greater. Data obtained from the 1975 eruption have been utilized to upgrade the original lahar protection system and extend it into areas previously thought to be free from risk. The 1975 eruption also demonstrated the serious hazard of future eruptions to public safety as well as to the fisheries and the power scheme.

1 INTRODUCTION

The Tongariro hydro-electric power scheme is located in the centre of the North Island of New Zealand. It involves the interception and diversion of numerous streams and rivers into Lake Taupo through a complex system of intakes, dams, canals and tunnels.

Most of the streams intercepted rise on the slopes of three active volcanoes - Ruapehu, Ngauruhoe and Tongariro - each of which have erupted ash and lava in historic time. In addition Ruapehu has produced lahars or volcanic mudflows which are generated by the sudden release of highly acidic water from Crater Lake (Fig. 1), either by collapse of the crater wall (1953), or by eruption (1969 and 1975). The resulting floods of water and volcanic debris which travel down existing valleys pose a serious threat to power scheme installations as well as to public safety.

The lahar on 24 December 1953 swept away a railway bridge spanning the Whangaehu River, resulting in a train disaster with the loss of 151 lives (Healy 1954). Lahars on 22 June 1969 and 24 April 1975 damaged skifield installations on the upper slopes of Ruapehu and probably would have killed a number of people had the eruptions occurred when the skifield was crowded (Healy et al 1978). The 1975 eruption also flooded one of the power development tunnels where a group of tunnellers were lucky to escape with their lives.

Lahars are also capable of blocking power scheme waterways, causing siltation in reservoirs and damaging bridges. In addition, because several natural lakes and rivers utilized by the power scheme are important trout fisheries, accidental diversion of toxic lahar material could have a serious effect on fish life and the local tourist industry. A lahar protection system therefore has the dual purpose of protecting both the fisheries and the power scheme installations.

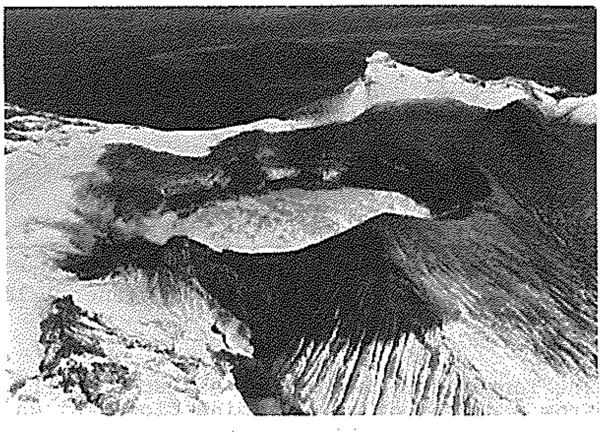

Fig. 1 Ruapehu Crater Lake after a minor eruption on April 27, 1975. Note the Whangaehu R outlet in lower centre.

In this paper the effects of the 1975 eruption on the power scheme are described, and data from major eruptions are utilized to delineate areas of greatest risk and devise an effective lahar protection system. The risk of similar future eruptions is assessed from previous recorded activity, and hydrological data is used to determine lahar velocities and volumes.

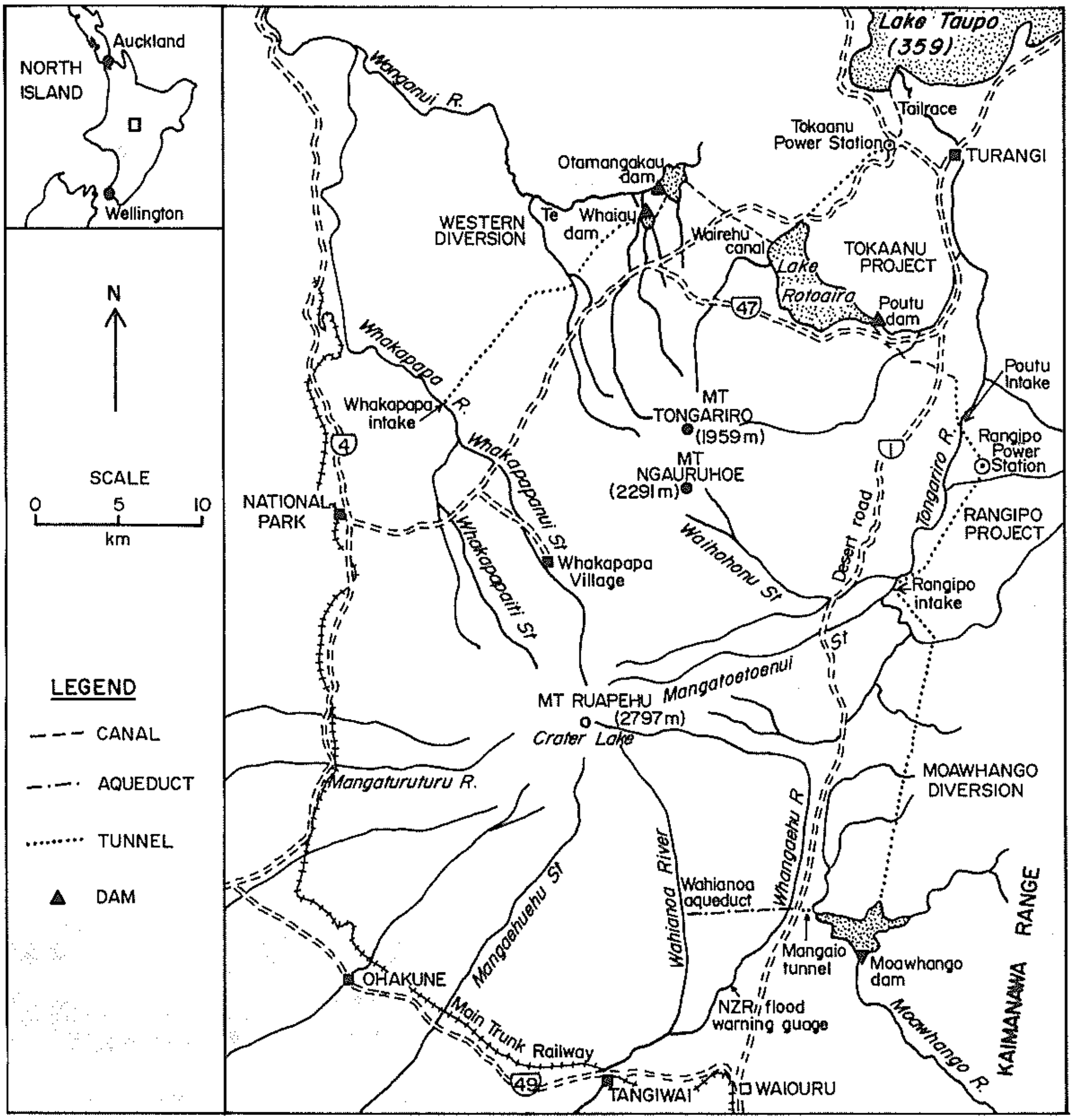

Fig. 2 Location and general layout of the Tongariro power scheme

2 TONGARIRO POWER SCHEME

The Tongariro power scheme collects water from a number of rivers which flow west and south from the volcanoes and diverts it northwards into Lake Taupo (Fig. 2). The water is utilized for power generation at the Rangipo (120 MW) and Tokaanu (200 MW) power stations, and in addition, the increased outflow from Lake Taupo raises the output from eight hydro-electric stations along the Waikato River (McCreight 1973).

The scheme can be subdivided into four sections as shown in Fig. 2. Because a large number of catchments are involved, environmental aspects required careful investigation to minimise possible harmful effects. Special provisions were incorporated into the design to preserve well known trout fisheries such as the Tongariro River and Lakes Rotoaira and Taupo. This entailed protection of important spawning streams and construction of special structures designed to prevent fish migration between catchments. Also the Whangaehu River which is the natural outlet of Ruapehu's crater lake was not incorporated in the power scheme because of the harmful effects the acid water would have on aquatic life. Because of the extent of these measures to protect the fisheries, it is logical that additional steps should be taken to prevent the spread of volcanic contamination between catchments during periodic lahar eruptions.

During investigation of the power scheme it was known that eruptions of lava and ash could be expected from Ruapehu and Ngauruhoe, but apart from minor siltation these were not considered to be a serious threat to the operation of the power scheme. It was recognized that lahars from Ruapehu were the greatest volcanic hazard to public safety in the area, but their threat to the power scheme was not realised until the eruption in 1969, after construction had commenced.

3 LAHARS FROM THE 1975 RUAPEHU ERUPTION

The main eruption of Ruapehu Crater Lake occurred on 24 April 1975 at 3:59 a.m. Heavy rain prevented any observation of the eruption. Ash deposits covered the summit area and fell in a narrow strip extending at least 115 km south-east of the volcano. At least 1.6 x 10^6 m^3 of Crater Lake water, lake floor deposits and blocks of hot rock were erupted onto the summit area, generating large lahars in several main valleys draining the volcano. The eruption resulted in an 8 m drop in lake level which represents 23% of the total lake volume of 7 x 10^6 m^3 from lake bathymetry. Details of the eruption are described by Nairn et al (1979).

On the upper slopes damage caused by the blast of the eruption and the impact of hot blocks of rock was limited to destruction of geophysical equipment and shelter huts. Most of the destruction was caused by lahars in the Whakapapa, Mangaturuturu and Whangaehu valleys and their main rivers downstream (Fig. 2).

3.1 Whakapapa Lahar

Lahars travelled down both tributaries of the Whakapapa River which meet 2.5 km upstream of the Whakapapa intake structure. In the headwaters, skifield installations and a refreshment kiosk were damaged, and further downstream within the Tongariro National Park two small suspension bridges were swept away. Near the Whakapapa Village a road bridge spanning the Whakapapanui River sustained slight damage when it was overtopped by the lahar.

At the Whakapapa intake, despite the installation of lahar detectors, a large volume of debris entered the tunnel and was deposited throughout its length. At the northern end of the tunnel, sediment and contaminated water flowed into the small Te Whaiau reservoir where it was spilled down the headwaters of the Wanganui River by emergency closure of the intake gate to the Wairehu canal (Fig. 2). This action averted the spread of contaminants into Lake Rotoaira and Lake Taupo but threatened the recently established fishery in Lakes Te Whaiau and Otamangakau.

Following the 1969 Ruapehu eruption when serious fish losses occurred in the Whakapapa and Wanganui Rivers, an investigation was carried out to determine the effects on fish life if contaminants from future eruptions were inadvertently diverted into Lakes Rotoaira and Taupo once the Western Diversions came into operation. Recommendations were made to install a lahar detector upstream of the Whakapapa intake to automatically close the tunnel gates before a lahar arrived, thereby preventing the spread of contamination (Paterson 1972). However because the conductivity probes were installed on the intake structure - not upstream as recommended - and a number of faults and deficiencies developed during the operation of the lahar protection system, a detailed study of the 1975 eruption was instigated with the view to upgrading the existing system.

3.2 Mangaturuturu Lahar

The lahar in the upper Mangaturuturu valley was highly erosive judging by the scouring of the valley floor, overtopping of spurs up to 8 m high, and the surging effects at river bends. Scouring and deposition altered the riverbed profile at the SH47 and main trunk railway bridges causing concern over the long term stability of these structures.

3.3 Whangaehu Lahar

The Whangaehu lahar was the largest from the eruption and was also highly erosive in the upper reaches of the valley. However, because of the remoteness of the area there was no property damage.

At the Wahianoa aqueduct the Whangaehu River changes from a wide floodplain upstream to a narrow incised valley. This constriction caused ponding of the lahar, and flooding of the aqueduct on either side of the river. The lahar flowed 0.6 km westwards along the aqueduct excavation to a stream-bed intake where it gained entry to the aqueduct pipeline below and filled it with debris over a length of 1.9 km.

Fig. 3 View looking west along Wahianoa aqueduct showing level of lahar, and flooded tunnel portal in foreground.

East of the river the lahar flooded the large aqueduct trench and buried the western portal of the Mangaio tunnel (Fig. 3). The material drained through the tunnel and emerged from the eastern portal where it flooded the portal establishment and spilled into the Mangaio Stream. The flow joined the Moawhango River upstream of the Moawhango dam and continued downstream where it eventually reached the Rangitikei River.

At the aqueduct a lahar warning system had been installed to protect workmen engaged in extending the pipeline beneath the Whangaehu River. The warning system was first installed in 1973 when high Crater lake temperatures were recorded, indicating a high risk of eruption and possible lahars in the Whangaehu valley. A fail-safe water level recorder was installed in the river upstream from the aqueduct which was designed to trigger an alarm at the construction site in the event of a lahar.

Although there were no eruptions during this period, the warning system was retained while construction continued in the western section of the Mangaio tunnel. When the 1975 eruption occurred the warning system was still in operation but had not been extended into the eastern tunnel section where tunnel work was being carried out at the time. Fortuitously the tunnellers were having a meal break outside when the lahar arrived and therefore escaped injury. Because there was no one working at the western end of the tunnel it is not known whether the warning system operated as planned.

Immediately downstream of the aqueduct the lahar completely filled the narrow river channel to approximately 6.5 m above normal river level, and overtopped the decking of a Bailey bridge. Approximately 5 km further downstream the New Zealand Railway Department had installed a flood warning device which is located in the river-bed 11 km upstream of the Tangiwai railway bridge. This structure was installed after the railway disaster in 1953 and consists of a robust concrete tower which houses a series of paired electrodes at staged heights (Fig. 4). It is linked by a land line to the Waiouru and Ohakune railway stations (located on either side of the Tangiwai railway bridge) where audible alarms are triggered in the event of a lahar, and a visual display indicates the height of the lahar. Approaching rail traffic is then delayed until the railway bridge is inspected and declared safe (pers. comm. L.I.D. Jamieson, N.Z. Railways Dept.).

The alarms were triggered in the railway stations 60 minutes after the 1975 eruption, and the visual display showed the lahar had reached level 4 on the 5 stage scale. Later inspection revealed that the lahar had overtopped the tower; by comparison the lahar from the 1969 eruption failed to reach level 1 on the same scale.

At Tangiwai both railway and SH49 bridges were undamaged by the lahar, but during the peak flow the road bridge - a recent concrete structure - vibrated alarmingly as large boulders carried in suspension hit the piers. A small wooden farm bridge spanning the Whangaehu River 6.5 km downstream from Tangiwai was swept away, and 10 km further downstream another bridge was overtopped and slightly damaged. In this area there were reports from residents living near the river of ground vibration similar to an earthquake during the peak flow.

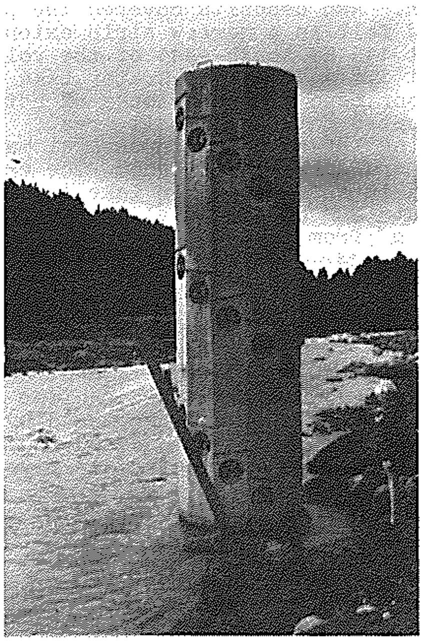

Fig. 4 N.Z. Railways Dept. lahar warning tower in the Whangaehu R.

4 LAHAR VELOCITIES AND VOLUMES

Automatic water level recorders registered the arrival times and stage heights of lahars from the 1969 and 1975 eruptions from which velocities and volumes were computed. Because the recorder sites are either near the base of the volcano or further downstream, no accurate hydrological data are available for the upper reaches where the velocities were greatest.

Lahars have a distinctive hydrograph peak which can be distinguished from those generated by rainfall (Fig. 5). Although it was raining when the 1975 eruption occurred, it was possible to differentiate the portions of the hydrographs attributed to rainfall and the lahars by analysis of rainfall data, and comparison with hydrographs of other rivers in the area unaffected by the eruption (Page and Paterson 1976).

The success of a lahar warning system relies on an adequate knowledge of the behaviour of lahars in different sections of the valleys. Calculated lahar velocities and volumes from recent Ruapehu eruptions are given in Table I. Lahar velocities depend on the nature and gradient of the channel as well as the viscosity and volume of the lahars. The highest average velocity recorded was

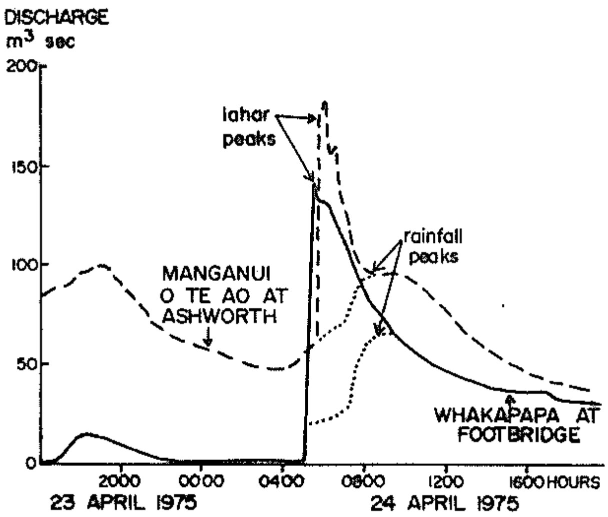

Fig. 5 Hydrographs of the 1975 lahars

8 m/sec for the first 22.1 km section of the Whangaehu lahar, although the actual velocities of the three main lahars in the first 5 km or so downstream from Crater Lake must have been considerably greater. The Whakapapanui lahar from the 1969 eruption was very viscous and achieved an average velocity of only 1.6 m/sec for the first 13.2 km (Healy et al 1978), whereas the Whakapapaiti lahar from the same eruption which was larger and less viscous had an average velocity of 4.0 m/sec for the first 27.9 km (Paterson 1972).

In the Whangaehu valley at Karioi (57.1 km downstream of Crater Lake) a water level recorder was operating during the period 30-10-62 to 5-1-72 during which numerous surges attributed to minor Crater Lake eruptions were recorded (Table I). The velocities of these flows were obtained by comparing the seismological record of Ruapehu (pers. comm. J.H. Latter, D.S.I.R. Geophysics Div.) with the hydrological record (pers. comm. C.E. Page, M.W.D. Hydrological Surveys). In general the velocities of these flows (0.9 - 3.2 m/sec) are considerably less than the 1975 lahar (5.6 m/sec). According to Healy (1954) the average velocity of the 1953 lahar between Crater Lake and Tangiwai was 5.2 m/sec compared with 6.4 m/sec for the 1975 lahar over the same reach.

Comparison of peak discharge levels near the Tangiwai road and railway bridges of the 1953 and 1975 Whangaehu lahars showed the former to be greater (Page and Paterson 1976). However judging by a 7.9 m drop in lake level in 1953 (Turner 1954), a total volume of 1.9 x 10^6 m^3 was released down the Whangaehu River which is only slightly larger than the volume of 1.8 x 10^6 m^3 calculated for the 1975 Whangaehu lahar. In 1953 the lake water was not released instantly (Turner 1954) which would have effectively lowered the peak discharge compared with that from an eruption. This factor was probably more than compensated for by debris accumulated during its passage downstream, whereas the 1975 lahar volume takes this factor into account.

Nairn et al (1979) recorded an 8 m drop in lake level following the 1975 eruption which indicates an apparent volume loss of 1.6 x 10^6 m^3. The latter is only about half the total lahar volume of 3.3 x 10^6 m^3 calculated from hydrological data, which suggests that the accumulation of debris from the river beds is a significant factor. This view is substantiated by the scouring of the river-beds in the headwaters, and

TABLE I

LAHAR VOLUMES AND VELOCITIES FROM RUAPEHU CRATER LAKE ERUPTIONS

Water-level recorder sites	Distance from Crater Lake (km)	Date of eruption	Lahar volume (m^3)	Lahar velocity (m/sec)	Average channel slope
Whakapapa at Footbridge N111/960859	24.9	22. 6.69 24. 4.75	117,000 900,000	4.0 4.1	1:13
Mangaturuturu at Ashworth N121/723621	40.2	22. 6.69 24. 4.75	24,000 600,000	1.9 4.9	1:17
Whangaehu at Karioi N131/965389	57.1	24. 7.66 26. 4.68 22. 6.69 8. 5.71 16. 5.71 16. 5.71 19. 5.71 21. 5.71 3. 7.71 4. 7.71 24. 4.75 2.11.77	1,000 729,000 67,000 41,000 72,000 58,000 18,000 9,000 5,000 19,000 1,800,000 130,000	0.9 2.4 2.6 2.9 2.8 2.3 1.6 2.0 5.6 3.2	1:29
Whangaehu at Kauangaroa N138/790874	169	24. 4.75	1,600,000	2.8	1:66

deposition of vast quantities of material in the lower reaches.

The apparent lake loss from the 1969 eruption was 0.5 x 10^6 m^3, and the total lahar volume calculated from hydrographs was only 0.2 x 10^6 m^3. The apparent reversal of volumes could be due to the high proportion of solid material erupted, and the thick coating of snow and ice on the summit area prior to the eruption (Healy et al 1978). Much of the solid material remained on the upper slopes, and melt water partly replenished the lake loss, both of which contribute to the discrepancy in volume calculations.

5 HAZARD OF FUTURE RUAPEHU ERUPTIONS

The volcanic activity of Ruapehu has been documented by Gregg (1960) for the period from the first eruption witnessed by Europeans in 1861 until 1959, and by Healy et al (1978) from 1959 to 1969. Eruptions since 1969 have been recorded by Nairn et al (1979).

Since 1861 numerous phreatic eruptions of Crater Lake have been recorded including at least 12 events that produced lahars in the Whangaehu valley. Only the three most explosive eruptions (1895, 1969 and 1975) ejected water and debris a sufficient distance from the crater to form lahars in the northwest catchments as well as in the Whangaehu valley. The 1895 eruption appears to have been the most violent event, but because the lake level was not checked until 26 days after the eruption (Gregg 1960) a direct comparison of lake loss with the 1975 eruption cannot be made. According to Allen (in Gregg 1960), during the 1895 eruption "the Wanganui River was discoloured down to the sea," the Whangaehu River" was for several days a river of mud" and the Mangatoetoenui Stream became "a mere sludge channel."

The total amount of material ejected onto the summit area is dependent on the magnitude and mechanism of the eruption although the distribution of the ejecta, and hence the size of lahars in any particular valley is strongly influenced by wind velocity and direction during the eruption. The snow conditions on the upper slopes will also effect the mobility and volume of the lahars; hence if the 1975 eruption had occurred during winter, more water would have passed down the Whakapapa valleys and damage may have been more severe.

Although volcanic activity of Ruapehu is continuously monitored from the Chateau seismological station and by regular inspections of Crater Lake, it is unlikely that eruptions will be able to be predicted in the foreseeable future. The greatest danger to lives is concentrated mainly on the upper slopes of Ruapehu, particularly during the skiing season, although some danger also exists on the lower slopes along the paths of lahars.

The hazard of lahars is well known in countries with active volcanoes, particularly in the circum-Pacific region. They are responsible for the greatest destruction of property of any other single volcanic process, and have caused the loss of thousands of lives during the past few centuries. A single eruption of Kelud volcano in Java in 1919 for example, caused massive destruction including the loss of 5500 lives when mudflows swept down the volcano following an explosive eruption beneath the crater lake (Bolt et al 1975).

Neall (1976a) reviewed the literature on lahars and included a classification based on their origins as well as a description of the most important lahars of each type that have occurred in historic times. Ruapehu was cited as a source of two types of lahar i.e. (a) an eruption through a crater lake, e.g. 1969 (b) collapse of a crater lake (non-eruptive), e.g. 1953. In a separate paper Neall (1976b) also discussed the hazard of lahars and referred to lahar protection measures adopted on several volcanoes including Ruapehu; the threat of lahars to the Tongariro power scheme was not mentioned however.

6 POSSIBLE EFFECTS OF FUTURE LAHARS ON THE POWER SCHEME

Future major eruptions of Crater Lake are almost certain to produce lahars in the Whangaehu, Mangaturuturu and Whakapapa valleys. During the 1975 eruption major lahars were restricted to these valleys although there was evidence of a flood flow 1.2 m above normal river level in the Wahianoa River (Nairn et al 1979). Small mudflows were reported in the headwaters of the Wahianoa, Mangaehuehu Rivers (Fig. 2), and water samples from these streams had a lower pH than normal indicating chemical contamination from the eruption. The Waihohonu Stream appeared to have been slightly contaminated, probably from ash fall as indicated by the acidity of a water sample collected the day of the eruption.

For several years after the 1975 eruption the Wahianoa Stream became slightly acidic during periods of summer thaw, when contaminants from the eruption were released from the ice into the headwaters (Paterson 1976a). A detailed investigation of the long term contamination was carried out by Carr (1978), who concluded that although the recorded pH levels were unlikely to be a danger to fish life, the surveillance of water quality should continue particularly after commissioning of the aqueduct.

Judging from Allen's description of the 1895 eruption and the contamination resulting from the 1975 eruption, the Mangatoetoenui Stream must be considered at risk from future major eruptions. There are no records of major lahars in the Wahianoa River although in the case of the 1895 eruption this may be due to lack of information. The headwaters of the Wahianoa River are closer to Crater Lake than the Mangatoetoenui headwaters. Hence, although a ridge approximately 50 m higher than the Summit Plateau separates the Crater Lake from the Wahianoa headwaters, the risk of lahars in both rivers is considered to be similar.

Since the 1975 eruption, construction of the Wahianoa aqueduct and Mangaio tunnel has been completed so that the only access for lahars to the Moawhango reservoir is through the aqueduct stream-bed intakes or the Mangaio tunnel access shaft. The latter has been built to a height above the level of the 1975 Whangaehu lahar, and embankments have been constructed on the west bank of the Whangaehu River to prevent lahars from flowing westwards along the aqueduct excavation. Therefore unless future lahars in the Whangaehu River are much larger than occurred in 1975, the only access for volcanic contaminants to the Moawhango reservoir is through the intake structure on the Wahianoa River.

The large volume of sulphurous water (pH = 1.2) forming Ruapehu's Crater Lake is the main threat to the power scheme and public safety. If the lake could be permanently drained the danger of future lahars would be eliminated. In a similar geological setting this was partially achieved in Java where drainage tunnels were driven through the crater wall of an active volcano and most of the lake water evacuated (Bolt et al 1975). A feasibility study of this method was suggested by Neall (1976b) and Paterson (1976b), but no action has been taken.

An early warning system to protect skiers on the upper slopes of Ruapehu has also been proposed (Hewson and Latter 1976). This system consists of a series of sensors designed to trigger alarms on the skifield immediately after an eruption. Although the prime purpose of this scheme is to save lives on the upper slopes of Ruapehu, if it is approved it could also act as an early warning system for the power scheme and communication routes. This would supplement rather than replace a power scheme lahar warning system, but it would provide extra time to execute emergency systems.

7 IMPROVEMENTS TO THE POWER SCHEME LAHAR WARNING SYSTEM

7.1 Western Diversions

The problems encountered in Western Diversions from the 1975 Whakapapa lahar would have been less serious had the Whakapapa tunnel gate been closed before the lahar arrived. The lahar would then have continued on its natural path down the Whakapapa River. To achieve this, paired conductivity probes are being shifted from the previous site at the Whakapapa intake and installed in the Whakapapaiti and Whakapapanui Rivers at the SH47 bridges 8 km and 6 km upstream of the intake structure (pers. comm. W. Strauss, Ministry of Energy, Electricity Div.) Provided the system functions as planned, this will give a minimum warning of 25 minutes (based on a lahar velocity of 4 m/sec) in which to close the gates before the arrival of a lahar.

Radio signals from one of each pair of probes are designed to activate an alarm in the Tokaanu power station, and the other to initiate emergency closure of the Whakapapa tunnel gate. The gate is designed to close completely from the parked position in a time of one and one-third minutes, and it will be capable of remote control from the Tokaanu control room as well as automatically by the probe, and manually at the intake structure (W. Strauss pers. comm.).

7.2 Moawhango Diversion and Rangipo Project

Prior to the 1975 eruption it was not considered necessary to have a lahar protection system for the Moawhango Diversion except to protect workmen during construction. Because of the risk of future lahars in the Wahianoa valley it is now proposed to install a lahar protection system, consisting of early warning devices which will operate an alarm in the Tokaanu power station and initiate automatic closure of a gate on the Wahianoa aqueduct. This should prevent contaminants from reaching the Moawhango reservoir.

The sites proposed for the detectors are in the headwaters of the Whangaehu River and at the Wahianoa intake. Because of the harsh climatic conditions, remoteness of the sites, and the variable pH of the water (particularly the Whangaehu River) it is proposed to use level sensing devices rather than conductivity probes. As there are no fish in the Whangaehu River the main threat is from lahars in the Wahianoa River. Hence it is not necessary to monitor small lahars in the Whangaehu River because minor eruptions would not affect the Wahianoa catchment.

A level sensing device on the Wahianoa River would not be capable of monitoring the long term contamination of the type that occurred after the 1975 eruption (Paterson 1976a and Carr 1978). If this level of contamination is unacceptable on the grounds that it could be harmful to fish life, a conductivity monitoring system will be necessary for the Wahianoa River either as a replacement or in addition to a level sensing device.

The Mangatoetoenui Stream could be affected by lahars during the operational life of the power scheme as proved by the 1895 and to a less extent the 1975 eruptions. The Waihohonu Stream is unlikely to be affected by lahars but could be temporarily contaminated by volcanic ash. Both streams are tributaries of the Tongariro River and once construction is completed they will be diverted through the Rangipo power scheme. As the water from these streams must travel either down the Tongariro River or be diverted through the Rangipo power station, it may be advisable to allow it to continue down the river because of possible harmful effects to power station equipment. In this case it would also be necessary to close the Poutu tunnel gates to prevent contaminated water from being diverted into Lake Rotoaira.

To date no system has been devised nor procedures established to perform these steps automatically. However, if an emergency procedure is formulated and accepted by the parties concerned, adequate protection of the Lake Rotoaira fishery could be accomplished by closing the Poutu tunnel gates by remote control as soon as the lahar alarm is activated in the Tokaanu power station. The resumption of diversion would then be delayed until a field inspection had ascertained the extent of the eruption.

8 CONCLUSIONS

Lahars formed by the eruption of Ruapehu's Crater Lake are the greatest volcanic risk to public safety and to the Tongariro power scheme. These large floods of highly acidic water and volcanic debris travel down existing valleys, and because of their high density and velocity are capable of damaging power installations and communication networks located along their paths. A popular skifield is located on the upper slopes of Ruapehu in the path of lahars which could result in serious loss of life if a major eruption occurred when the slopes were crowded. Also because of their chemical contamination lahars are a serious threat to fish life.

Since 1861 numerous phreatic eruptions of Crater Lake have been recorded, at least 12 of which generated lahars. To date methods of volcanic surveillance have failed to predict the two largest, most-recent eruptions and are unlikely to be successful in the foreseeable future.

During the 1975 eruption at least 23% of the total volume of Crater Lake was erupted, and it is possible that future eruptions could eject more than twice this volume; individual lahars could show an even greater increase in volume depending on wind conditions during the eruption.

Because the power scheme involves diversion of rivers prone to volcanic contamination, a lahar protection system is required which should operate effectively for all eruptions. Such a system has the dual purpose of restricting the spread of volcanic contaminants to important fisheries and protecting installations from damage and siltation.

Unless the serious threat of Ruapehu's lahars to public safety and property can be eliminated by draining Crater Lake, a co-ordinated effort should be made to devise a lahar protection system which will satisfy the requirements of all parties concerned.

9. ACKNOWLEDGEMENTS

For data included in this paper the author wishes to thank Mr W. Strauss, Ministry of Energy, Electricity Division, and Mr C.E. Page, Ministry of Works and Development, Hydrological Survey. The helpful assistance given by Mr S.A.L. Read and Mr S. Nathan is also acknowledged.

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