Lee Dam Sites – Mike Johnston's Report

1 Introduction

Two potential dam sites, approximately 250 m apart, have been identified in the middle reaches of the Lee River, one of two major tributaries of the Wairoa River which drains the ranges east of the Waimea Plains. The eastern ranges rise to over 1721 m in the headwaters of the Lee River, which apart from the mountain tops, is in indigenous forest. In its lower reaches, where the ridge crests are very approximately up to 1000 m above the Lee River, steep slopes are largely planted in exotic forestry, with narrow terraces flooring the valley in pasture. The dam sites are towards the upper end of the lower section. The Wairoa River, below its junction with the Lee River, flows through lower hills in grass before abruptly emerging onto the Waimea Plains at the mouth of the Wairoa Gorge.

2 Regional Geological Setting

2.1 Geology

The eastern ranges are composed of Upper Mesozoic-Lower Paleozoic rocks that are dominated by sandstone, siltstone and mudstone although igneous and metamorphic rocks of mafic and ultramafic composition are present. The rocks are divided into northeast trending belts or terranes which are from several to many kilometres wide. The terranes are separated by major faults, such as those comprising the Waimea-Flaxmore Fault System in the west, or other tectonic contacts. Eastwards from the mouth of the Wairoa Gorge, the terranes are Murihiku, Dun Mountain-Maitai and Caples. The Murihiku terrane, exposed in the Wairoa River downstream of the Lee River junction, is bounded on its northwestern side by the Waimea Fault which marks the edge of the Waimea Plains. The terrane comprises fossiliferous sedimentary rocks, rich in igneous debris, of the Richmond Group. To the southeast, the Murihiku terrane is separated by the Eighty-eight Fault from the Dun Mountain-Maitai terrane. In the west of the latter terrane is the sedimentary Maitai Group, which in contrast to the Richmond Group lacks igneous detritus. The Maitai Group unconformably overlies the Dun Mountain Ophiolite Belt of Lower Permian age. The ophiolite belt, locally known as the Nelson Mineral Belt, is dominated by serpentinite.

The ophiolite belt is separated from the Caples terrane by the Patuki Melange, a mixture of blocks of sedimentary and igneous rocks, particularly basalt, in a serpentinitic matrix. The blocks range from fist size to masses hundreds of metres across. While the ophiolite typically grades into the melange, which in turn grades into the Caples terrane, in the Lee River the contacts are sharp due to faulting. The lower dam site is about 300 m upstream of the melange. The Caples terrane comprises the Caples Group (formerly mapped as Pelorus Group) and at the dam sites consists of well bedded grey siltstone and minor sandstone of the Rai Formation[1]. Although the bedding is commonly aligned northwest-southeast, with a variable dip to either the northeast or southwest, small mesofolds are common. Bedding plane shear is also widespread and a cleavage, developed in the siltstone, is commonly parallel or sub-parallel to bedding.

2.2 Faults

2.2.1 Waimea-Flaxmore Fault System

While faults are widespread through the eastern ranges, the Waimea-Flaxmore Fault System is the dominant structural feature[2]. The fault system branches off the Alpine Fault at Tophouse and extends northeast to separate the eastern ranges from the Moutere Depression and Waimea Plains. The major faults in the system are, from northwest to southeast, Flaxmore, Waimea, Eighty-eight and Whangamoa. With the exception of the Whangamoa Fault, which is within the Dun Mountain-Maitai terrane, the faults separate the western most terranes of the eastern ranges. The Whangamoa Fault is 2.5 km west of the proposed dam sites. In addition to the major faults, there are a number of lesser faults within the fault system that strike obliquely to Waimea and other faults. Many of the faults in the fault system are active, with the ground on the southeast side of the major faults being uplifted. This progressive uplift has led to the formation of the eastern ranges and the Moutere Depression. Uplift rates on the faults are poorly known but are on average in the order of 0.2 mm/year. However, uplift is not gradual but occurs periodically, during earthquake events. In addition to vertical uplift, the faults also have a horizontal component of displacement with the northwest sides of the faults moving northeast relative to the other sides of the faults. As a consequence, the major faults, from their southeasterly dip and the sense of horizontal and vertical movements, are reverse dextral faults.

2.2.2 Alpine Fault

The Alpine Fault trends ENE from Tophouse into the Wairau valley and is about 23 km southeast of the dam sites. This major fault represents the progression of the boundary between the Australian and Pacific plates through the South Island of New Zealand. Although in the Wairau valley the fault has a vertical component of movement, resulting in the uplift of the Richmond Range, it is largely a dextral strike-slip feature with the eastern ranges on its northwestern side moving northeast relative to the other side of the fault. In contrast to the Waimea-Flaxmore Fault System, the Alpine Fault is largely confined to a single trace that offsets alluvial and other deposits filling the Wairau valley. The slip rate on this section of the fault has been estimated at 4.5 mm/year.

2.2.3 Other faults

In addition to the Waimea-Flaxmore Fault System and the Alpine Fault, there are numerous other faults within the eastern ranges. Most are relatively minor but two, the Wards Pass and Totara Saddle faults, are of more significance. The Wards Pass Fault is a relatively major fault with a well developed crush zone and has been traced from the Alpine Fault northwards into the Wairoa catchment where it crosses the Lee River 3.5 km upstream of the uppermost dam site. North of the dam site the fault has not been identified. Approximately 3 km north of the proposed dam sites is the Totara Saddle Fault, which trends ENE and appears to be the most southwestern part of the Queen Charlotte Fault Zone that extends through the northeast of the South Island. Neither the Wards Pass nor the Totara Saddle faults display any known evidence indicating that they are active. While most of the faults within the eastern ranges are categorised as dead faults, reactivation cannot be totally discounted for some faults such as the Wards Pass Fault and the Totara Saddle Fault. Inactive or dead faults are still important from an engineering perspective as they can comprise zones of very weak material as well as being potential conduits for groundwater.

3 Earthquake Risk

The eastern ranges are subject to earthquakes that could originate on the Waimea-Flaxmore Fault System, the Alpine Fault or from more distant events.

3.1 Waimea-Flaxmore Fault System

The Waimea-Flaxmore Fault System extends from Tophouse northeastwards into the Taranaki Region and is a major structural feature. Although the position of the faults within the fault system are, except where concealed by alluvium, well defined on shore, the activity of the system, and its component faults, is generally poorly known. From Tophouse northeast to almost the mouth of the Wairoa Gorge most of the major faults within the fault system display evidence of rupture of the ground surface, the result of large shallow earthquake events. Northeast of the Wairoa Gorge, evidence of surface rupture is limited to a 2 km length of the Eighty-eight Fault east of Richmond, a 14 km section of the Whangamoa Fault in the Whangamoa and Wakapuaka valleys and along the 2 km long Bishopdale Fault, which connects the Flaxmore and Waimea faults near Bishopdale. All of this evidence indicates that the activity on the Waimea-Flaxmore Fault System decreases northeastwards away from the Alpine Fault.

Because the age of surfaces offset by the faults is poorly constrained or, where dated, are relatively old (such as the Last Glaciation outwash surface that was deposited c.18,000 years ago) it is, without subsurface investigations such as trenching or seismic surveys, generally impossible to assign either frequency of earthquakes (recurrence interval) or determine the amount of displacement, both in a vertical and particularly horizontal sense. This information is critical in determining the magnitude of earthquake events arising on the fault system. This in turn constrains the determination in the eastern ranges of the level and frequency of the risk posed by severe earthquake induced ground shaking arising from movement of a fault within the Waimea-Flaxmore Fault System. However, because the dominant characteristic of the faults within the fault system is reverse, it is likely that surface rupture during an earthquake event is confined to relatively short lengths of a particular fault, as is borne out of the ground displacements recorded by the Eighty-eight and Whangamoa faults northeast of the Wairoa Gorge.

On the Waimea Plains near the mouth of the Wairoa Gorge, the Waimea Fault vertically displaces a last glaciation gravel outwash surface by about 3.5 m and, from trenching, it has been determined that this has arisen from three earthquake events[3]. Thus the amount of vertical displacement during each earthquake averages a little over 1.0 m but the horizontal component has not been determined. Dating shows that the last earthquake event occurred between 5,650 and 6,810 years before present but the earlier events are less well constrained (between 7,200 and 13,800 and 1,300 and 20,000 years before present) so that, without further information, the apparent RI of 6000 years should be treated with caution. In other words, it is not known whether the fault moves at regular or irregular intervals. It also needs to be recognised that the Waimea-Flaxmore Fault System comprises a large number of faults so that the frequency of earthquakes will be higher than indicated by the trenching at one location on a segment of a single fault, in this instance the Waimea Fault.

From the available information, the maximum credible earthquake is likely to be between M=6.9 and 7.1 as defined on the Richter Scale. Assuming that this occurred on the Whangamoa Fault, the closest known component of the Waimea-Flaxmore

Fault System to the proposed dam sites, this could result in ground shaking at the site, as measured on the Modified Mercalli Scale, of MM=IX. Because of the nature and configuration of the Whangamoa Fault in relation to the rest of the Waimea-Flaxmore Fault System, it is more probable that an earthquake would originate on one of the more western faults, such as the Waimea or Eighty-eight. Nevertheless, if the earthquake were centred on the lower Wairoa River, then the level of ground shaking at the dam site(s) would only be marginally reduced. Because the Waimea-Flaxmore Fault System has a low recurrence interval (that is earthquake events originating on it are relatively rare), and that only a relatively a short length of one of the component faults would likely be involved, this decreases the possibility of an earthquake being centred close to the dam sites. Thus rupture further away would reduce the level of ground shaking to MMVIII.

3.2 Alpine Fault

The active Alpine Fault lies 22 km southeast of the Lee River dam sites. While the activity on the fault southwest of Tophouse is relatively well known, there is uncertainty with respect to the section within the Wairau valley. At Tophouse, trenching has determined that an earthquake event has occurred on the fault sometime in the past 1600 years. From the trench results, Yetton (2002) concludes that sufficient strain has accumulated so that there is a high risk of rupture on the Wairau Section within conventional planning periods. Yetton's data is also consistent with that obtained by the Institute of Geological & Nuclear Sciences on the Alpine Fault in the middle Wairau valley[4]. However, subsequent work[5] in the lower Wairau valley near Renwick indicates that there may have been fault rupture within the last 500 years. Because, near Renwick, there are two distinct, but sub-parallel, faults this does not necessarily negate the work of the Institute of Geological & Nuclear Sciences. For the purposes of this report it is assumed that there is a high probability of rupture along the Wairau Section of the Alpine Fault within the planned life of the dam. The resulting Maximum Credible Earthquake, accompanied by up to 3.5 m or greater horizontal displacement with vertical displacement exceeding 1 m, is likely to be in the range of M7.3-7.7. Unlike the Waimea-Flaxmore Fault System, the Alpine Fault will likely rupture along its entire length in the Wairau valley, and possibly even further afield, and the level of ground shaking at the dam sites will be MM VIII, bordering on MM IX. Consequently, the level of ground shaking from rupture on either the Alpine Fault in the Wairau valley or on a component of the Waimea-Flaxmore Fault System will produce similar levels of ground shaking at the potential dam site(s).

3.3 More Distant Events

Earthquakes centred beyond the proposed dam site(s) and its environs will cause severe ground shaking but less than anticipated for an event originating on the Alpine Fault or the Waimea-Flaxmore Fault System. The 1848 Marlborough Earthquake, M7.4-7.7, produced ground shaking levels estimated at MM=VII at the potential dam sites, whereas for the 1929 Murchison Earthquake (M7.8) and the 1968 Inangahua Earthquake (M7.1) the levels would have been MM VIII, bordering on MM VII, and MM V respectively.

3.4 Return period for Ground Shaking at the Potential Dam Sites

The return period for strong to very strong ground shaking in the area within which the dam sites occur has been calculated as follows[6]:

Estimated Mean Return Periods	% probability for MM VII	% probability for MM VIII
MM VII 25 years	50 years 87%, 100 years 98%	50 years 43%, 100 years 67%
MM VIII 88 years		
MM IX 350 years		

4 Slope Failure

The slopes enclosing the dam site(s), and its reservoir, consist of a shallow mantle of superficial deposits arising from the weathering of the underlying bedrock of the Caples Group. The bedrock is generally competent and, although well-bedded with an abundance of siltstone, bedding planes are generally steep and aligned obliquely to the Lee River. Consequently, except for shallow failure involving the superficial mantle, the risk of large scale slope failure directly impacting on the dam or its reservoir is assessed as low. Nevertheless, a MM VIII level of ground shaking would result in numerous slope failures throughout the Lee catchment, which would increase bed load of the Lee River and ultimately lead to a reduction in reservoir capacity. However, this situation would apply throughout the eastern ranges.

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[1] Johnston, M.R. 1982: Sheet N28BD – Red Hills. Geological Map of New Zealand 1:50 000. Wellington, Department of Scientific and Industrial Research.

[2] Rattenbury, M.S.; Cooper, R.A.; Johnston, M.R. 1998: Geology of the Nelson area. Institute of Geological & Nuclear Sciences 1:250 000 geological map 9.

[3] Fraser, J.G.; Nicol, A.; Pettinga, J.R.; Johnston, M.R. 2006: Paleoearthquake investigation of the Waimea-Flaxmore Fault System, Nelson, New Zealand. Proceedings of New Zealand Geotechnical Society 2006 Symposium, Nelson, February 2006

[4] Zachariasen, J. et al. 2001: Size and timing of large prehistoric earthquakes on the Wairau Fault, South Island

[5] Yetton, M.D. 2003: Paleoseismic trench investigation of the active trace of the Wairau section of the Alpine Fault, Renwick Area, Marlborough Distri

[6] Coote, T.P.; Downes, G.L. 1995: Preliminary assessment of Earthquake and Slope Instability Hazards in Tasman District. Institute of Geological and Nuclear Sciences Client Report 41430D.16 prepared for the Tasman District Council.