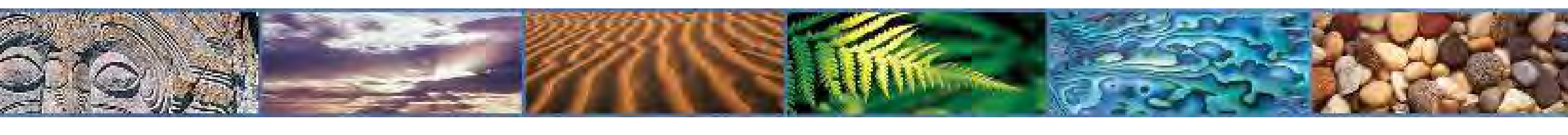
REPORT

Hawkes Bay Regional Council

Ruataniwha Water Augmentation Scheme
Advanced Prefeasibility Geotechnical Investigation Report

Tonkin & Taylor

ENVIRONMENTAL AND ENGINEERING CONSULTANTS



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Ruataniwha Water Augmentation Scheme
Advanced Prefeasibility Geotechnical Investigation Report

Report prepared for:

Hawkes Bay Regional Council

Report prepared by:

Tonkin & Taylor Ltd

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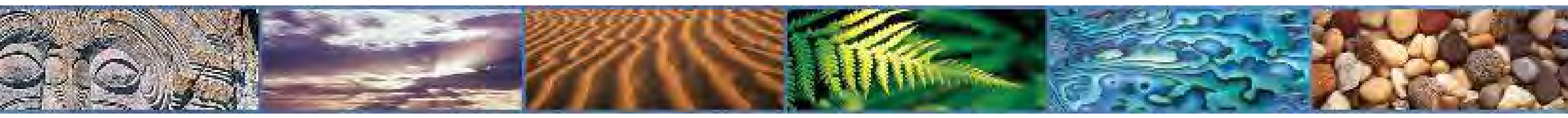

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Executive summary

Initial prefeasibility studies for irrigation of the Ruataniwha Plains in Central Hawkes Bay, largely as a desk study, have identified up to 12 potential dam storages located off the main rivers. Tonkin & Taylor has been commissioned to undertake an extension of prefeasibility studies, described as “Advanced Pre-feasibility”, with more detailed feasibility studies to follow. The geotechnical investigation presented in this report comprises an important component of the Advanced Pre-feasibility studies. The 12 potential dam storages identified during the initial prefeasibility studies plus three further storages identified subsequently have been investigated.

The main objectives of the geotechnical investigation are summarised below:

- Walk over each of the prospective sites, which previously have only been assessed by a desk study, or for some of the sites, by a brief site visit;
- Highlight any sites that appear “fatally flawed” or difficult to consent in terms of geotechnical issues based on a walkover inspection in order to prioritise remaining sites for further investigation and design stages;
- Identify issues and risks related to the geology and geotechnical aspects with the intention of ranking the sites and so as to provide guidance for further investigation.

These objectives were achieved via a geological mapping exercise carried out by Bernard Hegan, a senior geologist, accompanied by a geotechnical engineer (either Dewi Knappstein or Graeme Twose depending on the site). The mapping exercise was carried out over three visits in 2010: 3rd - 6th May, 24th - 27th May and 17th November. Approximately half a day was spent at each site. A 13th site (D3) was added into the roster for the second block of inspections (24th-27th May) following unfavourable findings for two sites at the southern end of the subject area during first block inspections. A further two sites, A7 and D5, were identified during the civil engineering studies progressing in parallel with the geotechnical investigation, and were inspected on the 17th November.

Our findings from this study are summarised in the following table. In terms of geotechnical issues, Sites A1, A2, A4, A7, B1, B2, C2, C3, D3 and D5 were deemed appropriate for study during further design stages, whereas Sites A5, B3, C1, D1 and D2 were judged as unfavourable. The favoured sites are highlighted in the table below.

Table 1-1 Severity of Issues and Risks for Sites in terms of Consenting

Site	Active faulting	Dam footprint foundation issues	Abutment foundation issues	Reservoir rim instability	Leakage potential	Borrow scarcity
A1	High	High	Moderate	Moderate	High	Minor
A2	Minor	Moderate	Moderate	Moderate	Moderate	Minor
A4	Minor	Moderate	Moderate	Minor	High	Moderate
A5	High	High	Minor	High	High	Moderate
A7	High	Moderate	Moderate	Moderate	Moderate	Minor
B1	Moderate	Moderate	Minor	Moderate	Moderate	Moderate
B2	Minor	Minor	Minor	Moderate	Moderate	Moderate
B3	Minor	Moderate	High	Moderate	Moderate	Moderate
C1	High	Moderate	High	High	Moderate	Moderate
C2	Minor	Moderate	Minor	Moderate	Moderate	Moderate
C3	Minor	Minor	Minor	Minor	Moderate	Minor
D1	Severe					
D2	Severe					
D3	Minor	Minor	Minor	Minor	High	Moderate
D5	Minor	Moderate	Moderate	Moderate	Moderate	Minor

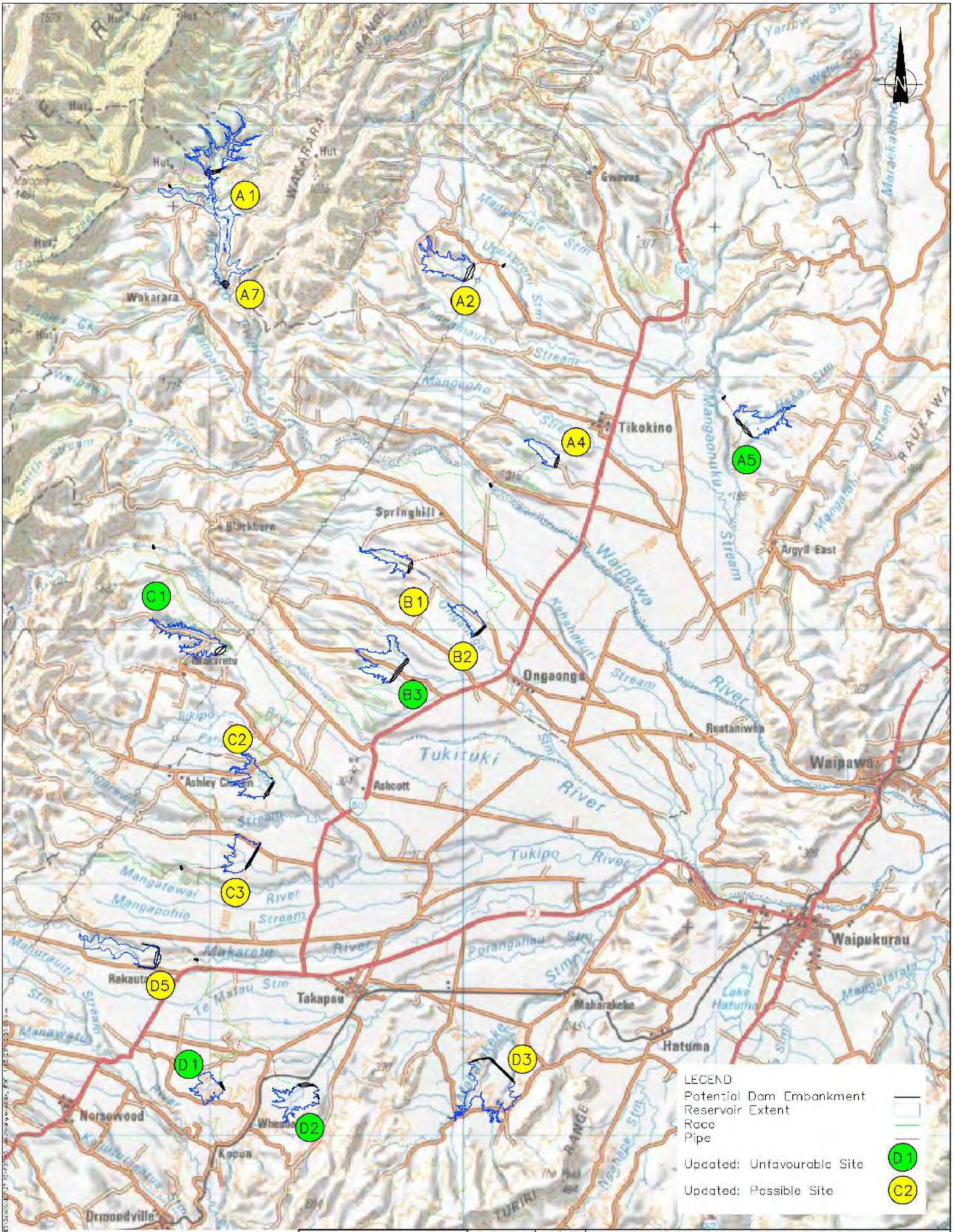
The seriousness of the identified issues and risks is identified in terms of four categories, in order of increasing inclemency: minor, moderate, high, and severe.

1 Introduction

This report presents the findings from a "walkover" geotechnical investigation carried out as part of an Advanced Prefeasibility study for water augmentation opportunities on the Ruataniwha Plains in Central Hawkes Bay. The study has been carried out for Hawkes Bay Regional Council (HBRC) by Tonkin & Taylor Limited (T&T), Environmental and Engineering Consultants. Fifteen potential off-river dam storage sites were inspected during the investigation with the aim to identify any "fatal" flaws based on the field inspection and rank sites in terms of geotechnical issues and risks. These sites are identified in the following figure.

Section 2 of this report provides an overview of the regional geology in the subject area. The main body is comprised by Section 3, which describes each site in terms of the published geology, our observations on site, geotechnical issues and risks identified and further investigation recommended for later stages. Section 4 presents an assessment of borrow sources in the region including discussion of laboratory test results. Lastly, Section 5 addresses the relative importance of the geotechnical issues and risk presented in Section 3 by ranking the sites with respect to these aspects.

The criteria used to assess geotechnical issues and risks was based on the field identification of features such as active faults, landslides and leakage features (tomos) both within the dam footprint and the proposed reservoir. The assessment was judgement based.



A3 SCALE 1:125,000

0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 (km)

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SCALES (AT A3 SIZE)	AS SHOWN	
PROJECT No.	27195	

Hawkes Bay Regional Council

Ruataniwha Water Augmentation Scheme

Central Hawkes Bay

Preliminary Scheme Arrangement (June 2010)

FIG. No. Figure 1 REV. 1

2 Regional Geology

2.1 Geological history

The Ruataniwha Plains lie in an intermontane basin, formed by downwarp and faulting between the Ruahine Range in the west and Turiri/Ruakawa Ranges in the east. North-east trending faults bounding the plains have been active throughout the life of the basin. Sediments within the basin record a history of gravel outwash terraces with interbedded siltstone/sandstone beds of both freshwater and shallow marine origins.

In general, the highest and most dissected terrace surfaces are the oldest and are underlain by the most weathered "red metal" greywacke gravels. Younger, lower level, terraces form flights within the recent valleys and are underlain by less weathered gravels. Figure 2-1 illustrates a typical arrangement of different ages of terraces.

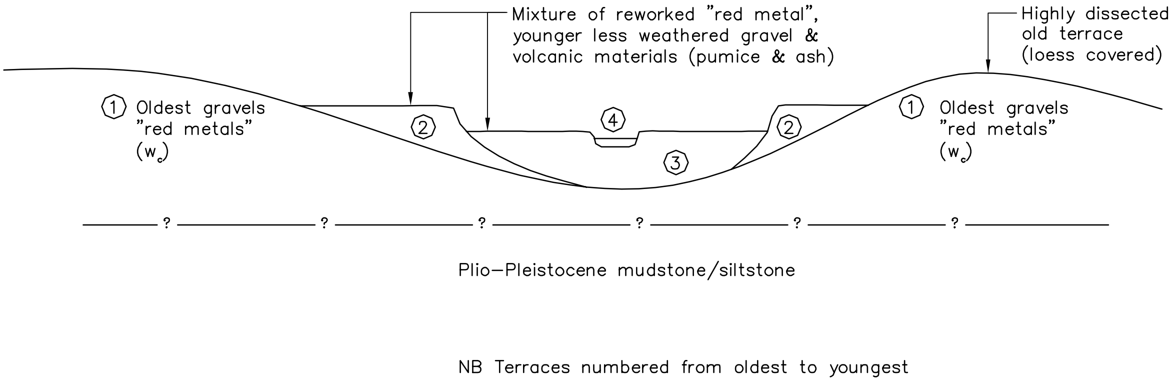

Figure 2-1 Typical cross valley section showing different ages of terraces

At the northern end, subhorizontally bedded pumiceous sediments are preserved at similar heights on both sides of the basin, suggesting the presence of a lake or shallow marine environment.

2.2 Published maps

A description of the regional geology of the central Hawkes Bay is provided by Kingma in the 1:250,000 N.Z. Geological Survey Map for Dannevirke[1]. The basement rocks in the subject area are described as Mesozoic aged indurated greywacke sandstone and argillite of the Ruahine and Wakarara Ranges. Tertiary aged soft weak sedimentary rocks outcrop in the lower Turiri and Raukawa Ranges to the east, and in the Ohara Depression between the Ruahine and Wakarara Ranges in the west. The low land of the Ruataniwha plains between these two north-east aligned ranges appears structurally controlled, either as a down warping of a synclinal structure or as a fault bounded graben that has been filled with the younger alluvium during Late Pleistocene to Quaternary times. The younger sediments are dominated by weathered greywacke fluvioglacial gravels (red metal) forming a series of terrace surfaces extending east from Ruahine and Wakarara Ranges. Pumiceous materials from volcanic eruptions in the Central North Island are interbedded in the gravels and the older terrace surfaces are mantled by windblown loess.

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand 1:250,000" Department of Scientific and Industrial Research, Wellinton, New Zealand.

2.3 Active faulting

Active faults with a north-east alignment are present on both sides of the Ruataniwha plains. The Institute of Geological and Nuclear Sciences (IGNS) has produced a report detailing locations of faults, and estimated return periods and slip rates for movement along these faults. Spectral accelerations at dam sites for various return period seismic events, including the Maximum Design Earthquake (MDE), are also provided in the IGNS report. This report is included as Appendix E.

Active faults were also identified in the field at sites A5, D1 and D2, confirming the IGNS active fault database which, in part, is based on aerial photograph interpretation.

3 Site Specific Investigations

3.1 Introduction

The field investigation was carried out by Bernard Hegan, senior engineering geologist, and Dewi Knappstein or Graeme Twose (depending on the particular site), geotechnical engineers. Access was arranged with landowners by Kelvin Fergusson (HBRC), with a follow up phone call from T&T to confirm dates and times we would be on site.

The T&T team spent approximately half a day at each of the dam sites, mapping geological features such as landslides, investigating exposures in river and road cuttings and measuring bedding and joint angles and directions. The features identified were located using a hand held GPS, and the observed landforms and exposures were documented via photography.

In addition, aerial photography and contours derived from LiDAR supplied by HBRC provided critical information for our investigations. Inspection of these photos and contours allowed us to identify features of interest prior to our site visit, and subsequent to our visit provided a view of features encountered in the field in a broader context.

The primary reference used as a guideline for geological setting has been Sheet 11 Dannevirke 1962 1:250,000 N.Z. Geological Survey Map for Dannevirke[1]as the QMAP for the Hawkes Bay is still being developed by GNS Science and is currently not available. Sheet 11 was mapped by J.T. Kingma in 1962 and when the new mapping becomes available the interpretation of the structural geology is likely to change.

3.2 Site A1

3.2.1 Site visit details

Site A1 was visited on the afternoon of Monday 3rd May 2010. Access was via Wakarara Road. The dam is located on Dutch Creek, a tributary of Makororo River.

3.2.2 Geological setting

Site A1 is located within the Ohara Depression, a downthrown block (graben) of Plio-Pleistocene sediments lying between Jurassic aged greywacke of the Ruahine Range and the Wakarara Range. The block is bounded by the major north-north-east Ruahine and Mohaka Faults. The Plio-Pleistocene sediments within the Ohara Depression comprise light blue grey, fossiliferous, calcareous sandy siltstones with sandstone bands and lines of concretions.

3.2.3 Detailed observations

Our detailed field observations are summarised in Figure A1 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X1 of Appendix B.

Access to the proposed dam site was gained from the end of Wakarara Road at Makororo River. From the DOC information board on the south side of Makororo River, we walked downstream to the confluence of Makororo River with Dutch Creek and then continued up Dutch Creek to the dam site (originally proposed) and 800m beyond into the reservoir.

Extremely weak fine sandstone is exposed in the cliff at the northern edge of Makororo River (refer Figure 3-2). A cemented layer was seen in the sandstone separating dry (upper) and wet

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand.

(lower) sandstone, and minor slabbing was visible near the base of the cliff (refer Figure 3-3). Figures follow on pages 8 to 15, and are similarly included for each dam site.

The dam site and the observed portion of the reservoir is sited in extremely weak to very weak siltstone with minor shell beds (dipping 10°-20° S downstream). The transition from sandstone to siltstone is located about halfway between the Makororo River-Dutch Creek confluence and within the original proposed dam site. (The locations of the original and modified dam sites as discussed below are shown in Appendix A. The "original" dam site referred to is the site identified in the "Prefeasibility Study of Water Augmentation Opportunities – Ruataniwha Plains" (T&T June 2009)). A capping of red metal gravel was observed overlying the siltstone at the top of the incised river banks. Concretions, up to 2m in diameter, outcrop in the stream bed near the upstream toe of the original dam site.

Landsliding and tectonically disturbed zones in the rock mass were observed at many places along Dutch Creek. Shearing was evident on defects and in particular on low angle downstream dipping bedding planes and on steeper dipping joints (refer Figure 3-7).

In particular, landsliding on a shear zone dipping at 40° towards 285°-290° was mapped within the footprint of the original dam site (refer Figure 3-6) and 250m downstream (refer Figure 3-4). The two observations of the shear zone plot on a straight line and it is likely that the defect is continuous between the two observations. If so, the shear zone may indicate the presence of faulting subparallel to the nearby major Ruahine and Mohaka faults.

An alternative dam site was identified some 500m upstream of the originally proposed site (refer Figure 3-11). At the alternative site the rock mass appears more massive, and the postulated fault would cross the embankment east of the deeply incised stream valley. Both sites are characterised by bedding plane defects dipping at low angles downstream that may transmit reservoir water pressures beneath the dam (refer Figure 3-8), and a zone of highly disturbed rock mass indicative of significant tectonic disturbance was noted at the location of the upstream toe of the alternative dam (refer Figure 3-12).

Figure 3-1 Fine sandstone exposed in cliff along northern edge of Makororo River capped by red metals

Figure 3-2 Fine sandstone exposed in cliff along northern edge of Makororo River (top to bottom: red metals, dry fine sandstone, cemented layer, wet fine sandstone with slabbing)

Figure 3-3 Minor slabbing at base of cliff along Makaroro River

Figure 3-4 Landsliding on joint dipping 40 degrees to 290 degrees 250m downstream of original dam location

Figure 3-5: Landsliding on a shear zone dipping 40 degrees W

Figure 3-6 Landsliding on a low angle bedding plane defect

Figure 3-7 Slope failure on steep joints 85 degrees to 360 degrees

Figure 3-8 Bedding plane measurement near upstream toe of original dam location 16 degrees to 170 degrees

Figure 3-9 Seeps from stress relief jointing near upstream toe of original dam location.

Figure 3-10 Landsliding on bedding plane shear 15 degrees to 158 degrees

Figure 3-11 Alternative dam site

Figure 3-12 Disturbed zone at upstream toe of alternative dam location indicating significant tectonic disturbance

Figure 3-13 Defects developed above bedding plane shear at 16 degrees to 150 degrees (at upstream extent of survey)

3.2.4 Issues and risks

Dam footprint foundation

Significant tectonic disturbance of the rock mass was noted in some areas of the site. A probable shear zone (fault) was identified trending parallel to major nearby faults. This shear zone would cross under the originally proposed embankment in the valley floor where the embankment is close to its maximum height. An alternative site has been nominated where the rock mass appears less disturbed and more massive. However, the identified shear zone will still cross under the embankment but at a lower dam height. The site will require design for high ground accelerations and may also need to allow for movement under the embankment should sympathetic movement along this zone occur during nearby major fault rupture.

Bedding was observed dipping between 10 to 20 degrees in the downstream direction. If not addressed by appropriate design, reservoir water pressures can be transmitted via the unfavourably oriented bedding planes under the embankment reducing its stability. Note that some shearing was detected along bedding planes. However, this may be related to tectonic stresses rather than ongoing instability, which should be confirmed via drilling.

Some minor slabbing and stress relief jointing associated with seeps was noted during our site visit.

Abutment foundations & reservoir rim stability

Our inspection was restricted to the main stream channel, which was bounded by steep sides in the order of 30m high. The embankment is expected to extend up to 30m or so higher than these cliffs so that the reservoir rim and abutments would be located well beyond the area directly inspected.

However, based on our observations in the general area and published geological maps, we expect that issues for the abutment and reservoir rim integrity will be similar to those discussed above regarding the dam footprint. Although the terrace beyond the river banks is expected to be capped in red metals, the underlying Opoitian siltstone (and possibly sandstone) is likely to be subject to significant tectonic disturbance. As for the dam footprint, design for high ground accelerations will be necessary.

Water tightness

The terrace beyond the steep river banks / cliffs of Dutch Creek is expected to be capped in red metals. A thickness of 4m was measured at one point along the creek. As mentioned above, the embankment will extend above the river banks and across this terrace. Investigation efforts and design works will need to address seepage through the terrace gravels under the embankment.

In addition, seepage via bedding planes and joints in the siltstone will need to be considered. Although, seepage through the siltstone may not involve significant rates of water loss, it is likely to have implications for stability as described above.

Borrow material

A capping of red metal was observed intermittently at the top of the Dutch Creek banks, and was measured as 4m thick at one location. This red metal could provide a source of bulk fill. Greater thicknesses (17m) were observed at Makororo River, but at a longer haul distance. The Opoitian siltstone is also expected to be suitable as borrow based on visual inspection.

3.2.5 Recommendations for future investigation

Further investigation into the shear zone or fault that has been identified during our investigation will be valuable in determining the viability of Site A1. In particular, this investigation should include confirming / disproving the fault's presence, locating its extent precisely, assessing its activity, and estimating its likely extent of movement (whether sympathetic or otherwise).

Laboratory testing of the potential borrow sources collected by test pitting will, as is customary, be required to confirm viability as fill and provide parameters for embankment and filter design. Test pitting could also be of use in determining the thickness of terrace gravels, which will provide information on estimating the quantity available as fill, and assessing seepage potential under the embankment on the terrace.

Investigations within the dam footprint in the valley floor should include a series of cored drill holes and installation of standpipe piezometers for permeability testing. Drilling will also help determine whether bedding plane shears and jointing are related to tectonic stresses or ongoing instability.

If this site is selected for development, we also recommend direct inspection and mapping of the reservoir rim and abutments.

3.3 Site A2

3.3.1 Site visit details

The site was visited by our team on the afternoon of Thursday 27th May 2010. Access was via a private driveway at 1031 Matheson Road.The dam is located on the Middle Upokororo Stream, a tributary to Mangamauku Stream.

3.3.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] indicates that the dam is located within Pleistocene aged materials close to the contact between Castlecliffian sediments and the Hawera Terraces.

The Hawera Terraces are identified as “h2” in the N.Z. Geological Survey Map, and follow the valley downstream of the dam. Kingma describes these “h2” terrace systems as mostly intact, or only slightly dissected, comprising slightly weathered gravels with volcanic sands and lignite bands.

The Castlecliffian sediments, identified as “w_c”, are mapped upstream of the dam site. The “w_c” sediments are described as gravels, sands and silts with or without pumice bands, either in marine sequences or in much dissected high terraces, with terrace gravels being strongly weathered.

3.3.3 Detailed observations

Our detailed field observations are summarised in Figure A2 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X1 of Appendix B.

Highly weathered greywacke gravels (red metal) with interbedded loess derived silt bands are exposed in the upper valley sides as remnants of old high level terraces (refer Figure 3-18). These older high level terrace greywacke gravels (refer Figure 3-14) appear to overlie the blue-grey siltstone with well developed “greasy” sub horizontal bedding planes exposed in the stream bed in the valley floor (refer Figure 3-15). Exposures of cemented unweathered greywacke gravels are encountered in the stream bed with increasing frequency in the downstream direction including at the proposed dam site (refer Figure 3-17). The reason the exposures of older cemented greywacke gravels and siltstone alternate in the stream bed is unclear and may indicate the presence of paleochannels. Lignite clasts were seen in the river channel, though the source was not found. Younger, lower level greywacke terrace deposits form the flat valley floor.

Large scale landsliding, predominantly rotational, was observed in the nearby Mangamauku Stream valley (refer Figure 3-19). Inspection of exposures in the Mangamauku Stream valley

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand

show that the materials involved in the landsliding are similar to those exposed in the valley at the proposed dam site. The landsliding is likely to be occurring on the upper surface of the siltstone or on well developed bedding planes within siltstone as noted in the Middle Upokororo Stream valley, possibly due to strong earthquake shaking. Inspection of contours suggests there might be similar instability upstream of 394mRL (Mean Sea Level = 10mRL) in the Middle Upokororo Stream, which will be within the upper reaches of the proposed reservoir if the storage volume is set above 13 million m^3.

Figure 3-14 Stream meanders eroded into the lower (younger) red metal terrace. Older heavily dissected terrace deposits form the background hills

Figure 3-15 Red metals (interlayered with silt) overlying blue-grey clayey SILTSTONE with well developed "greasy" bedding planes

Figure 3-16 Unweathered cemented greywacke gravel with bedding exposed within dam footprint

Figure 3-17 Cemented greywacke gravel dipping downstream

Figure 3-18 Highly weathered greywacke gravel (red metal) with interbedded loess derived SILTSTONE in upper ridges

Figure 3-19 Landsliding in Mangamauku Stream valley

Figure 3-20 Extremely weak SILTSTONE with thin white pumice sands interbeds exposed in the floor of the Mangamauku Stream

3.3.4 Issues and risks

Dam footprint foundation

The dam footprint crosses a number of material types and design will need to address the potential for differential settlement.

Abutment foundations

The large scale slope instability seen in the neighbouring Mangamauku Stream valley indicates that bedding plane defects in the underlying older siltstone are characterised by lower shear strength, and if present in the proposed dam abutment, their potential impact will need to be carefully assessed under earthquake loading.

Reservoir rim stability

As mentioned above, contours indicate instability in the Middle Upokororo Stream banks upstream of 394mRL (MSL=10mRL), which will be within the upper reaches of the proposed reservoir if the storage volume is set above 13 million m^3. Only minor instability was observed around the remainder of the reservoir.

Water tightness

Seepage through the younger terrace gravels under the dam, particularly along paleochannels, if present, is an issue that will need to be addressed by investigation and design.

Borrow material

Younger red metals are present in sufficient thickness for borrow within the reservoir footprint. This is preferred in terms of increasing reservoir volume and minimising impact on surrounding land. However, there is variability in the fines content and corresponding permeability of the gravels in the region, and if the younger red metals prove unsuitable it may be possible to borrow from the older more weathered red metals in the valley ridges. Alternatively there may be potential to borrow from the siltstone bands within the valley ridges or floor to blend with the red metal or use as a core in a zoned embankment dam. It may also be possible to locate areas of (thin) surface loess to blend with gravels.

Other

Lignite clasts were observed within the stream bed, and if the source is within the reservoir there may be issues with weak bedding planes associated with coal measure deposition.

The impact of filling the reservoir and increasing ground water pressures on the Mangamauku landslide should be assessed.

3.3.5 Recommendations for future investigation

Investigations within the dam footprint in the valley floor should include a series of cored drill holes and installation of standpipe piezometers for permeability testing. If the underlying paleotopography appears irregular, geophysical surveys (such as seismic refraction) may provide better definition of the paleotopography. The presence or not of weak bedding plane surfaces (shears) will require careful assessment in the subsurface investigations.

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests.

During feasibility design the mechanism of the Mangamauku Stream landsliding should be assessed in greater detail, to facilitate the assessment of abutment stability and impacts on the Mangamauku landsliding, if any, of filling the proposed reservoir.

3.4 Site A4

3.4.1 Site visit details

Site A4 is located on a tributary of Mangaoho Stream. Our team visited the site on the afternoon of Wednesday 26th May 2010. Access was via 191 Glenavon Road at the end of the no-exit road.

3.4.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke (Kingma[1]) shows the dam located within Castlecilffian aged sediments described as gravels, sands and silts with or without pumice bands, either in marine sequences or in dissected high terraces, with terrace gravels being strongly weathered. Younger terrace gravels floor the valley.

3.4.3 Detailed observations

Our detailed field observations are summarised in Figure A4 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X1 of Appendix B.

The local materials forming the ridges to the valley appear to comprise predominantly weathered greywacke gravel (red metal) interbedded with silt and minor pumice. These ridges are the remnants of the old high level terrace now deeply eroded by the present streams. Exposures of these materials were seen within the reservoir, upstream of the reservoir where Holden Road crosses the subject stream (refer Figure 3-26), and at road cuttings on SH50 north of Glenavon Road. Drillers' logs, provided by HBRC, for three water bores (ID 1333, ID 109778 & ID 10979) up to 34m deep near the right abutment also accord with observations of red metals interbedded with silts.

Medium dense sand is exposed in the stream banks within the dam footprint and may underlie the weathered greywacke gravels in the abutments. While on site we noted that the water flowing in the permanent stream bed disappears underground for sections (refer Figure 3-21, 246mRL approximately). The driller's log for water bore ID 1333 above the right abutment also recorded water bearing sand at a depth of 33.2m (approximately 233 mRL).

The valley is floored by young terrace gravels which may obscure an older deeper channel beneath the dam footprint on the left side of the valley floor.

In discussions during our site visit, local landowners indicated that there had been significant changes in the local surface and ground water systems, recalling when the land was covered by Kahikatea forest and that some areas of swamp had developed into relatively dry land crossed by distinct streams. They also described work within the last 45 years to control local stream bank erosion. Concrete erosion control structures are still in evidence.

Observations during our site visit confirmed that a complex groundwater system exists. For instance, despite heavy rain during the night prior to our visit, the stream bed was dry in most places with ponding in other places. Seeps were also observed close to the top of the ridge downstream of the left abutment and emerging within the terraces. The drying of the stream bed is likely to be related to a high permeability layer, such as the sand noted in the stream bed downstream of the dam embankment. The high level seeps may be related to the less permeable lenses and beds of silt within the red metals.

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand 1:250,000" Department of Scientific and Industrial Research, Wellinton, New Zealand

Figure 3-21 In creek downstream of dam: red metal overlying horizontally bedded sand

Figure 3-22 Downstream of left abutment: Fence displaced at wet gully bulge

Figure 3-23 Downstream of left abutment: Seeps near top of ridge

Figure 3-24 At left abutment looking towards right abutment

Figure 3-25 Holden Road crosses subject stream, upstream of reservoir: panning from downstream to upstream

Figure 3-26 Holden Road crosses dammed stream, upstream of reservoir: red metals with occasional siltstone lenses

3.4.4 Issues and risks

Dam footprint foundation

Seepage under the dam appears likely over a range of depths and requires thorough investigation.

Abutment foundations

Likewise, seepage through the abutment ridges requires investigation as localised land instability is currently occurring where permeability contrasts exist.

Reservoir rim stability

Only minor apparently shallow seated land slippage was observed within the reservoir (refer Figure 3-26).

Water tightness

Extensive investigation will be required to address water tightness under the dam and through the dam abutments. The seeps observed downstream of the left abutment indicate that there are seepage paths through the ridges bounding the reservoir. The dry stream bed combined with the sand exposed in the stream bed downstream of the proposed embankment indicates that seepage under the dam is also an issue for consideration.

Borrow material

The red metals exposed within the reservoir footprint could be used for borrow. However, there is variability in the fines content and corresponding permeability of the gravels in the region. Therefore a low permeability material may need to be sourced, either to blend with the red metal or use as a core in a zoned embankment dam. This lower permeability source might possibly be provided by the older more weathered red metals in the valley ridges, or from the bands of silt interbedded in the gravels within the valley ridges and floor if present in sufficient thickness. However, further investigation is needed to confirm these sources are suitable.

3.4.5 Recommendations for future investigation

Investigations within the dam footprint by cored drill holes with the installation of standpipe piezometers for permeability testing should be undertaken to determine leakage potential. If the underlying paleotopography appears irregular geophysical surveys (seismic refraction) may provide better definition of the paleotopography.

These investigations are required to provide information for addressing water tightness under the dam.

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests. This testing would enable the borrow locations to be identified for landowner negotiations.

3.5 Site A5

3.5.1 Site visit details

Site A5 was visited on the morning of Wednesday 5th May 2010. The proposed dam would be located on Te Heka Stream, a tributary of Mangaonuku Stream. The site was approached from upstream along private farm tracks off 1783 Argyll Road. We understand that others have previously accessed the site from downstream (from the west).

3.5.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the dam located within Castlecliffian sediments (as per Site A4) described as gravels, sands and silts with or without pumice bands, either in marine sequences or in much dissected high terraces, with terrace gravels being strongly weathered.

3.5.3 Detailed observations

Our detailed field observations are summarised in Figure A5 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X2 of Appendix B.

Exposures generally comprised interbedded weathered greywacke gravels (red metal) and pumiceous silts and sands with occasional thin carbonaceous layers (refer Figure 3-28 and Figure 3-31). An extremely weak to very weak blue-grey siltstone underlies the pumiceous sediments in Te Heka Stream in the central portion of the reservoir (Figure 3-29). The siltstone forms a permeability contrast and groundwater seepage along the interface has produced a number of

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand 1:250,000" Department of Scientific and Industrial Research, Wellinton, New Zealand

tomos in the pumiceous sediments by internal erosion (suffusion) in the pumiceous silts (refer Figure 3-30).

Approximately 250m upstream of the proposed dam, the stream is deeply incised into a layer of pumice sands and silts at least 10m thick (refer Figure 3-32). This exposure is of particular significance for the proposed dam, which is discussed in the following section in greater detail.

The head scarp of a substantial landslide was noted on a ridge immediately north of the reservoir (refer Figure 3-33). The graben of this landslide is approximately 60m wide. Based on typical translational landslide geometry, this indicates the base of sliding is likely to be in the order of 60m deep, the toe of which will emerge near or at the top of the blue-grey siltstone overlain by pumiceous silts and carbonaceous layers observed in Te Heka Stream. Chaotic bedding in the stream at the toe of this landslide supports this observation (refer Figure 3-31). Another landslide was also observed to the east of this larger landslide, as indicated in Appendix A.

Geologically active faults are indicated within the reservoir in GNS' database. Fault expression is supported by the LiDAR contours which show the lateral transposition of the streams crossing the fault. The active fault crosses the dam axis close to the left abutment.

Figure 3-27 Eastern landslide, scarp at right of photo, smaller than landslide to west

Figure 3-28 Thin horizontal beds of pumiceous silts and sands beside stream at toe of eastern landslide

Figure 3-29 Interbedded pumiceous siltstone over softened clayey SILTSTONE

Figure 3-30 Suffusion through pumiceous silts in forming a tomo

Figure 3-31 White pumice sands and silts dipping 35 degrees to 330 degrees, underlying red metal. Chaotic bedding of pumiceous tephra indicative of major disruption at toe of landslide. Cliff height 10m.

Figure 3-32 250m upstream of dam: Pumice silts and sands, 10m thick, dipping 5-10 degrees to 260 degrees

Figure 3-33 60m wide graben of large scale landslide, viewed from west

3.5.4 Issues and risks

Dam footprint foundation

The thick (10m +) layer of pumiceous silts/sands observed 250m upstream of the proposed embankment are likely to extend under the embankment. Seepage through the pumice sediments under the dam could lead to large scale piping erosion as observed in the two tomos (caves) in the central part of the reservoir.

Abutment foundations

The presence of the active fault in the left abutment of the proposed dam has a significant impact on future development of this site with the design of the embankment having to take into account the translational movement from future fault rupture.

The substantial landslide located upstream in the right side of the valley and instabilities downstream along the edge of the Mangaonuku Stream also indicate the presence of a low strength shear surface between the underlying siltstone and overlying gravels, which may have implications for the abutment stability especially during seismic loading.

Reservoir rim stability

A further risk to reservoir rim stability relates to the remobilisation of the large landslide observed in the right side of the valley extending from the ridgeline to the stream invert during reservoir filling. It is judged likely that landslide will require either stabilisation or allowance for a significant loss of reservoir storage without overtopping should movement occur during reservoir filling.

Water tightness

Seepage via the pumiceous sands and silts, including the 10m+ thick layer expected to continue under the dam, is a significant issue to be addressed during investigation and design.

3.5.5 Recommendations for future investigation

Significant and costly investigations will be required to determine requirements for a safe high dam at this site. Even more expensive works will be required, likely making the dam uneconomic. The study team decided that Site A5 should not be considered further so recommendations are not set out.

3.6 Site A7

3.6.1 Site visit details

The site was visited on the morning of 17 November 2010. Access was gained through two farm properties on Wakarara Road. The dam is located on the Makaroro River some four kilometres south of the confluence with Dutch Creek.

3.6.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke (Sheet 11) by Kingma[1] indicates that the dam is located within an active fault bounded block of Mesozoic aged greywacke rocks. Upstream of the site Tertiary aged marine sediments (Wc) crop out within the reservoir area.

The Hawera Terraces are identified as “h2” in the N.Z. Geological Survey Map, and follow the valley downstream of the dam. Kingma describes these “h2” terrace systems as mostly intact, or only slightly dissected, comprising slightly weathered gravels with volcanic sands and lignite bands.

3.6.3 Detailed observations

The proposed dam site is located within a narrow gorge cut down through greywacke rock mass. The gorge is approximately 40m deep measured down from the true right terraced bank side and 20m wide at the base. The left abutment rises steeply to a height of 90m above river level. Our detailed field observations are presented on Figure A7 in Appendix A and a topographic section along the proposed dam centre line measured while on site using a hand held laser with an accuracy of ±2m with annotated geology observations is presented as Figure X6 in Appendix B

The rock mass exposed in the bed of the river and the sides of the gorge is generally unweathered interbedded strong indurated greywacke sandstone with interbedded argillite (indurated mudstone/siltstone). The rock mass is broken by a number of continuous joint sets. Apparently severely dilated rock conditions were observed on the entire left abutment face with what appeared to be upslope facing scarps occurring 60m above river level. Based on observations of the rock mass defects exposed at river level the dilated rock is expected to be as a result of a complex toppling/planar failure encompassing the entire face and most likely due to severe earthquake shaking. Site measurements suggest the failure extends some 30m back into the face over its full height and that the depth (horizontal width) to competent rock mass will be in the order of 20-30m (Figure 3-34).

The terrace surface on the right abutment of the proposed dam site is approximately 40m above river level and 200m wide with a slightly irregular surface. Observations of gravel thickness along the upper edge of terrace exposed in the gorge indicates a variable terrace gravel thickness ranging from a thin veneer of less than 2m up to 20m thick immediately downstream of the proposed dam site. Based on these observations it is possible that an older, higher level, meander channel is present somewhere between the present river gorge and extreme right abutment (Figure 3-35). The exposed terrace gravel consists of unweathered greywacke sandstone boulders up to 200mm diameter and cobbles with a sand matrix. In general the river alluvium consists of sub-angular to sub rounded, well graded unweathered greywacke sandstone boulders and cobbles with a sand fraction. Very little in the way of alluvium derived from the Tertiary aged sediments were observed in the river bed.

Other observations pertinent to dam development are:

- The Mohaka fault trace separating the greywacke rock mass form the Tertiary rock mass was located in the field some 900m NW from the proposed dam site (Figure 3-36)
- Tertiary aged marine sediments exposed on both the farm track into the proposed dam site and along Wakarara Road consist of extremely weak silty fine sandstone and are non plastic (Figure 3-37)

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand

Landslides were noted at reservoir margins, particularly to the west (Figure 3-38). A rapidly eroding gully associated with an observed argillite band was also observed at the reservoir margin

Figure 3-34- Dilated rock mass seen from river bed – looking south

Figure 3-35- Right abutment terrace surface, looking north

Figure 3-36 - Mohaka fault trace, looking west

Figure 3-37- Local exposures of Tertiary materials (fine sandy SILT)

Figure 3-38- Instability at reservoir margins

3.6.4 Issues and risks

<u>Abutment foundations and reservoir rim stability</u>

The left abutment is located on a steep, severely dilated rock face. The dilated rock is expected to be some 30m thick based on site observations and will require careful consideration with dam design.

Active landsliding is evident over much of the true right bank of the reservoir margin where underlain by Tertiary sediments. Flooding the toe of these mainly translational landslides is likely to reduce their stability.

The active Mohaka Fault (within 1km of the dam site) is capable of producing high ground accelerations.

<u>Water tightness</u>

The right abutment terrace may be bisected by an old meander channel, now in-filled with gravels. This meander channel daylights in the river bank upstream of the dam, and would be submerged by the reservoir providing a potential seepage path past the dam.

3.6.5 Recommendations for future investigation

A staged approach to future investigations is recommended and following the production of a topographic survey of the site detailed engineering geology mapping should be undertaken to identify the major structural elements present within the greywacke rock mass. Following this the location of the proposed dam should be reviewed to avoid as much as possible the suspect rock mass on the left abutment. Investigations including fully cored drilling with Lugeon water pressure testing are required on both abutments along with seismic refraction survey of the right abutment to determine the presence and extent of the potential meander channel (or channels).

A range of borrow materials are available near the site and will require testing for suitability for construction, either for an embankment dam or concrete faced rock fill dam.

3.7 Site B1

3.7.1 Site visit details

Site B1 was visited on the morning of Tuesday 4th May 2010. Access was via McLeod Road which terminates a short distance upstream of the reservoir. The proposed dam would be located on Ongaonga Stream, immediately upstream of Site B2.

3.7.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the proposed dam located on Castlecliffian-aged sediments described as gravels, sands and silts with or without pumice bands, either in marine sequences or in much dissected high terraces, with terrace gravels being strongly weathered.

3.7.3 Detailed observations

Our detailed field observations are summarised in Figure B1 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X2 of Appendix B.

Based on our field observations and inspection of aerial photography the proposed B1 reservoir may be subdivided into two parts separated by an inferred fault trending in a north-east direction, parallel to the major regional fault systems. Refer to Figure B1 of Appendix A for the location and orientation of this fault. The younger low level terrace deposits are not offset where the inferred fault crosses the valley floor indicating that recent movement is unlikely. This inferred fault is located upstream of the proposed embankment within the proposed reservoir and does not cross the embankment. The inferred fault would lie within side valleys (local gullies flowing into Ongaonga Stream), and differences in the materials and bedding noted in exposures and surface topography upstream and downstream of its location.

Upstream of the inferred fault, extremely weak white pumiceous siltstone and fine sandstone in thin subhorizontal beds is exposed in the valley floor (refer Figure 3-39). In some of these exposures, dark brown carbonaceous siltstone beds were noted interbedded within the pumiceous siltstone (refer Figure 3-44 and Figure 3-45). Downstream of the inferred fault, exposures comprised interbedded siltstone, sandstone and cemented gravel, in some places overlain by red metals (refer Figure 3-46 and Figure 3-47) dipping 5°S to 15°S were observed.

Active landsliding and earthflows of moderate depth were observed on both sides of the valley upstream of the inferred fault, particularly on the left side of the valley at the head of the proposed reservoir (refer Figure 3-41 and Figure 3-42). The local landowner observed that these features tended to move following periods of intense rain extending beyond three days. The landslides on the left side of the valley have active headscarps and toe bulges with the latter occurring above 312mRL approximately e.g. close to but above the potential maximum reservoir level (refer Figure 3-43). Based on the width of the headscarp and graben and the location of the

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toe bulge, the instability is most likely occurring by slippage on a horizontal bedding plane within the local materials which may also be acting as an aquiclude.

Figure 3-39 Pumiceous white silts and fine sand, subhorizontally bedded, in floor of valley

Figure 3-40 Instability in left side of valley towards upstream end of reservoir

Figure 3-41 Instability in left side of valley towards upstream end of reservoir

Figure 3-42 Pumiceous siltstone exposed in cracks associated with instability in left side of valley

Figure 3-43 Toe of landsliding in left side of valley - instability limited to above 312mRL approximately

Figure 3-44 Pumiceous siltstone with two thin dark grey carbonaceous siltstone beds (subhorizontal)

Figure 3-45 (Top to bottom:) 3m red metal, 0.4m soil, 0.8m blue-grey siltstone, 0.1m mudstone, 0.6m carbonaceous siltstone, 0.1m medium sand

Figure 3-46 Downstream of possible fault: extremely weak fine to medium sandstone interbedded with minor siltstone, dipping 5 deg downstream, overlain by gravel

Figure 3-47 Downstream of original dam location: Red metal above white massive siltstone at side of road

3.7.4 Issues and risks

<u>Dam footprint foundation</u>

The pumiceous sediments and carbonaceous beds, observed upstream of the inferred fault, may be downthrown and lie under the embankment at the currently proposed dam site. Drilling at the proposed dam site is necessary to confirm the depth to the pumiceous and carbonaceous sediments (if present). The driller's log, supplied by HBRC, for a water bore located 700m downstream of the proposed site encountered a thick layer of brown ash and white pumice 13-33m below ground, which adds weight to this interpretation of fault movement. Design works should include a consideration of the magnitude of seepage and any associated instability due to elevated water pressures and softening (as we see in the left side of the valley in the upper reservoir).

Abutment foundations

The flat tops of the ridges and exposures in the valley sides indicate that the dam abutments are likely to comprise weathered greywacke gravel (red metal) associated with old high level river terraces. These materials are expected to provide suitable foundations for abutments but will need investigation by drilling to prove continuity.

Reservoir rim stability

The main risk to reservoir rim stability relates to the active landslides and earthflows observed above reservoir level upstream of the inferred fault. The risk of material sliding into the reservoir from these areas of instability and potential displacement volume will need to be assessed, and if significant, then design will need to allow for a reduction in available storage volume during a landslide event. In addition, if the fault described in Section 3.7.3 is found to be active or subject to reactivation, a reduction in storage volume due to movement of the fault will need to be investigated and assessed.

Water tightness

Seepage via pumiceous sediments under the embankment is a potential issue if these sediments are found at a shallow depth.

The red metals observed in exposures appeared weathered, and are considered unlikely to have high permeability. Therefore seepage through the abutments is not expected to be a significant issued. However, this will need to be confirmed by drilling and laboratory testing.

Borrow material

Red metals are expected to be present in suitable thicknesses for borrow in the upper slopes of the valley downstream of the possible fault.

3.7.5 Recommendations for future investigation

Further investigation into the nature of the inferred fault is recommended to confirm/disprove its presence, assess whether it is active, and assess direction and magnitude of movement during a design event. This information will be critical for determining whether design will need to allow for reduction in available storage volume due to fault movement.

Investigations within the dam footprint in the valley floor and beneath abutments should include a series of cored and non-cored drill holes and installation of standpipe piezometers for permeability testing. This will provide information for estimating seepage volumes and pressures beneath the dam and through abutments, which has implications for stability as well as water loss.

Drilling may also be necessary in the area of instability identified in the slopes at the left side of the valley towards the upstream end of the reservoir. This would provide information on the depth of movement and allow an estimate of the volume of debris (if any) that could enter the reservoir.

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests. This testing would enable the borrow locations to be narrowed down for landowner negotiations.

3.8 Site B2

3.8.1 Site visit details

Site B2 is located on Ongaonga Stream downstream of Site B1. Our team visited the site on the morning of Tuesday 25th May 2010. The dam embankment would cross Ngaruru Road, and the site was accessed from Ngaruru Road.

3.8.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the valley floor at the dam site is located on the young Hawera terrace surface with the abutments founded on the older, higher level, Castlecliffian weathered greywacke terrace deposits.

3.8.3 Detailed observations

Our detailed field observations are summarised in Figure B2 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X2 of Appendix B.

The exposures in the true right stream bank on the valley floor comprise weathered greywacke gravel (red metal) interbedded with siltstone and pumiceous layers (refer Figure 3-48 and Figure 3-49). These sediments are overlain by gravelly sandy SILT seen exposed in the gully above the stream at the right abutment and at the top of the red metal quarry on the true left side of the valley. All are part of the Castlecliffian high terrace sediments mapped by Kingma in the ridges. Also there is a noticeable change in alignment of the side gullies where they encounter the gravelly silts above the main valley floor.

The valley slopes on the true left of Ongaonga Stream have a “puckered” appearance (refer Figure 3-50), which might reflect surficial creep or differences in material properties of the interbedded silts and red metals. A seep was observed well up the valley sides on the left side of the valley upstream of the reservoir, which may be associated with a continuous layer of lower permeability material. A linear feature, which may also be associated with a low permeability layer, was also noted near the foot of the true left valley slope within the reservoir, (refer Figure 3-55).

Some landsliding was observed within the reservoir (refer Figure 3-52 and Figure 3-53). In particular, landslide debris is exposed in the right abutment, but an alternative abutment location immediately upstream appears suitable (refer Figure 3-54). A major gully shaped feature previously identified on Google imagery is not a landslide feature (refer Figure 3-51).

[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand

Figure 3-48 Moderately weathered red metals overlying 200mm pumice overlying siltstone

Figure 3-49 Quarry at left abutment: Moderately weathered red metals capped by siltstone

Figure 3-50 Left side of valley visible in background with "puckered" appearance

Figure 3-51 Looking up right side of valley, gulley feature visible at right

Figure 3-52 Landslide feature in right side of valley at foot of gully

Figure 3-53 Landslide debris from feature in right side of valley at foot of gully

Figure 3-54 Right abutment: disrupted debris at current location at left of photo, alternative proposed location at right of photo

Figure 3-55 Left side of valley: linear feature visible near foot of slope

3.8.4 Issues and risks

Dam footprint foundation

No specific issues were identified regarding the stability of the foundation below the embankment at this stage of investigation.

Abutment foundations

The left abutment is located at or close to an existing local red metal quarry, and no significant stability issues have been identified. Disrupted debris is exposed at the proposed location for the right abutment. However, an alternative location immediately upstream appears suitable.

Reservoir rim stability

Some instability has been noted in the reservoir rim as described in Section 3.8.3 above. This should be addressed via appropriate investigation and design.

Water tightness

Further investigation and design will need to address seepage through the reservoir rim ridges and via any paleochannels under the dam.

Borrow material

The red metals exposed within the reservoir footprint could be used for borrow. However, there is variability in the fines content and permeability of gravels in the region. A low permeability material may need to be sourced, either to blend with the red metal or use as a core in a zoned embankment dam. Further investigation in the area is needed to locate a nearby source of low permeability material.

3.8.5 Recommendations for future investigation

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests. This testing would enable the borrow locations to be identified for landowner negotiations.

Investigations within the dam footprint in the valley floor should include a series of cored and non-cored drill holes and installation of standpipe piezometers for permeability testing. If the underlying paleotopography appears irregular, geophysical surveys (seismic refraction) may provide better definition of the paleotopography.

3.9 Site B3

3.9.1 Site visit details

Site B3 is located on a tributary of Ongaonga Stream. The site area was visited by the T&T team on the afternoon of Thursday 6th May 2010, and again on the afternoon of Monday 24th May 2010 afternoon.

During our initial visit, access was restricted to the property owned by Sylvester Eaton at173 Blackburn Road. This comprised the right abutment and a sliver of reservoir bounded by a row of trees. Access to the left abutment was still not available on our second visit, so our inspection was carried out within the road reserve on Blackburn Road and Petit Valley Road. (Note that we initially phoned Bill Jerram and James and Lesley Barnes regarding access to the reservoir for our second site visit, but could not reach Bill in person so restricted ourselves to the road reserve.)

3.9.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the same stratigraphy at Site B3 as seen at Site B2.

3.9.3 Detailed observations

Our detailed field observations are summarised in Figure B3 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X3 of Appendix B.

Exposures along the valley side at the right abutment comprised extremely weak sandstone capped by red metal (refer Figure 3-58) and overlying extremely weak coarse siltstone of Castlecliffian age. The sandstone is bedding dips 5° to 360° (north) (refer Figure 3-57), and contains interbedded pumiceous layers. Sandstone was also observed in the floor of the creek at the toe of the right abutment slope.

A ridge running parallel with the dam embankment, located at the right abutment, has landslides both on its south east (refer Figure 3-56) and north east (Figure 3-60) faces. The toe of the landslide on the south-east side of the ridge, located close to the interface between the sandstone and underlying siltstone, is marked by a strong groundwater seep (refer Figure 3-59) reflecting lower permeability in the siltstone relative to the sandstone. Multiple uphill facing scarps were seen in the south east landslide, indicating the landslide is likely to be translational. The landsliding may be occurring on the softened interface between the siltstone and sandstone, and is likely to have occurred during severe earthquake shaking.

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand

Some landsliding in the remainder of the reservoir was observed from Blackburn Road. This comprised slumping in the stream bed, and larger scale instabilities in the valley sides and a central "fin" of material located at and downstream of the embankment. The extent and mechanisms of this landsliding is uncertain without closer inspection, but may involve sliding on softened interfaces within or on top of siltstone as noted at the right abutment.

The "fin" of material described above was also viewed from Petit Valley Road. From visual inspection at a distance, the slope appeared unlikely to comprise red metals and may consist of similar materials as the right abutment.

HBRC has provided the drillers' logs for two water bores at the upstream end of the reservoir (ID 1662) and 1.1km upstream of the reservoir (ID 10945). These logs record 34-39m of silt and clay sometimes with shell and rare sand layers. The marine silt and clay layers overlie a 13-22m thick layer of sandstone, which is likely to provide the water flow to the bores, and the base of the bores is floored in siltstone. The materials logged appear similar to the materials observed at the right abutment during our site visit.

There is a further collection of water bores, for which HBRC has also provided the drillers' logs, located approximately 1.8km downstream of the dam embankment. These shallow bores, ranging from 10 to 30m in depth, comprise gravels.

Figure 3-56 Landslide in southeast face of ridge at right abutment

Figure 3-57 Sub horizontally bedded sandstone in ridge at right abutment

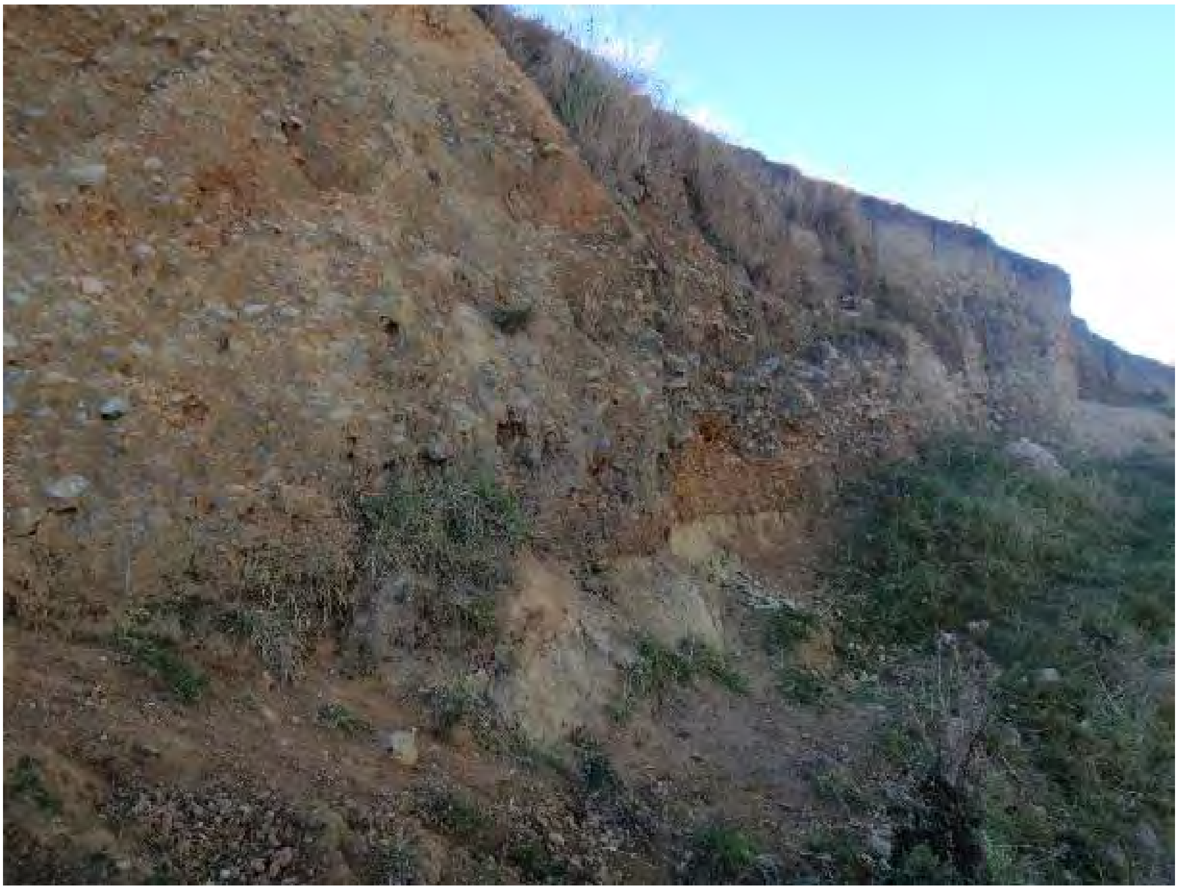

Figure 3-58 Red metal capping sandstone in ridge at right abutment

Figure 3-59 Siltstone exposure and seep at toe of landslide in southeast face of ridge at right abutment

Figure 3-60 Landslide in northeast face of ridge at right abutment

Figure 3-61 Landsliding in left side of valley

3.9.4 Issues and risks

Dam footprint foundation

In later stages of design, stability of the embankment against sliding on the interface of red gravels and siltstone at the base of the dam under seismic loading will need to be assessed.

Abutment foundations

Possibly the most critical issue for this site is stability of the abutments against sliding along the sub-horizontal softened siltstone - sandstone interface either under seismic loading and/or with the water pressures of the reservoir transmitted through the sandstone. Design to address this issue could involve significant and expensive excavation into the ridges to “key in” the abutments, which might also entail shifting the embankment upstream.

Reservoir rim stability

Instability has been noted throughout the reservoir as discussed above, and will need to be assessed and accommodated as necessary by design works.

Water tightness

Seepage through the abutments via sandstone and seepage under the dam via sandstone and red metals are issues that will need to be investigated and addressed during design.

Borrow material

Red metals in sufficient quantities for borrow were not observed within the reservoir during our constrained site visit (right abutment walk over only). Only a 1m thick cap of material was identified in the ridge inspected. Red metals may need to be hauled from a nearby location such as 2.6km upstream of the reservoir where an exposure of red metals was seen.

In addition to a source of red metals, a source of low permeability material may also have to be identified, either for blending with the red metals or to provide a core in a zoned embankment type dam.

3.9.5 Recommendations for future investigation

After consideration of all storage options, the study team decided that Site B3 should not be considered further so recommendations are not set out.

3.10 Site C1

3.10.1 Site visit details

The site is located on the Avoca River. Our team visited the site on the afternoon of Tuesday 25th May 2010. Access was from Tukituki Makaretu Road.

3.10.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] indicates that the majority of the reservoir is located in Castlecliffian sediments but the dam embankment itself is located in younger Holocene aged Ruataniwha Alluvium. The boundary between the units is mapped close to the upstream toe of the embankment.

Kingma describes the Castlecliffian sediments as gravels, sands and silts with or without pumice bands, either in marine sequences or in much dissected high terraces, with terrace gravels being strongly weathered. Ruataniwha Alluvium is described as fluviatile deposits generally located in the Ruataniwha Plains, with a tilted surface due to the rapid rise of the Ruahine Range and deeply incised near the range.

The GNS active fault data base shows a short active fault segment crosses the valley immediately upstream from the head of the reservoir.

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand

3.10.3 Detailed observations

Our detailed field observations are summarised in Figure C1 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X3 of Appendix B.

Exposures seen during our site visit generally comprised coarse extremely weak to very weak jointed siltstone underlying weathered, in places cemented, greywacke gravel (red metal) (refer Figure 3-65, Figure 3-66, Figure 3-67 and Figure 3-68). The siltstone exposures continued well up the valley sides, 6m above the stream invert in one place. Seeps emerging part way up the valley slope and truncated ridges also are taken to indicate that siltstone, which is likely to be less permeable than the red metals, is present at high elevations in the valley sides (refer Figure 3-70). Note that in some places the stream was floored in red metals indicating that there is some variation in the level of the top of the siltstone, and there may be paleochannels

Based on inspection of contours and exposures on site, an inferred fault was identified sub parallel with and immediately upstream of the dam. In line with this, cemented red metals were exposed on the right side of the valley upstream of the inferred fault, but were not seen extending along the ridge in the downstream direction. The activity of the inferred fault is not known. However, as noted above GNS have mapped an active fault immediately upstream of the head of the reservoir which is aligned sub parallel to the inferred fault.

Extensive landsliding was observed in the reservoir involving translational movement of the weathered greywacke gravels out over the underlying siltstone. For instance, a detached block was observed 1.5km upstream of the embankment dam within the reservoir (refer Figure 3-69). A large scale landslide is present 150m upstream of the right abutment (refer Figure 3-64) extending well above the proposed reservoir level. There is also probable large scale landsliding upstream of left abutment (refer Figure 3-62). The landsliding is most likely as a result of severe earthquake shaking.

Pleasant Valley Road runs through the centre of reservoir alongside Avoca River. Towards the upstream end of the reservoir, Hall Road branches off Pleasant Valley Road and a sign indicates that Lime Terrace can be found off Hall Road. Local residents indicate that limestone is exposed at Lime Terrace. This limestone is most likely Totaranui limestone, part of the Nukumaruan sediments mapped by Kingma upstream of the reservoir.

Figure 3-62 Landslide upstream of left abutment photographed from road

Figure 3-63 Upstream of right abutment: Panning from upstream to downstream

Figure 3-64 Upstream of right abutment, looking upstream: Graben visible at left side of photo

Figure 3-65 Red metals overlying siltstone in stream bed upstream of embankment

Figure 3-66 Moderately to highly weathered slightly cemented red metal overlying slightly weathered iron stained extremely weak fine sandy coarse SILTSTONE with a 15mm thick cemented bed dipping 50 deg to 265 deg

Figure 3-67 In stream bed close to upstream toe of embankment: Highly jointed, iron stained siltstone

Figure 3-68 Upstream of Tukituki Makaretu Road: Highly fractured siltstone in creek overlain by cemented red metals

Figure 3-69 Graben of detached block

Figure 3-70 Truncated ridges along left side of valley within reservoir, seeps at level of top of siltstone

3.10.4 Issues and risks

Dam footprint foundation

Sliding on the siltstone-red metals interface beneath the dam during seismic loading will need to be assessed.

Abutment foundations

Movement on the inferred fault identified upstream of the dam may have negative impacts on abutment stability because of its proximity to the dam even though it appears to be subparallel to the embankment axis. In addition the large scale landslides identified immediately upstream of the abutments indicate that abutment stability may be an issue during seismic loading such as caused the existing landslides.

Reservoir rim stability

As noted above, large scale landsliding has been observed within the reservoir. This landsliding will need to be stabilised or allowed for in the design.

Water tightness

The location and extent of any paleochannels, which could act as seepage paths under the dam, should be investigated and designed for.

Borrow material

The red metals exposed within the reservoir footprint could be used for borrow. However, a low permeability material may also need to be sourced, either to blend with the red metal or use as a core in a zoned embankment dam. This material may possibly be provided by the siltstone exposed in the reservoir.

Other

Relocation of roading will need to address landslide issues on both sides of the valley.

3.10.5 Recommendations for future investigation

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests. This testing would enable the borrow locations to be identified for landowner negotiations.

Investigations within the dam footprint in the valley floor should include a series of cored and non-cored drill holes and installation of standpipe piezometers for permeability testing. If the underlying paleotopography appears irregular geophysical surveys (seismic refraction) may provide better definition of the paleotopography.

Further investigation into the presence, location and activity of the inferred fault identified upstream of the dam should be carried out. This could comprise trenching across the identified fault trace in the first instance, and if confirmed by this first step, might involve work by GNS to identify recurrence intervals and magnitude of movement.

3.11 Site C2

3.11.1 Site visit details

Our team visited Site C2 on the afternoon of Tuesday 4th May 2010. Access was via Mill Road. The dam would be located on Parikaka Stream.

3.11.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows that the valley is floored in Holocene aged Ruataniwha Alluvium at the proposed dam site and that the ridges bounding the left and right sides of the reservoir and the main terrace surface are of Castlecliffian age.

3.11.3 Detailed observations

Our detailed field observations are summarised in Figure C2 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X3 of Appendix B.

Exposures were inspected at the quarry upstream of Mill Road at the head of the potential reservoir and in the steeply incised channel upstream of the proposed dam. Extremely weak white siltstone is exposed in the stream floor and up to 5m above the invert in one place (refer Figure 3-76). Weakly cemented weathered greywacke gravel (red metal) with interbedded sand was observed overlying the siltstone (refer Figure 3-71 and Figure 3-75). In the quarry the greywacke gravel (red metal) had been removed exposing the softened upper surface of the siltstone.

Some minor instability was noted (refer Figure 3-73) in the slopes upstream of Mill Road. Seeps were observed in the vicinity. It is possible that the instability relates to sliding on the interface between the red metals and less permeable siltstone, which can become softened by groundwater. Softening of the siltstone at the interface with the red metals was noted in the quarry (refer Figure 3-71).

Figure 3-71 Quarry upstream of Mill Road: Red metal on top of softened white siltstone

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand

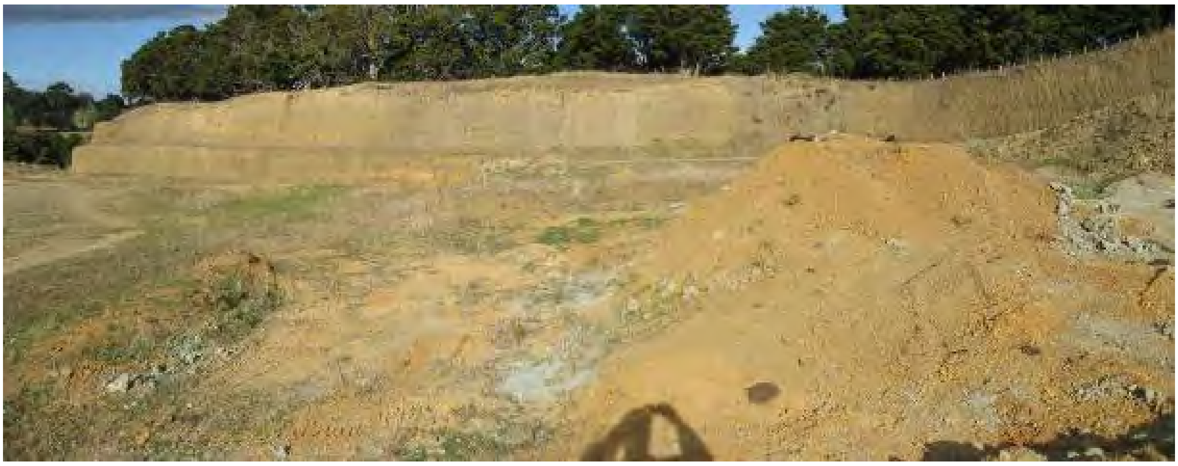

Figure 3-72 Red metal walls of quarry upstream of Mill Road

Figure 3-73 Minor instability north-east of quarry road upstream of Mill Road

Figure 3-74 Looking south-east from left side of valley downstream of Mill Road

Figure 3-75 Red metal capping incised river banks / cliffs approximately 350m upstream of dam location

Figure 3-76 White extremely weak siltstone in creek to 5m above, capped by red metal

Figure 3-77 Upstream toe of embankment: red metal in creek comprising greywacke gravel interbedded with sand. No siltstone seen. Dipping 5-10 deg to 180 deg.

3.11.4 Issues and risks

Dam footprint and abutment foundation

Design for Site C2 will need to address the issue of sliding on the softened interface between the red metals and underlying siltstone, particularly during seismic loading.

Reservoir rim stability

Some minor instability was noted upstream of Mill Road, which is expected to be related to sliding on the red metal – siltstone interface. Design will need to address this instability and potentially similar instability around the remainder of the reservoir rim under seismic loading and with all reservoir operating conditions such as rapid draw down.

Water tightness

Investigation and design will need to address the possibility of seepage via paleochannels under the dam.

Borrow material

Red metals are likely to be available in suitable thicknesses from within the reservoir extents. Laboratory testing is necessary to determine whether local materials have suitably low permeability for a homogeneous dam. If not, a low permeability material will need to be sourced to either blend with the red metal or use as a low permeability core in a zoned type embankment. Loess may be locally available and if suitable blended into the red metal.

3.11.5 Recommendations for future investigation

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests. This testing would enable the borrow locations to be narrowed down for landowner negotiations.

Investigations within the dam footprint in the valley floor should include a series of cored and non-cored drill holes and installation of standpipe piezometers for permeability testing. If the underlying paleotopography appears irregular geophysical surveys (seismic refraction) may provide better definition of the paleotopography.

3.12 Site C3

3.12.1 Site visit details

Site C3 is located on Rakautihiau Stream. The site was visited on the morning of Wednesday 26th May 2010. Access was from 161 Ashley Clinton Road.

3.12.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the dam is sited within Holocene aged Ruataniwha Alluvium. However our investigations indicate that the site is more likely to be underlain by weathered greywacke gravel (red metal) with interbedded siltstone and is therefore likely to be of Castlecliffian age.

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand 1:250,000" Department of Scientific and Industrial Research, Wellinton, New Zealand

3.12.3 Detailed observations

Our detailed field observations are summarised in Figure C3 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X4 of Appendix B.

Exposures in the stream bed comprised weathered greywacke gravel (red metal) interbedded with thick beds of siltstone with pumiceous layers (refer Figure 3-78, Figure 3-79 and Figure 3-81). The stream channel passes between shallow sloping banks formed by the red metal and narrow gorges through the thick siltstone beds (refer Figure 3-80). The variation in the levels of the siltstone beds indicates that paleochannels may be present.

Abandoned marshy meanders were observed (refer Figure 3-82).

A red metal quarry for the farm has been developed immediately downstream of the right abutment for the proposed dam a little below top water level. The highly weathered greywacke gravel exposed in the quarry is deficient in fine sand and silt materials.

Figure 3-78 Red metal quarry above right abutment: Moderately to highly weathered silty sandy fine GRAVEL with low fines content

Figure 3-79 Loess overlying two ages of red metals with siltstone inclusions

Figure 3-80 Gorge feature: Siltstone, possibly pumiceous, with sandstone beds

Figure 3-81 Red metals interbedded with white-grey siltstone, sub horizontal bedding

Figure 3-82 Unusual meanders developed within the red metal terrace surface

3.12.4 Issues and risks

Dam footprint foundation

No specific issues were identified regarding the stability of the embankment foundations. However, unusual meanders and potential paleochannels described in our observations above indicate that the geology underlying the embankment may be complicated.

Abutment foundations

No specific issues were identified regarding abutment stability.

Reservoir rim stability

No major instability was seen in the reservoir during our site visit.

Water tightness

The key issue for Site C3 is water tightness under the dam via the potential paleochannels noted above. The unusually complicated meanders observed also may indicate seepage paths at multiple levels, most likely related to the variation in permeability between the siltstone and red metals.

Further investigation is needed to determine the location and extent of paleochannels and address leakage potential.

Borrow material

The red metals exposed within the reservoir footprint could be used for borrow. However, there is variability in the fines content and hence permeability of the gravels in the region. Therefore a low permeability material may need to be sourced, either to blend with the red metal or use as a core in a zoned embankment dam. This material may possibly be provided by the thick bands of siltstone, if confirmed in suitable quantities, or by only selectively borrowing from the red metals that have higher fines contents.

3.12.5 Recommendations for future investigation

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests. This testing would enable the borrow locations to be identified for landowner negotiations.

Investigations within the dam footprint in the valley floor should include a series of cored and non-cored drill holes and installation of standpipe piezometers for permeability testing. If the underlying paleotopography appears irregular geophysical surveys (seismic refraction) may provide better definition of the paleotopography. These investigations will provide important information for addressing water tightness under the dam.

3.13 Site D1

3.13.1 Site visit details

Our team visited Site D1 on the afternoon of Wednesday 5th May 2010. The proposed dam site is located on Porangahau Stream.

3.13.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the dam is sited on Holocene aged Ruataniwha Alluvium. However, our observations indicate the site is underlain by older weathered greywacke gravels of Castlecliffian age and flanked by younger Holocene gravels.

3.13.3 Observations & issues

Our detailed field observations are summarised in Figure D1 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X4 of Appendix B.

Only a limited inspection was made since the presence of a geologically active fault trace in the GNS data base was confirmed during the site visit. Vertical bedding within the older Castlecliffian weathered greywacke gravel was seen in the creek within the dam footprint (refer Figure 3-85), and extensive jointing in an overlying limestone exposure indicating significant disruption was observed (refer Figure 3-86). In addition to the fault trace following the stream bed, a more recent fault trace was observed parallel and 100m south-east of the fault in the stream (refer Figure 3-87).

Developing a credible design able to allow for probable fault rupture is expected to involve significant time and cost. Furthermore, peer review and consenting risk for such a dam is higher than for the remaining dams.

3.13.4 Issues, Risks & Recommendations for future investigation

The study team considers the active fault to construe a fatal flaw and likely to require impractical (unaffordable) measures for achieving an adequately safe storage. After team discussion, Site D1 was abandoned and so further discussion of issues and risks and recommendations for future investigations have not been set out.

[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) “Geological Map of New Zealand 1:250,000” Department of Scientific and Industrial Research, Wellinton, New Zealand

Figure 3-83 Looking downstream at proposed dam site from right side of stream

Figure 3-84 Looking down fault trace in stream

Figure 3-85 Vertical bedding in stream fault trace

Figure 3-86 Jointed limestone exposure in main fault trace indicating significant disruption

Figure 3-87 Looking NE along the most recent fault rupture (the upthrown side is on the left)

3.14 Site D2

3.14.1 Site visit details

The site was visited on the morning of Thursday 6th May 2010. Site D2 is located on a tributary of Otutatari Stream, itself a tributary of Porangahau Stream.

3.14.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the stream on which the dam is sited lies mainly on Nukumaruan marine sediments in the south-east with younger Holocene aged Ruataniwha Alluvium to the north-west.

Kingma describes Ruataniwha Alluvium as fluviatile deposits in the Ruataniwha Plains, the surface of which is tilted and incised near the Ruahine Range due to the rapid rise of the range. The Nukumaruan sediments are described as fossiliferous sands and silts with thin limestone horizons, which have usually been recrystallised with sporadic greywacke gravels.

3.14.3 Detailed observations

Our detailed field observations are summarised in Figure D2 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X4 of Appendix B.

The GNS database indicates two geologically active fault traces within the reservoir footprint within 50m of the proposed embankment. The presence of these faults was confirmed during our

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand 1:250,000" Department of Scientific and Industrial Research, Wellinton, New Zealand

site visit by disruptions in bedding and the highly fractured nature of the rock mass exposed where the traces crossed the local stream. During our inspection of the remainder of the site, a bedding dip of 12 degrees towards 308 to 320 degrees was measured two locations. In the vicinity of the fault traces within a 100m long section of stream, bedding was measured at 40 degrees to 092 degrees (refer Figure 3-88), 85 degrees to 105 degrees and 20 degrees to 112 degrees (refer Figure 3-89).

Figure 3-88 Bedding dipping at 40 degrees towards 092 degrees in slightly to moderately weathered SILTSTONE, thinly fissile, highly fractured, likely related to fault

Figure 3-89 Disrupted coarse siltstone, most likely related to mapped fault

3.14.4 Issues and risks

The active fault has been mapped in the reservoir to within 50m of the dam embankment. The fault trace indicated in the GNS data base does not appear to extend across the embankment, but is aligned such that the next rupture could cut through the dam.

As for Site D1 the dam would need to be designed for probable fault rupture, which is likely to involve significant design cost and consenting risk. Other than the active fault, we consider the issues and risks associated with the local geology can likely be addressed via appropriate investigation and design.

3.14.5 Recommendations for future investigation

The study team considers the active fault to construe a fatal flaw and likely to require impractical (unaffordable) measures for achieving an adequately safe storage. After team discussion, Site D2 was abandoned and so recommendations for future investigations have not been set out.

3.15 Site D3

3.15.1 Site visit details

The proposed dam site is located on Maharakeke Stream, with two tributaries to the Maharakeke also crossing the dam alignment towards the right abutment. The site was visited by our team from T&T on the morning of Thursday 27th May 2010. Access was from 82 Hinerangi Road.

3.15.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] shows the dam site and reservoir is located in a syncline with Waitotaran limestone rising to either side of the valley, and dipping towards the Maharakeke Stream from both sides. Kingma describes the Waitotaran limestone as a coquina limestone, with or without greywacke gravels in the upper part of the stage, with conglomerates, calcareous sandstones and siltstones in the lower part.

Younger sediments, Holocene aged Ruataniwha Alluvium, is mapped infilling the floor of the valley. The contact between the Ruataniwha Alluvium and Waitotaran limestone is located close to the right hand side rim of the reservoir, whereas to the left of the reservoir the contact is some 1.5km distant.

Kingma has mapped Nukumaruan marine sediments between the Ruataniwha Alluvium and Waitotaran limestone at the upstream right extent of the reservoir. The Nukumaruan sediments are described as fossiliferous sands and silts with thin limestone horizons, which have usually been recrystallised with sporadic greywacke gravels. Note that we encountered exposures of the Nukumaruan sediments both further downstream and further west across the reservoir than mapped by Kingma[1].

3.15.3 Detailed observations

Our detailed field observations are summarised in Figure D3 of Appendix A. An indicative cross valley section through the dam axis is presented in Figure X5 of Appendix B.

Limestone slopes were observed rising to the east above the right abutment (refer Figure 3-90). Nukumaruan marine siltstones and sandstones are exposed in the banks of the eastern-most stream within the reservoir. The extremely weak siltstones and sandstones are shelly in places with a thin horizon of limestone seen in the right bank and coarse sand and gravel (greywacke and limestone) layers observed in the left bank (refer Figure 3-91). Limestone debris was also exposed in the stream banks. The contact between the limestone and siltstone / sandstones is expected to be close to the right side of the reservoir. HBRC has supplied the driller's log for a water bore located in the valley floor near the right abutment. The log indicates that the main limestone bed was encountered at a depth of 70m below ground level with the borehole having passed down through siltstone and fine sandstone with thin limestone beds.

In the next stream to the west crossing the proposed dam centreline , approximately 350m in from the right abutment, younger red metal gravels were exposed upstream of the dam (refer Figure 3-92), and Nukumaruan sandstones/siltstones are exposed in the floor of the stream at the dam centreline. In the Maharakeke Stream towards the left abutment, the bank exposures comprised red metals interbedded with younger sands and silts (refer Figure 3-93 and Figure 3-94). A red metal quarry was observed at the upstream extent of the reservoir beside the Maharakeke Stream (refer Figure 3-95).

The extremely weak Nukumaruan siltstones and sandstones with thin limestone beds are expected to extend out from the right abutment part way across the dam foundation, while the central and left side of valley is expected to be floored with younger sediments comprising bands of sand/silt and interbedded with medium dense open gravels with up to 10% limestone clasts. The contact between the Nukumaruan sediments and younger sediments is expected to be close to the stream 350m in from the right abutment.

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[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand 1:250,000" Department of Scientific and Industrial Research, Wellinton, New Zealand

Figure 3-90 Looking upstream and to true right side of reservoir: Dip angle of LIMESTONE visible in background.

Figure 3-91 Stream at right abutment: Grey shelly SILTSTONE overlain by 50mm white SILTSTONE then 100mm coarse SAND

Figure 3-92 In central creek upstream of dam embankment: red metals with sandstone floaters

Figure 3-93 In main stream: red metals with seep at base possibly overlying sandstone

Figure 3-94 Sands and silts in banks of main stream

Figure 3-95 Red metals in quarry with high energy foreset bedding, capped by loess

3.15.4 Issues and risks

Dam footprint foundation

Minor instability was observed in the most recently deposited sands and silts in the Maharakeke stream banks (refer Figure 3-94). These materials will need to be removed prior to construction of the embankment. However, as discussed below, the requirement for water tightness against seepage under the embankment may necessitate a more significant undercut beneath the dam footprint than required for stability.

Abutment foundations

The left abutment is expected to be founded in red metals. No significant issues with this abutment have been identified.

Based on exposures seen during our site visit, the right abutment is underlain by extremely weak sandstones/siltstones and weak to moderately strong limestone. These materials extend out under the dam footprint with increasing depth towards the left abutment. No specific issues have been identified at the right abutment, but this will need to be confirmed by further investigation.

<u>Reservoir rim stability</u>

No significant instability features were observed in the reservoir.

<u>Water tightness</u>

The key issue for Site D3 is water tightness both around the right abutment and under the dam via the main terrace surface. As noted above, the geology at the right abutment is complex and will need further investigation.

The issue of seepage under the dam via the red metals in the central and western parts of the valley may be more significant since the depth to a continuous low permeability stratum is unknown. There is a risk that if the depth is too great, the cost of a cut off may be prohibitive, and necessitate other seepage control measures such as upstream blanketing.

<u>Borrow material</u>

The red metals exposed within the reservoir footprint could be used for borrow. A low permeability material may also need to be sourced, either to blend with the red metal or use as a core in a zoned embankment dam. Further investigation in the area is needed to locate a nearby source of low permeability material.

3.15.5 Recommendations for future investigation

Feasibility investigations within the dam footprint and at abutment (especially the right abutment) should include a series of cored and non-cored drill holes and installation of standpipe piezometers for permeability testing. If the under lying paleotopography appears irregular geophysical surveys (seismic refraction) may provide better definition of the paleotopography.

The usual range of material tests for earthfill dam design will need to be undertaken, including laboratory testing of a range of potential borrow materials, such as effective strength, permeability and grading tests. Laboratory testing of the samples collected by pitting would provide the information to determine whether blending or a zoned embankment is appropriate, and also narrow down borrow locations for landowner discussions and costing purposes (haul distance).

3.16 Site D5

3.16.1 Site visit details

The site was visited on the afternoon of 17 November 2010. Access was gained through a farm property on Paget Road. The proposed dam site is located within a narrow (approximately 300m wide) flat bottomed valley where the Makaretu River has cut down through an older terrace surface.

3.16.2 Geological setting

The N.Z. Geological Survey Map 1:250,000 for Dannevirke by Kingma[1] indicates that the proposed dam site is located within Pleistocene aged materials close to the contact between Castlecliffian sediments and the Hawera Terraces.

The Hawera Terraces are identified as "h2" in the N.Z. Geological Survey Map, and follow the valley downstream of the dam. Kingma describes these "h2" terrace systems as mostly intact, or only slightly dissected, comprising slightly weathered gravels with volcanic sands and lignite bands.

The Castlecliffian sediments, identified as "w_c", are mapped upstream of the dam site. The "w_c" sediments are described as gravels, sands and silts with or without pumice bands, either in marine sequences or in much dissected high terraces, with terrace gravels being strongly weathered.

3.16.3 Detailed observations

The Makaretu River has cut down approximately 25m through a farmed older terrace surface creating steep cliff exposures on both banks of the river. The local geology exposed in the cliffs shows a sequence of moderately weathered greywacke gravels with interbedded sands overlying extremely weak siltstone and fine sandstone that crop out down to current river level. A blue-green clayey extremely weak siltstone is exposed within the river bed as a result of local stream erosion and river gravel extraction (Figure 3-97). The siltstone is sub horizontally bedded and has a disturbed or sheared fabric. It is likely that this siltstone is not the local basement Tertiary rock mass and rather is interbedded within the older terrace gravels.

A landslide involving failure of the full cliff height was noted within the proposed dam footprint on the right river bank. The failure appeared to be due to a translational movement on a basal shear surface within the extremely weak clayey siltstone (Figure 3-98).

A range of materials are available for dam construction with a limited amount of well graded unweathered greywacke alluvium present within the river bed (exposed due to local gravel-winning operations within the river bed). As discussed above clayey siltstone occurs in up to 10 m thick beds and is overlain by approximately 10 to 15 m of "red metal" (slightly to moderately weathered greywacke terrace gravel) on the valley sides. A thin mantle of loess caps the terrace gravel (Figure 3-96).

[1] Kingma J. T. 1962 Sheet 11 Dannevirke (1st Ed.) "Geological Map of New Zealand 1:250,000" Department of Scientific and Industrial Research, Wellinton, New Zealand

Figure 3-96 Profile of gravel deposits exposed upstream of dam

Figure 3-97 Siltstone outcrops in the river bed

Figure 3-98 Landslides within reservoir, appear to slide off siltstone contact at river bed

3.16.4 Issues and risks

The dam footprint foundation appears suitable for dam construction based on our walkover reconnaissance providing leakage and settlement of the local materials is taken into account.

The extremely weak to very weak siltstone exposed in the valley floor (possibly interbedded in weathered gravels) may be compressible.

Gravel beds are present in the valley walls and are expected to be present in the valley floor. The permeability of these deposits will control the water tightness of the reservoir and requires further investigation.

Land sliding following reservoir filling is possible over much of the reservoir margin due to the local geology.

3.16.5 Recommendations for future investigation

Cored drilling will be required across the dam footprint to determine the subsurface distribution of materials and the potential for both leakage and settlement of diversion works due to consolidation. Push tube sampling will be required in the extremely weak siltstone so that the appropriate laboratory testing may be carried out.

Testing of the red metal as a low permeability fill will also be required as part of the study.

4 Borrow Materials

Characterisation of foundation and potential embankment fill materials has been limited to grading tests on several gravel samples taken from various dam sites plus one grading of typical siltstone, and two permeability tests on typical recompacted gravels. (Further testing results from another project in the region are also reported.) Samples were taken from exposures in valley floors or adjacent local quarry faces. The degree of weathering is strongly dependent on the age of terrace gravels present at the site and varies at each site. Sample locations are noted on the topographical plan drawings comprising Appendix A and coordinates are tabulated in Appendix E along with photos of samples.

Some of the samples collected were less than the recommended size but the results are included as indicative. Testing results from another project, where a large sample was collected by digger, have also been included in Appendix E and labelled "Wakarara Road" in the figure and table below. The "Wakarara Road" sample was taken from a highly dissected ridgeline and represents the oldest "red metal" gravels.

The grading results are summarised in Figure 4-1 and permeability results are presented in Table 4-1 below. The complete test results are included in Appendix E.

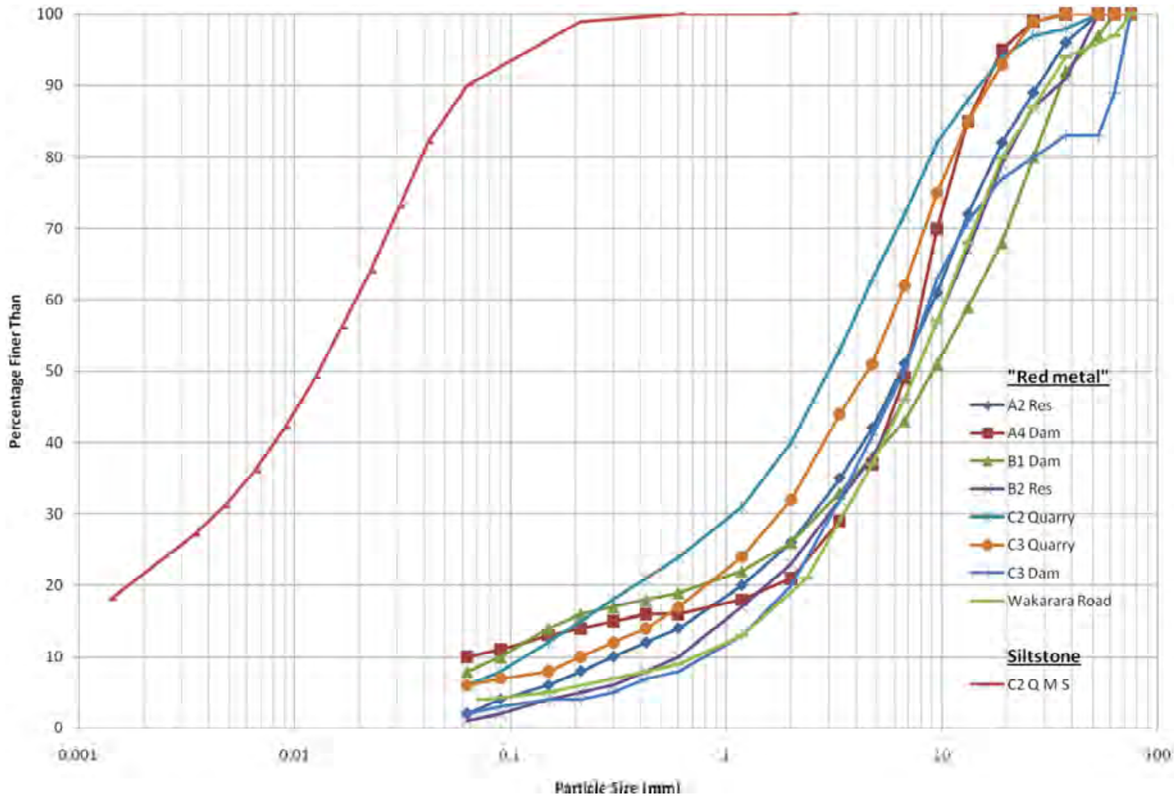

Figure 4-1 Particle Size Analysis Results

Table 4-1 Permeability Results

Sample	History	Test method	Water content (as compacted)	Compacted Dry Density	Coefficient of permeability at 20°C
Quarry C2	Remoulded at their visual Optimum Moisture Content with NZ heavy compaction effort	BS 1377: Part 8: 1990: Clause 5 Saturation and Clause 6 Constant Head Permeability in a Triaxial Cell	9.0-10.5% (initial to final)	2.07 t/m^3 (initial)	1.48 E-7 m/s
Quarry C3			7.4-11.6% (initial to final)	2.04 t/m^3 (initial)	2.10 E-7 m/s
Wakarara Road S1	Compacted to 95% of max dry density	Lab Permeability Test (Falling Head method) TW Lambe – Soils Testing	8.7 %	1.82 t/m^3	1.67 E-4 m/s
Wakarara Road S2			10.2 %	1.92 t/m^3	2.72 E-6 m/s

The following features are indicated from the testing and site observations:

- generally the gravels, wherever sourced, show consistent and well distributed grading within a relatively narrow band, with one sample lying outside the band and gap graded
- the gravels contain up to 10% silt sized fractions and vertical permeabilities on compacted material at high hydraulic gradients are about 10^{-7}m/s for the samples tested specifically for this project. The testing on the Wakarara Road samples indicates permeabilities of 10^{-4}-10^{-6} m/s, suggesting that there is variability in the permeability of the gravels in the region.
- the siltstone, where tested, has 22% clay fraction and effectively will be impermeable
- visual observations indicate that gravels adjacent to streams have reworked fine fractions and higher permeabilities are expected locally

The dominant gravels will be suitable for earthfill type dam construction with a design friction angle (ϕ') of 35-37° expected. Based on the laboratory permeability test results, the horizontal permeability for field compacted gravels may be around 10^{-6} m/s which for a homogeneous dam may result in more dam seepage than desired. A lower permeability seepage control zone will be achievable by blending typical gravel with local loess or siltstone depending on availability at the site, possibly requiring scalping off top gravels first. Scalpings may be acceptable in drainage zones.

Control of foundation seepage is likely to be a greater issue than dam seepage. Where the mudstone is at shallow depth, a trench cut off to the mudstone can be employed. Otherwise, an upstream low permeability blanket, filter compatible with the valley floor materials, may be the most cost effective way of restricting seepage to acceptable values. Material processing would be required for the blanket, similar to the dam seepage control zone.

While the main rivers through the plains and established quarry operations provide a source of high quality gravels for filter and drainage zones, the silty and sandy gravels at the dam sites could potentially be processed on site for filters and drainage.

5 Conclusions

A key aim of the geotechnical investigation presented in this report is to provide guidance regarding which sites are best to develop in terms of geotechnical issues and risks. Table 5-1 highlights those issues and risks considered most significant for each dam site. Table 5-2 (repeated from the Executive Summary) indicates the relative severity of these issues and risks to enable comparison between sites.

Based on our investigation, as summarised in these two tables, the following sites have been identified as favourable for further investigation and design efforts in terms of the geotechnical issues and risks:

- Site A1
- Site A2
- Site A4
- Site A7
- Site B1
- Site B2
- Site C2
- Site C3
- Site D3
- Site D5

Table 5-1 Summary of Findings

Site	Summary of geology	Key issues/risks
A1	Opoitian siltstone capped by red metals. Significant tectonic disturbance of rock mass noted. Probable shear zone parallel to major nearby faults through proposed site.	• Integrity of embankment with shear zone crossing dam (and generally widespread tectonic disturbance) • Stability of embankment with uplift pressures transmitted by seepage along bedding planes dipping downstream • High ground accelerations due to proximity to major fault systems • Seepage via terrace gravels under the dam • Potentially feasible depending on detailed investigation
A2	Old highly weathered red metal in abutments with interbedded silt bands. Younger red metal terraces in valley floor and infilling paleochannels. In stream bed, cemented gravels underlain by older siltstone with well developed "greasy" subhorizontal bedding planes. Lignite clasts were seen in the river channel. Large scale landsliding observed in nearby Mangamauku valley, which has similar geology.	• Abutment stability at top surface or within bedding planes in the older siltstone under seismic loading • Seepage through younger terrace gravels, possibly along paleochannels • Differential settlement associated with an unusual footprint geometry • Possible (but unlikely) impacts on the Mangamauku Stream landslides • Potentially feasible in terms of geotechnical issues
A4	Red metals interbedded with silt and sand. Complicated seepage system with stream bed dry in places, ponding in others and seeps present high up valley sides and in terrace.	• Water tightness under the dam and through the reservoir rim ridges • Uplift pressures related to seepage under the dam • Potentially feasible in terms of geotechnical issues
A5	Interbedded red metals and pumiceous silts and sands with occasional thin carbonaceous layers, overlying older blue grey siltstone. 10m + thick layer of pumiceous silts and sand expected in floor of valley at dam site. Extensive tunnel erosion noted in pumiceous sediments. Large translational landslippage on right side of reservoir from ridge line to valley floor. Active fault identified near left abutment	• Integrity of storage with large scale landsliding in reservoir • Seepage via thick pumice sediments under the dam and associated instability (piping erosion, uplift pressures plus seismic loading) • Integrity of left abutment with likely active fault nearby • Foundation costs and seismic risk likely to make not feasible
A7	Narrow gorge cut into greywacke with wide terrace surface on true right bank with possibility of gravel infilled higher level channels. Dilated greywacke rock mass on true left abutment. Landsliding within reservoir Active fault within 1 km of site.	• Stability and watertightness of true left abutment • Integrity of storage if fault ruptures or if landsliding spills debris into the reservoir • Potentially feasible in terms of geotechnical issues
B1	Large scale landsliding above reservoir level in left bank of upper reservoir. Probable fault transects reservoir upstream of dam. Interbedded pumiceous silts and sands in floor of valley upstream of fault, and interbedded siltstone,	• Seepage via pumiceous sediments under the dam (at a greater depth than at Site A5) • Integrity of storage if fault ruptures further or if landsliding identified in upper reservoir spills debris

	sandstone and cemented gravel in valley floor downstream of fault. Fault may have downthrown pumiceous sediments and carbonaceous bed below dam foundations. Red metals terraces form ridgelines.	into the reservoir • Potentially feasible in terms of geotechnical issues
B2	Red metals interbedded with siltstone and occasional pumiceous layers. Younger red metals infilling lowest terrace.	• Minor reservoir rim instability • Seepage through youngest red metals under dam, especially through any paleochannels • Potentially feasible in terms of geotechnical issues
B3	Sandstone capped by red metal and overlying siltstone (only right abutment directly inspected). Translational landslide observed at the interface sandstone-siltstone interface at the right abutment. Landsliding on the left abutment also noted in Google Earth. No significant red metal quantities noted at site.	• Sliding potential of right abutment (and possibly left abutment also) at sandstone-siltstone interface with elevated reservoir water pressures and seismic loading. May require large earthworks to address this. • Reservoir rim instabilities. Landsliding was observed from the road throughout the proposed reservoir – likely associated with extremely weak siltstone/sandstone as observed at the right abutment. • Abutment stabilisation cost likely to make not feasible
C1	Coarse siltstone extends from the valley floor up the valley sides and underlies red metals. Extensive landsliding observed in reservoir. Possible fault identified sub parallel with dam and immediately upstream of dam. Large scale landslide observed 150m upstream of right abutment. Probable large scale landsliding upstream of left abutment also.	• Integrity of storage if possible fault ruptures further or if large scale landslides mobilise • Relocation of roading will need to address landslide issues on both sides of the valley. This will be expensive • Sliding on the siltstone-red metals interface beneath the dam during seismic loading • Seepage via paleochannels under the dam • Landslide issues likely to make not feasible
C2	Red metal over extremely weak to very weak siltstone, softened zone on contact.	• Integrity of dam and abutments with sliding on the softened red metal – siltstone interface during seismic loading • Seepage via paleochannels under the dam • Minor reservoir rim instability • Potentially feasible in terms of geotechnical issues
C3	Red metals interbedded with thick beds of siltstone and occasional pumiceous layers forming narrow gorges in the stream channel. Complicated stream meanders.	• Seepage via paleochannels • Potentially feasible in terms of geotechnical issues
D1	Geologically active fault trace along stream at dam site. More recent fault trace parallel and 100m south-east of the stream, also crossing dam.	• Fault rupture through dam. • Active fault makes not feasible
D2	Geologically active fault traces identified within	• Fault rupture through dam.

	50m of embankment	• Active fault makes not feasible
D3	Contact between limestone and old (Nukumaruan) siltstone and sandstones close to the right side of the reservoir and extremely weak siltstone/sandstone extends part way across the dam foundation. Central and left side of valley floored with medium dense open gravels with up to 10% limestone clasts.	• Water tightness of right abutment and in flood plain under main terrace surface • Potentially feasible in terms of geotechnical issues
D5	Interbedded weathered gravels with extremely weak low modulus siltstone/mudstone under dam foundation. Landsliding within dam footprint and reservoir.	• Watertighness and stability of foundation and abutments. • Landsliding in to reservoir. • Potentially feasible in terms of geotechnical issues

Table 5-2 Severity of Issues and Risks for Sites in terms of Consenting

Site	Active faulting	Dam footprint foundation issues	Abutment foundation issues	Reservoir rim instability	Leakage potential	Borrow scarcity
A1	High	High	Moderate	Moderate	High	Minor
A2	Minor	Moderate	Moderate	Moderate	Moderate	Minor
A4	Minor	Moderate	Moderate	Minor	High	Moderate
A5	High	High	Minor	High	High	Moderate
A7	High	Moderate	Moderate	Moderate	Moderate	Minor
B1	Moderate	Moderate	Minor	Moderate	Moderate	Moderate
B2	Minor	Minor	Minor	Moderate	Moderate	Moderate
B3	Minor	Moderate	High	Moderate	Moderate	Moderate
C1	High	Moderate	High	High	Moderate	Moderate
C2	Minor	Moderate	Minor	Moderate	Moderate	Moderate
C3	Minor	Minor	Minor	Minor	Moderate	Minor
D1	Severe					
D2	Severe					
D3	Minor	Minor	Minor	Minor	High	Moderate
D5	Minor	Moderate	Moderate	Moderate	Moderate	Minor

The seriousness of the identified issues and risks is identified in terms of four categories, in order of increasing inclemency: minor, moderate, high, severe.

6 Applicability

This report has been prepared for the benefit of Hawkes Bay Regional Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor by:
....	....
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Geotechnical Engineer	Project Director
&	
Graeme Twose	
Geotechnical Engineer	

Report reviewed by:

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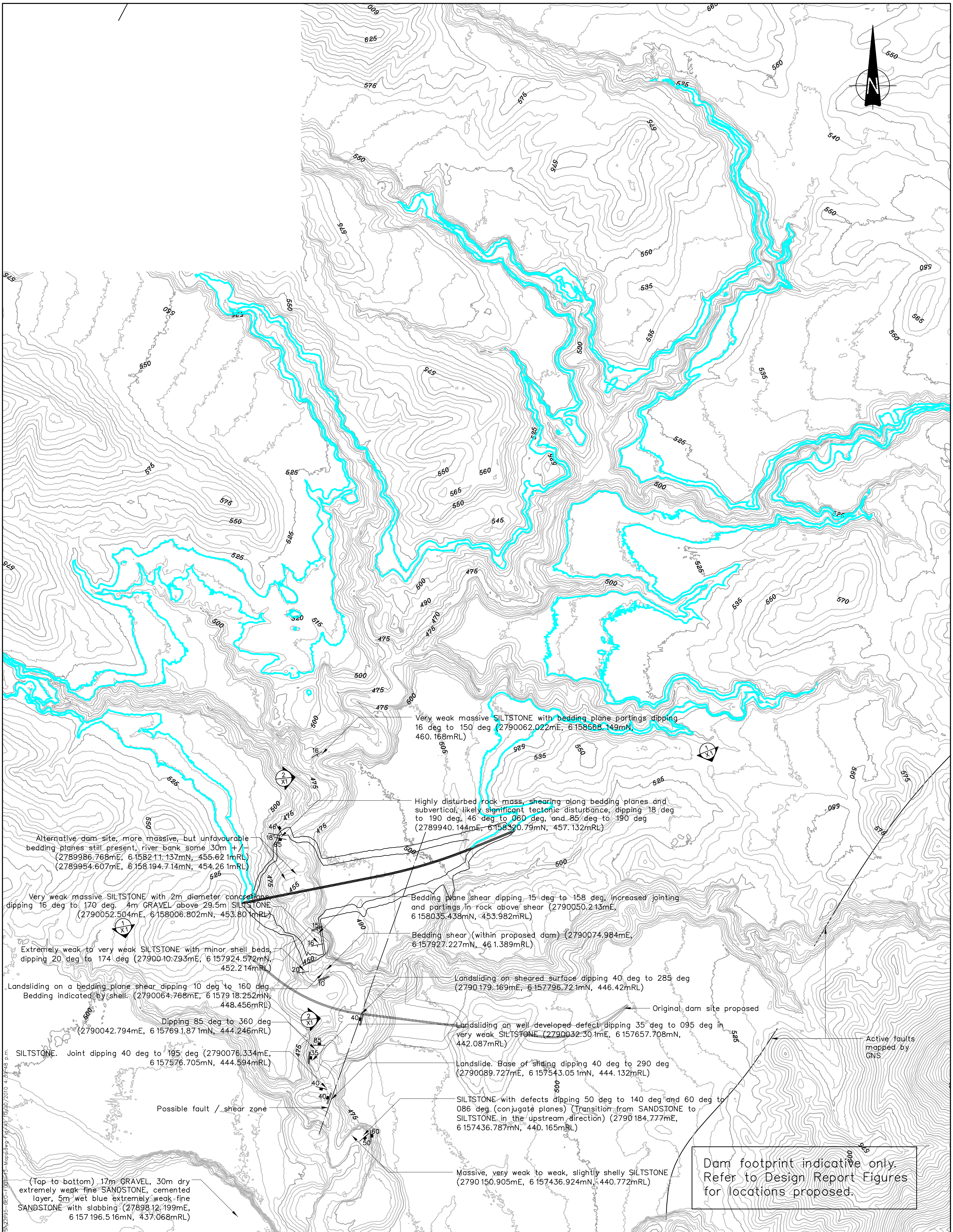
Bernard Hegan	David Leong
Senior Geologist	Project Manager
&	
Alan Pickens	
Dam Design Engineer	

DMK/dmk

dmk2010.10.10.GeotechRep.V04.doc

Appendix A: Field Observations Maps



NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates. Level Datum: MSL = 10 mRL

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SCALES (AT A3 SIZE) AS SHOWN		
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Hawkes Bay Regional Council
Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage A1

FIG. No. Figure A1

REV. 0

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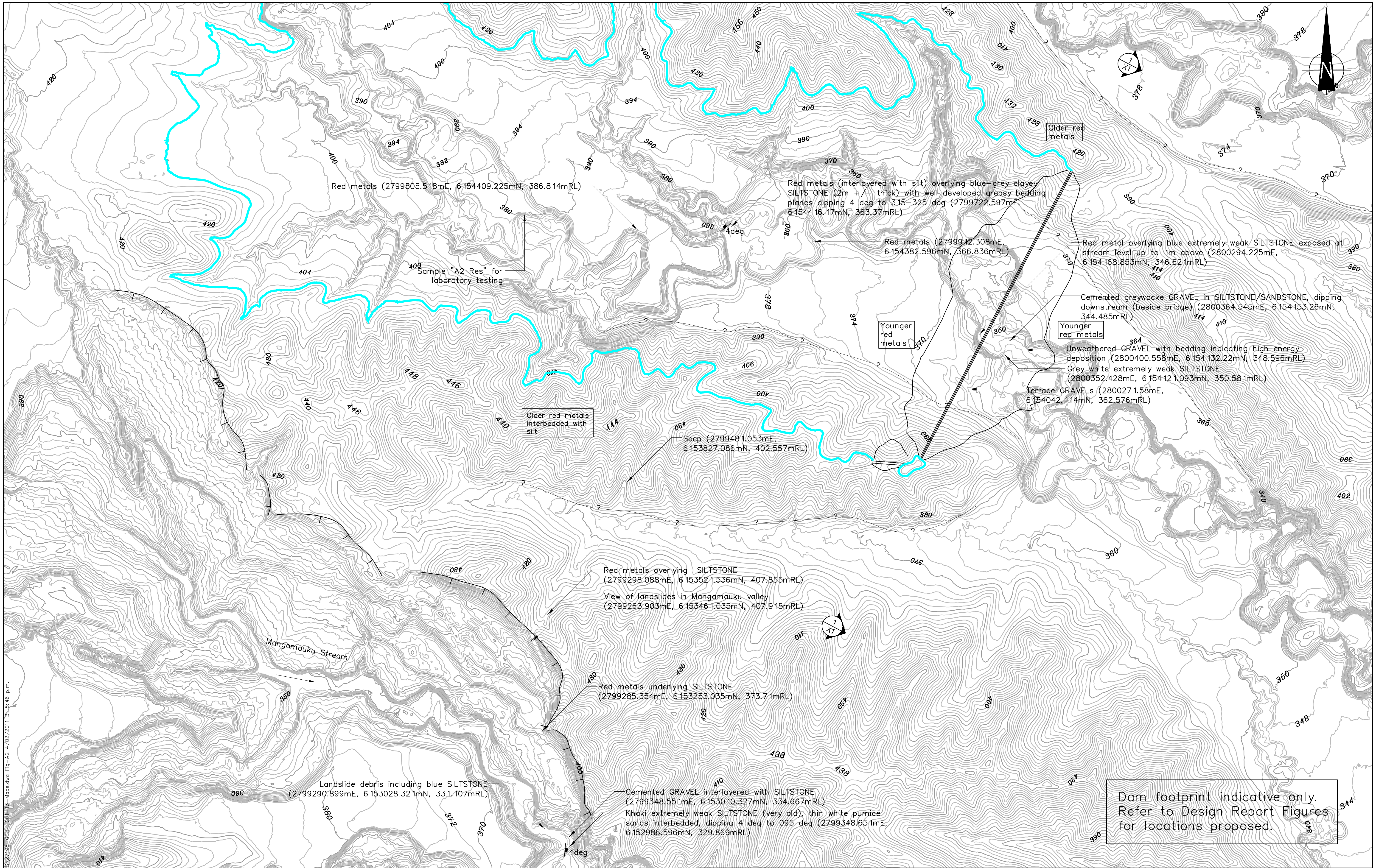

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NOTES:

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Ruataniwha Water Augmentation Scheme

Central Hawkes Bay

Field Observations for Storage A2

FIG. No. Figure A2

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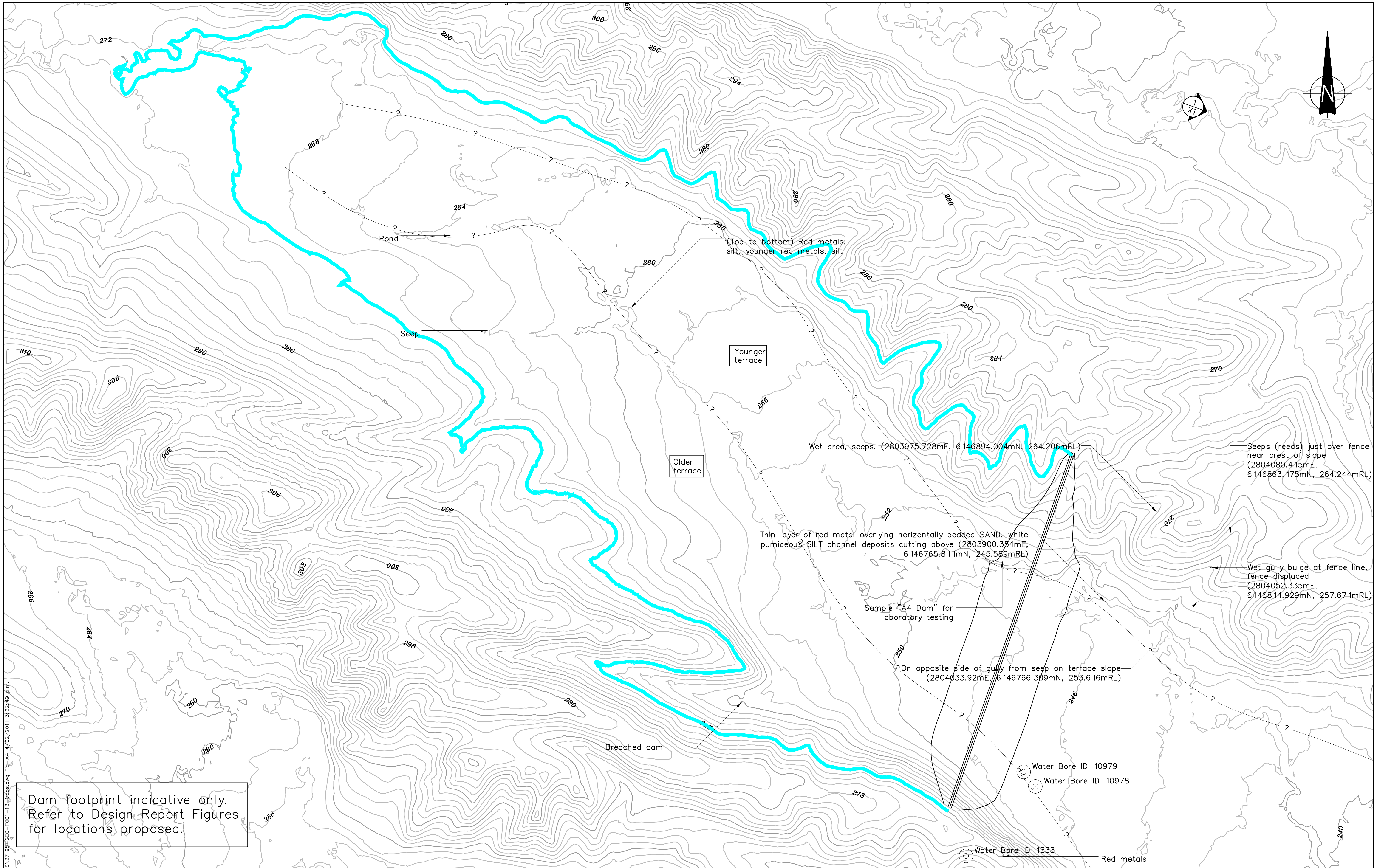

A3 SCALE 1:5000

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NOTES:

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Hawkes Bay Regional Council
Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage A4

FIG. No. Figure A4

REV. 0

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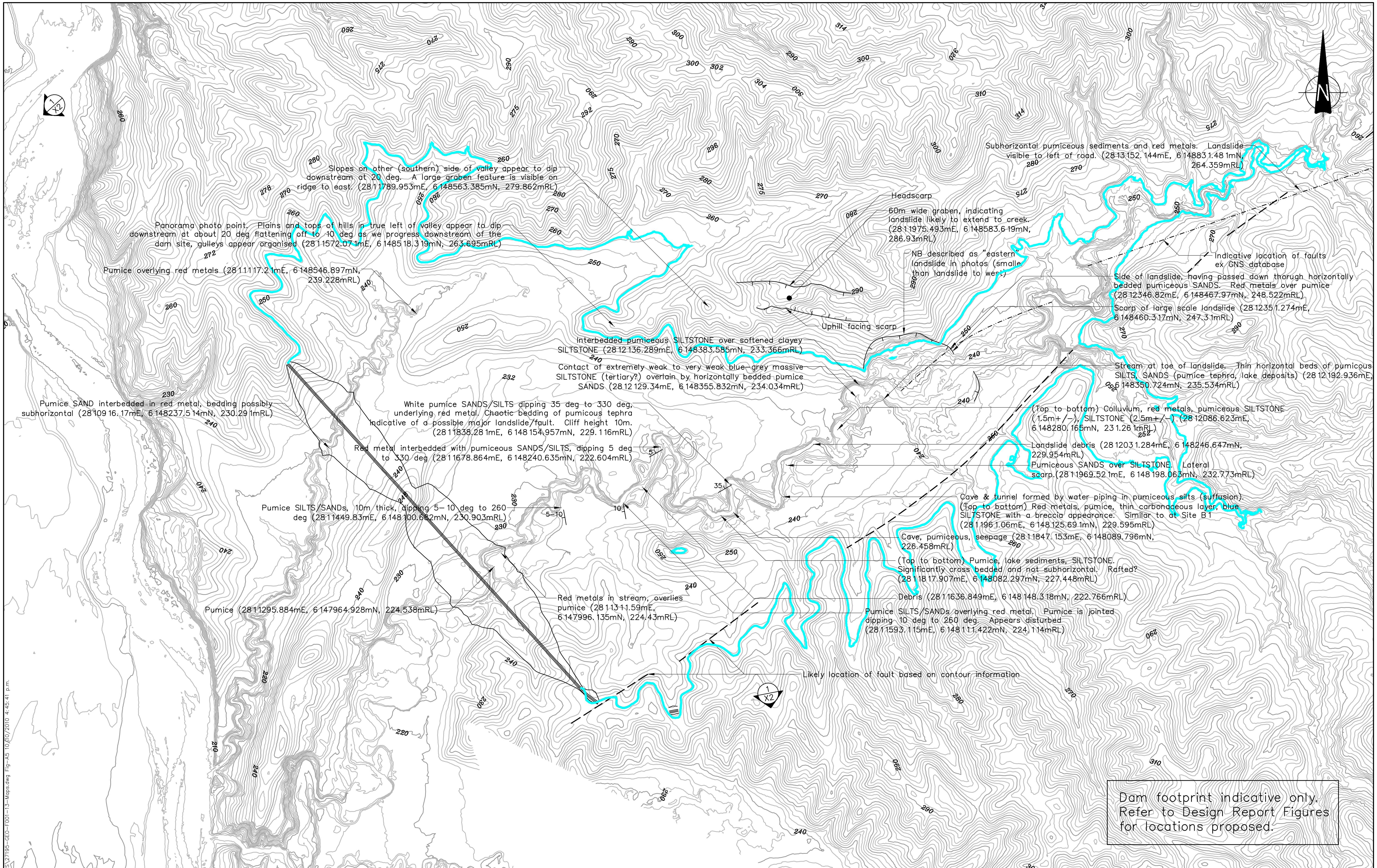

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NOTES:

1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates. Level Datum: MSL = 10 mRL

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Hawkes Bay Regional Council

Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage A5

FIG. No. Figure A5

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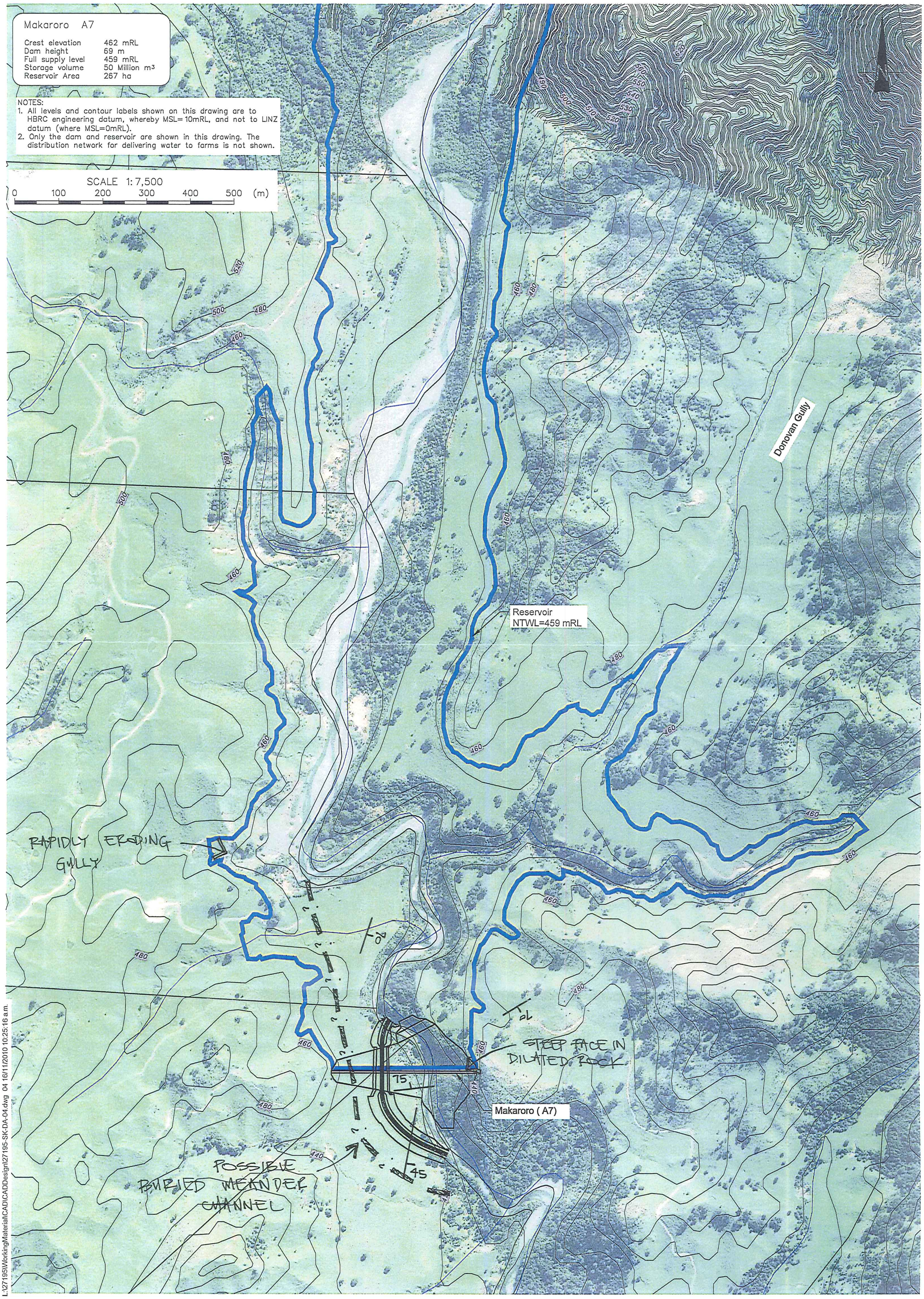
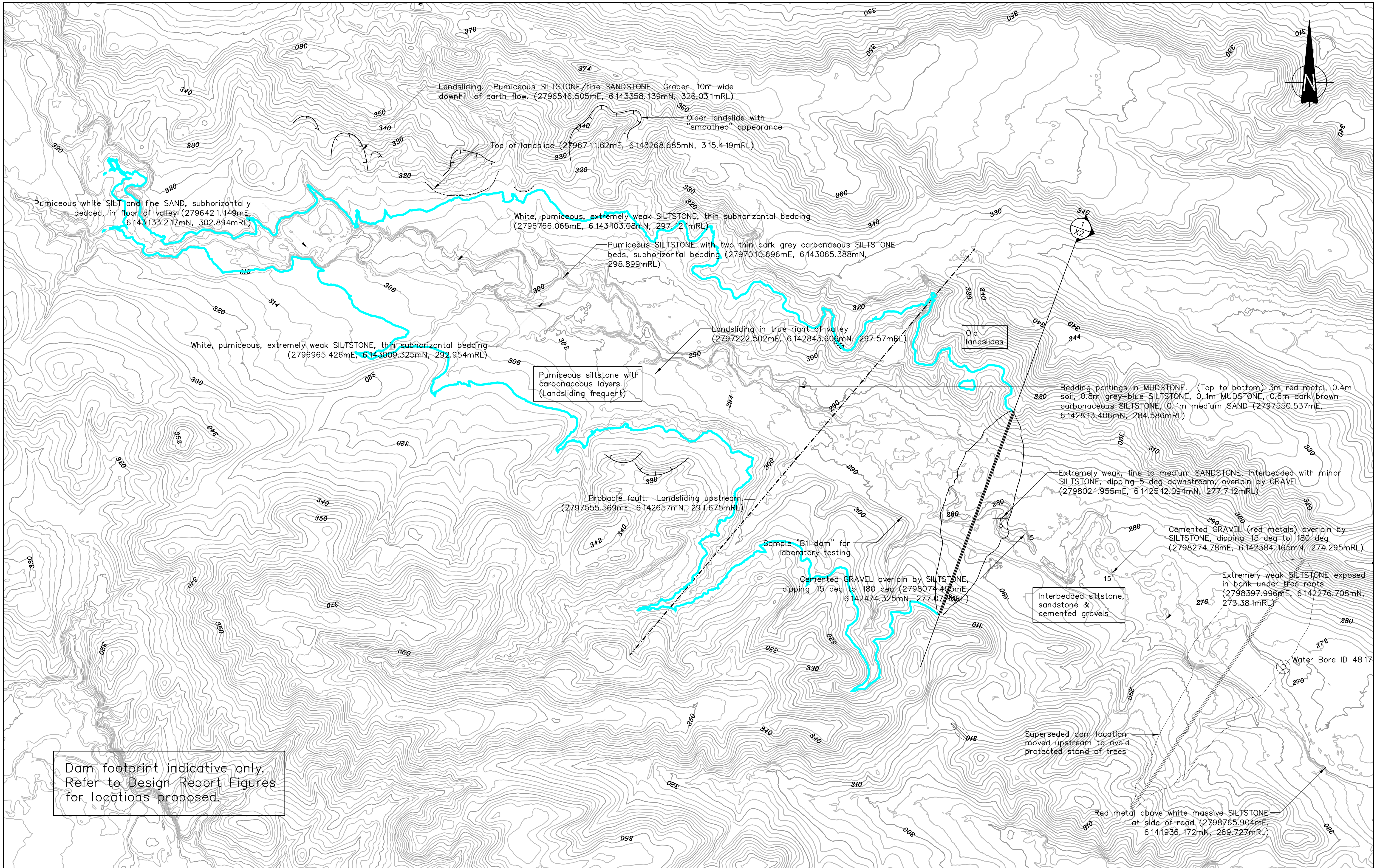


Makaroro A7
Crest elevation 462 mRL
Dam height 69 m
Full supply level 459 mRL
Storage volume 50 Million m³
Reservoir Area 267 ha
NOTES:
1. All levels and contour labels shown on this drawing are to HBRC engineering datum, whereby MSL= 10mRL, and not to LINZ datum (where MSL=0mRL).
2. Only the dam and reservoir are shown in this drawing. The distribution network for delivering water to farms is not shown.
SCALE 1: 7,500
0 100 200 300 400 500 (m)
Donovan Gully
Reservoir
NTWL=459 mRL
RAPIDLY ERODING GULLY
STEEP FACE IN DILATED ROCK
Makaroro (A7)
POSSIBLE BURIED MEANDER CHANNEL
L:\27195\WorkingMaterial\CAD\CADDesign\27195-SK-DA-04.dwg 04 16/11/2010 10:25:16 a.m.

Figure A7



A3 SCALE 1:8000

0 80 160 240 320 400 (m)

NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates. Level Datum: MSL = 10 mRL

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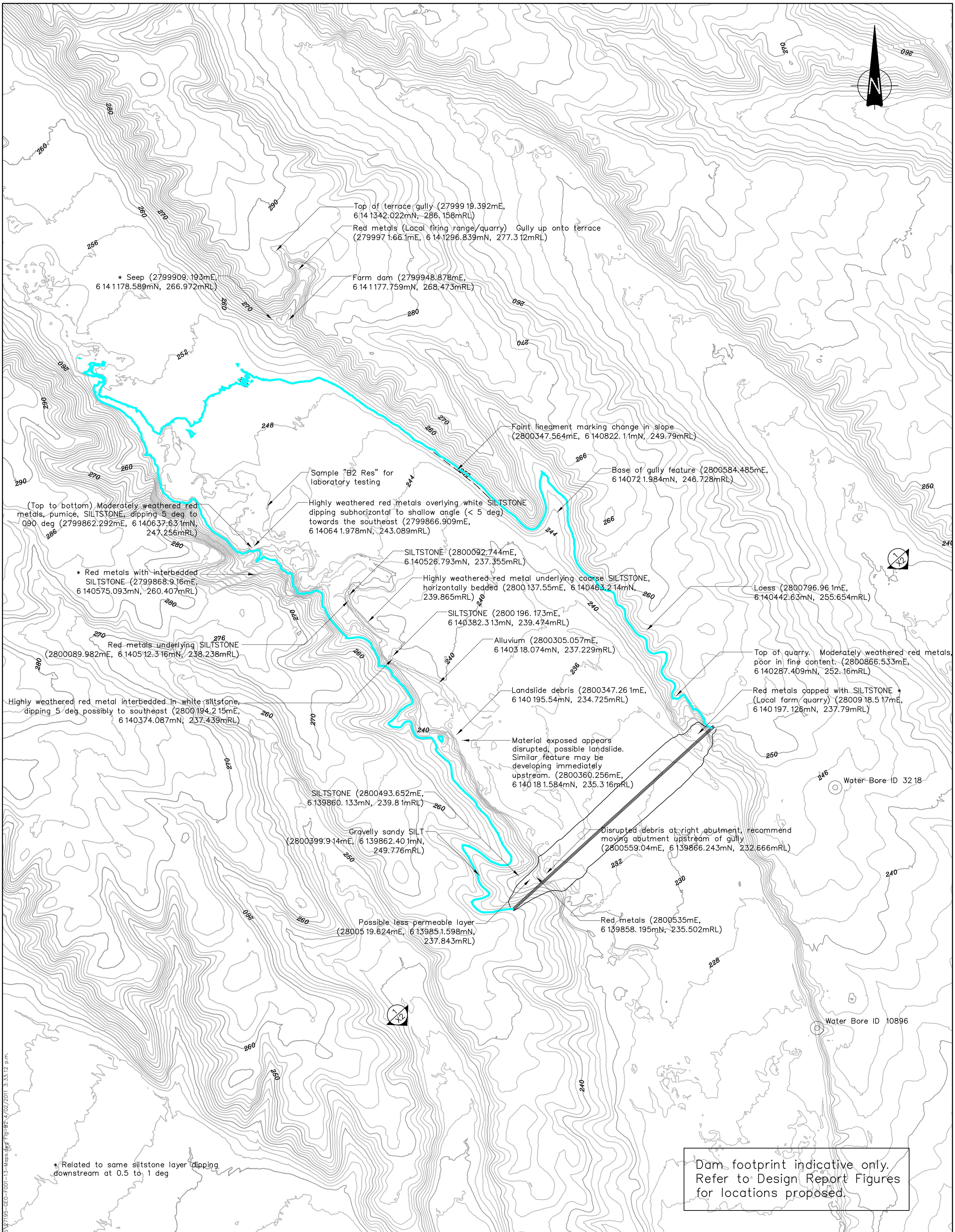
Hawkes Bay Regional Council
Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage B1

FIG. No. Figure B1

REV. 0



NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
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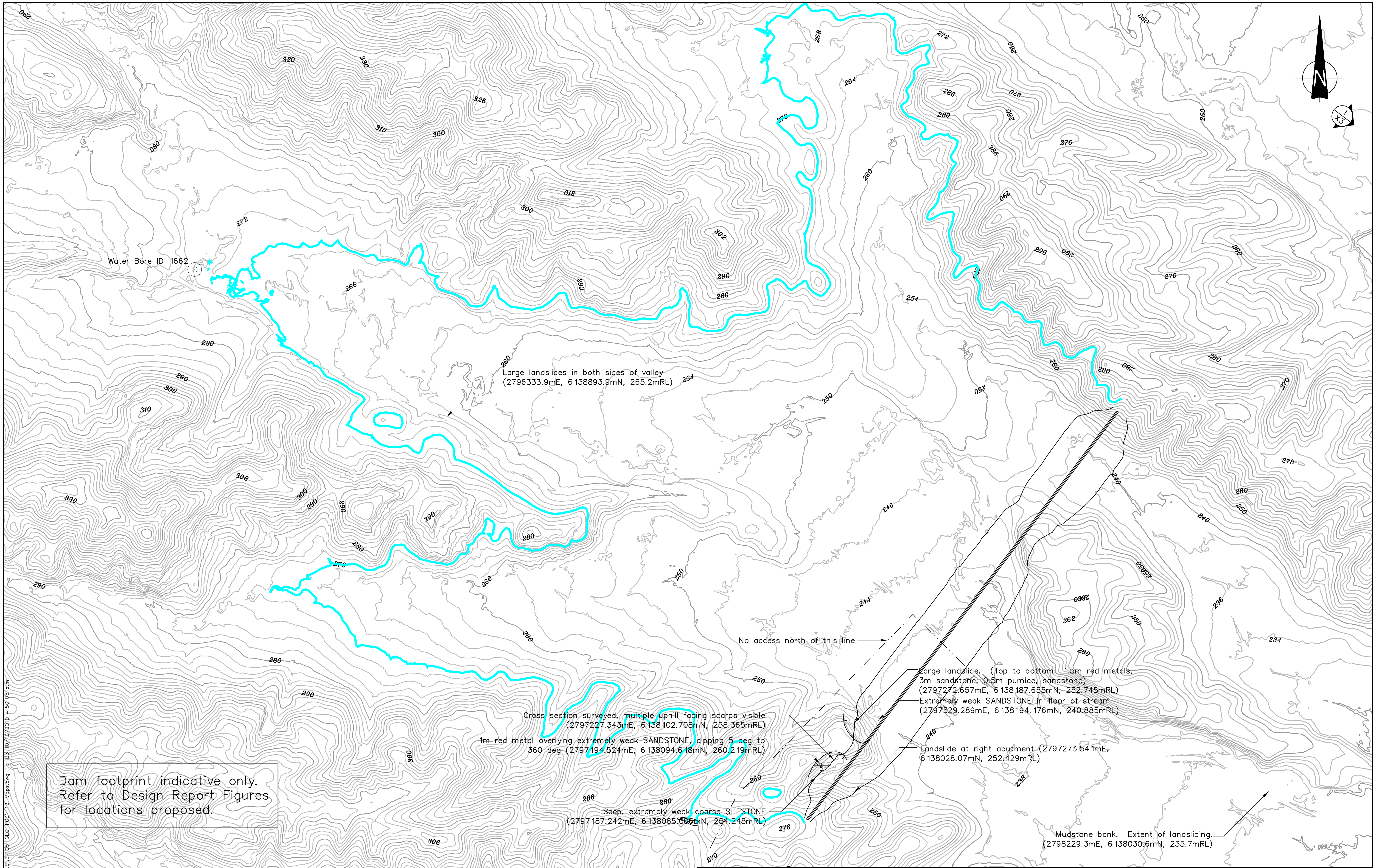
Hawkes Bay Regional Council
Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage B2

FIG. No. Figure B2 REV. 0



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NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
Level Datum: MSL = 10 mRL

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Hawkes Bay Regional Council
Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage B3

FIG. No. Figure B3

REV. 0

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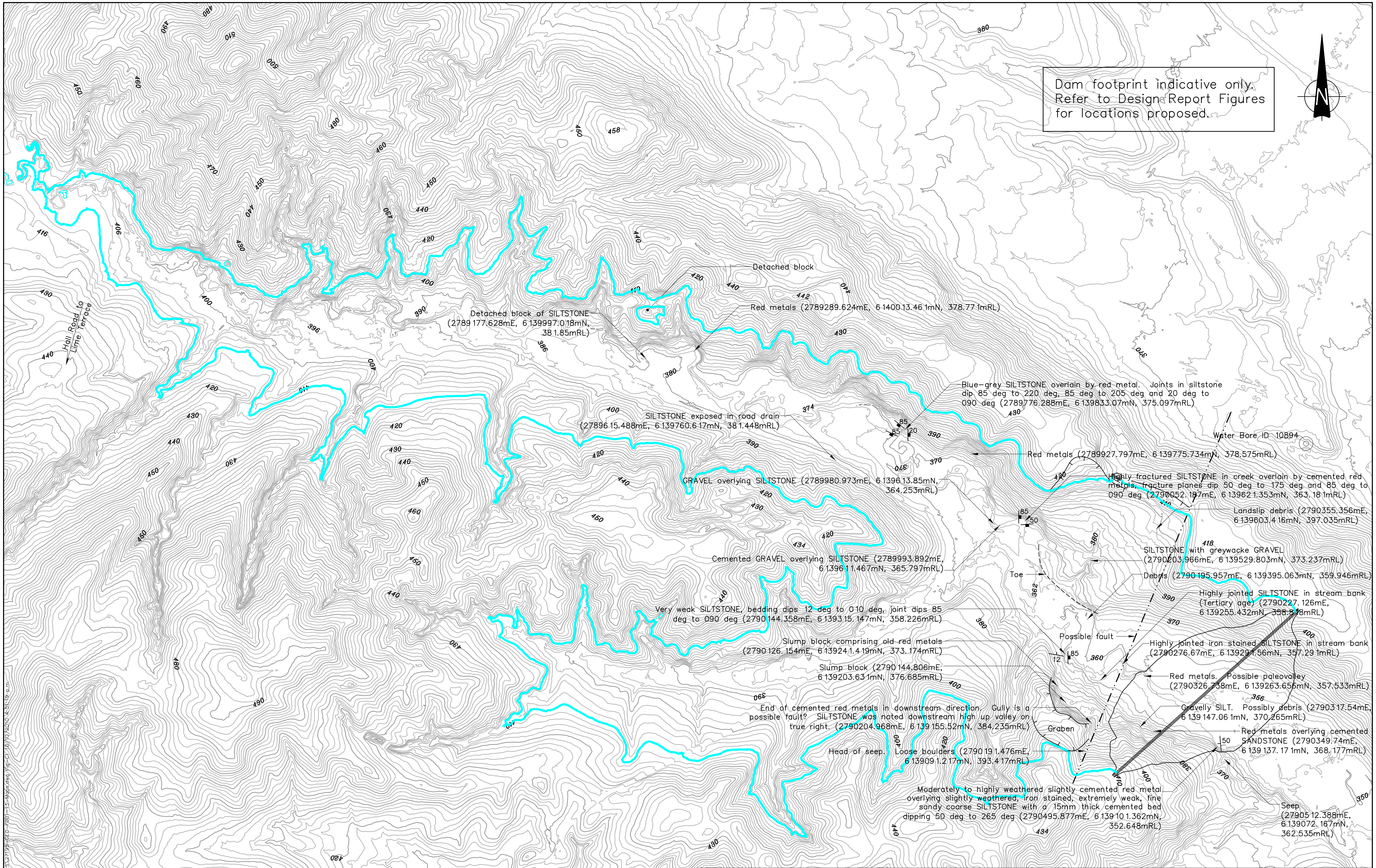

NOTES:

1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
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Hawkes Bay Regional Council

Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage C1

FIG. No. Figure C1

REV. 0

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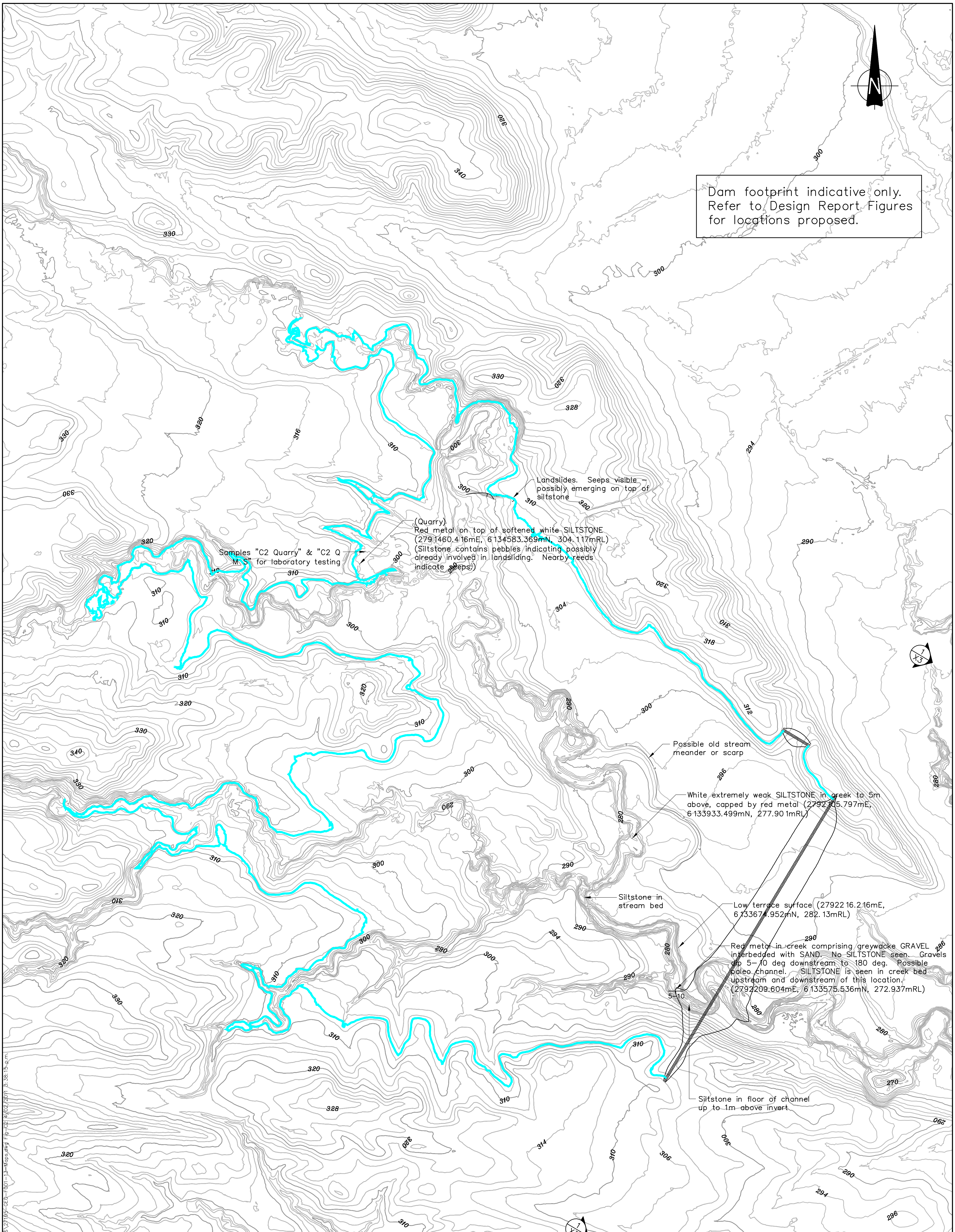

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NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
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Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage C2

FIG. No. Figure C2
REV. 0

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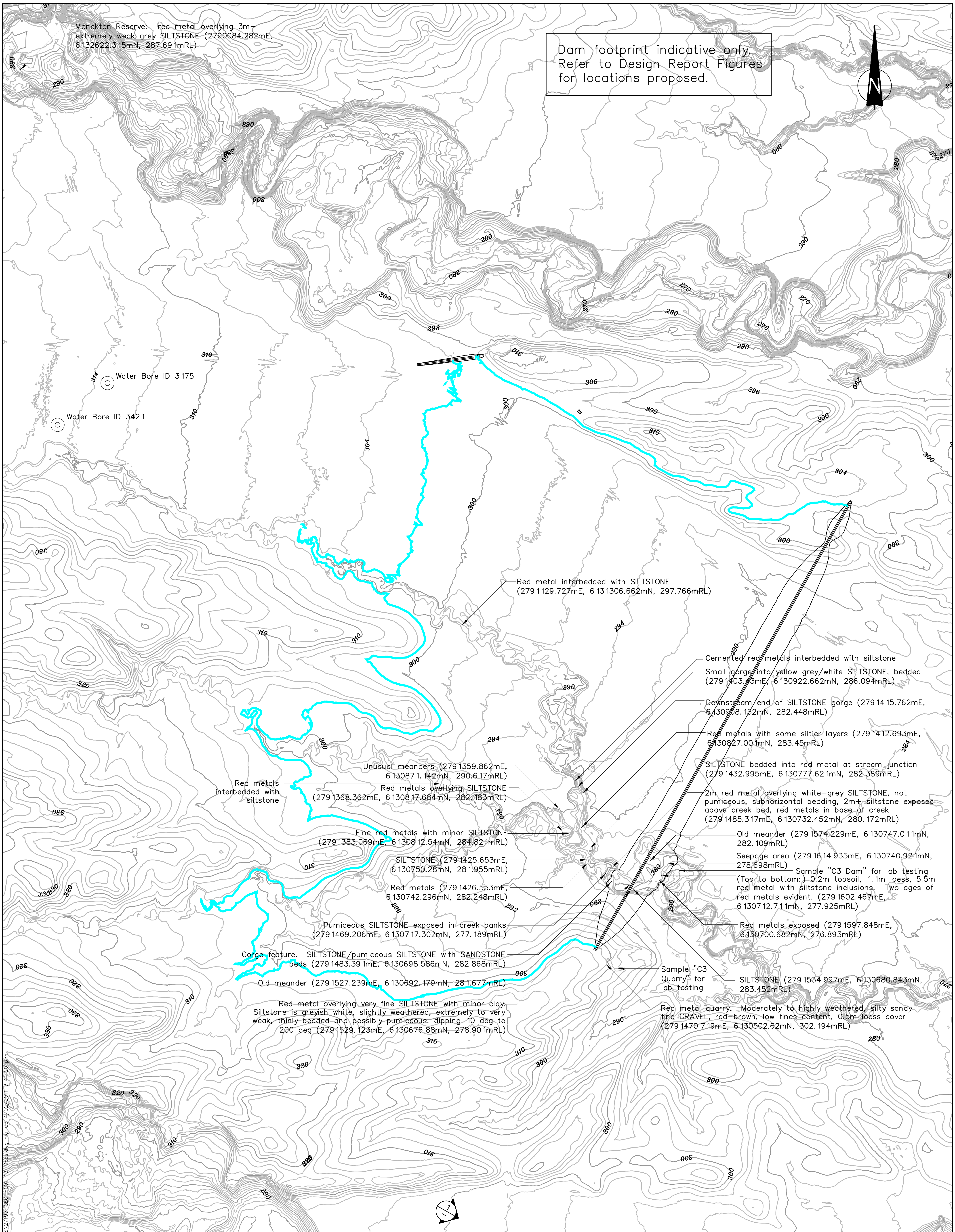

NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
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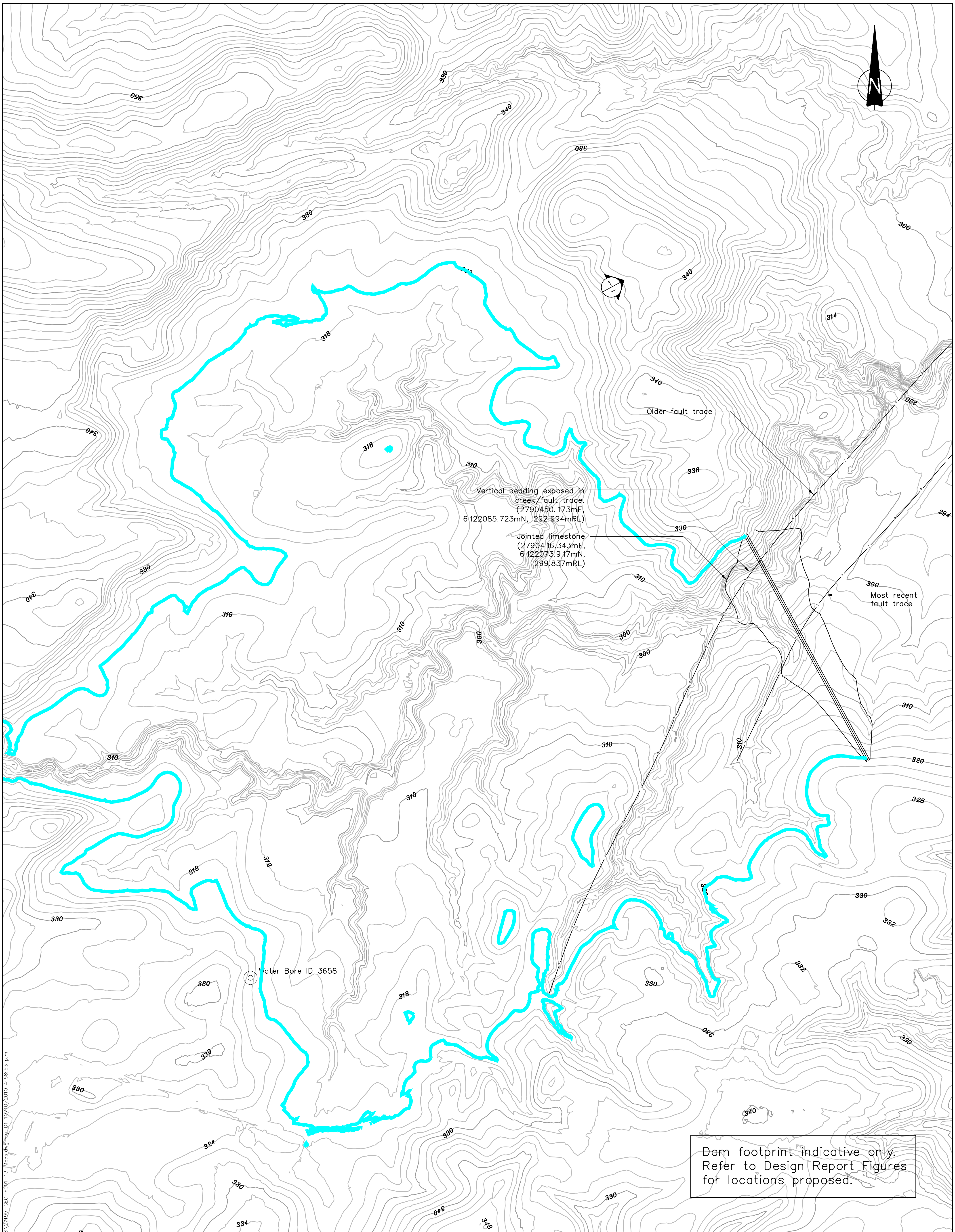
Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage C3

FIG. No. Figure C3

REV. 0



A3 SCALE 1:5000

0 50 100 150 200 250 (m)

NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
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Hawkes Bay Regional Council
Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage D1

FIG. No. Figure D1 REV. 0

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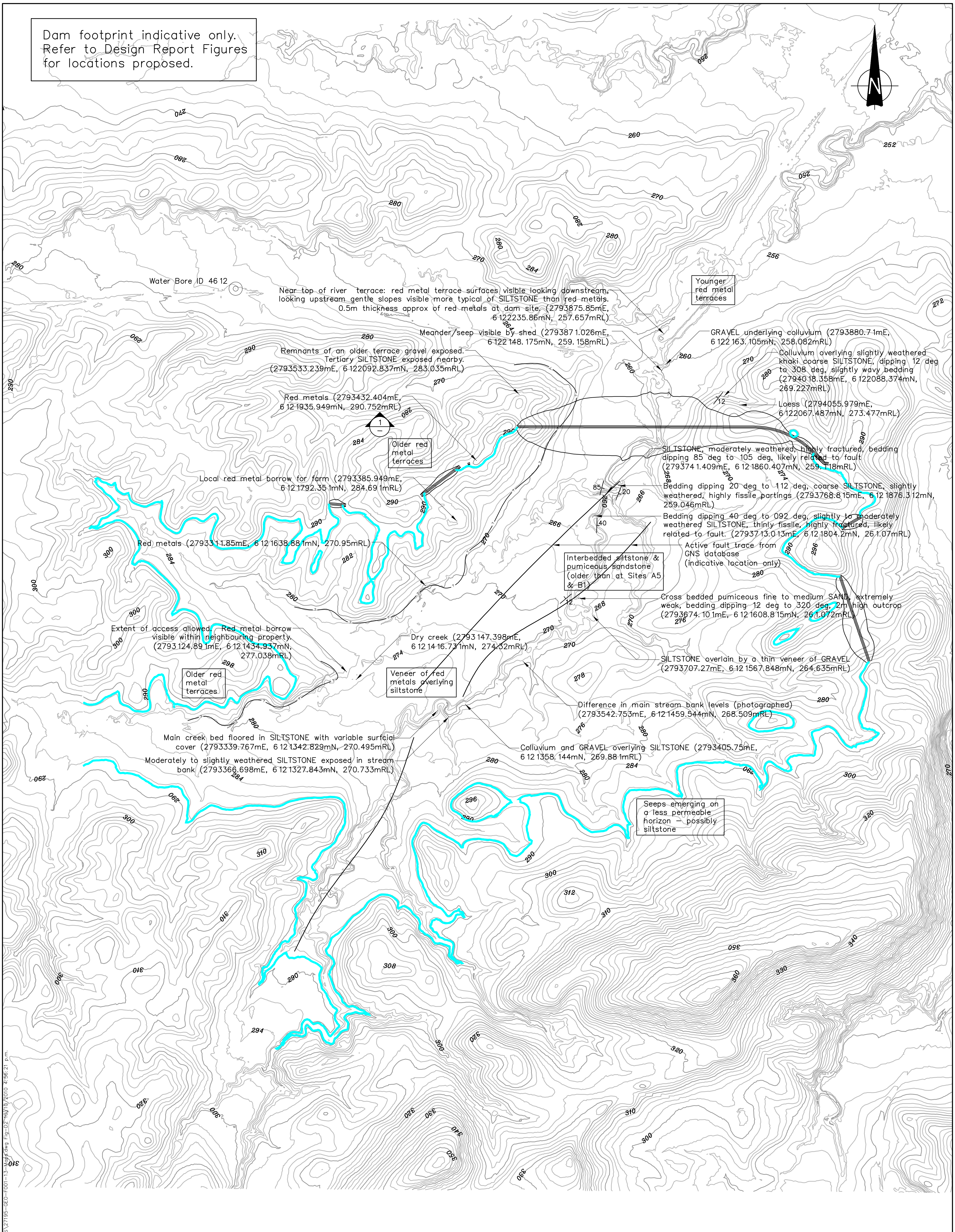

A3 SCALE 1:8000

0 80 160 240 320 400 (m)

NOTES:
1. Contours generated from LiDAR data sourced from Hawkes Bay Regional Council.
2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
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SCALES (AT A3 SIZE) AS SHOWN		
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Hawkes Bay Regional Council

Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage D2

FIG. No. Figure D2

REV. 0

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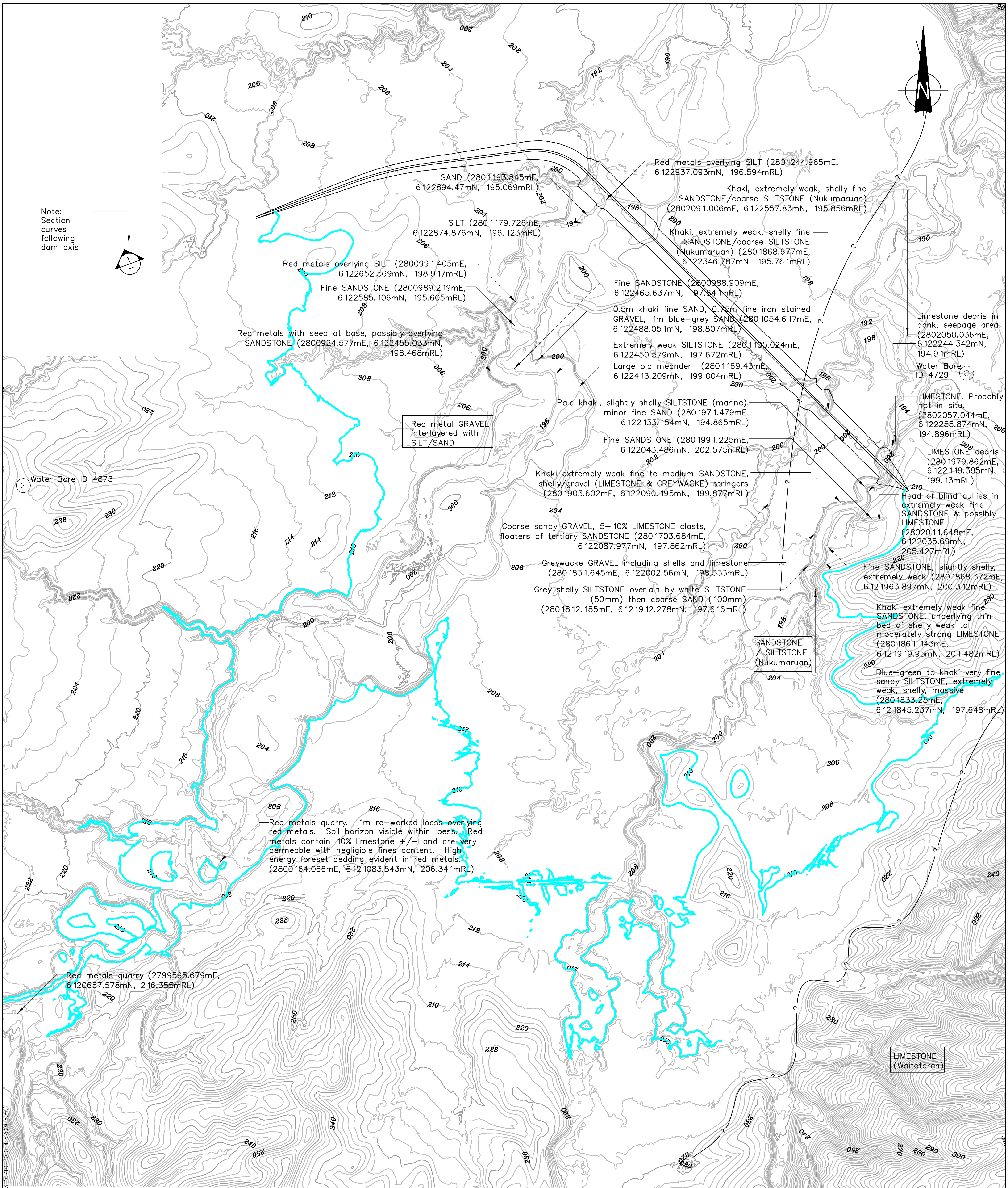

Dam footprint indicative only. Refer to Design Report Figures for locations proposed.

A3 SCALE 1:10,000

0 100 200 300 400 500 (m)

NOTES:
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2. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
Level Datum: MSL = 10 mRL

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Ruataniwha Water Augmentation Scheme
Central Hawkes Bay
Field Observations for Storage D3

FIG. No. Figure D3 REV. 0

Makaretu D5

Crest elevation	349 mRL
Dam height	41 m
Full supply level	346 mRL
Storage volume	25 Million m^3
Reservoir Area	155 ha

NOTES:
1. All levels and contour labels shown on this drawing are to HBRC engineering datum, whereby MSL= 10mRL, and not to LINZ datum (where MSL=0mRL).
2. Only the dam and reservoir are shown in this drawing. The distribution network for delivering water to farms are not shown.

SCALE 1:5000

0 50 100 150 200 250 (m)

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RUATANIWHA PLAINS WATER AUGMENTATION SCHEME
Central Hawkes Bay
Field Observations for Storage D5

FIG. No. Figure D5

REV. 0

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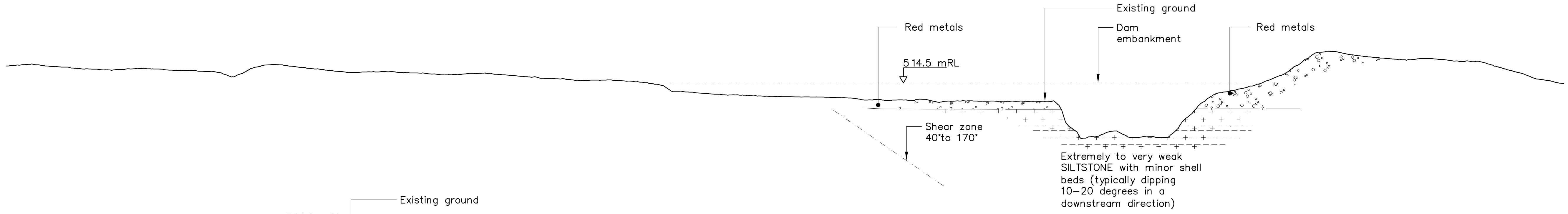
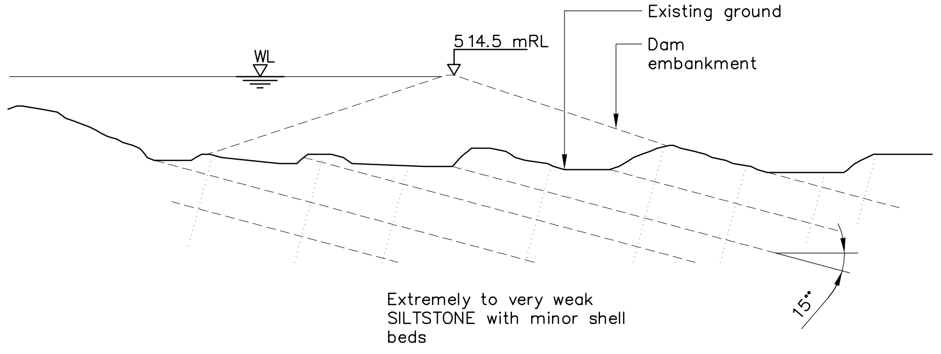
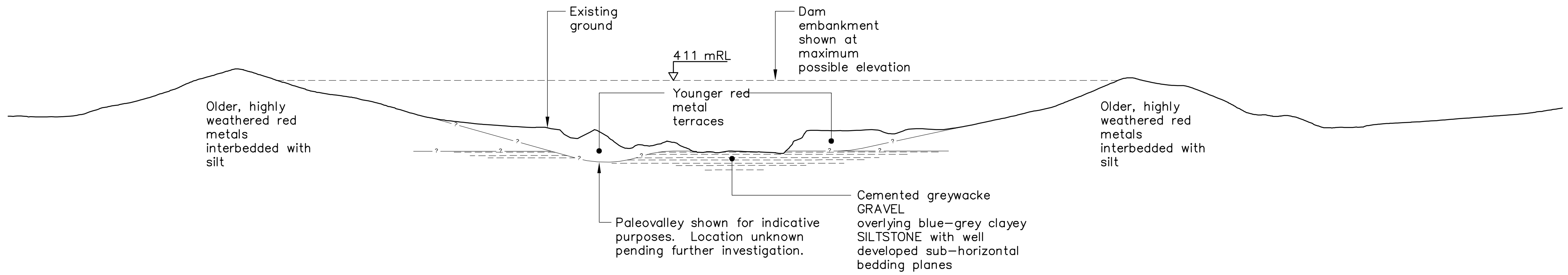
Appendix B: Indicative Cross Valley Sections at Potential Dams



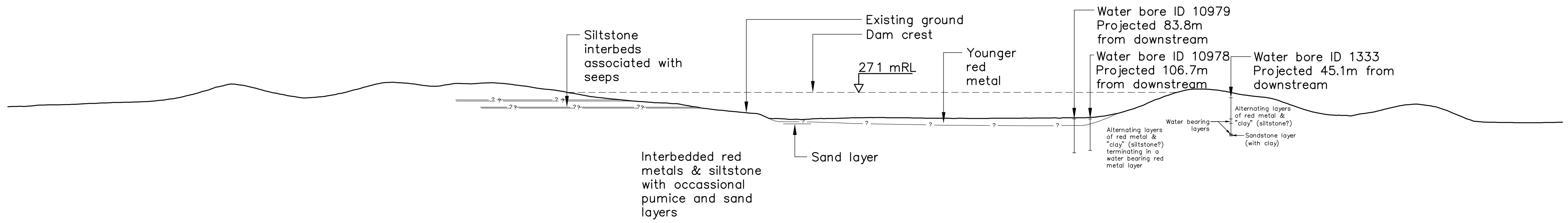
SECTION 1 A1 Indicative Cross Valley Section for Site A1
SCALE 1:5000



SECTION 2 A1 Indicative Long Section down Valley for Site A1
SCALE 1:5000



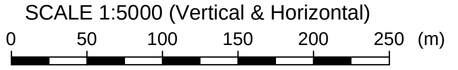
SECTION 1 A2 Indicative Cross Valley Section for Site A2
SCALE 1:5000



SECTION 1 A4 Indicative Cross Valley Section for Site A4
SCALE 1:5000

NOTES:
1. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
Level Datum: MSL = 10 mRL

SCALE 1:5000 (Vertical & Horizontal)



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SCALES (AT A3 SIZE) AS SHOWN		
PROJECT No. 27195		

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Central Hawkes Bay
Indicative Cross Valley Sections at Dams (1 of 6)

FIG. No. Figure X1 REV. 0

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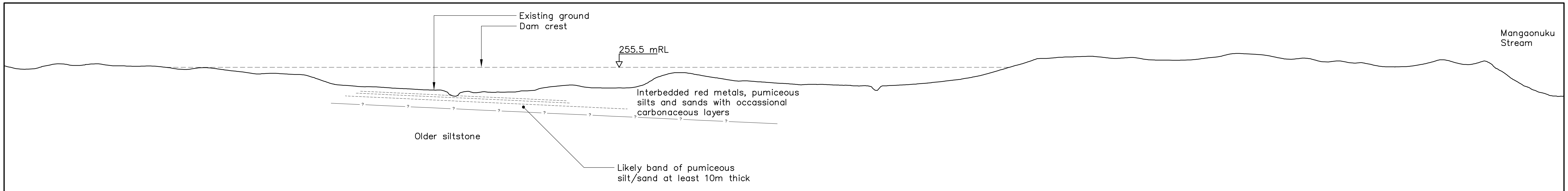
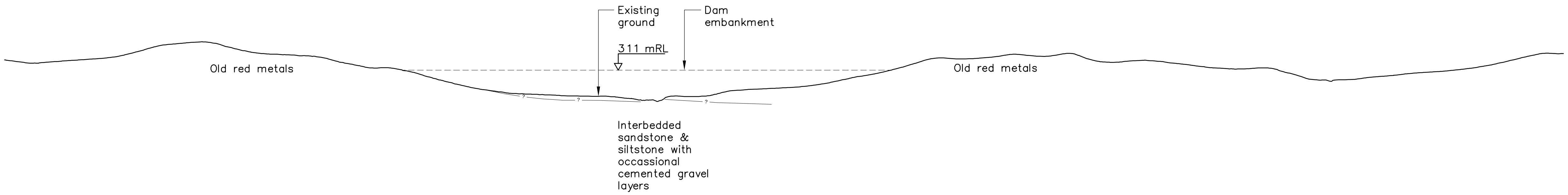


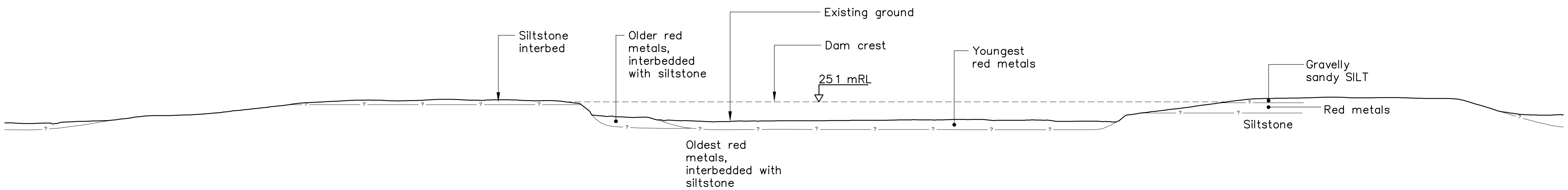
SECTION 1/A5 Indicative Cross Valley Section for Site A5

SCALE 1:5000



SECTION 1/B1 Indicative Cross Valley Section for Site B1

SCALE 1:5000



General materials:
interbedded siltstone and red metals with occassional pumiceous horizons

SECTION 1/B2 Indicative Cross Valley Section for Site B2

SCALE 1:5000

NOTES:
1. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates. Level Datum: MSL = 10 mRL

SCALE 1:5000 (Horizontal & Vertical)
0 50 100 150 200 250 (m)

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Central Hawkes Bay
Indicative Cross Valley Sections at Dams (2 of 6)

FIG. No. Figure X2

REV. 0

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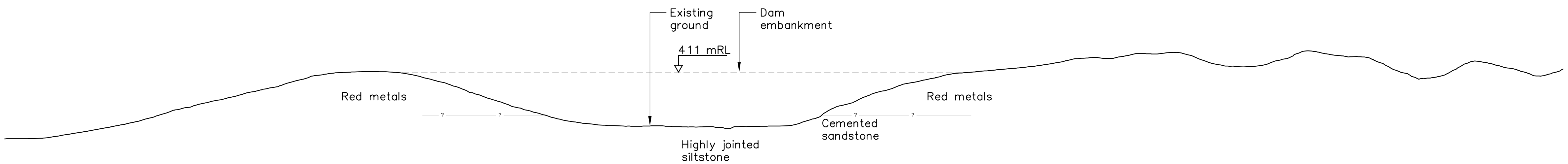
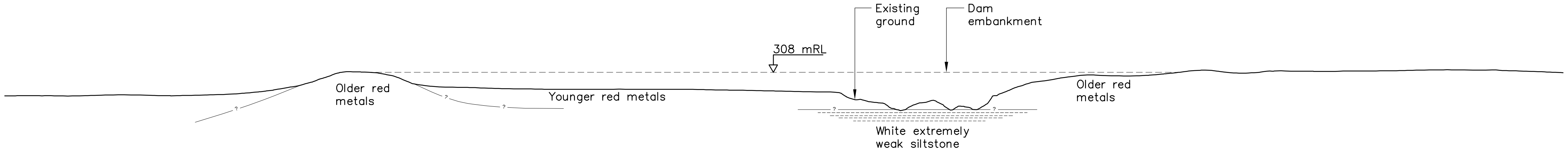
SECTION 1/B3 Indicative Cross Valley Section for Site B3
SCALE 1:5000

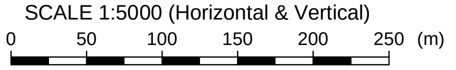


SECTION 1/C1 Indicative Cross Valley Section for Site C1
SCALE 1:5000



SECTION 1/C2 Indicative Cross Valley Section for Site C2
SCALE 1:5000

SCALE 1:5000 (Horizontal & Vertical)



NOTES:
1. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates. Level Datum: MSL = 10 mRL

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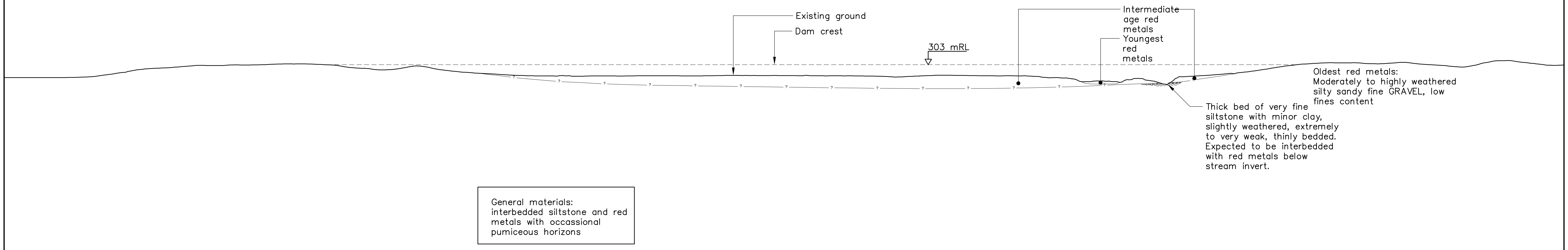
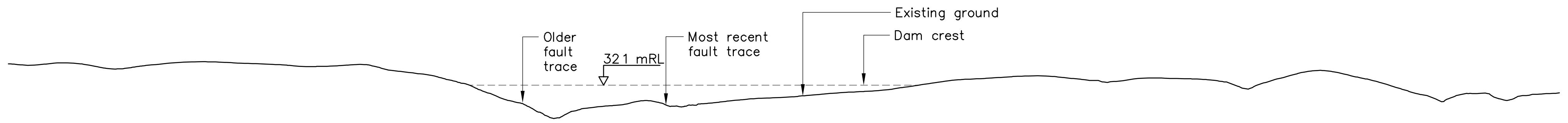
Indicative Cross Valley Sections at Dams (3 of 6)

FIG. No. Figure X3
REV. 0

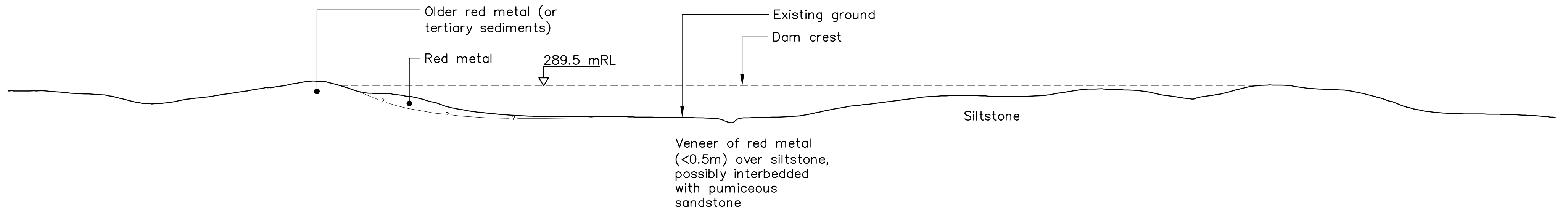
I:\27195\WorkingMaterial\CAD\FIGURES\27195-GEO-F001-13-Maps.dwg Fig-X3 4/02/2011 11:53:19 a.m.



SECTION 1/C3 Indicative Cross Valley Section for Site C3
SCALE 1:5000



SECTION 1/D1 Indicative Cross Valley Section for Site D1
SCALE 1:5000



SECTION 1/D2 Indicative Cross Valley Section for Site D2
SCALE 1:5000

NOTES:
1. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates. Level Datum: MSL = 10 mRL

SCALE 1:5000 (Horizontal & Vertical)
0 50 100 150 200 250 (m)

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PROJECT No. 27195		

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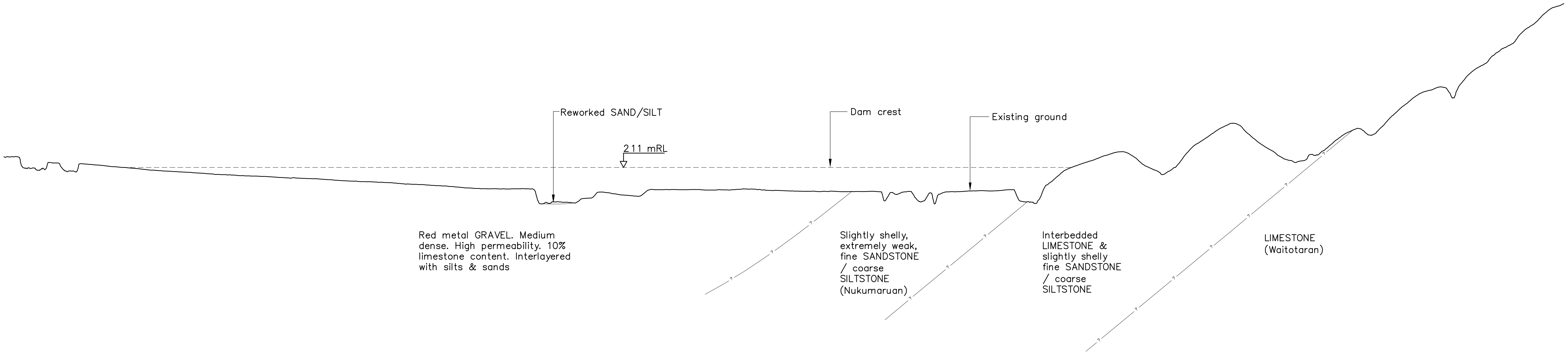
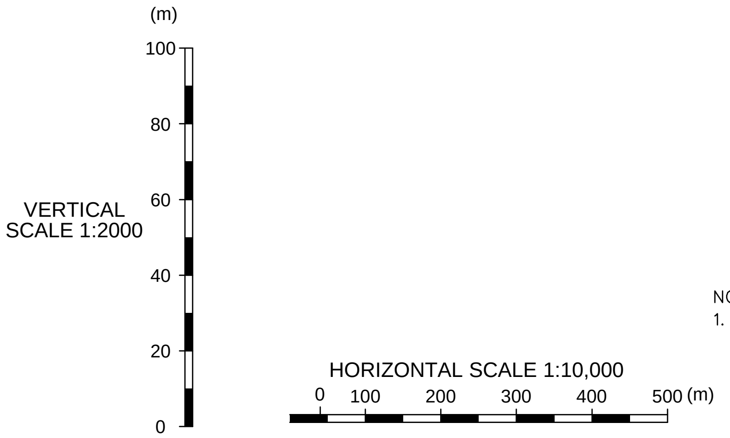
Central Hawkes Bay
Indicative Cross Valley Sections at Dams (4 of 6)

FIG. No. Figure X4
REV. 0

I:\27195\WorkingMaterial\CAD\FIGURES\27195-GEO-F001-13-Maps.dwg Fig-X4 4/02/2011 11:54:09 a.m.



SECTION 1 D3 Indicative Cross Valley Section for Site D3
VERTICAL 1:2000
HORIZONTAL 1:10000



NOTES:
1. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates. Level Datum: MSL = 10 mRL

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PROJECT No. 27195		

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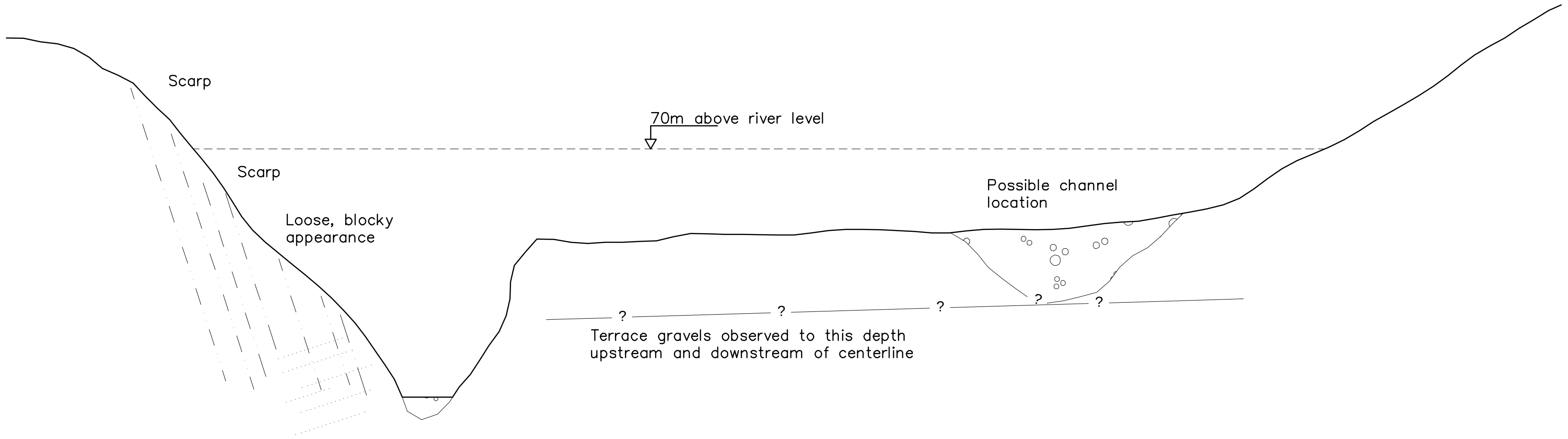
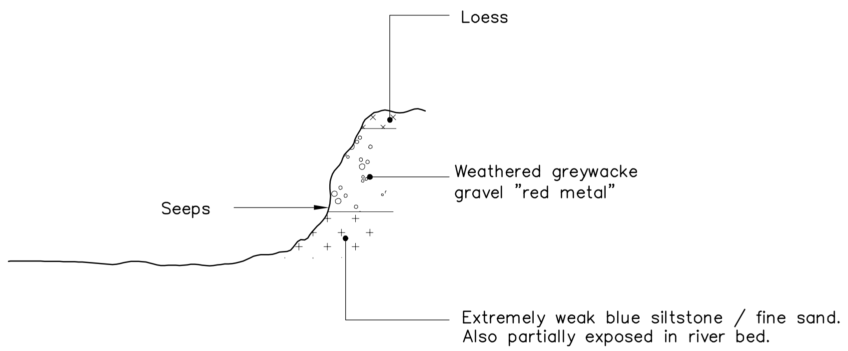
Central Hawkes Bay
Indicative Cross Valley Sections at Dams (5 of 6)

FIG. No. Figure X5 REV. 0



SECTION 1 A7 Indicative Cross Valley Section for Site A7
SCALE 1:2000



SECTION 1 D5 Indicative Cross Valley Section for Site D5
SCALE 1:2000

SCALE 1:2000 (Horizontal & Vertical)
0 20 40 60 80 100 (m)

NOTES:
1. Coordinate Datum: NZ Geodetic 1949 New Zealand Map Grid Coordinates.
Level Datum: MSL = 10 mRL

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SCALES (AT A3 SIZE) AS SHOWN		
PROJECT No. 27195		

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Central Hawkes Bay
Indicative Cross Valley Sections at Dams (6 of 6)

FIG. No. Figure X6
REV. 0

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Appendix C: Field Observations Table

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2789812.2	6157196.5	437.1	A1	(Top to bottom) 17m GRAVEL, 30m dry extremely weak fine SANDSTONE, cemented layer, 5m wet blue extremely weak fine SANDSTONE with slabbing	DMK23	3/05/2010	12:47:47pm
2790150.9	6157436.9	440.8	A1	Massive, very weak to weak, slightly shelly SILTSTONE	BDH4	03-MAY-10 1:15:18PM	
2790089.7	6157543.1	444.1	A1	Landslide. Base of sliding dipping 40 deg to 290 deg	DMK26	3/05/2010	01:23:12pm
2790076.3	6157576.7	444.6	A1	SILTSTONE. Joint dipping 40 deg to 195 deg	DMK27	3/05/2010	01:28:26pm
2790032.3	6157657.7	442.1	A1	Landsliding on well developed defect dipping 35 deg to 095 deg in very weak SILTSTONE	DMK28	3/05/2010	01:37:40pm
2790042.8	6157691.9	444.2	A1	Dipping 85 deg to 360 deg	BDH8	03-MAY-10 1:41:54PM	
2790179.2	6157796.7	446.4	A1	Landsliding on sheared surface dipping 40 deg to 285 deg	BDH9	03-MAY-10 1:48:45PM	
2790064.8	6157918.3	448.5	A1	Landsliding on a bedding plane shear dipping 10 deg to 160 deg. Bedding indicated by shell.	BDH10	03-MAY-10 1:59:54PM	
2790010.8	6157924.6	452.2	A1	Extremely weak to very weak SILTSTONE with minor shell beds, dipping 20 deg to 174 deg	BDH11	03-MAY-10 2:08:57PM	
2790052.5	6158006.8	453.8	A1	Very weak massive SILTSTONE with 2m diameter concretions, dipping 16 deg to 170 deg. 4m GRAVEL above 29.5m SILTSTONE	BDH12	03-MAY-10 2:15:26PM	
2790050.2	6158035.4	454.0	A1	Bedding plane shear dipping 15 deg to 158 deg, increased jointing and partings in rock above shear	BDH13	03-MAY-10 2:24:17PM	
2789954.6	6158194.7	454.3	A1	Alternative dam site	BDH14	03-MAY-10 2:36:45PM	
2789986.8	6158211.1	455.6	A1	Alternative dam site, more massive, but unfavourable bedding planes still present, river bank some 30m +/-	DMK32	3/05/2010	02:41:31pm
2789940.1	6158320.8	457.1	A1	Highly disturbed rock mass, shearing along bedding planes and subvertical, likely significant tectonic disturbance, dipping 18 deg to 190 deg, 46 deg to 060 deg, and 85 deg to 190 deg	DMK33	3/05/2010	02:50:12pm
2790062.0	6158568.1	460.2	A1	Very weak massive SILTSTONE with bedding plane partings dipping 16 deg to 150 deg	BDH17	03-MAY-10 3:02:25PM	

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2790075.0	6157927.2	461.4	A1	Bedding shear (within proposed dam)	DMK34	3/05/2010	03:33:29pm
2790184.8	6157436.8	440.2	A1	SILTSTONE with defects dipping 50 deg to 140 deg and 60 deg to 086 deg (conjugate planes) (Transition from SANDSTONE to SILTSTONE in the upstream direction)	BDH18	03-MAY-10 4:00:30PM	
2796421.1	6143133.2	302.9	B1	Pumiceous white SILT and fine SAND, subhorizontally bedded, in floor of valley	BDH19	04-MAY-10 10:53:45AM	
2796546.5	6143358.1	326.0	B1	Landsliding. Pumiceous SILTSTONE/fine SANDSTONE. Graben 10m wide downhill of earth flow.	BDH21	04-MAY-10 11:13:44AM	
2796711.6	6143268.7	315.4	B1	Toe of landslide	BDH22	04-MAY-10 11:25:44AM	
2796766.1	6143103.1	297.1	B1	White, pumiceous, extremely weak SILTSTONE, thin subhorizontal bedding	BDH23	04-MAY-10 11:30:31AM	
2796965.4	6143009.3	293.0	B1	White, pumiceous, extremely weak SILTSTONE, thin subhorizontal bedding	BDH24	04-MAY-10 11:38:31AM	
2797010.7	6143065.4	295.9	B1	Pumiceous SILTSTONE with two thin dark grey carbonaeous SILTSTONE beds, subhorizontal bedding	BDH25	04-MAY-10 11:41:35AM	
2797222.5	6142843.6	297.6	B1	Landsliding in true right of valley	BDH26	04-MAY-10 11:55:03AM	
2797550.5	6142813.4	284.6	B1	Bedding partings in MUDSTONE. (Top to bottom) 3m red metal, 0.4m soil, 0.8m grey-blue SILTSTONE, 0.1m MUDSTONE, 0.6m dark brown carbonaceous SILTSTONE, 0.1m medium SAND	BDH27	04-MAY-10 12:05:12AM	
2798022.0	6142512.1	277.7	B1	Extremely weak, fine to medium SANDSTONE, interbedded with minor SILTSTONE, dipping 5 deg downstream, overlain by GRAVEL	BDH28	04-MAY-10 12:37:35AM	
2798074.5	6142474.3	277.1	B1	Cemented GRAVEL overlain by SILTSTONE, dipping 15 deg to 180 deg	BDH29	04-MAY-10 12:43:43AM	

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2798274.8	6142384.2	274.3	B1	Cemented GRAVEL (red metals) overlain by SILTSTONE, dipping 15 deg to 180 deg	BDH30	04-MAY-10 12:59:33AM	
2798398.0	6142276.7	273.4	B1	Extremely weak SILTSTONE exposed in bank under tree roots	BDH31	04-MAY-10 1:06:42PM	
2798765.9	6141936.2	269.7	B1	Red metal above white massive SILTSTONE at side of road	BDH32	04-MAY-10 1:20:10PM	
2799036.0	6142203.0	292.2	B1	Red metal exposed in cutting	BDH33	04-MAY-10 1:30:10PM	
2797555.6	6142657.0	291.7	B1	Possible fault location? Landsliding upstream.	BDH34	04-MAY-10 2:16:09PM	
2791460.4	6134583.4	304.1	C2	Red metal on top of softened white SILTSTONE	BDH35	04-MAY-10 3:43:42PM	
2792105.8	6133933.5	277.9	C2	White extremely weak SILTSTONE in creek to 5m above, capped by red metal	BDH36	04-MAY-10 4:14:43PM	
2792216.2	6133675.0	282.1	C2	Low terrace surface	BDH37	04-MAY-10 4:42:54PM	
2792209.6	6133575.5	272.9	C2	Red metal in creek comprising greywacke GRAVEL interbedded with SAND. No SILTSTONE seen. Gravels dip 5-10 deg downstream to 180 deg. Possible paleo channel. SILTSTONE is seen in creek bed upstream and downstream of this location.	BDH38	04-MAY-10 4:45:59PM	
2813628.1	6148615.9	281.7	A5	Pumiceous SILT, horizontal bedding	DMK36	5/05/2010	09:31:55am
2812346.8	6148468.0	248.5	A5	Side of landslide, having passed down thorugh horizontally bedded pumiceous SANDS. Red metals over pumice	BDH39	05-MAY-10 9:47:17AM	
2812351.3	6148460.3	247.3	A5	Scarp of large scale landslide	DMK37	5/05/2010	09:43:31am
2812192.9	6148350.7	235.5	A5	Stream at toe of landslide. Thin horizontal beds of pumicous SILTS, SANDS (pumice tephra, lake deposits)	DMK38	5/05/2010	09:56:28am
2812136.3	6148383.6	233.4	A5	Interbedded pumiceous SILTSTONE over softened clayey SILTSTONE	DMK39	5/05/2010	10:03:18am
2812129.3	6148355.8	234.0	A5	Contact of extremely weak to very weak blue-grey massive SILTSTONE (tertiary?) overlain by horizontally bedded pumice SANDS	BDH41	05-MAY-10 10:02:24AM	

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2812086.6	6148280.2	231.3	A5	(Top to bottom) Colluvium, red metals, pumiceous SILTSTONE (1.5m+/-), SILTSTONE (2.5m+/-)	DMK40	5/05/2010	10:09:21am
2812031.3	6148246.6	230.0	A5	Landslide debris	DMK41	5/05/2010	10:14:16am
2811969.5	6148198.1	232.8	A5	Pumiceous SANDS over SILTSTONE. Lateral scarp	BDH42	05-MAY-10 10:16:10AM	
2811961.1	6148125.7	229.6	A5	Cave & tunnel formed by water piping in pumiceous silts (suffusion). (Top to bottom) Red metals, pumice, thin carbonaceous layer, blue SILTSTONE with a "breccia" appearance. Similar to at Site B1	DMK43	5/05/2010	10:26:26am
2811838.3	6148155.0	229.1	A5	White pumice SANDS/SILTS dipping 35 deg to 330 deg, underlying red metal. Chaotic bedding of pumicous tephra indicative of a possible major landslide/fault. Cliff height 10m.	DMK44	5/05/2010	10:32:48am
2811847.2	6148089.8	226.5	A5	Cave, pumiceous, seepage	DMK46	5/05/2010	10:39:00am
2811817.9	6148082.3	227.4	A5	(Top to bottom) Pumice, lake sediments, SILTSTONE. Significantly cross bedded and not subhorizontal. Rafted?	DMK47	5/05/2010	10:40:28am
2811678.9	6148240.6	222.6	A5	Red metal interbedded with pumiceous SANDS/SILTS, dipping 5 deg to 330 deg	DMK49	5/05/2010	10:53:31am
2811636.8	6148148.3	222.8	A5	Debris	DMK50	5/05/2010	10:58:32am
2811593.1	6148111.4	224.1	A5	Pumice SILTS/SANDs overlying red metal. Pumice is jointed dipping 10 deg to 260 deg. Appears disturbed	DMK51	5/05/2010	11:01:31am
2811449.8	6148100.7	230.9	A5	Pumice SILTS/SANDs, 10m thick, dipping 5-10 deg to 260 deg	BDH48	05-MAY-10 11:16:53AM	
2811311.6	6147996.1	224.4	A5	Red metals in stream, overlies pumice	DMK52	5/05/2010	11:26:59am
2811295.9	6147964.9	224.5	A5	Pumice	DMK53	5/05/2010	11:28:58am
2810916.2	6148237.5	230.3	A5	Pumice SAND interbedded in red metal, bedding possibly subhorizontal	DMK55	5/05/2010	11:54:28am
2811117.2	6148546.9	239.2	A5	Pumice overlying red metals	DMK56	5/05/2010	12:05:27pm

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2811572.1	6148518.3	263.7	A5	Panorama photo point. Plains and tops of hills in true left of valley appear to dip downstream at about 20 deg flattening off to 10 deg as we progress downstream of the dam site, gulleys appear "organised"	DMK57	5/05/2010	12:13:40pm
2811790.0	6148563.4	279.9	A5	Slopes on other (southern) side of valley appear to dip downstream at 20 deg. A large graben feature is visible on ridge to east.	DMK58	5/05/2010	12:20:52pm
2811975.5	6148583.6	286.9	A5	60m wide graben, indicating landslide likely to extend to creek.	BDH54	05-MAY-10 12:31:35AM	
2813152.1	6148831.5	264.4	A5	Subhorizontal pumiceous sediments and red metals. Landslide visible to left of road.	BDH55	05-MAY-10 12:53:40AM	
2813402.7	6148659.6	268.3	A5	Continuous exposed pumice sediments	BDH56	05-MAY-10 12:56:01AM	
2813784.1	6148665.6	289.5	A5	Continuous exposed pumice sediments	BDH57	05-MAY-10 12:57:24AM	
2790450.2	6122085.7	293.0	D1	Vertical bedding exposed in creek/fault trace.	DMK62	5/05/2010	03:28:38pm
2790416.3	6122073.9	299.8	D1	Jointed limestone	DMK63	5/05/2010	03:33:58pm
2794056.0	6122067.5	273.5	D2	Loess	DMK2	6/05/2010	09:30:41am
2794018.4	6122088.4	269.2	D2	Colluvium overlying slightly weathered khaki coarse SILTSTONE, dipping 12 deg to 308 deg, slightly wavy bedding	DMK3	6/05/2010	09:32:34am
2793871.0	6122148.2	259.2	D2	Meander/seep visible by shed	DMK4	6/05/2010	09:42:58am
2793880.7	6122163.1	258.1	D2	GRAVEL underlying colluvium	DMK5	6/05/2010	09:45:13am
2793875.9	6122235.9	257.7	D2	Near top of river terrace: red metal terrace surfaces visible looking downstream, looking upstream gentle slopes visible more typical of SILTSTONE than red metals. 0.5m thickness approx of red metals at dam site.	DMK6	6/05/2010	09:49:03am

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2793533.2	6122092.8	283.0	D2	Remnants of an older terrace gravel exposed. Tertiary SILTSTONE exposed nearby.	DMK7	6/05/2010	10:02:47am
2793432.4	6121935.9	290.8	D2	Red metals	DMK9	6/05/2010	10:12:28am
2793385.9	6121792.4	284.7	D2	Local red metal borrow for farm	DMK10	6/05/2010	10:17:13am
2793311.9	6121638.9	271.0	D2	Red metals	DMK11	6/05/2010	10:30:59am
2793124.9	6121434.9	277.0	D2	Extent of access allowed. Red metal borrow visible within neighbouring property.	DMK12	6/05/2010	10:36:57am
2793147.4	6121416.7	274.3	D2	Dry creek	DMK13	6/05/2010	10:43:55am
2793366.7	6121327.8	270.7	D2	Moderately to slightly weathered SILTSTONE exposed in stream bank	BDH66	06-MAY-10 10:55:05AM	
2793339.8	6121342.8	270.5	D2	Main creek bed floored in SILTSTONE with variable surfcial cover	DMK14	6/05/2010	10:50:51am
2793405.8	6121358.1	269.9	D2	Colluvium and GRAVEL overlying SILTSTONE	DMK15	6/05/2010	10:56:30am
2793542.8	6121459.5	268.5	D2	Difference in main stream bank levels (photographed)	DMK16	6/05/2010	11:01:02am
2793707.3	6121567.8	264.6	D2	SILTSTONE overlain by a thin veneer of GRAVEL	DMK18	6/05/2010	11:11:02am
2793674.1	6121608.8	261.1	D2	Cross bedded pumiceous fine to medium SAND, extremely weak, bedding dipping 12 deg to 320 deg, 2m high outcrop	DMK19	6/05/2010	11:17:00am
2793713.0	6121804.2	261.1	D2	Bedding dipping 40 deg to 092 deg, slightly to moderately weathered SILTSTONE, thinly fissile, highly fractured, likely related to fault.	DMK21	6/05/2010	11:50:00am
2793741.4	6121860.4	259.1	D2	SILTSTONE, moderately weathered, highly fractured, bedding dipping 85 deg to 105 deg, likely related to fault	DMK22	6/05/2010	12:03:40pm
2793768.8	6121876.3	259.0	D2	Bedding dipping 20 deg to 112 deg, coarse SILTSTONE, slightly weathered, highly fissile partings	BDH70	06-MAY-10 12:14:23AM	
2797273.5	6138028.1	252.4	B3	Landslide at right abutment	BDH71	06-MAY-10 3:13:40PM	

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2797187.2	6138065.0	254.2	B3	Seep, extremely weak coarse SILTSTONE	BDH72	06-MAY-10 3:20:08PM	
2797194.5	6138094.6	260.2	B3	1m red metal overlying extremely weak SANDSTONE, subhorizontally bedded dipping 5 deg to 360 deg	BDH73	06-MAY-10 3:24:07PM	
2797227.3	6138102.7	258.4	B3	Cross section surveyed, multiple uphill facing scarps visible	BDH74	06-MAY-10 3:34:26PM	
2797272.7	6138187.7	252.7	B3	Large landslide, (top to bottom): 1.5m red metal, 3m sandstone, 0.5m pumice, sandstone	BDH75	06-MAY-10 3:51:39PM	
2797329.3	6138194.2	240.9	B3	(Top to bottom:) Soil, loess, hard pan, gravels, and extremely weak SANDSTONE in floor of stream	BDH76	06-MAY-10 3:55:05PM	
2793530.5	6139534.0	386.5	B3	Red metals	Wk2DMK43	05/24/10	03:41:32pm
2794497.2	6139263.8	325.5	B3	Landslides	Wk2DMK44	05/24/10	03:44:02pm
2796333.9	6138893.9	265.2	B3	Large landslides in both sides of valley	Wk2DMK45	05/24/10	03:48:31pm
2798229.3	6138030.6	235.7	B3	Mudstone bank. Extent of landsliding.	Wk2DMK46	05/24/10	03:57:20pm
2799505.5	6154409	386.814	A2	Red metals	Wk2DMK1	05/27/10	12:32:55pm
2799722.6	6154416	363.37	A2	Red metals (interlayered with silt) overlying blue-grey clayey SILTSTONE (2m +/- thick) with well developed greasy bedding planes dipping 4 deg to 315-325 deg	Wk2DMK2	05/27/10	12:40:30pm
2799912.3	6154383	366.836	A2	Red metals	Wk2DMK3	05/27/10	12:51:49pm
2800294.2	6154169	346.621	A2	Red metal overlying blue extremely weak SILTSTONE exposed at stream level up to 1m above	Wk2DMK4	05/27/10	01:00:07pm
2800363.1	6154155	345.482	A2	Older cemented GRAVEL interlayered with SILTSTONE	Wk2DMK5	05/27/10	01:03:30pm
2800364.5	6154153	344.485	A2	Cemented greywacke GRAVEL in SILTSTONE/SANDSTONE, dipping downstream (beside bridge)	Wk2DMK7	05/27/10	01:11:59pm
2800400.6	6154132	348.596	A2	Unweathered GRAVEL with bedding indicating high energy deposition	Wk2DMK6	05/27/10	01:06:57pm
2800352.4	6154121	350.581	A2	Grey white extremely weak SILTSTONE	Wk2DMK8	05/27/10	01:14:50pm

P:\27195\WorkingMaterial\Excel\dmk2010.05.3.ObservationsTable.xls

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2800271.6	6154042	362.576	A2	Terrace GRAVELs	Wk2DMK9	05/27/10	01:18:53pm
2799298.1	6153522	407.855	A2	Red metals overlying SILTSTONE	Wk2DMK10	05/27/10	01:43:11pm
2799263.9	6153461	407.915	A2	View of landslides in Mangamauku valley	Wk2DMK11	05/27/10	01:46:06pm
2799285.4	6153253	373.71	A2	Red metals underlying SILTSTONE	Wk2DMK12	05/27/10	01:50:44pm
2799348.6	6153010	334.667	A2	Cemented GRAVEL interlayered with SILTSTONE	Wk2DMK13	05/27/10	01:56:01pm
2799348.7	6152987	329.869	A2	Khaki extremely weak SILTSTONE (very old), thin white pumice sands interbedded, dipping 4 deg to 095 deg	Wk2DMK14	05/27/10	01:58:19pm
2799290.9	6153028	331.107	A2	Landslide debris including blue SILTSTONE	Wk2DMK15	05/27/10	02:04:43pm
2799481.1	6153827	402.557	A2	Seep	Wk2DMK16	05/27/10	02:23:14pm
2799866.9	6140642	243.089	B2	Highly weathered red metals overlying white SILTSTONE dipping subhorizontal to shallow angle (< 5 deg) towards the southeast	Wk2DMK18	05/25/10	08:16:25am
2800092.7	6140527	237.355	B2	SILTSTONE	Wk2DMK19	05/25/10	08:35:18am
2800090	6140512	238.238	B2	Red metals underlying SILTSTONE	Wk2DMK20	05/25/10	08:37:08am
2800137.6	6140463	239.865	B2	Highly weathered red metal underlying coarse SILTSTONE, horizontally bedded	Wk2DMK21	05/25/10	08:40:14am
2800196.2	6140382	239.474	B2	SILTSTONE	Wk2DMK22	05/25/10	08:42:25am
2800194.2	6140374	237.439	B2	Highly weathered red metal interbedded in white siltstone, dipping 5 deg possibly to southeast	Wk2DMK23	05/25/10	08:48:47am
2800305.1	6140318	237.229	B2	Alluvium	Wk2DMK24	05/25/10	08:56:21am
2800347.3	6140196	234.725	B2	Landslide debris	Wk2DMK25	05/25/10	09:01:50am
2800360.3	6140182	235.316	B2	Material exposed appears disrupted, possible landslide	BDH80	25-MAY-10 9:05:47AM	
2800559	6139866	232.666	B2	Disrupted debris at right abutment, recommend moving abutment upstream of gully	Wk2DMK26	05/25/10	09:36:17am
2800519.6	6139852	237.843	B2	Possible less permeable layer	Wk2DMK27	05/25/10	09:41:28am

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2800493.7	6139860	239.81	B2	SILTSTONE	Wk2DMK28	05/25/10	09:43:19am
2800399.9	6139862	249.776	B2	Gravelly sandy SILT	Wk2DMK29	05/25/10	09:45:24am
2800535	6139858	235.502	B2	Red metals	Wk2DMK30	05/25/10	09:48:50am
2800918.5	6140197	237.79	B2	Red metals capped with SILTSTONE (Local farm quarry)	Wk2DMK31	05/25/10	10:00:18am
2800866.5	6140287	252.16	B2	Top of quarry. Moderately weathered red metals, poor in fine content.	BDH82	25-MAY-10 10:06:56AM	
2800797	6140443	255.654	B2	Loess	Wk2DMK33	05/25/10	10:16:36am
2800584.5	6140722	246.728	B2	Base of gully feature	Wk2DMK35	05/25/10	10:27:00am
2800347.6	6140822	249.79	B2	Faint lineament marking change in slope	Wk2DMK36	05/25/10	10:33:35am
2799862.3	6140638	247.256	B2	(Top to bottom) Moderately weathered red metals, pumice, SILTSTONE, dipping 5 deg to 090 deg	Wk2DMK37	05/25/10	10:53:46am
2799868.9	6140575	260.407	B2	Red metals with interbedded SILTSTONE	Wk2DMK38	05/25/10	11:06:09am
2799948.9	6141178	268.473	B2	Farm dam	Wk2DMK39	05/25/10	11:13:46am
2799971.7	6141297	277.312	B2	Red metals (Local firing range/quarry) Gully up onto terrace	Wk2DMK40	05/25/10	11:16:03am
2799919.4	6141342	286.158	B2	Top of terrace gully	Wk2DMK41	05/25/10	11:17:42am
2799909.2	6141179	266.972	B2	Seep	Wk2DMK42	05/25/10	11:24:05am
2790355.4	6139603	397.035	C1	Landslip debris	Wk2DMK47	05/25/10	12:37:16pm
2790196	6139395	359.946	C1	Debris	Wk2DMK48	05/25/10	12:45:40pm
2790144.4	6139315	358.226	C1	Very weak SILTSTONE, bedding dips 12 deg to 010 deg, joint dips 85 deg to 090 deg	Wk2DMK49	05/25/10	12:50:00pm
2790126.2	6139241	373.174	C1	Slump block comprising old red metals	Wk2DMK50	05/25/10	12:57:15pm
2790144.8	6139204	376.685	C1	Slump block	Wk2DMK51	05/25/10	12:58:39pm
2790191.5	6139091	393.417	C1	Head of seep. Loose boulders	Wk2DMK53	05/25/10	01:13:59pm
2790512.4	6139072	362.535	C1	Seep	Wk2DMK55	05/25/10	01:31:26pm

Field Observations

Coordinates in New Zealand Map Grid
Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2790495.9	6139101	352.648	C1	Slightly weathered, iron stained, extremely weak, fine SANDSTONE to coarse SILTSTONE, 15mm thick cemented bed dipping 50 deg to 265 deg, overlying moderately to highly weathered slightly cemented red metal	Wk2DMK56	05/25/10	01:34:29pm
2790349.7	6139137	368.177	C1	Red metals overlying cemented SANDSTONE	Wk2DMK58	05/25/10	01:51:27pm
2790317.5	6139147	370.265	C1	Gravelly SILT. Possibly debris	Wk2DMK59	05/25/10	01:53:10pm
2790326.7	6139264	357.533	C1	Red metals. Possible paleovalley	Wk2DMK60	05/25/10	01:56:07pm
2790276.7	6139292	357.291	C1	Highly jointed iron stained SILTSTONE in stream bank	Wk2DMK61	05/25/10	02:01:29pm
2790227.1	6139255	358.818	C1	Highly jointed SILTSTONE in stream bank (Tertiary age)	Wk2DMK62	05/25/10	02:06:07pm
2790205	6139156	384.235	C1	End of "cemented" red metals in downstream direction. Gully is a possible fault? SILTSTONE was noted downstream high up valley on true right.	Wk2DMK64	05/25/10	02:12:31pm
2790204	6139530	373.237	C1	SILTSTONE with greywacke GRAVEL	Wk2DMK65	05/25/10	02:33:15pm
2789177.6	6139997	381.85	C1	Detached block of SILTSTONE	Wk2DMK66	05/25/10	03:09:46pm
2789289.6	6140013	378.771	C1	Red metals	Wk2DMK67	05/25/10	03:13:47pm
2789993.9	6139611	365.797	C1	Cemented GRAVEL overlying SILTSTONE	Wk2DMK68	05/25/10	03:20:57pm
2790052.2	6139621	363.181	C1	Highly fractured SILTSTONE in creek overlain by "cemented" red metals, fracture planes dip 50 deg to 175 deg and 85 deg to 090 deg	Wk2DMK69	05/25/10	03:22:57pm
2789981	6139614	364.253	C1	GRAVEL overlying SILTSTONE	Wk2DMK70	05/25/10	03:32:07pm
2789927.8	6139776	378.575	C1	Red metals	Wk2DMK71	05/25/10	03:37:43pm
2789776.3	6139833	375.097	C1	Blue-grey SILTSTONE overlain by red metal. Joints in siltstone dip 85 deg to 220 deg, 85 deg to 205 deg and 20 deg to 090 deg	Wk2DMK72	05/25/10	03:47:12pm
2789615.5	6139761	381.448	C1	SILTSTONE exposed in road drain	Wk2DMK73	05/25/10	04:10:28pm

Field Observations

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Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2791470.7	6130503	302.194	C3	Red metal quarry. Moderately to highly weathered, silty sandy fine GRAVEL, red-brown, low fines content, 0.5m loess cover	BDH93	26-MAY-10 8:17:47AM	
2791602.5	6130713	277.925	C3	(Top to bottom:) 0.2m topsil, 1.1m loess, 5.5m red metal with siltstone inclusions. Two ages of red metal evident.	BDH94	26-MAY-10 8:32:41AM	
2791597.8	6130701	276.893	C3	Red metals exposed	Wk2DMK74	05/26/10	08:32:45am
2791614.9	6130741	278.698	C3	Seepage area	Wk2DMK75	05/26/10	08:38:34am
2791574.2	6130747	282.109	C3	Old meander	Wk2DMK76	05/26/10	08:39:39am
2791527.2	6130692	281.677	C3	Old meander	Wk2DMK77	05/26/10	08:42:01am
2791535	6130681	283.452	C3	SILTSTONE	Wk2DMK78	05/26/10	08:44:08am
2791529.1	6130677	278.901	C3	Red metal overlying very fine SILTSTONE with minor clay. Siltstone is greyish white, slightly weathered, extremely to very weak, thinly bedded and possibly pumiceous, dipping 10 deg to 200 deg	Wk2DMK79	05/26/10	08:45:42am
2791483.4	6130699	282.868	C3	"Gorge" feature. SILTSTONE/pumiceous SILTSTONE with SANDSTONE beds	BDH96	26-MAY-10 9:01:21AM	
2791469.2	6130717	277.189	C3	Pumiceous SILTSTONE exposed in creek banks	Wk2DMK80	05/26/10	09:12:27am
2791485.3	6130732	280.172	C3	2m red metal overlying white-grey SILTSTONE, not pumiceous, subhorizontal bedding, 2m+ siltstone exposed above creek bed, red metals in base of creek	Wk2DMK81	05/26/10	09:17:16am
2791426.6	6130742	282.248	C3	Red metals	Wk2DMK82	05/26/10	09:24:47am
2791425.7	6130750	281.955	C3	SILTSTONE	Wk2DMK83	05/26/10	09:25:17am
2791433	6130778	282.389	C3	SILTSTONE bedded into red metal at stream junction	Wk2DMK84	05/26/10	09:29:32am
2791412.7	6130827	283.45	C3	Red metals with some siltier layers	Wk2DMK85	05/26/10	09:33:31am
2791415.8	6130908	282.448	C3	Downstream end of SILTSTONE gorge	Wk2DMK86	05/26/10	09:37:50am
2791403.4	6130923	286.094	C3	Small gorge into yellow grey/white SILTSTONE, bedded	BDH99	26-MAY-10 9:39:06AM	
2791359.9	6130871	290.617	C3	Unusual meanders	Wk2DMK87	05/26/10	09:50:07am

Field Observations

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Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2791368.4	6130818	282.183	C3	Red metals overlying SILTSTONE	Wk2DMK88	05/26/10	09:52:01am
2791383.1	6130813	284.821	C3	Fine red metals with minor SILTSTONE	Wk2DMK89	05/26/10	09:53:26am
2791129.7	6131307	297.766	C3	Red metal interbedded with SILTSTONE	Wk2DMK91	05/26/10	10:13:43am
2790084.3	6132622	287.691	C3	Monckton Reserve: red metal overlying 3m+ extremely weak grey SILTSTONE	Wk2DMK92	05/26/10	10:52:30am
2802057	6122259	194.896	D3	LIMESTONE. Probably not in situ.	Wk2DMK94	05/27/10	08:03:17am
2802050	6122244	194.91	D3	Limestone debris in bank, seepage area	Wk2DMK95	05/27/10	08:04:40am
2801971.5	6122133	194.865	D3	Pale khaki, slightly shelly SILTSTONE (marine), minor fine SAND	Wk2DMK96	05/27/10	08:09:54am
2801979.9	6122119	199.13	D3	LIMESTONE debris	Wk2DMK97	05/27/10	08:13:55am
2801861.1	6121920	201.482	D3	Khaki extremely weak fine SANDSTONE, underlying thin bed of shelly weak to moderately strong LIMESTONE	Wk2DMK99	05/27/10	08:26:35am
2801868.4	6121964	200.312	D3	Fine SANDSTONE, slightly shelly, extremely weak	Wk2DMK100	05/27/10	08:28:34am
2802011.6	6122036	205.427	D3	Head of blind gullies in extremely weak fine SANDSTONE and possibly LIMESTONE	Wk2DMK101	05/27/10	08:32:48am
2801991.2	6122043	202.575	D3	Fine SANDSTONE	Wk2DMK102	05/27/10	08:34:50am
2801833.3	6121845	197.648	D3	Blue-green to khaki very fine sandy SILTSTONE, extremely weak, shelly, massive	Wk2DMK103	05/27/10	08:55:13am
2801812.2	6121912	197.616	D3	Grey shelly SILTSTONE overlain by white SILTSTONE (50mm) then coarse SAND (100mm)	Wk2DMK104	05/27/10	09:01:47am
2801831.6	6122003	198.333	D3	Greywacke GRAVEL including shells and limestone	Wk2DMK105	05/27/10	09:06:47am

Field Observations

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Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2801903.6	6122090	199.877	D3	Khaki extremely weak fine to medium SANDSTONE, shelly/gravel (LIMESTONE & GREYWACKE) stringers	Wk2DMK106	05/27/10	09:09:50am
2801703.7	6122088	197.862	D3	Coarse sandy GRAVEL, 5-10% LIMESTONE clasts, floaters of tertiary SANDSTONE	Wk2DMK107	05/27/10	09:21:57am
2801169.4	6122413	199.004	D3	Large old meander	Wk2DMK108	05/27/10	09:37:28am
2801105	6122451	197.672	D3	Extremely weak SILTSTONE	Wk2DMK109	05/27/10	09:39:51am
2801054.6	6122488	198.807	D3	0.5m khaki fine SAND, 0.75m fine iron stained GRAVEL, 1m blue-grey SAND	Wk2DMK110	05/27/10	09:41:18am
2800988.9	6122466	197.841	D3	Fine SANDSTONE	Wk2DMK111	05/27/10	09:45:05am
2800924.6	6122455	198.468	D3	Red metals with seep at base, possibly overlying SANDSTONE	Wk2DMK112	05/27/10	09:47:38am
2800989.2	6122585	195.605	D3	Fine SANDSTONE	Wk2DMK113	05/27/10	09:52:11am
2800991.4	6122653	198.917	D3	Red metals overlying SILT	Wk2DMK114	05/27/10	09:54:09am
2801179.7	6122875	196.123	D3	SILT	Wk2DMK115	05/27/10	10:00:14am
2801193.8	6122894	195.069	D3	SAND	Wk2DMK116	05/27/10	10:02:41am
2801245	6122937	196.594	D3	Red metals overlying SILT	Wk2DMK117	05/27/10	10:05:46am
2801868.7	6122347	195.761	D3	Khaki, extremely weak, shelly fine SANDSTONE/coarse SILTSTONE (Nukumaruan)	Wk2DMK118	05/27/10	10:23:27am

Field Observations

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Elevations based on Mean Sea Level = 10 mRL

Easting (m)	Northing (m)	Elevation (mRL)	Dam Site	Description	Observation Field ID	Date & Time Recorded	
2802091	6122558	195.856	D3	Khaki, extremely weak, shelly fine SANDSTONE/coarse SILTSTONE (Nukumaruan)	Wk2DMK119	05/27/10	10:34:26am
2799595.7	6120658	216.355	D3	Red metals quarry	Wk2DMK120	05/27/10	10:53:31am
2800164.1	6121084	206.341	D3	Red metals quarry. 1m re-worked loess overlying red metals. Soil horizon visible within loess. Red metals contain 10% limestone +/- and are very permeable with negligible fines content. High energy foreset bedding evident in red metals.	Wk2DMK121	05/27/10	11:07:53am
2803900.4	6146766	245.589	A4	Thin layer of red metal overlying horizontally bedded SAND, white pumiceous SILT channel deposits cutting above	BDH103	26-MAY-10 12:51:01PM	
2804033.9	6146766	253.616	A4	On opposite side of gully from seep on terrace slope	BDH104	26-MAY-10 1:02:45PM	
2804052.3	6146815	257.671	A4	Wet gully bulge at fence line, fence displaced	BDH105	26-MAY-10 1:07:38PM	
2804080.4	6146863	264.244	A4	Seeps (reeds) just over fence near crest of slope	BDH106	26-MAY-10 1:11:56PM	
2803975.7	6146894	264.206	A4	Wet area, seeps.	BDH107	26-MAY-10 1:18:26PM	

Appendix D: Laboratory Testing Results

Laboratory Testing

Sample locations

The locations of sampling for laboratory testing are summarised in the table below (WGS84) and presented in Appendix A.

Sample ID	Latitude	Longitude
A2 Reservoir	-39.7658073	176.3771656
A4 Dam	-39.8328509	176.4329353
B1 Dam	-39.873733	176.3650621
B2 Reservoir	-39.8891117	176.3902059
C2 Quarry & C2 QMS	-39.946969	176.2945734
C3 Quarry	-39.9839218	176.2969047
C3 Dam	-39.9819365	176.2982527

Photographs of samples

A2 Reservoir

A4 Dam

B1 Dam

B2 Reservoir

C2 Quarry

C3 Quarry

C3 Dam

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Form No.:	PT1
Form Date:	Oct 2002
P:\615379\615379.001\WorkingMaterial\Summary.xlsx	

Your Ref. No.: 27195 Page of
Site: Ruataniwha Plains, Hawkes Bay Job No.: 615379.001
Test Method Used: BS 1377 : Part 8 : 1990 : Clause 5 Saturation Clause 6 Consolidation
BS 1377 : Part 6 : 1990 : Clause 6 Constant Head Permeability Test in a Triaxial Cell

SUMMARY OF PERMEABILITY RESULTS

BOREHOLE / TEST PIT No.			--	--
SAMPLE No.			Quarry C2	Quarry C3
DEPTH			--	--
SAMPLE HISTORY			Remoulded	Remoulded
TARGET VALUES	Target Moisture Content	(%)	Samples were remoulded at their visual Optimum moisture content with NZ heavy compaction effort.	
	Target Dry Density	(t/m³)		
SAMPLE PARAMETERS	Height	(mm)	115.04	115.04
	Diameter	(mm)	105.07	105.07
	Sample mass	(g)	2251.00	2189.00
	Initial bulk density	(t/m³)	2.26	2.19
	Initial dry density	(t/m³)	2.07	2.04
	Initial water content	(%)	9.0	7.4
	Final water content	(%)	10.5	11.6
	Final bulk density	(t/m³)	2.30	2.26
	Saturation at test (B)*	(%)	96	96
TESTING CONDITION	Mean effective stress	(kPa)	200	200
	Head difference	(kPa)	20	20
	Hydraulic gradient		18	18
COEFFICIENT OF PERMEABILITY AT 20 °C		(m/s)	**1.48E-07**	**2.10E-07**

COMMENTS: *: The sample was saturated by increments of cell pressure and back pressure

Entered by: [signature] Date: 20/08/10 Checked by: SJA Date: 23/08/10

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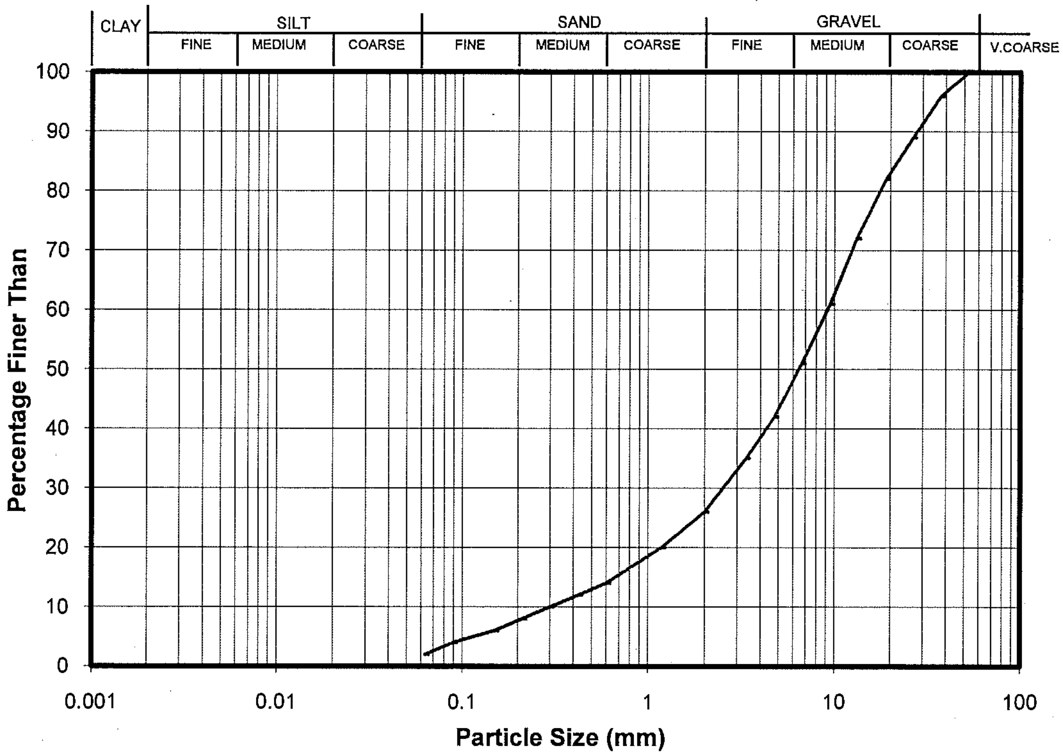
Form No.: S5
Form Date: JANUARY 2004
File: P:\615379.000\Working Material\A2 Res_Wet Sieve.xls

Plate No.: Page of
Site : **Ruataniwha Plains, Hawkes Bay**
BH No.: --- Sample ID.: **A2 Res**
Test Method Used : NZS 4402 : 1986 Test 2.8.1 Wet Sieve

Your Job No.: **27195**
Our Job No.: **615379.000**
Depth: **--- (m)**

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing
63.0	---
53.0	100
37.5	96
26.5	89
19.0	82
13.2	72
9.50	61
6.70	51
4.75	42
3.35	35

Sieve (mm)	Total % Passing
2.00	26
1.18	20
0.600	14
0.425	12
0.300	10
0.212	8
0.150	6
0.090	4
0.063	2

Sample history : As received.
Description : sandy GRAVEL with trace of silt, loose, brown with light to dark grey.
Remarks: The minimum mass of sample required for sieving is 40 kg, but due to insufficient sample mass the sieving was carried out on ~ 7.6 kg.
Percentage passing the finest sieve was obtained by difference.
The classification of gravel and sand was described on the basis of particle size analysis.
Sample description and test results are not IANZ endorsed.

Entered by : ST Date : 18/8/10 Checked by : MJRA Date : 18/08/10

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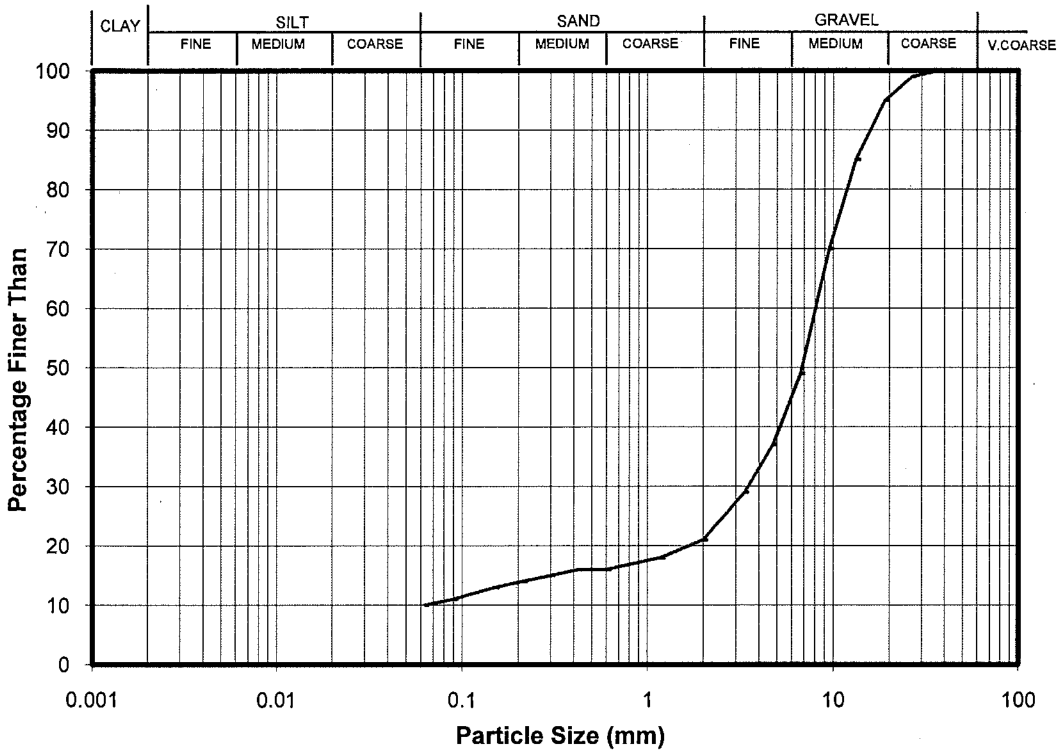
Form No.: S5	
Form Date: JANUARY 2004	
File: P:\615379.000\Working Material\A4 Dam_Wet Sieve.xls	

Plate No.: Page of
Your Job No.: **27195**
Site : **Ruataniwha Plains, Hawkes Bay**
Our Job No.: **615379.000**
BH No.: **---** Sample ID.: **A4 Dam**
Depth: **--- (m)**
Test Method Used : NZS 4402 : 1986 Test 2.8.1 Wet Sieve

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing
63.0	---
53.0	---
37.5	100
26.5	99
19.0	95
13.2	85
9.50	70
6.70	49
4.75	37
3.35	29

Sieve (mm)	Total % Passing
2.00	21
1.18	18
0.600	16
0.425	16
0.300	15
0.212	14
0.150	13
0.090	11
0.063	10

Sample history : As received.
Description : GRAVEL with minor sand, minor silt and trace of clay, loose, brown with light to dark grey.
Remarks: The minimum mass of sample required for sieving is 15 kg, but due to insufficient sample mass the sieving was carried out on ~ 4.29 kg.
Percentage passing the finest sieve was obtained by difference.
The classification of gravel and sand was described on the basis of particle size analysis.
Sample description and test results are not IANZ endorsed.

Entered by : ST Date : 18/8/10 Checked by : MJRA Date : 18/8/10

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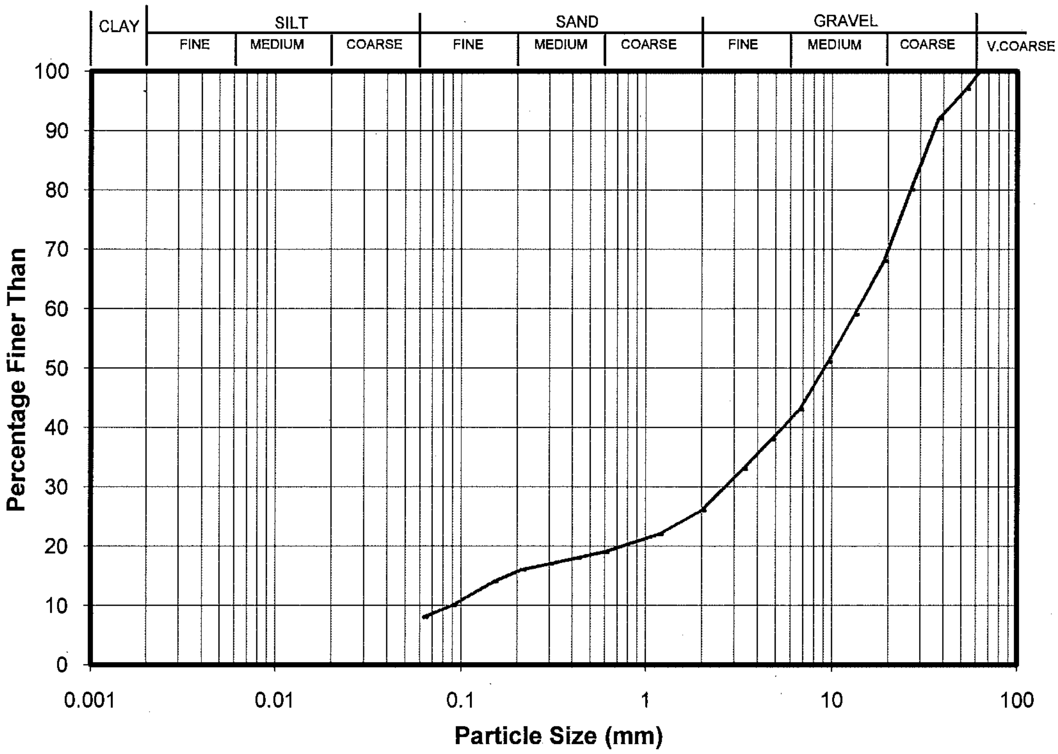
Form No.: S5
Form Date: JANUARY 2004
File: P:\615379.000\Working Material\B1 Dam_Wet Sieve.xls

Plate No.: Page of
Your Job No.: **27195**
Site : **Ruataniwha Plains, Hawkes Bay**
Our Job No.: **615379.000**
BH No.: ---
Sample ID.: **B1 Dam**
Depth: **--- (m)**
Test Method Used : NZS 4402 : 1986 Test 2.8.1 Wet Sieve

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing
63.0	100
53.0	97
37.5	92
26.5	80
19.0	68
13.2	59
9.50	51
6.70	43
4.75	38
3.35	33

Sieve (mm)	Total % Passing
2.00	26
1.18	22
0.600	19
0.425	18
0.300	17
0.212	16
0.150	14
0.090	10
0.063	8

Sample history : As received.
Description : GRAVEL with some sand, minor silt and trace of clay, loose, brown with light to dark grey.
Remarks: The minimum mass of sample required for sieving is 50 kg, but due to insufficient sample mass the sieving was carried out on ~ 9.6 kg.
Percentage passing the finest sieve was obtained by difference.
The classification of gravel and sand was described on the basis of particle size analysis.
Sample description and test results are not IANZ endorsed.

Entered by : ST Date : 18/8/10 Checked by : MJRA Date : 18/8/10

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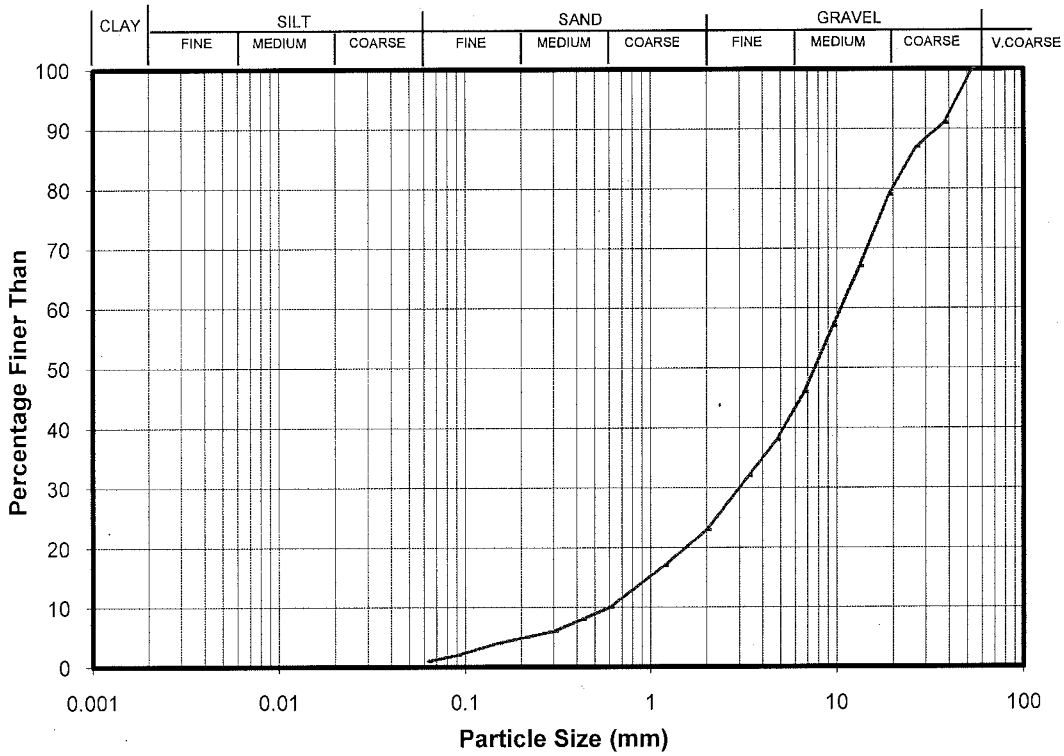
Form No.: S5
Form Date: JANUARY 2004
File: P:\615379.000\Working Material\B2 Res_Wet Sieve.xls

Plate No.: Page of
Your Job No.: **27195**
Site : **Ruataniwha Plains, Hawkes Bay**
Our Job No.: **615379.000**
BH No.: --- Sample ID.: **B2 Res**
Depth: **--- (m)**
Test Method Used : NZS 4402 : 1986 Test 2.8.1 Wet Sieve

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing
75.0	---
63.0	---
53.0	100
37.5	91
26.5	87
19.0	79
13.2	67
9.50	57
6.70	46
4.75	38

Sieve (mm)	Total % Passing
3.35	32
2.00	23
1.18	17
0.600	10
0.425	8
0.300	6
0.212	5
0.150	4
0.090	2
0.063	1

Sample history : As received.
Description : sandy GRAVEL with trace of silt, loose, brown with light to dark grey.
Remarks: The minimum mass of sample required for sieving is 40 kg, but due to insufficient sample mass the sieving was carried out on ~ 11.4 kg.
Percentage passing the finest sieve was obtained by difference.
The classification of gravel and sand was described on the basis of particle size analysis.
Sample description and test results are not IANZ endorsed.

Entered by : ST Date : 18/8/10 Checked by : MORA Date : 18/08/10

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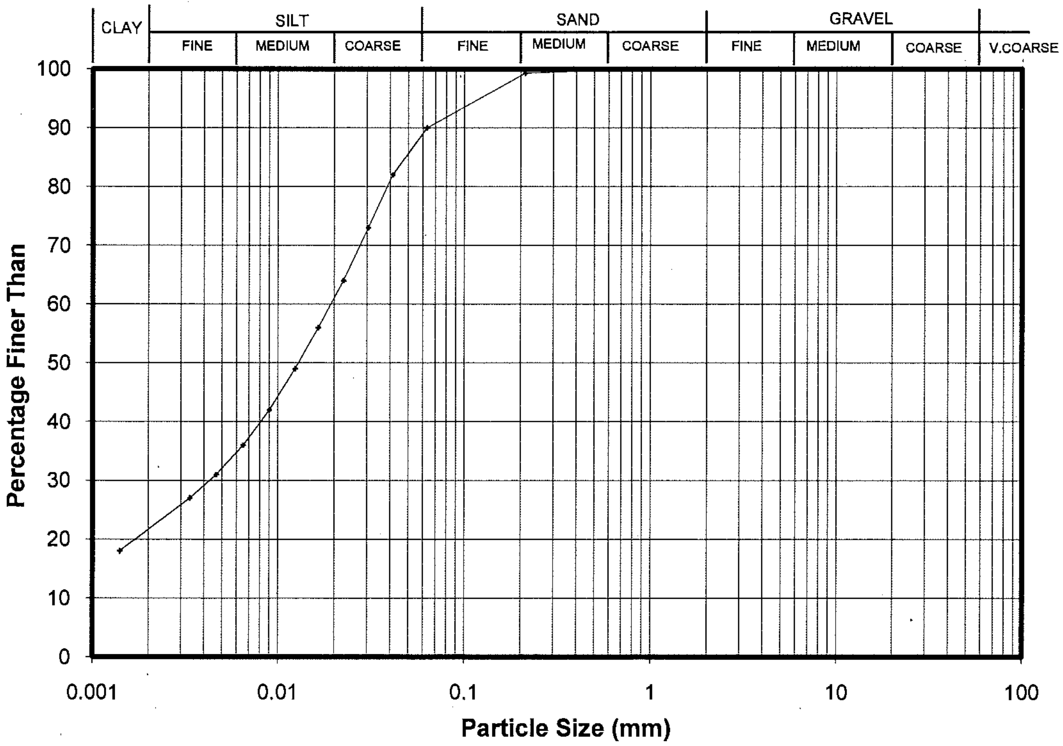
Form No.: P6
Form Date: January 2004
File: P:\615379\Working material\C2 QMS_Hydro.xls

Plate No.: Page of
Your Job No.: **27195**
Site : **Ruataniwha Plains, Hawkes Bay**
Our Job No.: **61379.000**
Test Pit No.: ---
Sample ID.: **C2 Q M S**
Depth: **--- (m)**
Test Method Used : NZS 4402:1986 Test 2.8.4 Hydrometer

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing	Sieve (mm)	Total % Passing
2.00	100		
0.600	100		
0.212	99		
0.063	90		

Equivalent Particle Diameter D (mm)	% of Particles Finer than D
0.0412	82
0.0305	73
0.0225	64
0.0164	56
0.0124	49
0.0090	42
0.0065	36
0.0047	31
0.0034	27
0.0014	18

Sample history : As received.
Description: UW, dark grey, extremely weak, SILTSTONE/MUDSTONE - clayey SILT with minor sand, stiff to very stiff, dark grey, high plasticity.
Solid Density (assumed) : 2.70 t/m^3

Remarks : A sub sample was split from the original sample for hydrometer analysis. This sample was soaked with a dispersing agent (~16 hours), then the mechanical shaker was used, until the material was brought into suspension, before proceeding with the test.
The classification of sand,silt and clay components are described on the basis of particle size analysis.
Suspension pH 8.0
Sample description is not IANZ endorsed.

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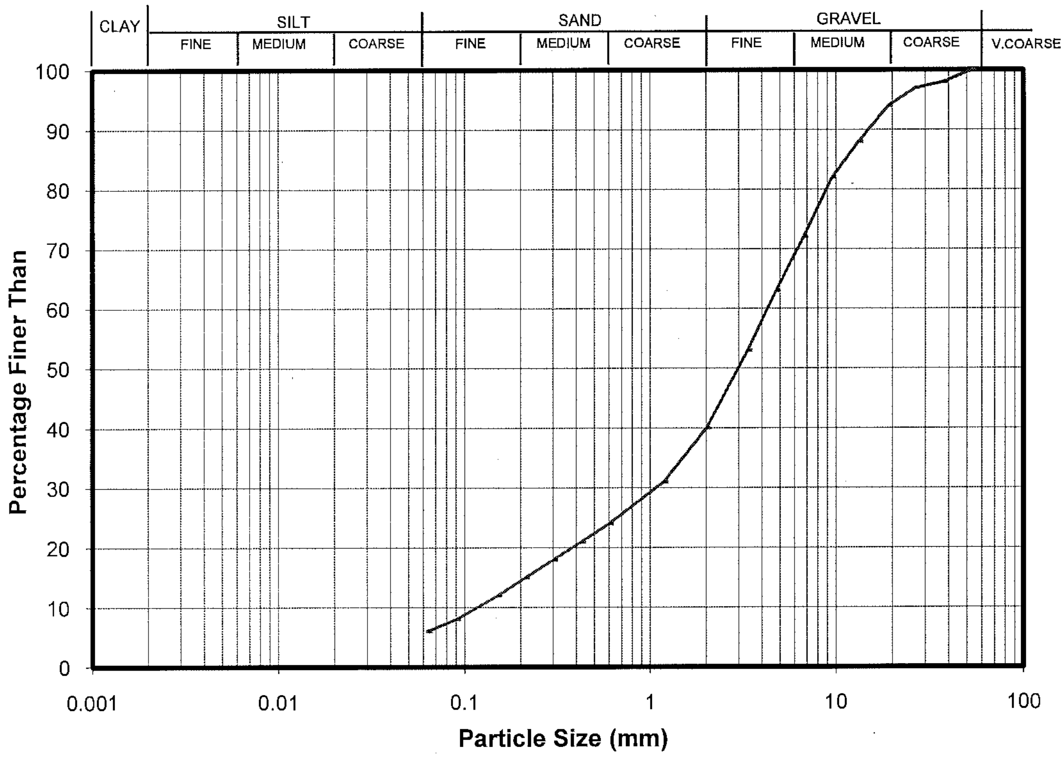
Form No.: S5
Form Date: JANUARY 2004
File: P:\615379.000\Working Material\C2 Quarry_Wet Sieve.xls

Plate No.: Page of
Your Job No.: **27195**
Site : **Ruataniwha Plains, Hawkes Bay**
Our Job No.: **615379.000**
BH No.: **---** Sample ID.: **C2 Quarry**
Depth: **--- (m)**
Test Method Used : NZS 4402 : 1986 Test 2.8.1 Wet Sieve

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing
63.0	---
53.0	100
37.5	98
26.5	97
19.0	94
13.2	88
9.50	82
6.70	72
4.75	63
3.35	53

Sieve (mm)	Total % Passing
2.00	40
1.18	31
0.600	24
0.425	21
0.300	18
0.212	15
0.150	12
0.090	8
0.063	6

Sample history : As received.

Description : sandy GRAVEL with trace of silt and trace of clay, loose, brown with light to dark grey.

Remarks: The minimum mass of sample required for sieving is 40 kg, but due to insufficient sample mass the sieving was carried out on ~ 4.26 kg.
Percentage passing the finest sieve was obtained by difference.
The classification of gravel and sand was described on the basis of particle size analysis.
Sample description and test results are not IANZ endorsed.

Entered by : ST Date : 18/8/10 Checked by : MURA Date : 18/08/10

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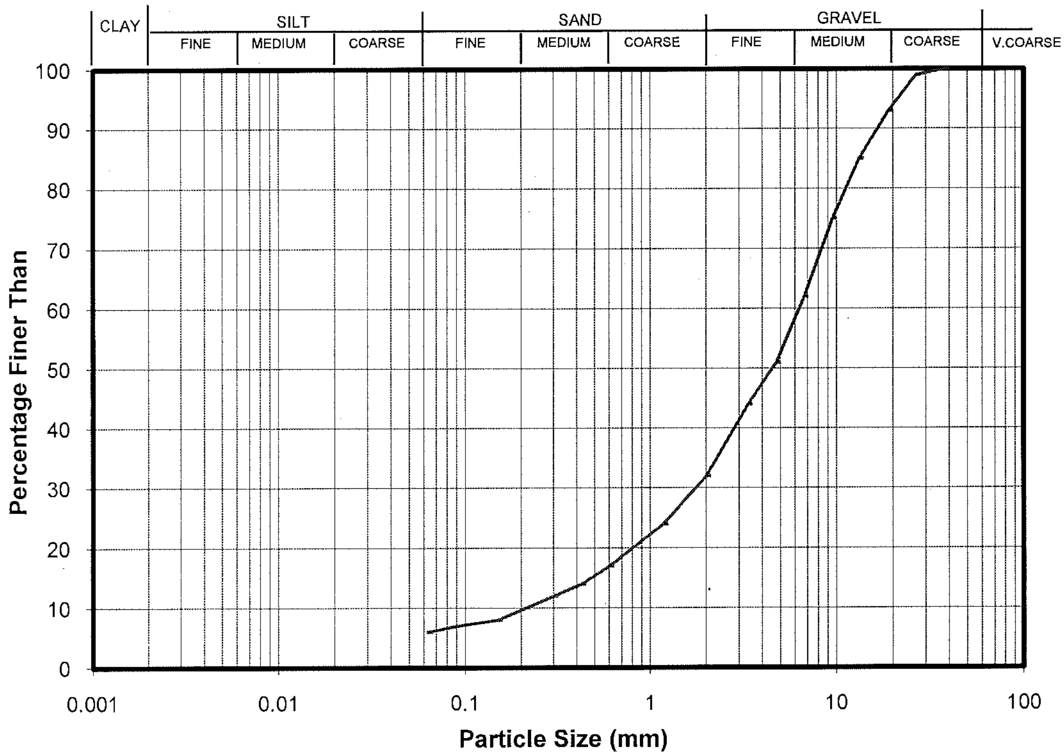
Form No.: S5
Form Date: JANUARY 2004
File: P:\615379.000\Working Material\C3 Quarry_Wet Sieve.xls

Plate No.: Page of
Your Job No.: **27195**
Site : **Ruataniwha Plains, Hawkes Bay**
Our Job No.: **615379.000**
BH No.: **---** Sample ID.: **C3 Quarry**
Depth: **--- (m)**
Test Method Used : NZS 4402 : 1986 Test 2.8.1 Wet Sieve

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing
63.0	---
53.0	---
37.5	100
26.5	99
19.0	93
13.2	85
9.50	75
6.70	62
4.75	51
3.35	44

Sieve (mm)	Total % Passing
2.00	32
1.18	24
0.600	17
0.425	14
0.300	12
0.212	10
0.150	8
0.090	7
0.063	6

Sample history : As received.
Description : sandy GRAVEL with trace of silt and trace of clay, loose, brown with light to dark grey.
Remarks: The minimum mass of sample required for sieving is 15 kg, but due to insufficient sample mass the sieving was carried out on ~ 3.07 kg.
Percentage passing the finest sieve was obtained by difference.
The classification of gravel and sand was described on the basis of particle size analysis.
Sample description and test results are not IANZ endorsed.

Entered by : ST Date : 18/8/10 Checked by : MURA Date : 18/08/10

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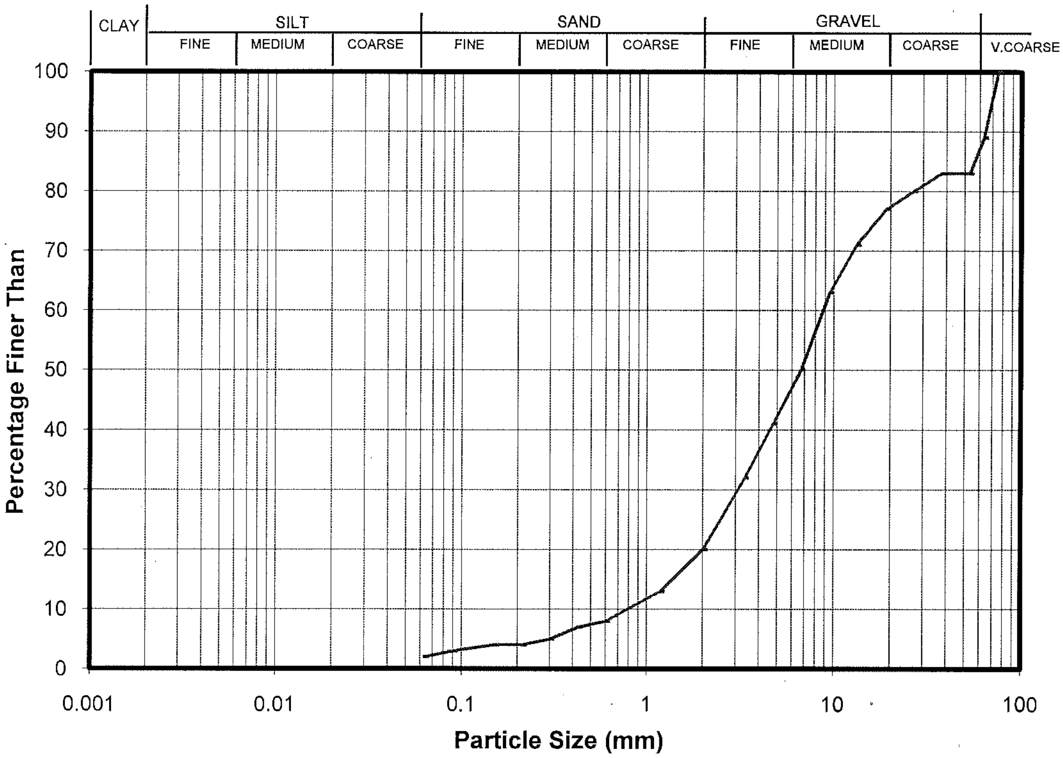
Form No.: S5
Form Date: JANUARY 2004
File: P:\615379.000\Working Material\C3 Dam_Wet Sieve.xls

Plate No.: Page of
Site : **Ruataniwha Plains, Hawkes Bay**
BH No.: --- Sample ID.: **C3 Dam**
Test Method Used : NZS 4402 : 1986 Test 2.8.1 Wet Sieve

Your Job No.: **27195**
Our Job No.: **615379.000**
Depth: **--- (m)**

PARTICLE SIZE ANALYSIS



Sieve (mm)	Total % Passing
75.0	100
63.0	89
53.0	83
37.5	83
26.5	80
19.0	77
13.2	71
9.50	63
6.70	50
4.75	41

Sieve (mm)	Total % Passing
3.35	32
2.00	20
1.18	13
0.600	8
0.425	7
0.300	5
0.212	4
0.150	4
0.090	3
0.063	2

Sample history : As received.
Description : GRAVEL with some sand and trace of silt, loose, brown with light to dark grey.
Remarks: The minimum mass of sample required for sieving is 75 kg, but due to insufficient sample mass the sieving was carried out on ~ 5.85 kg.
Percentage passing the finest sieve was obtained by difference.
The classification of gravel and sand was described on the basis of particle size analysis.
Sample description and test results are not IANZ endorsed.

Entered by : ST Date : 18/8/10 Checked by : MURA Date : 18/08/10

WET SIEVE ANALYSIS
TEST REPORT

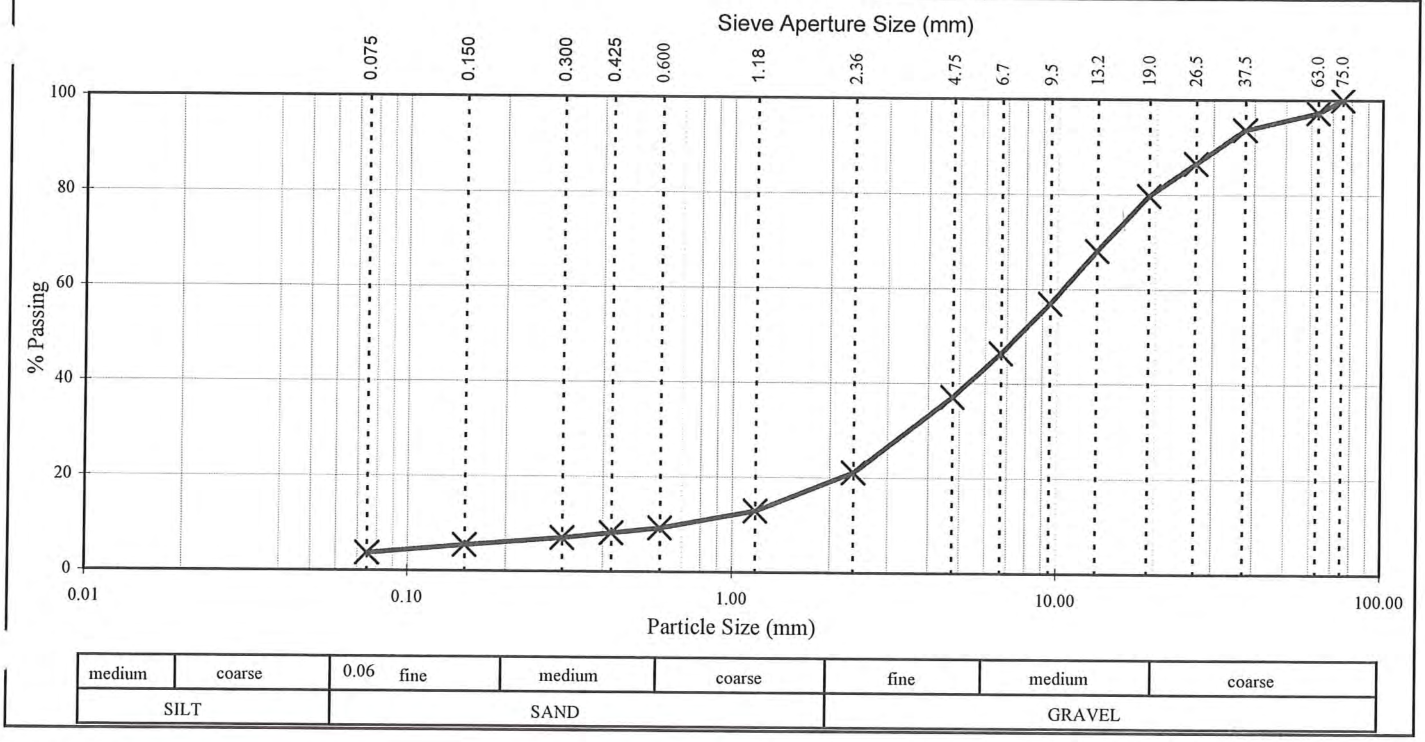
OPUS

Project :	**Dam Site**
Location :	**Wakarara Rd**
Client :	**Tonkin & Taylor Ltd** **P.O Box 5271, Auckland**
Sampled by :	**A.Pomfret / B.Hegan**
Date sampled :	**8/08/2006**
Sampling method #:	**Not stated**
Sample description :	**Red Metal**
Sample condition	**Wet**

Project No :	**2-S173G.1L**
Lab Ref No :	**N06.634**
Client Ref No :	**23783**

Sieve Analysis

Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing	Size (mm)	% Passing
75.00	**100**	19.00	**80**	4.75	**37**	0.425	**8**
63.00	**97**	13.20	**68**	2.36	**21**	0.300	**7**
37.50	**94**	9.50	**57**	1.18	**13**	0.150	**5**
26.50	**87**	6.70	**46**	0.600	**9**	0.075	**4**



Test Method	**Notes**
NZS 4407 : 1991 Test 3.8.1	History : On site borrow Fraction tested : Whole sample Water Content % 27.7 *Fraction passing finest sieve is by difference.*

Date tested : 11/08/06
Date reported : 14/08/06

Testing is covered by IANZ Accreditation
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IANZ Approved Signatory
A. Ching
Designation : *Laboratory Manager*
Date : 25/08/06

new zealand accredited laboratory

Tests indicated as # not accredited are outside the scope of the laboratory's accreditation

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Private Bag 6019
Napier
Telephone +64 6 833 5590
Facsimile + 64 6 835 3892
Website www.opus.co.nz

DRY DENSITY / WATER CONTENT RELATIONSHIP COMPACTION

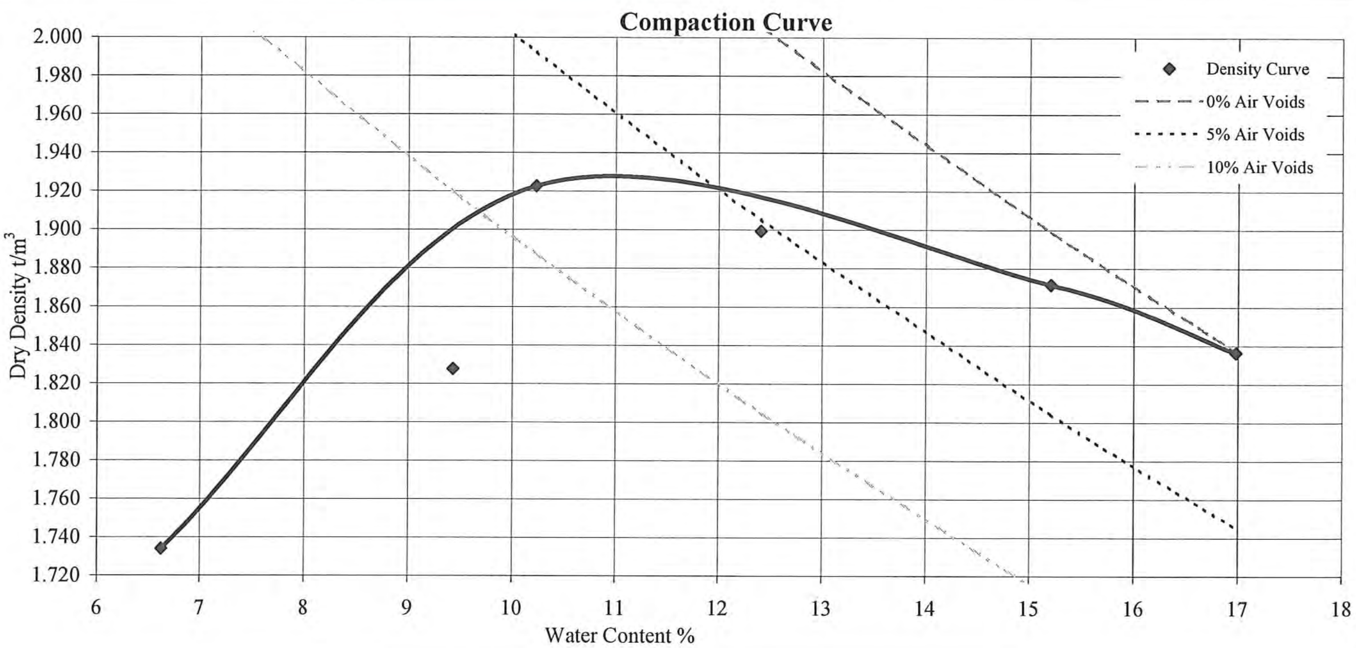
Project :	**Dam Site**
Location :	**Wakarara Road**
Client :	**Tonkin & Taylor, P.O Box 5271, Auckland**
Sampled by :	**A.Pomfret / B.Hegan**
Date sampled :	**08/08/06**
Sampling method :#	**Client Sampled**
Sample description :	**Red Metal**
Sample condition :	**Wet**
Solid density :#	**2.67 t/m^3 (Assumed)**
Source :	**On site borrow**

Project No :	**2-S173G.1L**
Lab Ref No :	**N06.634**
Client Ref No :	**Job No. 23783**

Test Results

Maximum dry density	**1.92** t/m^3		Natural water content	- %
Optimum water content	**11.0** %		Fraction tested	Passing 19mm

Sample ID							0	
Bulk density	t/m^3	1.849	2.000	2.119	2.135	2.156	2.148	
Water content	%	6.6	9.4	10.2	12.4	15.2	17.0	
Dry density	t/m^3	1.734	1.828	1.923	1.899	1.872	1.836	
Sample condition		Dry Dense	Moist Dense	Moist Dense	Moist Dense	Wet Hard	Saturated Dense	



Test Methods		Notes
Compaction	NZS 4402 : 1986 Test 4.1.1 (Standard)	

Date tested : 14/08/2006
Date reported : 25/08/06

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IANZ Approved Signatory
A.Ching
Designation : *Laboratory Manager*
Date : 25/08/06

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Facsimile + 64 6 835 3892
Website www.opus.co.nz

SOIL PERMEABILITY TEST REPORT

Mr. A. Pomfret
Tonkin & Taylor Ltd
P.O Box 5271
Wellesley St
Auckland

Project :	**Dam Site**
Location :	**Wakarara Road - Central HB**
Client :	**Tonkin & Taylor Ltd**
Sampled by :	**A.Pomfret / B.Hegan**
Date sampled :	**8/08/06**
Sampling method :	**Not stated**
Sample description :	**Red Metal**
Sample condition :	**Wet**

Project No :	**2 - S173G.1L**
Lab Ref No :	**N06. 634**
Client Ref No :	**Job No. 23783**

Test Results

Test No.	**1**	**2**
Material type:	Gravel (Red Metal)	
Sample location:	On site borrow	
Proposed use:	Lining material	
Water Content (as compacted) %:	**8.7**	**10.2**
Compacted Dry Density t/m^3:	**1.82**	**1.92**
Permeability (k) cm/sec:	**1.67×10^{-2}**	**2.72×10^{-4}**

Test method:	Notes:
Lab Permeability Test (Falling Head method) TW Lambe - Soils Testing	Test 1 compacted to approx 95% of max dry density

Date tested : 14/8/06 to 24/8/06
Date reported : 25/08/06

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Approved

A. Ching

Designation : *Laboratory Manager*
Date: 25/08/06

Appendix E: IGNS Report

BIBLIOGRAPHIC REFERENCE

Langridge, R.M; Zhao, J.X.; Zajac, A.; McVerry, G.H. 2010. Spectra and compilation of fault data for Central Hawke's Bay Water Augmentation Scheme, *GNS Science Consultancy Report* CR 2010/121. 51 p.

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

GNS Science has undertaken a combined geological and spectral assessment of the hazards of surface faulting and seismic shaking for a number of possible water retention embankments and related infrastructure as part of the Central Hawke's Bay Water Augmentation Scheme.

Active fault mapping in a Geographic Information System has confirmed the presence of many active faults, including a number of new or recently identified faults. The latter include the Te Heka, Wakarara, Rangefront, Ruataniwha and Takapau faults, which are all reverse-slip faults. The most active faults in the area are the strike-slip Mohaka and Ruahine faults, oblique-slip Oruawharo Fault, and the reverse-slip Poukawa Fault Zone. The Hikurangi subduction zone is also considered as a late earthquake source. Field reconnaissance has aided in the derivation of fault slip rates and single-event displacements for many of these faults. These have been used to design a series of new or modified fault sources for an alternative source model (c.f. the standard 2010 model) for the New Zealand National Seismic Hazard model. As well as these faults for which new information has become available very recently, the alternative model adds relatively poorly-defined faults that are included to accommodate strain in the eastern part of the study region that is accounted for further south by sources in the standard model.

Some of the potential embankment, pipe, race and reservoir locations are within 200 m of active fault traces. These include embankment A5, and races or pipes related with embankments B3 and C1.

The characterisation of the faults in this report in terms of their location, geometry and activity level is sufficient for determination of spectra, but not sufficiently detailed to address fault-avoidance or deformation issues. In future, analysis of available LiDAR imagery may help in the identification and location of active fault traces. It is recommended that site-specific investigations focused on fault location and/or deformation characterisation should be undertaken if the scheme is to avoid the crossing of active fault/fold deformation with a high likelihood of occurrence or be designed with sufficient resilience to be able to accommodate tectonic deformations that may impact on the scheme. For example, site A1 is situated within a zone of closely-spaced strike-slip faults in the Ohara Depression between the Mohaka and Ruahine faults.

A probabilistic seismic hazard analysis has been carried out for two sites in the Central Hawke's Bay Water Augmentation Scheme. Site A1 was classified as a weak rock site (NZS1170 site class B), and Site B1 was classified as a shallow soil site (site class C) according to the available geotechnical information for the region. Magnitude-weighted PGA maps have also been prepared showing the hazard across all sites in the scheme. Results have been obtained using two seismic hazard models, the "standard model" corresponding to the recently updated 2010 National Seismic Hazard Model and the "alternative model", incorporating the new and modified sources.

For Site A1, the largest contributions to the exceedance rates of earthquake motions with return periods of several thousand years that are of concern for the design of water retention structures are from the Mohaka South source at a distance of only 1.5 km. The change in the fault parameters in the alternative fault model has virtually no effect on the spectra estimated

for this site. The 84-percentile spectrum from a Mohaka South scenario earthquake is very close to the hazard spectrum with a 5000-year return period as shown in Figure ES1.

For site B1, our results show that the alternative fault model enhanced the hazard spectra by 10-17% from those estimated by using the standard model. Site B1 is at 4.6km from the Ruataniwha Fault that has an expected moment magnitude of 7.1 and a reverse focal mechanism. The scenario earthquake from the Ruataniwha Fault has an 84-percentile spectrum that is slightly larger than the 10,000-year smoothed hazard spectrum at short periods, decreases more rapidly with increasing period, and is similar to the 2500-year smoothed hazard spectrum at periods over 1s, as shown in Figure ES2. Given the long average recurrence interval of 12,000 years for the Ruataniwha Fault in the alternative model, we recommend the 10,000-year spectrum rather than the 84-percentile Ruataniwha Fault spectrum for the MDE motions for site B1.

The NZS1170.50 requires near-fault factors to be applied to the spectra for both sites. For Site A1, we recommend applying the average near-fault factors calculated for five rupture-initiation scenarios of the Mohaka South Fault (where they exceed 1.0) for hazard spectra derived from the probabilistic seismic hazard analyses, and the 84-percentile Mohaka Fault near-fault factors for the 84-percentile scenario spectrum. These are listed in Table ES1 together with the NZS1170 factors for this location. At site B1, four of five rupture-initiation scenarios produce a set of near-fault factors less than 1.0, and the average near-fault factors of the five rupture scenarios are also less than 1.0. We recommend that the near-fault factor for Site B1 be taken as 1.0.

For Site A1, we recommend the 84-percentile spectrum of a scenario earthquake from the Mohaka South fault with 84-percentile near-fault factors for the Maximum Design Earthquake (MDE) motions. Although the recommended spectrum is very close to the 5000-year hazard spectrum and considerably less than the 10,000-year spectrum, it is difficult to identify a causative earthquake and reasonable percentile-level to justify a MDE spectrum higher than the 84-percentile scenario spectrum from the nearby Mohaka South fault. The use of the 10,000-year hazard spectrum as the MDE spectrum would be overly conservative.

For Site B1, we recommend the 10,000-year smoothed hazard spectrum using the alternative model, with the near-fault factors taken as 1.0. The hazard for this site is not dominated by a single source as for Site A1, so it is prudent to select an MDE spectrum based on the probabilistic rather than scenario analysis.

The recommended spectra are presented in Figure ES3 and listed in Table ES2. For Site A1, the recommended spectrum is listed with and without the recommended near-fault factors, to allow application of the NZS1170 factors if these are preferred by the designers. The equations and parameters used to construct the recommended spectra are presented in section 4.2

Contour maps for the 10,000-year PGA and 5% damped response-spectral accelerations at other periods are shown in section 4.6 for rock and shallow soil site conditions, using the standard and alternative fault models.

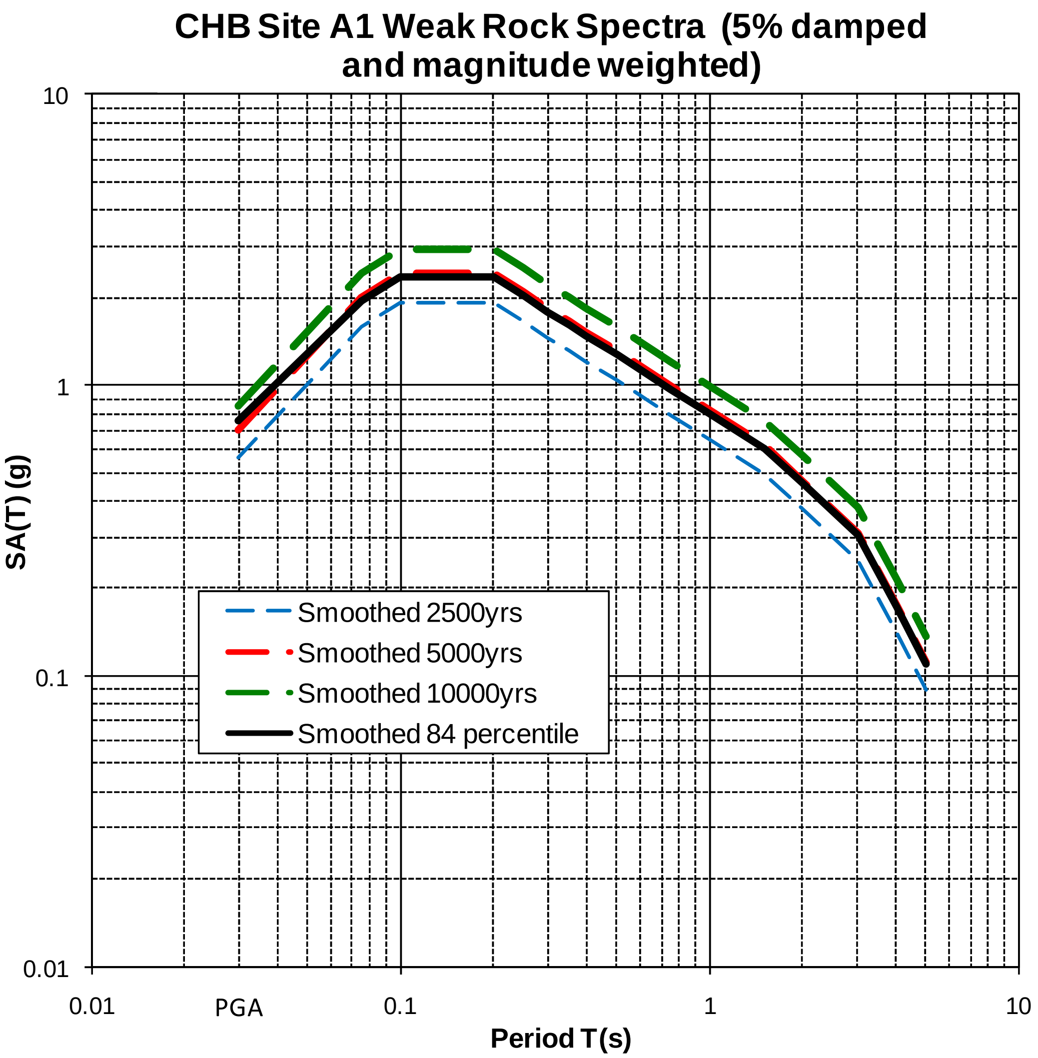

Figure ES1 The smoothed hazard spectra at Site A1 (weak rock) from the standard model, for three return periods, 2500, 5000 and 10,000 years, and the 84-percentile spectrum for a scenario earthquake from the Mohaka South fault. Near-fault factors are added to the scenario spectrum for the final recommended MDE spectrum for Site A1 shown in Figure ES3.

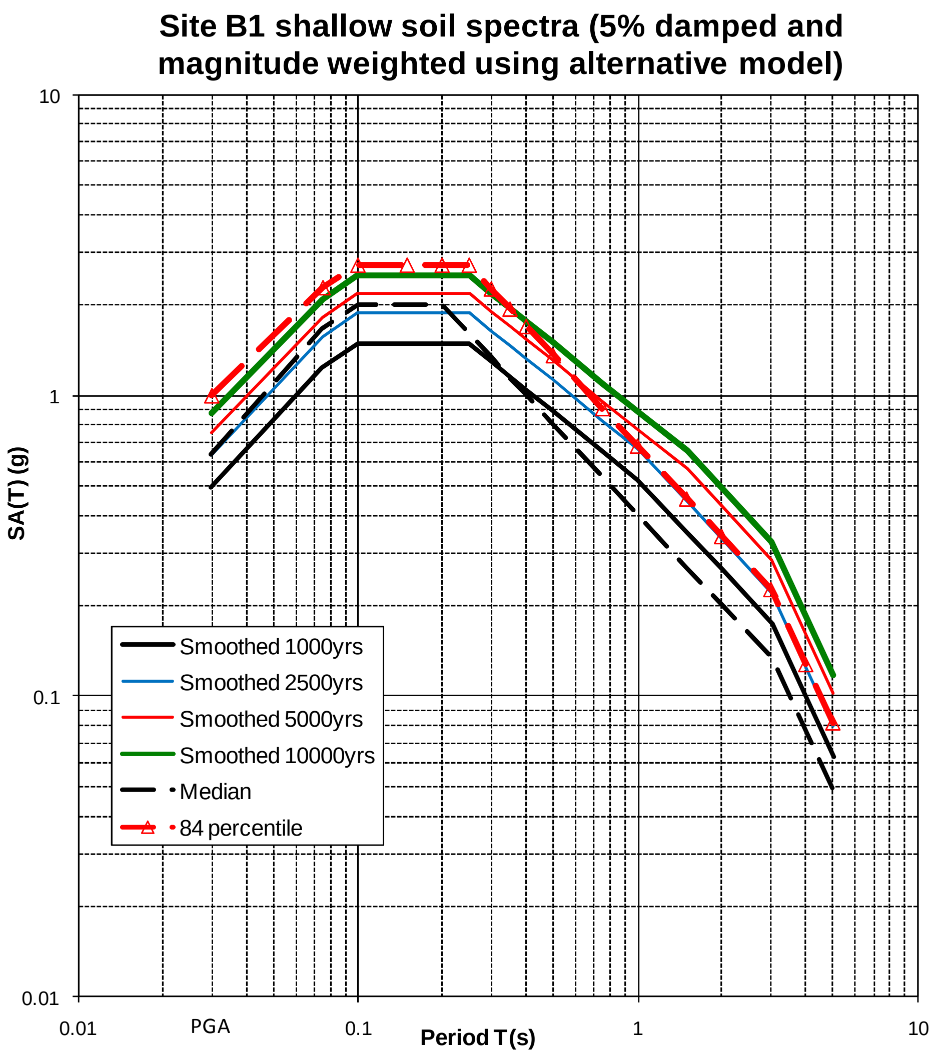

Figure ES2 The smoothed hazard spectra at Site B1 (shallow soil) for the alternative model, for four return periods, 1000, 2500, 5000 and 10,000 years, and median and 84-percentile spectra for a scenario earthquake from the modified Ruataniwha Fault used in the alternative model. PGA is plotted at 0.03s. Near-fault factors are excluded here and in the recommended 10,000-year MDE spectrum for Site B1 shown in Figure ES3.

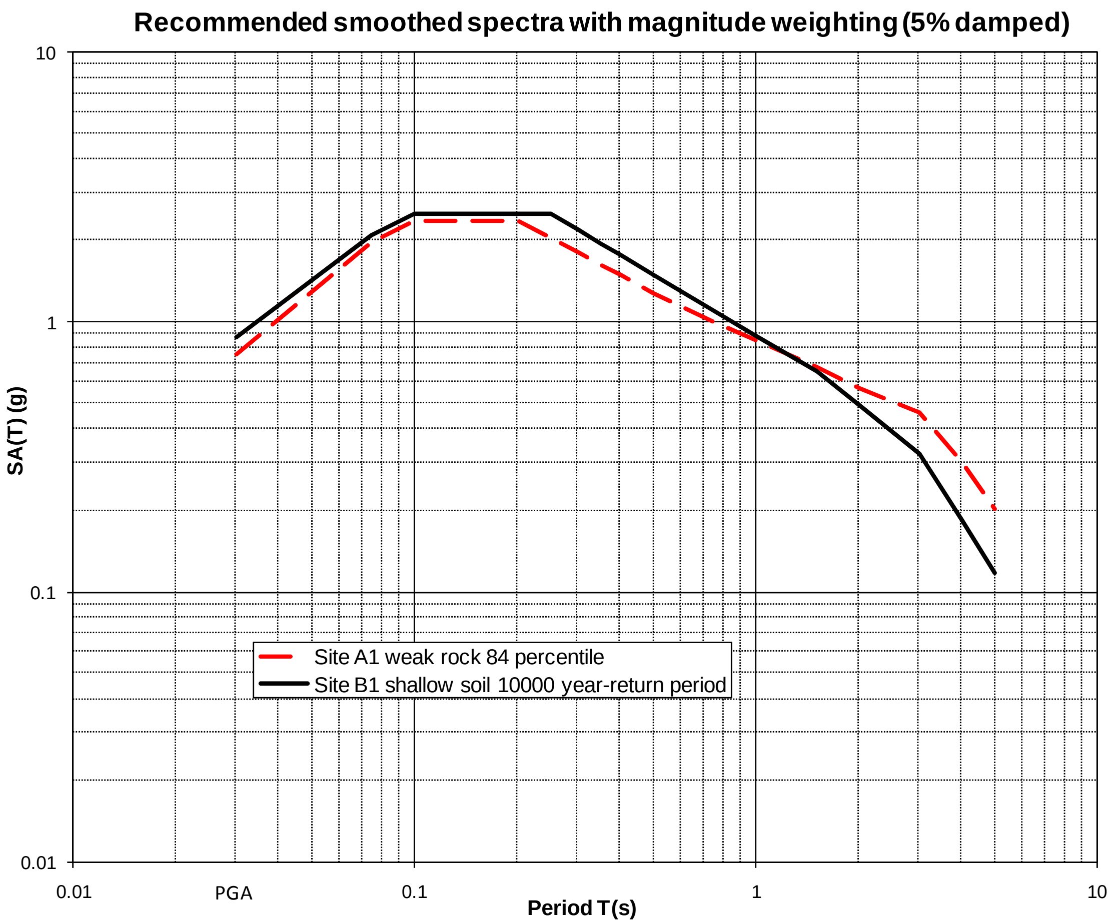

Figure ES3 Recommended design spectra for MDE motions at Site A1 (weak rock, 84-percentile Mohaka Fault spectrum including 84-percentile near-fault factors) and Site B1 (shallow soil, 10,000-year spectrum with recommended near-fault factors of 1.0). The spectrum recommended for site B1 was derived using the alternative fault model.

Table ES1 Near-fault factors for Site A1.

Spectral period	Average[1]	84-percentile[2]	NZS1170 factor
0.5	1.00	1.00	1.0
0.6	1.00	1.00	1.0
0.7	1.00	1.02	1.0
0.75	1.00	1.03	1.0
0.8	1.00	1.03	1.0
0.9	1.00	1.05	1.0
1	1.00	1.06	1.0
1.5	1.00	1.11	1.0
2	1.00	1.23	1.12
2.5	1.06	1.37	1.24
3	1.14	1.51	1.36
3.5	1.21	1.65	1.48
4	1.26	1.75	1.60
4.5	1.29	1.81	1.66
5	1.30	1.84	1.72
6	1.30	1.84	1.72

1 Recommended for hazard spectra
2 Recommended for 84-percentile scenario spectrum

Table ES2 Recommended design spectra (g) for MDE motions, with the values without near-fault factor presented in brackets for Site A1.

Spectral period (s)	Site A1 (weak rock)[1]	Site B1 (shallow soil)[2]
PGA	0.75	0.87
0.075	1.96	2.09
0.1	2.36	2.50
0.15	2.36	2.50
0.2	2.36	2.50
0.25	2.03	2.50
0.3	1.80	2.18
0.35	1.62	1.94
0.4	1.48	1.76
0.5	1.28	1.49
0.75	1.00 (0.97)	1.10
1	0.85 (0.80)	0.88
1.5	0.68 (0.61)	0.65
2	0.57 (0.46)	0.49
3	0.46 (0.31)	0.33
4	0.30 (0.17)	0.18
5	0.20 (0.11)	0.12

1 84-percentile spectrum for Mw 7.5 Mohaka South fault earthquake at 1.5km distance
2 10,000-year spectrum

1.0 PROJECT OUTLINE AND BRIEF

Tonkin & Taylor Ltd requested GNS Science to provide a report of the active faulting in the vicinity of a planned Water Augmentation Scheme in Central Hawke's Bay and provide 5% damped acceleration response spectra for two representative dam sites. The technical content of the project brief stated:

"The summary of information on active faulting in the vicinity of the proposed water scheme will include information on locations, mechanisms, magnitudes, single-event displacements, slip rates and recurrence intervals of faults likely to affect the water project. The fault study will involve a compilation of existing information, with no provision for new field work. If it is identified that better information on some faults could significantly alter current estimates of seismic hazard for the project in terms of ground shaking or location of fault displacements, recommendations will be included for the work required to obtain this information."

In addition to the information on active faulting the brief required:

"Earthquake motions at two specified locations will be estimated in terms of peak ground accelerations and 5% damped acceleration response spectra for a return period of 10,000 years, as appropriate for Maximum Design Earthquake (MDE) motions for High Potential Impact Classification structures. These will be compared with 50- and 84-percentile scenario motions for rupture of fault sources, estimated to produce the strongest motions at the two sites."

"One of the sites will be location A1 situated between the Mohaka and Ruahine Faults. The other location will be one chosen to be representative of the sites east of the Mohaka Fault. In addition, a map will be provided with contours of the 10,000-year hazard in terms of a parameter that can be used to scale the spectrum for the representative site for other locations in the eastern region. The spectra at each location will be estimated for one NZS1170 site class to be specified by Tonkin & Taylor." Site B1 was chosen as the second site for spectral analysis.

"The fault compilation and spectra will be internally reviewed at GNS Science, and will include comment on any differences between QMap (1:250,000 scale geologic mapping) and the fault modelling used in the National Seismic Hazard Model (NSHM)."

2.0 HAZARDS FROM EARTHQUAKES

The study area occurs within the southern part of Hawke's Bay region (within Central Hawke's Bay District) (Figure 1). Up to twelve possible water-retention structures are listed for this study, from which a lesser number (5-8 sites) will be taken to the next phase of investigation. These possible storages form the most significant hazard prone structures required for the potential irrigation development, but there will also be transfer races of modest capacity and a distribution system of pipes and/or races. The proposed sites occur between the Ruahine Ranges in the northwest and the Hawke's Bay coastal ranges in the southeast. Most of the proposed reservoirs occur within a tectono-morphic zone known as the Dannevirke or Ruataniwha Depression, an area of subdued topography, typically young (Quaternary) geology and somewhat lesser tectonic activity compared to the ranges to the northwest and southeast of it.

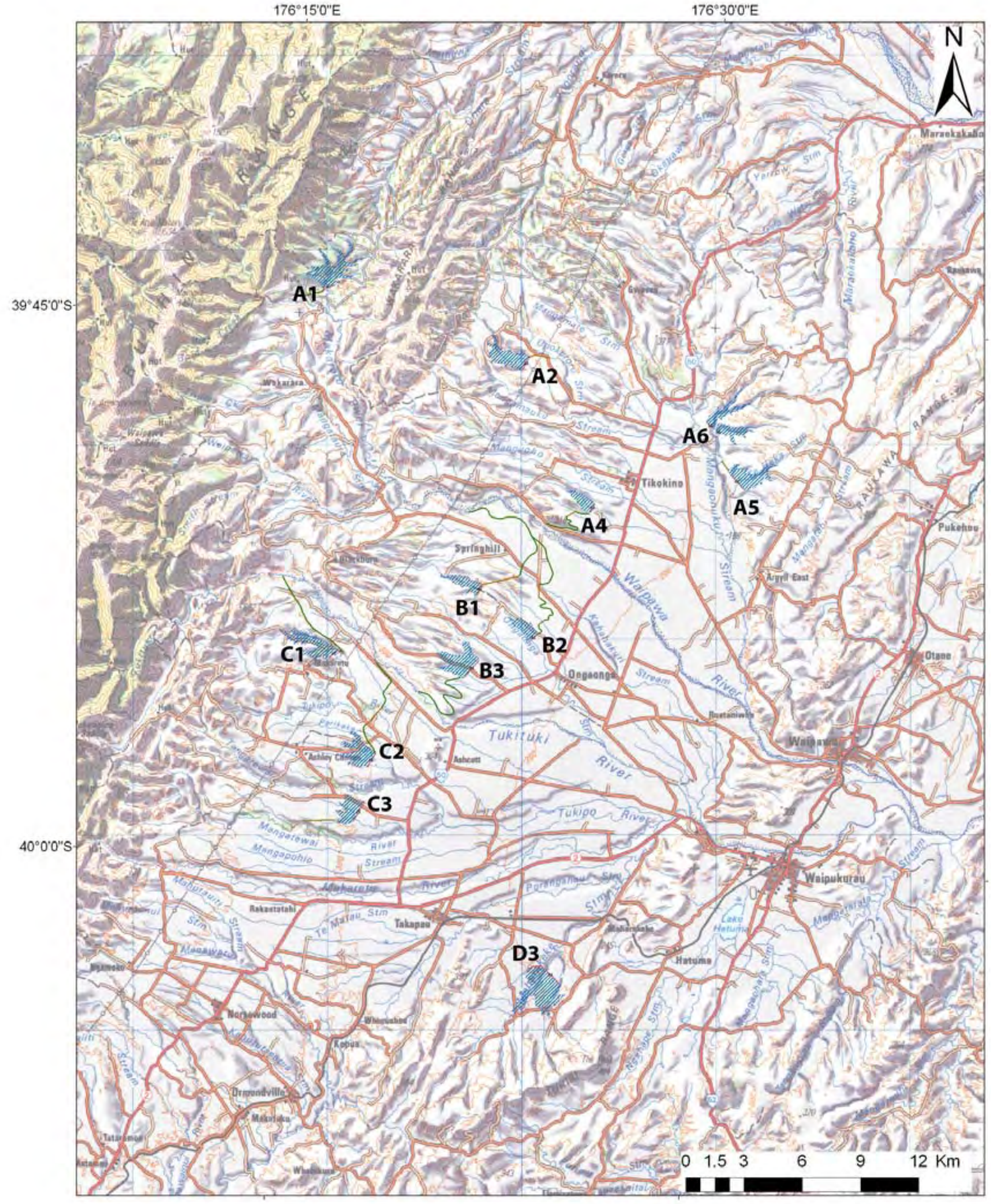

Figure 1 The study area and locations of the possible Water Augmentation structures, including dams, pipes, races and reservoirs as labelled.

2.1 Tectonic setting of New Zealand

New Zealand straddles the boundary of the Australian and Pacific plates, where relative plate motion (which varies from 30 to 50 mm/year) is obliquely convergent across the plate boundary (Figure 2). The relative plate motion is expressed in New Zealand by the presence of many active faults (Figure 3), a high rate of "small-to-moderate" earthquakes (M<7), the occurrence of many "large" earthquakes (M7-7.9) and one "great" earthquake (M>8) in historical time (Figure 4). A southeast-dipping subduction zone lies at the far south-western end of the country (“Fiordland subduction zone”). It is linked to a major northwest-dipping subduction zone in the eastern North Island ("Hikurangi subduction zone") by a 1000 km long zone of right-lateral oblique slip faults ("Axial tectonic belt"). The vast proportion of the relative plate motion is accommodated by the faults of the axial tectonic belt in the area between the Fiordland and Hikurangi subduction zones. The Hikurangi subduction interface dips beneath the eastern North Island. Only one large (M_w>7) earthquake and no great (M_w>8) earthquakes are known to have been produced by the Hikurangi subduction zone in historical times (since 1840), and so little is known about its earthquake potential.

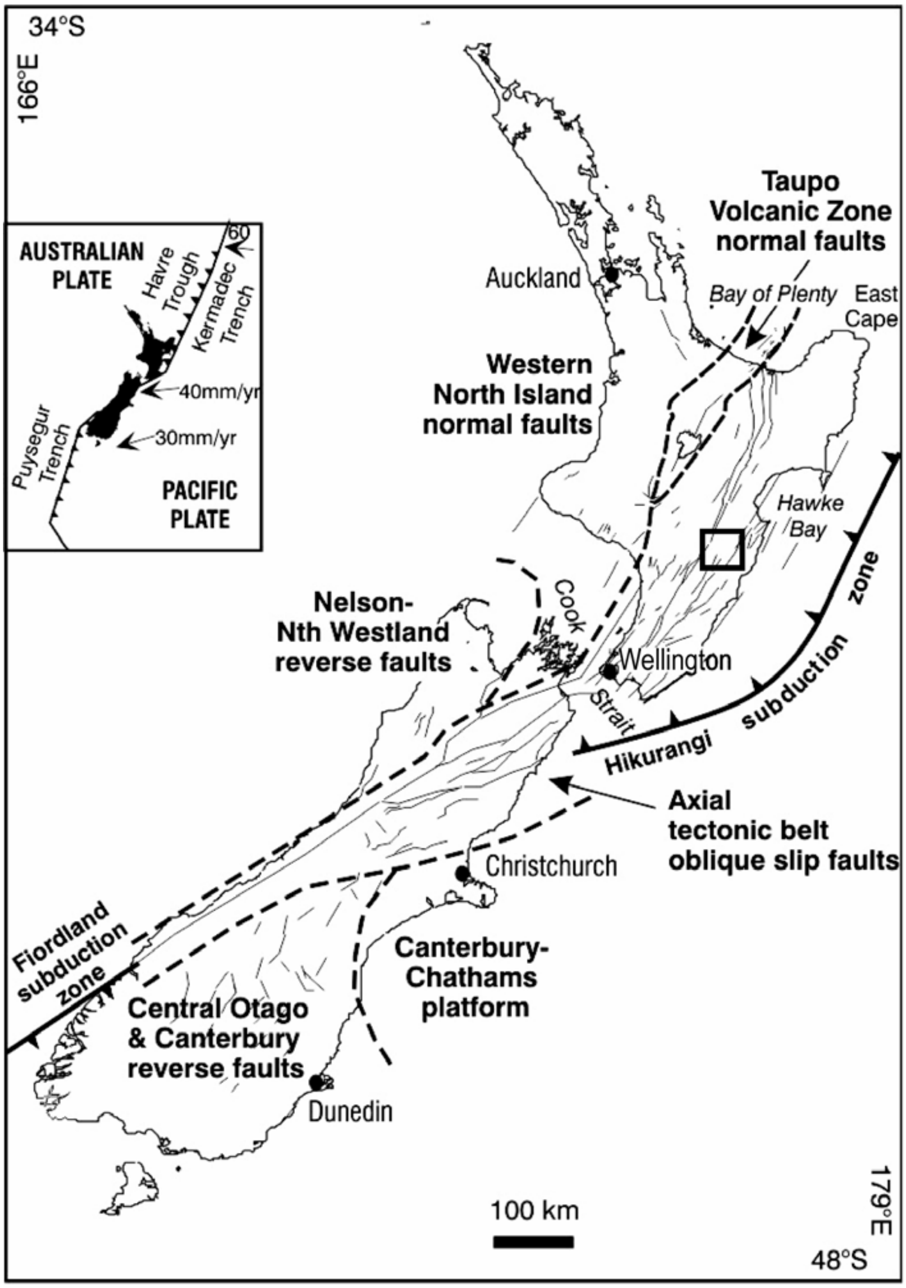

Figure 2 Tectonic setting of New Zealand showing the major seismo-tectonic zones and their styles of movement. The study are in Hawke’s Bay is outlined by a bold box.

The proposed Central Hawke’s Bay Water Augmentation Scheme lies between the eastern edge of the North Island Axial Ranges and the western edge of the Hawke’s Bay coastal ranges, within one of the more tectonically active parts of this boundary zone. In addition to being underlain by the subducting Pacific plate (Figure 2), the area is traversed by a number of significant active faults, with estimated magnitudes in the range of about M 6.8 to 7.6 and with average recurrence intervals ranging from <1000 years to in excess of 10,000 years, that are capable of generating large earthquakes associated with large (i.e. metre-scale) single event surface rupture displacements. These faults, including the Mohaka Fault, Ruahine Fault, Ruataniwha Fault (RF), and Waipukurau Fault Zone (WFZ) (Figure 3), pose a seismic shaking and surface rupture hazard. The faults have a variety of structural styles, ranging from strike-slip, e.g. Mohaka Fault, to reverse or reverse-oblique slip, e.g. Ruataniwha Fault (Klos 2009).

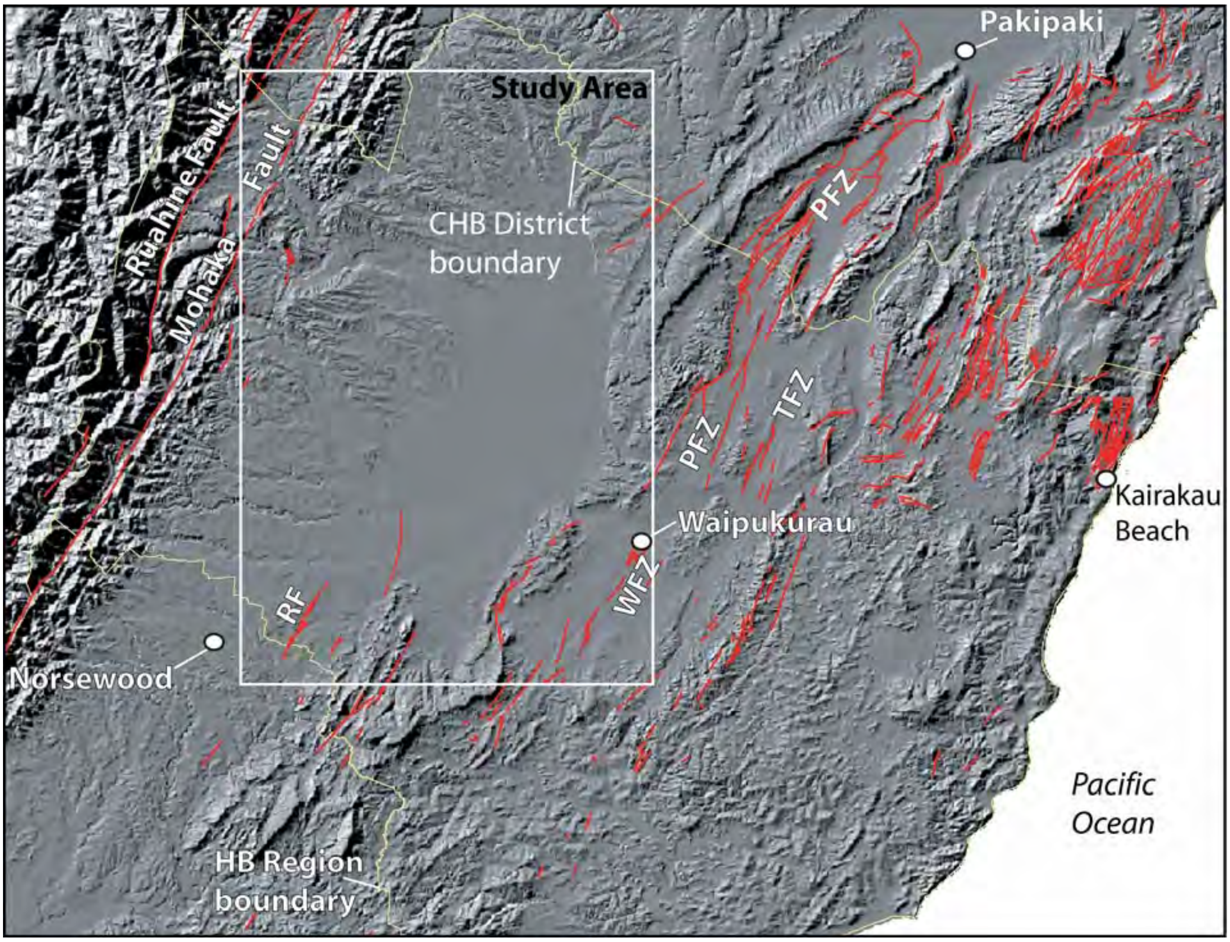

Figure 3 Digital Elevation Model and preliminary fault map of central Hawke's Bay and surrounds. The area of the proposed Water Augmentation Scheme study is within the white box. Red lines represent known active fault traces from the GNS Science Active Faults database (http://data.gns.cri.nz/af/), including the: RF, Ruataniwha Fault, WFZ, Waipukurau Fault Zone, PFZ, Poukawa Fault Zone, and TFZ, Tukituki Fault Zone. The regional and district boundaries are coloured yellow, and the study area is shown in the white box.

2.2 Regional seismicity

The Hawke's Bay region has a well documented record of historical earthquakes (Figure 4) that have been both damaging and destructive. Two significantly large earthquakes occurred between 1840 and 1870. Based on shaking intensity contours, a large event in 1843 has been assigned to the area of the Axial Ranges in Hawke's Bay, while in 1863 the M 7.5 Waipukurau earthquake is believed to have occurred on a reverse fault source in the vicinity of that town (Grouden 1966; Downes and Dowrick, in prep.). These events and the M 8+ 1855 Wairarapa earthquake produced strong ground motions in the study area. During the early part of the 20th century, Hawke's Bay was rocked by a number of large earthquakes, including the M 7.8 1931 Hawke's Bay earthquake which killed 256 persons and destroyed the cities of Napier and Hastings. This event also caused damaging to very damaging (MM 7-8) ground motions in the vicinity of the study area[1]. Other damaging earthquakes in the region include the M 6.9 1932 Wairoa, M 7.4 1934 Pahiatua, and M 7.2 1942 Masterton earthquakes (Downes 1995; Schermer et al. 2004).

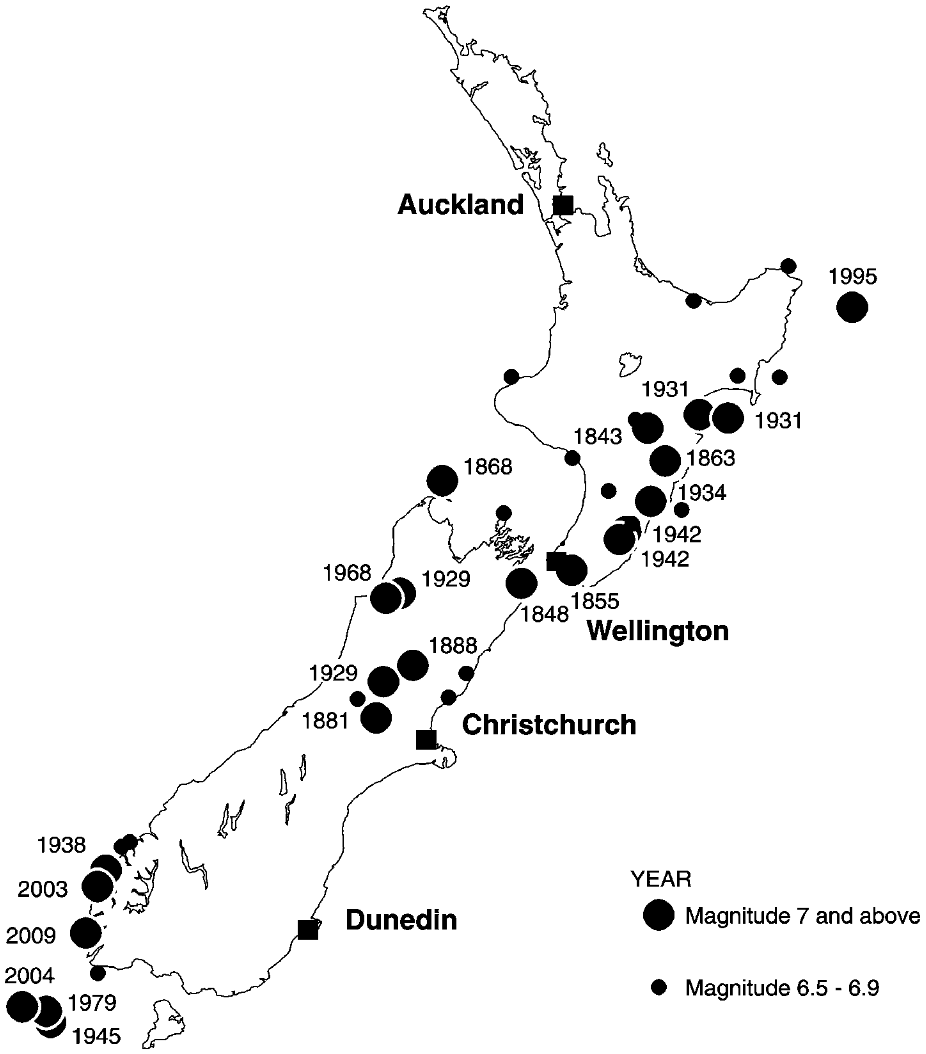

Figure 4 Epicentral locations of large earthquakes in New Zealand since 1840.

[1] http://www.geonet.org.nz/earthquake/quakes/2178228g-shaking.html

3.0 FAULTS AND FOLDS IN THE SOUTHERN HAWKE'S BAY AREA

3.1 Characterisation of near-field active fault and fold displacement

The location of known active fold and fault traces that are in close proximity to the proposed scheme are highlighted in red in Figure 5. This data comes from the GNS Science Active Faults database (http://data.gns.cri.nz/af/; Van Dissen et al. 2003) and from the 1:250,000 scale QMap geological mapping of the Hawke's Bay area (Lee et al. in prep). Active faults and folds typically have a NNE strike though central Hawke's Bay. Table 1 also presents approximate single-event displacements, slip rates, and recurrence intervals for these faults.

From northwest to southeast, the major faults that are in proximity to the proposed sites are the Ruahine Fault, Mohaka Fault, Wakarara Fault (new to Active Faults database), Rangefront Fault (new), Ruataniwha Fault, Te Heka Fault (new), Oruawharo Fault, and Glendevon Fault (Figure 5). Two additional active faults, the Cullens Fault and Hinerua Thrust (HT), are recognised at the western edge of the study area from Raub et al. (1987). A one-day field reconnaissance was undertaken on 17th June, 2010 to examine the location and activity of a number of these faults for the purposes of the seismic parameters input into the spectral models.

3.1.1 Major faults and folds

The Ruahine and Mohaka faults are NNE-striking, right-lateral strike-slip faults of the western strand of the North Island Dextral Fault Belt (Beanland 1995). These have the highest slip rates and single-event displacements, and shortest recurrence intervals for faults in the area (Table 1). Within the study area, these faults are sub-parallel to each other at a distance of c. 3 km apart. The corridor between the two faults is called the Ohara Depression. (Raub et al., 1987; Erdman and Kelsey, 1992). Within the Ohara Depression, these authors recognised several additional, short fault and fold traces, such as the Cullens Fault. Although portions of these faults are shown as active by Kingma (1962), there is currently no definitive evidence to show that the Cullens Fault, or those immediately north of site A1, have been active (or not active) during the last 125,000 years (see Raub et al. 1987).

A similarly wide tectonic sliver to the east of the Ohara Depression is called the Wakarara Range, which is bounded on the east by the Wakarara Fault (Figure 5). The Wakarara Fault (and associated Wakarara Monocline) and Rangefront Fault are two new[2] active features that have been confirmed as part of this study (Raub et al., 1987). Several active fold and fault traces have been mapped along this trend by Lee et al. (in prep.) at the edge of the Wakarara Range. These faults reflect a small amount of reverse movement (tectonic shortening) associated with the edge of the Axial Ranges in this area (Beanland et al. 1998; Erdman and Kelsey, 1992). Raub et al. (1987) demonstrate from down valley terrace profiles that the Wakarara Monocline deforms Ratan age (i.e. Q3; c. 30-40,000 yr) alluvial terraces and older, but has not deformed Ohakean aged (i.e. Q2/ postglacial; c. 15-30,000 yr) terraces and younger. Field reconnaissance of the Wakarara and Rangefront faults in this study documents that both structures have active traces across Ohakean aged alluvial terraces.

[2] these faults are new or named for the first time in the GNS Active Faults database (http://maps.gns.cri.nz/website/af/).

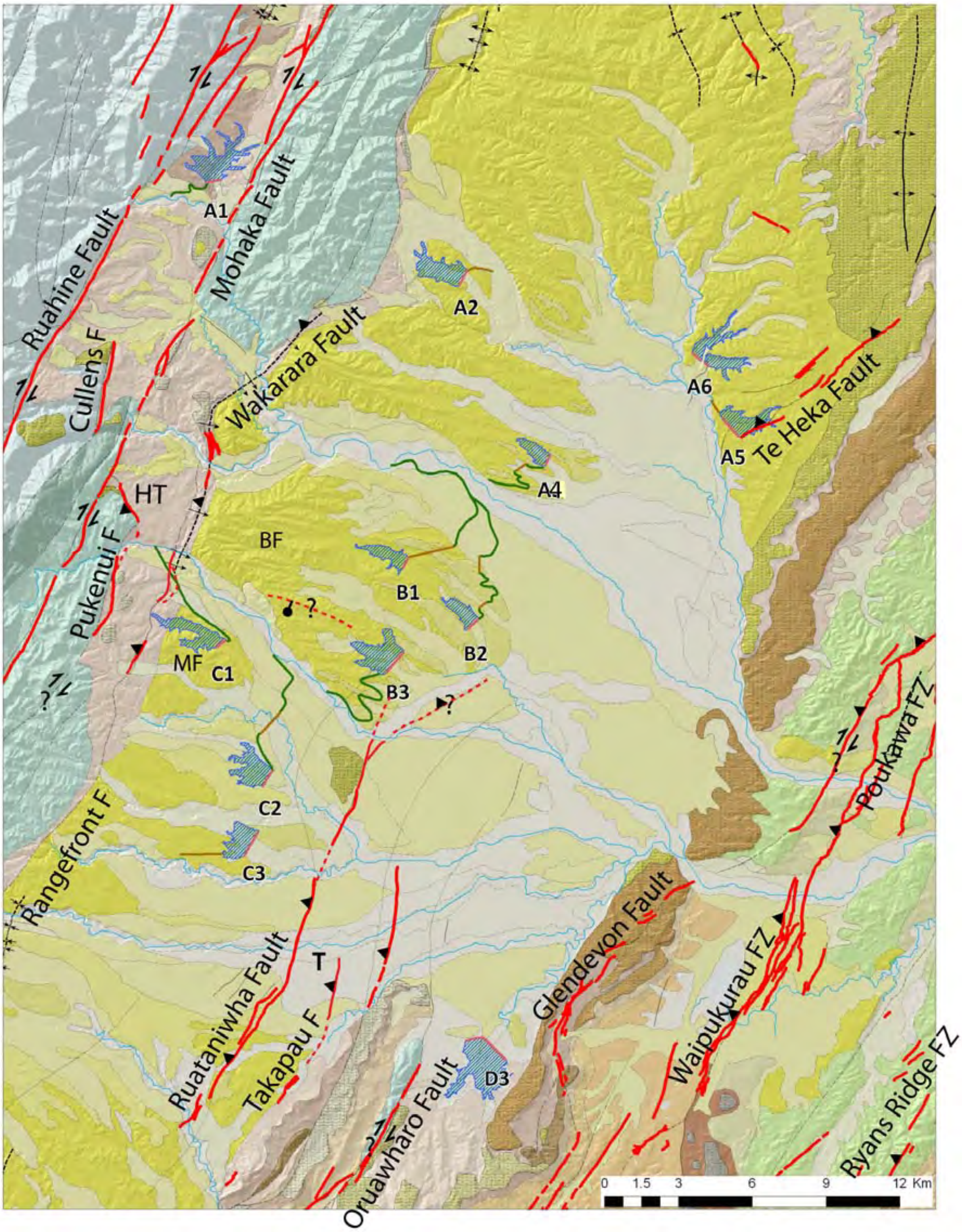

Figure 5 Known active fault (red) and fold traces (black dashed lines) that are in close proximity to the proposed scheme. From 1:250,000 scale geological map of the Hawke's Bay area (Lee et al. in prep; lithologies follow QMap patterns and colours). In addition, possible fault (red dashed lines) and fold (thin black lines) locations are also included. Teeth, strike-slip and tick/ball symbols indicate fault style. Proposed embankment dams are labelled A1 through D3. New faults, e.g. the Te Heka, Takapau, Wakarara and Rangefront faults, have been defined as part of this study. HT marks the Hinerua Thrust, and BF and MF refer to the Blackburn and Makaretu alluvial fan complexes. T marks the proximity to Takapau and Tikokino junction.

The Ruataniwha, Takapau and Te Heka faults are a set of at least three, NNE-striking reverse-slip faults with associated folds that occur within the Ruataniwha/ Dannevirke Depression. The scarp of Ruataniwha Fault can clearly be identified near Tikokino (Highways 2 & 50) junction. The fault has been mapped to the southwest crossing Q2 (c. 15,000 yr) to possibly Q6 (128-186,000 yr) surfaces (Klos 2009). To the northeast, the fault trace is inferred to occur just beyond the truncation of older alluvial fan surfaces related to the Blackburn and Makaretu fans (BF and MF). Farther northeast along this trend, the Te Heka Fault occurs to the north of the Waipawa River (Figure 5). Reconnaissance mapping confirmed active traces across hill country adjacent to Argyll East Road. Near and within the town of Takapau, a small scarp of only 30-40 cm has been recognised from LiDAR[3] imagery and in field reconnaissance. This scarp has been interpreted to belong to the Takapau Fault.

To the southeast of these faults, the Oruawharo Fault is a dextral-reverse fault that juxtaposes greywacke against Pliocene limestone. Although this area is generally considered to be dominated by coast-vergent, reverse faulting, Beanland (1995) recognised strike-slip displacements along the trace of the Oruawharo Fault. As this is the best data currently available for this fault, it has been assigned a higher slip rate and single-event displacements than other nearby faults, based on Beanland (1995). The Glendevon Fault is a flexural-slip fault that is characterised by bedding plane slip, associated with folding (Van Dissen et al. 1989).

A series of fault traces that typically strike ESE to SE have been recognised across the area described as the Blackburn alluvial fan complex (Figure 5; Lee et al. in prep). These features are discontinuous and difficult to characterise, but appear to be extensional in nature, so have been described as normal faults (‘Blackburn Fault Zone’; Table 1). The Blackburn Fault Zone has been included as it represents a potential zone of surface deformation near some of the embankment and pipe locations. However, there is little to no seismic hazard parameter information for these features. For this study, we assume a recurrence interval for movements of 10,000-20,000 years (RI Class V).

3.1.2 Proximity of active faults and folds

Table 1 shows the closest approximate distance from several of the proposed reservoir sites (incl. embankment, pipes and races) to active fold and fault traces and their projected positions (see Figure 5). Unfortunately, the location, continuity and characterisation of expected tectonic displacement for most, if not all, of the traces depicted in Figure 5 are not known well enough at this time to offer design-specific constraints on expected fault displacements for the proposed scheme. Site-specific investigations focused on fault location and/or deformation characterisation are required if the scheme is to avoid the crossing of active fault/fold deformation or be designed with sufficient resilience to be able to accommodate tectonic deformations that may impact on the scheme that have a suitably high likelihood of occurrence to be of concern to the scheme.

[3] Light Distance and Ranging - an airborne laser technique for producing accurate Digital Elevation models of the Earth’s surface

Table 1 Fault rupture displacement sources for proposed sites within the central Hawke's Bay area.

Fault/ Fold Name	Fault/ fold style	Potential impact to Reservoir site	Proximity to Embankment (c. km)	Proximity to Races & Pipes (c. km)	Single Event Displacement (m)	Net slip-rate (mm/yr)	Recurrence Interval (yrs)†	References
Mohaka	Dextral	A1	1.0	1.5	4 ± 1	3-4	<2000	Beanland (1995); Raub et al. (1987)
Ruahine	Dextral	A1	1.8	< 0.9	4 ± 1	1-2	2000-3500	Beanland & Berryman (1987)
Te Heka	Reverse	A5	**< 0.2**	1.4	1-1.5	c. 0.2	5000-10,000	http://data.gns.cri.nz/af/; this study
Ruataniwha	Reverse	B2* B3*	2.0 c. 1	2.3 **< 0.2**	1-2	c. 0.2	5000-10,000	Klos (2009)
Oruawharo	dextral-reverse	D3	1.6	-	4 ± 1	0.5-1	3500-5000	Beanland (1995); Van Dissen et al. (2003)
Glendevon	flexural-slip (with M c. 5.7)	D3	2.0	-	1	0.1-0.2	3500-5000	Van Dissen et al. (1989)
Rangefront	Reverse	C1	3.0	**crossing**	1-2	0.3	5000-10,000	Beanland et al. (1998); this study
Hinerua Thrust	Reverse	C1	5.5	< 0.9	1-1.5	c. 0.2	5000-10,000	Raub et al. (1987); this study
Wakarara	Reverse	A2	3.2	3.2	1	0.3	5000-10,000	Beanland (1995); this study
Blackburn FZ	normal ?	B3 B1	2.7 2.7	2.7 3.4	?	?	10,000-20,000 ?	Lee et al. (in prep.); this study

Notes:
Bold values are within 500 m of an active fold or fault trace and should be sites considered for further active fault location studies.
* Sites occur close to unmapped, but possible, fault or fold traces – defined by the geometry of old traces and the surficial geology of late Quaternary alluvial fans.
† Recurrence interval based on RI Classes of Kerr et al. (2003) and Van Dissen et al. (2003).

Distances shown in Table 1 vary from several kilometres to less than 500 m. In terms of surface deformation and fault rupture, distances of >500 m from the currently mapped traces of folds and faults are probably insignificant in terms of hazard from fault (or fold) displacement during large earthquakes. Values in Table 1 that are <500 m are probably sufficiently close to mapped and potential (unmapped/ projected) structures that further fault location work may be justified. For example, it is noted that Embankment A5 is sited c. 200 m from the Te Heka Fault and may even intercept the projection of fault and fold structures related to the Te Heka Fault (Figure 5). As a second example, a race proposed for Embankment C1 crosses the trace of the Rangefront Fault near the south bank of the Tukituki River.

Other additional unmapped faults and folds may exist near the reservoir dam structures that are currently not shown on the GNS Science Active Faults database or from the published literature. Additional mapping near the proposed dam sites should be undertaken to assess the possibility of further faults and folds that could cause surface displacements. For example, Kingma (1962) and Lee et al. (in prep.) show several faults with SE-striking traces across young geologic surfaces that emanate from the Axial Ranges, e.g. the Blackburn Fault Zone, which cuts the Blackburn alluvial fan (Figure 5; Table 1).

In addition, due to the close spacing of faults in the Ohara Depression, Wakarara Range and Takapau area it would be useful to create a detailed fault and fold trace map of the sites that are close to major active faults, (e.g. site A1), as secondary faults may occur at short distances from these faults. We are aware that good LiDAR coverage now exists across this area and it should be used to better locate and characterise active faults in future.

3.1.3 Measures of the key seismic hazard parameters

Some broad generalisations regarding the location and style of deformation of some of the traces depicted in Figure 5 can be made (Table 1). Future single-event earthquake surface-ruptures of the Mohaka and Ruahine faults are expected to be several metres in size (3-5 m), and predominantly right-lateral in sense, with a subordinate vertical component. Slip rate estimates for these faults are c. 3-4 mm/yr, and c. 1-2 mm/yr, respectively (Beanland 1995; Beanland & Berryman, 1987; Raub et al. 1987; Langridge et al., unpublished data). Using the Ministry for the Environment's (MfE) classification for active fault recurrence (Kerr et al., 2003; Van Dissen et al., 2003), the Mohaka and Ruahine faults are Class I (2000 yr) and Class II (2000-3500 yr) recurrence interval faults. More definitive values of earthquake recurrence are given in Table 2 and used in the estimation of ground motion spectra.

Slip rates and single-event displacements for most other faults listed in Table 1 are not well characterised. Despite the fact that these structures deform late Quaternary alluvial surfaces, little is known about their seismic potential. In many cases, seismic parameters are designed from basic geomorphic observations, e.g. scarp height, surface ages etc., or from a comparison to 'similar' faults throughout the region that are better characterised.

Based on research on the Ruataniwha Fault by Klos (2009), an estimated dip-slip rate of c. 0.2 mm/yr for that fault has also been applied to the Te Heka Fault. A fault scarp across a Holocene surface along the Ruataniwha Fault suggests a single event displacement of 1.5-2 m. This value is again applied to the Te Heka Fault. The estimated MfE recurrence interval class for these faults is Class IV (5000-10,000 yr).

Similar rates and amounts of tectonic deformation have been assigned to the Wakarara and Rangefront faults. Scarp heights ranging from c. 2 to 4 metres across alluvial surfaces that correspond to the Ohakean (Q2; c. 15,000 yr) surface, are used to estimate rates of c. 0.3 mm/yr or more for these faults.

Data for the Oruawharo Fault comes from Beanland (1995). The fault has a series of dextral offsets that are larger than the vertical expression of the fault scarp. Therefore, the fault is considered to have a dextral-reverse sense of movement with multi-metre sized displacements (Table 1). The estimated slip rate is inferred to be larger than the adjacent reverse faults and the recurrence interval is Class III (3500-5000 yr), using the MfE Guidelines (Kerr et al., 2003; Van Dissen et al., 2003). Hazard parameters for the Glendevon Fault are poorly known. In this study, values used for the Poukawa Fault System along-strike to the northeast, from Kelsey et al. (1998), have been used to characterise the Glendevon Fault.

3.2 Determination of preferred fault parameters

In Section 4 of this report, spectra are estimated for expected ground motions in the area. Table 2a displays seismic hazard parameters for a series of the most important fault sources nearby to the study area, e.g. MohakaS = Mohaka South fault segment. Faults in Table 2a are those included in the most recent iteration of the NSHM (i.e. the 2010 version).

In the first case, the NSHM 2010 code is ‘output’ in its current, peer-reviewed form (Stirling et al., in prep). In the region of southern Hawke’s Bay the NSHM includes many of the faults discussed above, as indicative earthquake fault sources, including the Ruahine and Mohaka faults, the Hikurangi subduction zone (including bending moment sources) and a component of background seismicity.

For a subsequent run of the NSHM, the active fault earthquake sources closest to the proposed scheme have been re-assessed and, where warranted, re-parameterised (Figure 6; Table 2b) to account for new information. In addition, a number of new regional sources not included in the NSHM 2010 model have been added within c. 40 km of the study area. The reasons to attempt this are: (i) that new sources will fill out (complete) areas that have a low density of seismic sources; and (ii) that they connect up zones of active faulting that play a throughgoing, kinematic role in eastern North Island. These sources should therefore help to account for a probable, long-term seismic moment deficit across parts of this region. Justification for the chosen parameter values is outlined below and in Table 2b and its notes.

Table 2a Relevant active fault earthquake sources in the Hawke's Bay region (from the 2010 "standard" National Seismic Hazard Model).

Name	Comment	Length* (km)	Mw*	Net slip-rate* (mm/yr)	Recurrence Interval* (yrs)	Distance to A1 (km)	Distance to B1 (km)
MohakaS	Mohaka Fault (South) source –extends from near Dannevirke to near Big Hill area. Connected to WellP and MohakaN sources.	73.6	7.5	4	1300	1.5	12.2
RuahineC	Ruahine Fault (Central) source –extends from Tukituki headwaters to Ngaruroro River headwaters. Connected to WellP and Patoka/Rangiora sources.	45.3	7.2	1.1	2800	2.1	16.8
WaipukPouk	Combined Waipukurau and Poukawa Fault Zone source – extends from east of Dannevirke to south of Pakipaki.	64.3	7.5	1.0	4500	33.9	19.0
Ruataniwha	Original Ruataniwha fault source – extends from NE of Dannevirke to Takapau area.	16.3	6.6	0.2	5600	32.6	17.0
Oruawharo	Oruawharo fault source – extends from east of Dannevirke to east of Takapau.	20	6.7	0.2	7000	37.1	20.0
KairakauS	Kairakau South fault source –this is an offshore reverse fault source off the Hawke's Bay coast extending from near Cape Kidnappers to area.	33.6	7.1	3	790	70.2	40.2
SaundWaipuaka	Saunders Road- Waipukaka fault source – this source is equivalent to the M 7.6 1934 Horoeka (Pahiatua) earthquake.	48.4	7.2	2	1700	72.8	58.2
Napier1931	This source is equivalent to the M 7.8 1931 Hawke's Bay earthquake to the north of the Poukawa Fault Zone.	81.3	7.6	2.0	2800	45.1	41.7
HikHBay-avg	Hikurangi Subduction Zone (Hawke's Bay segment) – this source extends from offshore of Castlepoint area to offshore of Mahia Peninsula.	200	8.5	8.8	1800	48.3	35.4

Notes:
* mean values taken from Seismic Hazard Parameter Table in the standard version of the 2010 NZ National Seismic Hazard Model (Stirling et al., in prep).

Table 2b Revised additional active fault earthquake sources for the central Hawke's Bay area developed for the "alternative" source model.

Name	Comment	Length* (km)	Mw *	Net slip-rate* (mm/yr)	Recurrence Interval* (yrs)	Distance to A1 (km)	Distance to B1 (km)
Wakarara	New Source – northern part of Axial Rangefront source in the Hawke's Bay region.	39.3	7.1	0.3	9100	6.0	8.2
Rangefront	New Source – southern part of Axial Rangefront source in the Hawke's Bay/ Manawatu region.	40.5	7.1	0.3	9400	25.2	16.4
Te Heka	New Source – possibly the northern continuation of the Ruataniwha Fault, west of, and parallel to, the Poukawa Fault Zone.	27.7	6.9	0.2	9600	17.1	7.5
Ruataniwha-long	Modified Source – a longer version of this fault than resides in the NSHM. The source has been extended to the NNE toward the Te Heka source.	35.6	7.1	0.2	12,000	19.5	4.6
Waipukurau	Modified Source – replaces the southern part of the WaipukPoukawa source in the NSHM, source extended in length.	42	7.2	1.2	2400	37.9	18.4
Poukawa	Modified Source – replaces the northern part of the WaipukPoukawa source in the NSHM, source extended in length to the NE.	36.5	7.2	1.2	2400	34.1	18.9
Te Uri	New Source – northern continuation of a zone of active faulting on strike from the SaunWaipukaka and PongaroaWeber sources.	27.1	6.9	1.5	1300	51.0	33.9
Ryans Ridge	New Source – northern continuation of a zone of active faulting on strike from the SaunWaipukaka, PongaroaWeber and Te Uri sources.	37.8	7.1	1.2	2200	43.8	27.0
Mangaorapa	New Source – link between the offshore Kairakau fault sources to the north and Waitawhiti source to the south.	37.5	7.2	2.0	1300	63.7	32.6

Notes:
* mean values taken from Seismic Hazard Parameter Table developed for these calculations (GNS Science).

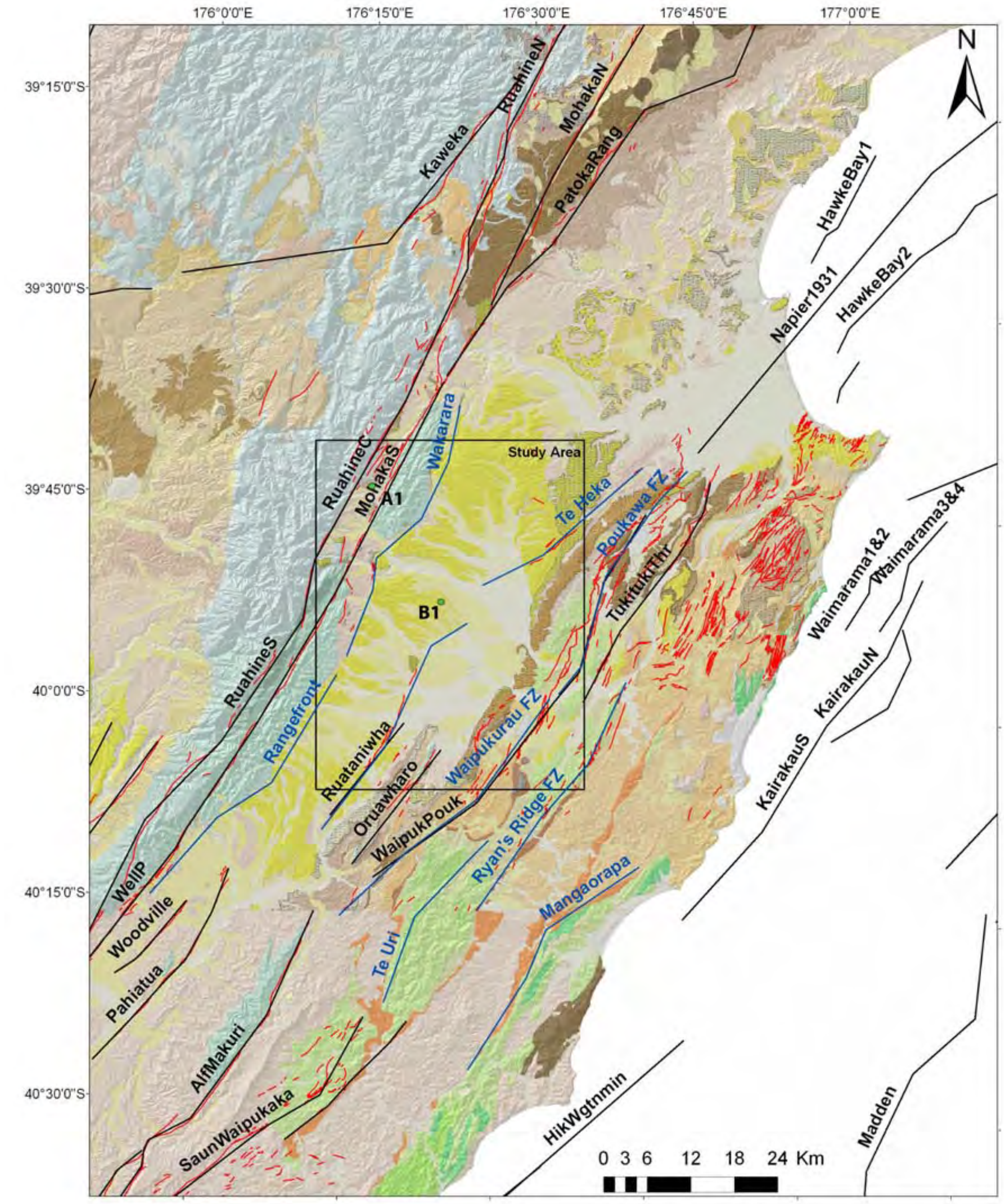

Figure 6 Active fault earthquake source model(s) encompassing the Central Hawke's Bay area. The base map for the figure is from QMap geology (e.g. Lee and Begg 2002, Lee et al. in prep).The red lines represent visible evidence of faulting, represented in the NSHM by earthquake sources shown by the blue and black lines. The blue lines are the new and modified sources developed in this study (see Table 1). The black lines represent the active fault source as they are in the 2010 version of NSHM (many have abbreviated names). The positions of sites A1 and B1 are shown by green dots.

Figure 6 shows the alternative source model used in this study. The blue lines represent sources that are new or have been redefined in this study, e.g. Te Uri, the northward continuation of the Saunders-Waipukaka source (i.e. the 1934 Pahiatua earthquake source). The black lines represent NSHM sources that have been used unaltered in this study. They include the Mohaka South segment (MohakaS), Oruawharo and Wellington-Pahiatua (WellP) sources, which are within the broader study region. In addition to upper (Australian) plate faults including offshore sources, the Hikurangi Subduction thrust exists in the National Seismic Hazard model as a series of dipping segments beneath the North Island. Finally, the possibility of intra-plate earthquakes in the downgoing slab of the Pacific plate is also accounted for in the NSHM as potential shaking sources in the background seismicity model.

Figure 6 and Table 2b define several new active fault earthquake sources (Te Heka, Wakarara, Rangefront, Te Uri, and Mangaorapa) that have been appended to the 2010 version of the NSHM, for the alternative fault model. It also includes the re-definition of the location, length, and/or segmentation of several existing NSHM sources. For example, the WaipukPoukawa source has been split into two sources and modified. These new or modified representations are the result of the active fault and fold mapping portrayed on the QMap Hawke's Bay sheet (Lee et al., in prep) and the Wairarapa sheet (Lee and Begg 2002), and through confirmation based on field reconnaissance. The Takapau and Glendevon faults are not entertained as new seismic sources in this study. The latter is considered as a flexural-slip fault that can only generate earthquakes of up to c. M 5.7 (Van Dissen et al. 1989).

As described in Section 3.1, the slip rates for many of the active fault earthquake sources depicted in Figure 6, and listed in Table 1, are not well constrained. In lieu of "good" slip rate data, slip rates have been assigned based on relative geomorphic expression of the faults, and their associated tectonic landforms, focussing on the expression of deformation as shown across Ohakean aged (or post-glacial) alluvial terraces.

The revisions to NSHM sources 2010 are as follows:

1. The Ruataniwha source has been increased in length from 16 to 35.6 km, mostly to the northeast of its old co-ordinate parameters based on mapping done as part of this study, Klos (2009) and Lee et al., in prep) (see Figure 6). A bend in the fault near the Tikokino junction is proposed, based on the location of a NE-striking scarp. This scarp is parallel to a fold trace that coincides with the SE end of a large, late Quaternary alluvial fan complex ("Blackburn fan"), i.e. a fault may mark the end of these fans. This concealed trace lies immediately to the southeast of embankments B1, B2 and B3.

2. The Waipukurau-Poukawa source has been split into the Waipukurau and Poukawa sources. Each source has been extended in length to the southwest, and northeast, respectively, though both are shorter than the original fault source (64 km). The lengths of the two revised sources are 42 and 36.5 km, respectively. This is to entertain the effects of shorter segment lengths and a north-south split in the system near Waipawa (and its possible impacts on site B1).

In the NSHM, earthquake recurrence interval for active fault sources is derived using a scaling-relationship that calculates single-event earthquake displacement from fault rupture length. The calculated displacement is then divided by assigned slip rate to calculate recurrence interval. Table 2b lists the derived recurrence interval based on the assigned length and slip rate for each of the sources. These scaling-relationship derived recurrence intervals are in good agreement with what is known about the activity and/or recency of movement of the actual active faults and folds that comprise the sources.

4.0 DETERMINATION OF SPECTRA

A probabilistic seismic hazard analysis has been carried out for two sites, A1 and B1 (Figure 1), in the Central Hawke's Bay Water Augmentation Scheme. Site A1 occurs in the northwestern corner of the study area within the Axial Ranges, and site B1 occurs on older Quaternary fan deposits north of Tikokino junction (Figure 5). Maps will also be produced covering the region of interest. Site A1 was classified as an NZS1170 (Standards New Zealand, 2004) weak rock site (site class B), and Site B1 was classified as a shallow soil site (site class C) according to the available geotechnical information for the region. Maps have also been prepared showing the hazard across a region encompassing all sites in the scheme. Site A1 is arguably a special case, while site B1 is probably more representative of other storage sites.

Results have been obtained using two seismic hazard models, the "standard model" corresponding to the recently updated 2010 National Seismic Hazard Model (NSHM; Stirling et al., in prep.), and the "alternative model" as discussed in detail in the previous section with the addition of more fault sources in the Central Hawke's Bay region and the modification of some from the standard model. The additional or modified faults considered in the alternative model are either ones for which new information has become available very recently (the Ruataniwha, Te Heka, Wakarara and Range Front Faults), or relatively poorly-defined faults that are included to accommodate strain in the eastern part of the study region that is accounted for further south by sources in the standard model.

The standard 2010 NSHM incorporates significant updates to the published NSHM results of Stirling et al. (2002). In the Hawke's Bay region, these updates include: (i) modifications to the Hikurangi subduction zone sources; (ii) the addition of further offshore, upper plate fault sources, e.g. Kairakau South (Figure 6); (iii) re-considerations of fault segmentation patterns for strike-slip faults in the Axial Ranges; (iv) other minor changes to on-land faults; (v) different "scaling relations" between fault length and magnitude ; and (vi) substantial update of the background seismicity model. The updates have led to slightly higher seismic hazard estimates for the region.

4.1 NZSOLD Guidelines for Maximum Design Earthquake Motions

Smoothed 5% damped acceleration response spectra are presented in this report for various return periods and for various fault-rupture scenarios to determine spectra that satisfy the criteria of the NZSOLD (2000) *New Zealand Dam Safety Guidelines* for Maximum Design Earthquake (MDE) motions for High Potential Impact Category (PIC) structures. In MDE motions, some damage is acceptable, but it must not result in catastrophic failure, and it is required that at least the impounding capacity of the dam be maintained.

The MDE spectra are determined by considering both probabilistic spectra and scenario spectra for the estimated 50- and 84-percentile motions from rupture of nearby faults. The NZSOLD Guidelines specify the return period to be considered for MDE motions for High PIC dams as "a 1 in 10,000 AEP event if probabilistically derived" (AEP is Annual Exceedance Probability). The MDE may also be Maximum Credible Earthquake, described as the "largest reasonably conceivable earthquake that appears possible along a recognised fault or within a geographically defined tectonic province, under the presently known or interpreted tectonic framework".

4.2 Smoothing of the spectra

Unsmoothed spectra were first computed from the NSHM and were then smoothed by using a procedure similar to that specified in NZS1170.5:2004, generally aiming to produce a set of smoothed spectra that are closer to the unsmoothed spectra than is achieved by using the NZS1170 spectral shapes.

The following equations were used for each return period for obtaining the smoothed spectrum $SA_{smooth}(T)$ from the spectrum $SA(T)$ calculated from the NSHM for the same site class:

$$SA_{smooth}(T) = SA(0) \qquad T=0$$

$$SA_{smooth}(T) = SA(0) + \frac{T\left[SA_{max} - SA(0)\right]}{T_o} \qquad 0 < T \le T_0$$

$$SA_{smooth}(T) = SA_{\max} \qquad T_0 < T < T_c$$

$$SA_{smooth}(T) = SA_{Ref}\left(\frac{T_{Ref}}{T}\right)^{\gamma} \qquad T_C < T \le T_V$$

$$SA_{smooth}(T) = SA_{TV}\,\frac{T_V}{T} \qquad T_V < T \le T_D$$

$$SA_{smooth}(T) = SA_{TD}\left(\frac{T_D}{T}\right)^{2} \qquad T > T_D$$

where

$$SA_{Ref} = SA(T_{Ref})$$

$$SA_{max} = SA_{Ref}\left(\frac{T_{Ref}}{T_c}\right)^{\gamma}$$

$$SA_{TV} = SA_{Ref}\left(\frac{T_{Ref}}{T_V}\right)^{\gamma}$$

$$SA_{TD} = SA_{TV}\left(\frac{T_V}{T_D}\right)$$

where T is spectral period, $SA(0)$ is the spectral acceleration computed from the NSHM at zero second spectral period, T_0=0.1s and T_c are the short- and long-period corners of the plateau of amplitude SA_{max} at the peak of the spectrum, and T_V =1.5s and T_D =3s are the periods at which the constant-velocity and constant-displacement branches of the spectrum start, and γ is the exponent of the descending branch from the plateau from period T_c to 1.5s. The smoothed spectra match the NSHM spectra at 0s and the reference period T_{Ref}. The values selected for the parameters T_c, T_{Ref} and γ are given in Table 3, along with the spectral values SA_{ref}, SA_{max} , SA_{TV} and SA_{TD} corresponding to the MDE spectra recommended in Table 5 in Section 4.5.

Table 3 Parameters for constructing the smoothed MDE spectra.

Parameters	**Site A1** **Site class B (weak rock)**	**Site B1** **Site class C (shallow soil)**
T_o	0.1s	0.1s
T_c	0.2s	0.25s
T_{ref}	1.5s	0.75s
T_V	1.5s	1.5s
T_D	3s	3s
γ	0.67	1.00
SA(0s)	0.75g	0.87g
SA_{ref}	0.61g	1.1g
SA_{max}	2.36g	2.5g
SA_{TV}	0.61g	0.65g
SA_{TD}	0.31g	0.33g

4.3 Spectra determined for Site A1 (weak rock site)

Figure 7 compares the smoothed spectra (without near-source factors) with the raw spectra derived from the probabilistic seismic hazard analysis using the standard model. A common feature for the smoothed spectra for all return periods is the truncation of the peaks of the hazard spectra that occur around 0.2s period. This truncation is intended to offset the effect that hazard spectra calculated using the New Zealand attenuation model by McVerry et al. (2006) tend to over-estimate the recorded spectra at 0.2s period. Similar truncation of the peaks of the spectra was applied in deriving the NZS1170 spectral shape factors. In the spectral period range of 0.3s-1.0s, the raw hazard spectra are considerably smaller than the smoothed spectra at site A1, with the largest differences at 0.4s spectral period. For the 10,000-year return period, the raw hazard spectrum is about 64% the value of the smoothed spectrum. The large difference is likely caused by the “un-smoothness” of the spectrum predicted by the McVerry et al. (2006) attenuation model, especially at short distances. The effect of “un-smoothness” is exacerbated by the dominant contribution to the hazard spectra from the Mohaka South fault at a distance of only 1.5 km from the site. At spectral periods over 1s, the smoothed spectra are nearly identical to the raw hazard spectra.

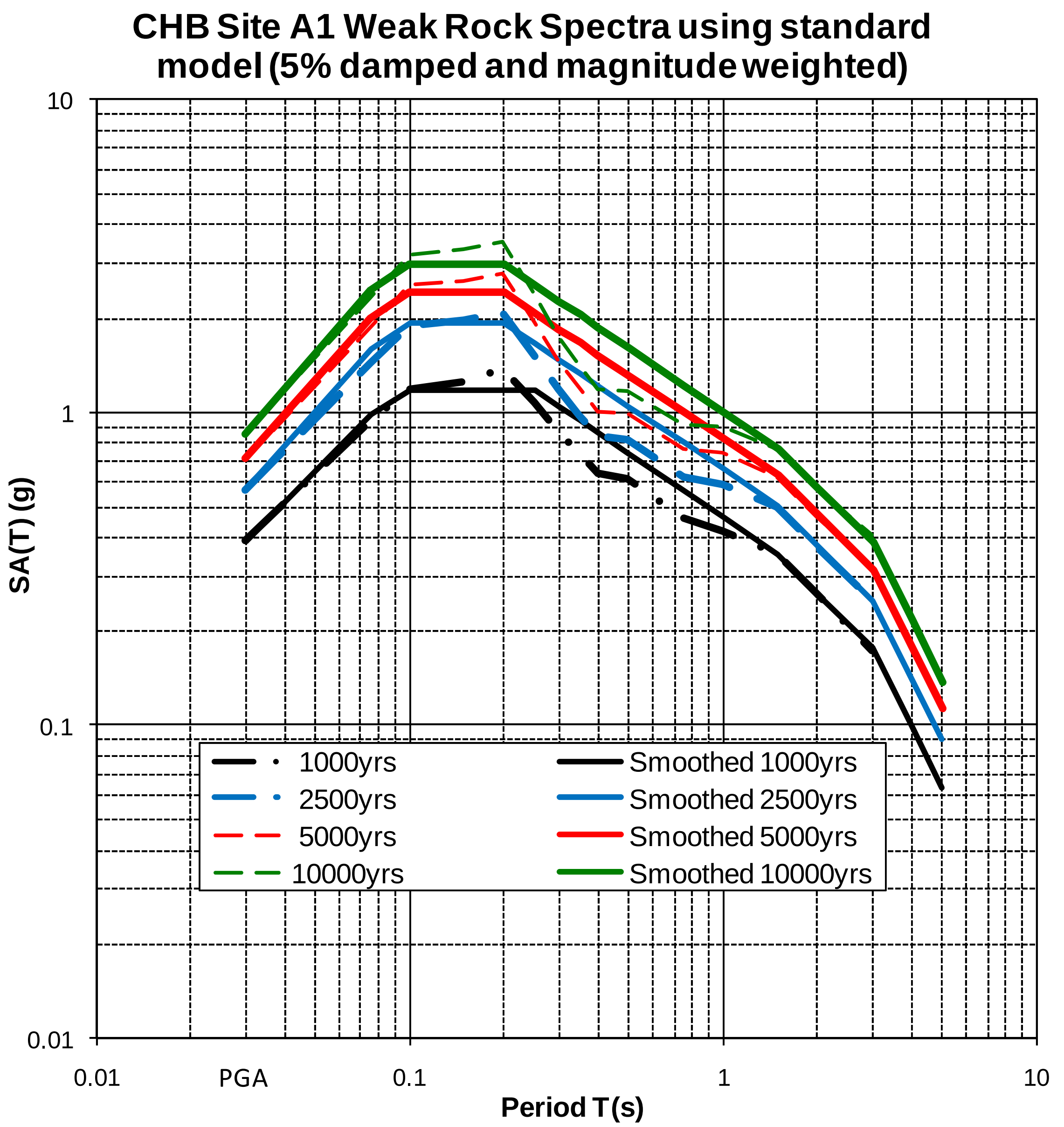

Figure 7 Unsmoothed and smoothed magnitude-weighted rock spectra for site A1 using the standard fault model. PGA is plotted at 0.03s.

The changes to the standard model in the alternative fault model presented in Table 2b have virtually no effect on the estimated hazard spectra for site A1, and the results presented for this site were derived by using the standard fault model.

Figure 8 shows the raw and smoothed median and 84-percentile spectra from a scenario earthquake from the Mohaka South fault source with a magnitude 7.5 at a distance of 1.5 km from site A1, together with the raw and smoothed hazard spectra with a return period of 5000 years. The 84-percentile spectrum is very close to the 5000-year hazard spectrum at all periods.

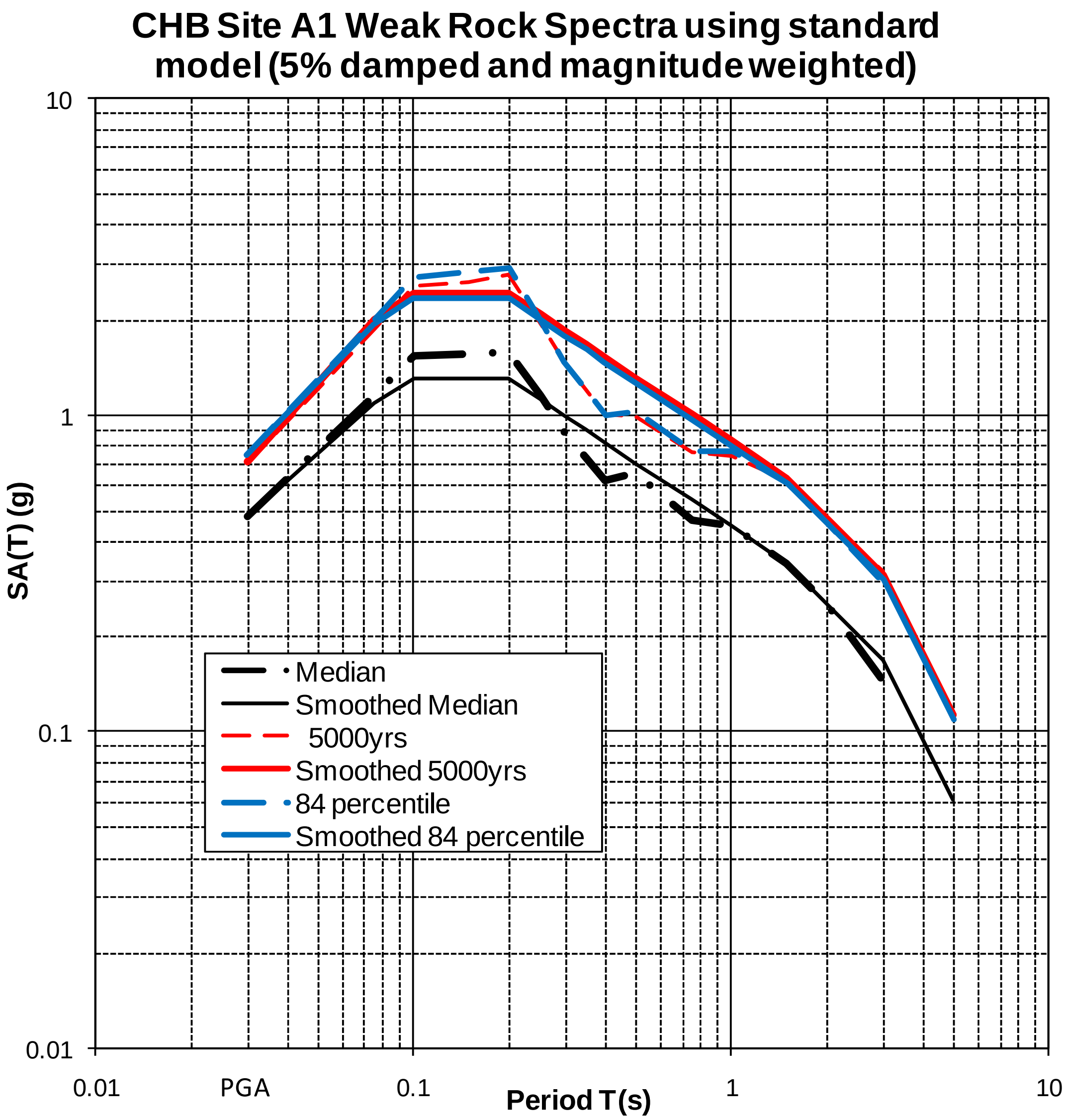

Figure 8 Unsmoothed and smoothed magnitude-weighted median and 84-percentile spectra for the Mohaka South Fault scenario earthquake and the 5000-year hazard spectra for site A1 (weak rock) using the standard 2010 fault model. PGA is plotted at 0.03s.

NZS1170.05 requires near-fault factors for site A1 because of its short distance from the Mohaka South fault. The Mohaka South fault is also the source that makes the largest contribution to the hazard exceedance rates at site A1 (see deaggregation results in Section 5). Rather than using the NZS1170 Near-Fault factors that are appropriate for the distance of the site from the fault, the smoothed hazard spectra were modified by near-fault factors derived from the Somerville et al. (1997) broad-band model for rupture of the Mohaka South fault, the largest contributor to the estimated hazard.

Figure 9 shows the near-fault factors for site A1 established for five rupture-initiation scenarios of the Mohaka South fault, with rupture initiating at the southern end (the worst scenario), southern quarter-point, centre, northern quarter-point and the northern end, together with the 84-percentile factors estimated across all full-fault rupture-initiation scenarios. Figure 9 also shows the average near-fault factors of the five rupture-initiation scenarios and the NZS1170.50 code maximum near-fault factors that apply within 2 km of the fault. Two of the five rupture-initiation scenarios have a near-fault factor close to 1.0 and the near-fault factor from the rupture-initiation at the northern end of the fault has a near-fault factor of 0.5 for spectral periods of 3s or longer. This leads to values of the average factor that are considerably reduced from the NZS1170 factor. The near-fault factors for the 84-percentile rupture initiation scenario are, on average, about 10% larger than the code maximum near-fault factors, but much less than those from the worst rupture scenario (rupture initiating at southern end). For Site A1, we recommend applying the average near-fault factors (where they exceed 1.0) for hazard spectra derived from the probabilistic seismic hazard analyses, and the 84-percentile near-fault factors for the 84-percentile spectrum. These are listed in Table 4 together with the NZS1170 factors for this location. The near-fault factors are also listed in Table ES1 in the Executive Summary.

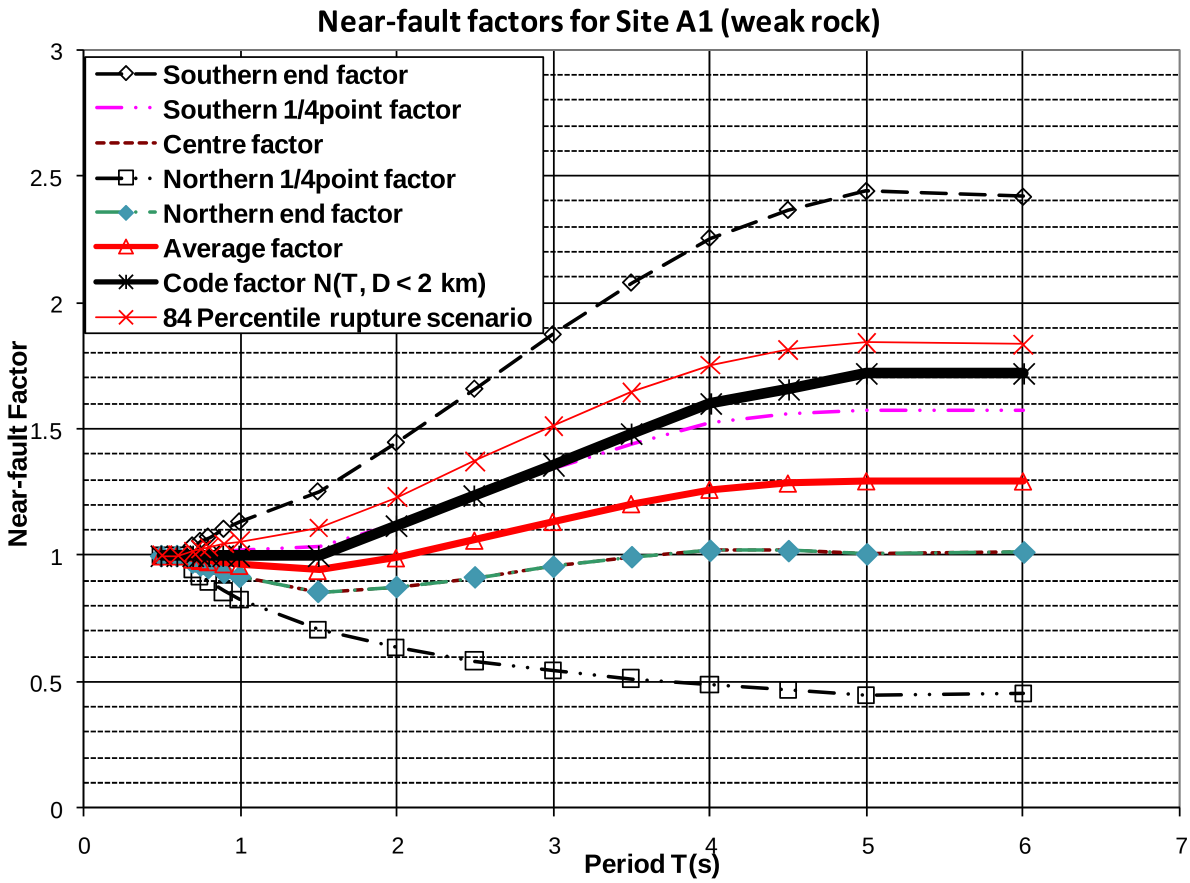

Figure 9 Near-fault factors for site A1 for five rupture scenarios of the Mohaka South fault, for rupture initiating at the southern end, southern quarter-point, centre, northern quarter-point, and northern end. The 84-percentile, average and NZS1170 code factors are also presented. The average factors (thick red line), where they exceed 1.0, are recommended for the hazard spectra, and the 84-percentile factors (thin red line) for the 84-percentile Mohaka South scenario spectrum.

Table 4 Near-fault factors for Site A1.

Spectral period	Average[1]	84-percentile[2]	NZS1170 factor
0.5	1.00	1.00	1.00
0.6	1.00	1.00	1.00
0.7	1.00	1.02	1.00
0.75	1.00	1.03	1.00
0.8	1.00	1.03	1.00
0.9	1.00	1.05	1.00
1	1.00	1.06	1.00
1.5	1.00	1.11	1.00
2	1.00	1.23	1.12
2.5	1.06	1.37	1.24
3	1.14	1.51	1.36
3.5	1.21	1.65	1.48
4	1.26	1.75	1.60
4.5	1.29	1.81	1.66
5	1.30	1.84	1.72
6	1.30	1.84	1.72

1 Recommended for hazard spectra
2 Recommended for 84-percentile scenario spectrum

We recommend the smoothed spectrum for 84-percentile motions from rupture of the Mohaka South fault with 84-percentile near-fault factors as the Maximum Design Earthquake (MDE) spectrum for site A1 (see Section 4.5). The equations for the smoothed spectrum are presented in Section 4.2, with the parameter values listed in Table 3.

4.4 Spectra determined for Site B1 (shallow soil site)

Figure 10 compares the raw hazard spectra calculated by using the standard fault model with those derived using the alternative fault model for site B1. The spectra derived from the alternative model are larger than those derived from the standard model, with the largest increase of 17% at 0.2s period for the 10,000-year return period. The stronger spectra from the alternative model are recommended as appropriate for this site.

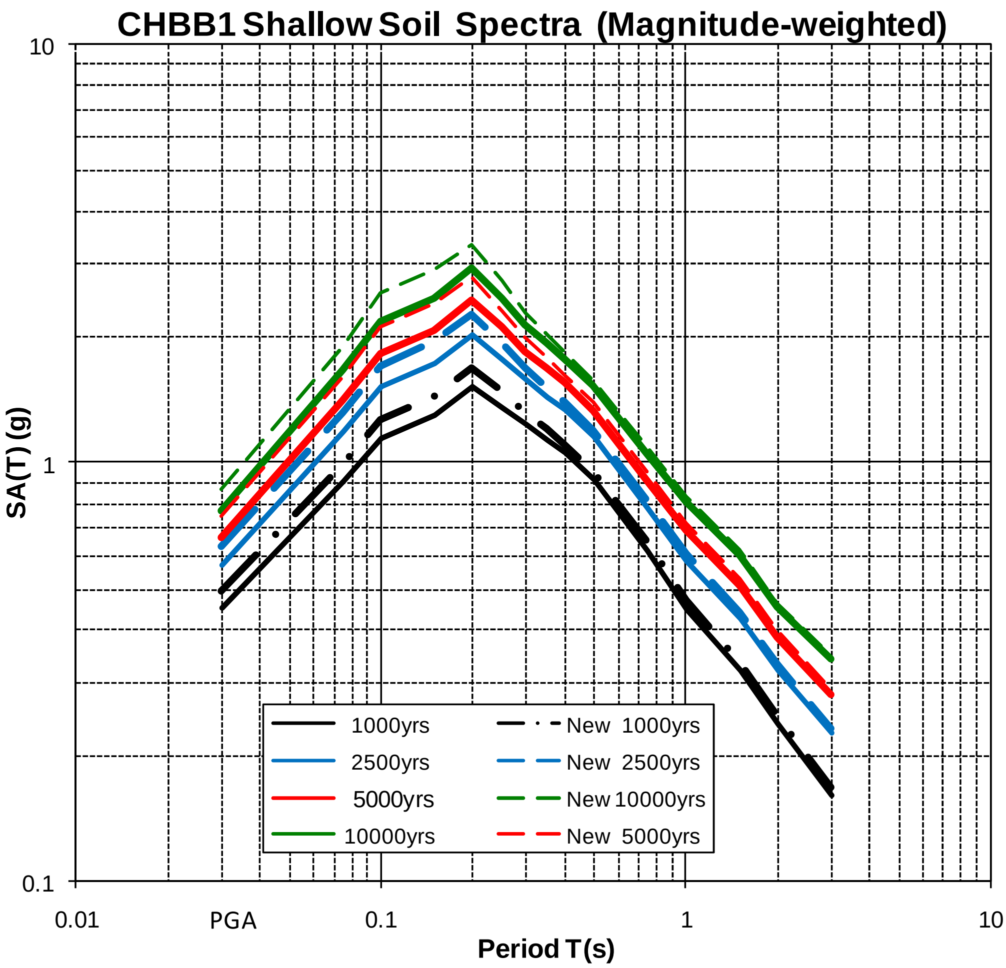

Figure 10 Comparison between raw hazard spectra derived by using the standard model and those derived by using the alternative fault model for site B1 (labelled as New).

Figure 11 compares the smoothed spectra with the raw hazard spectra computed using the alternative model. The smoothed spectra generally envelop the raw spectra except at 0.2 s period.

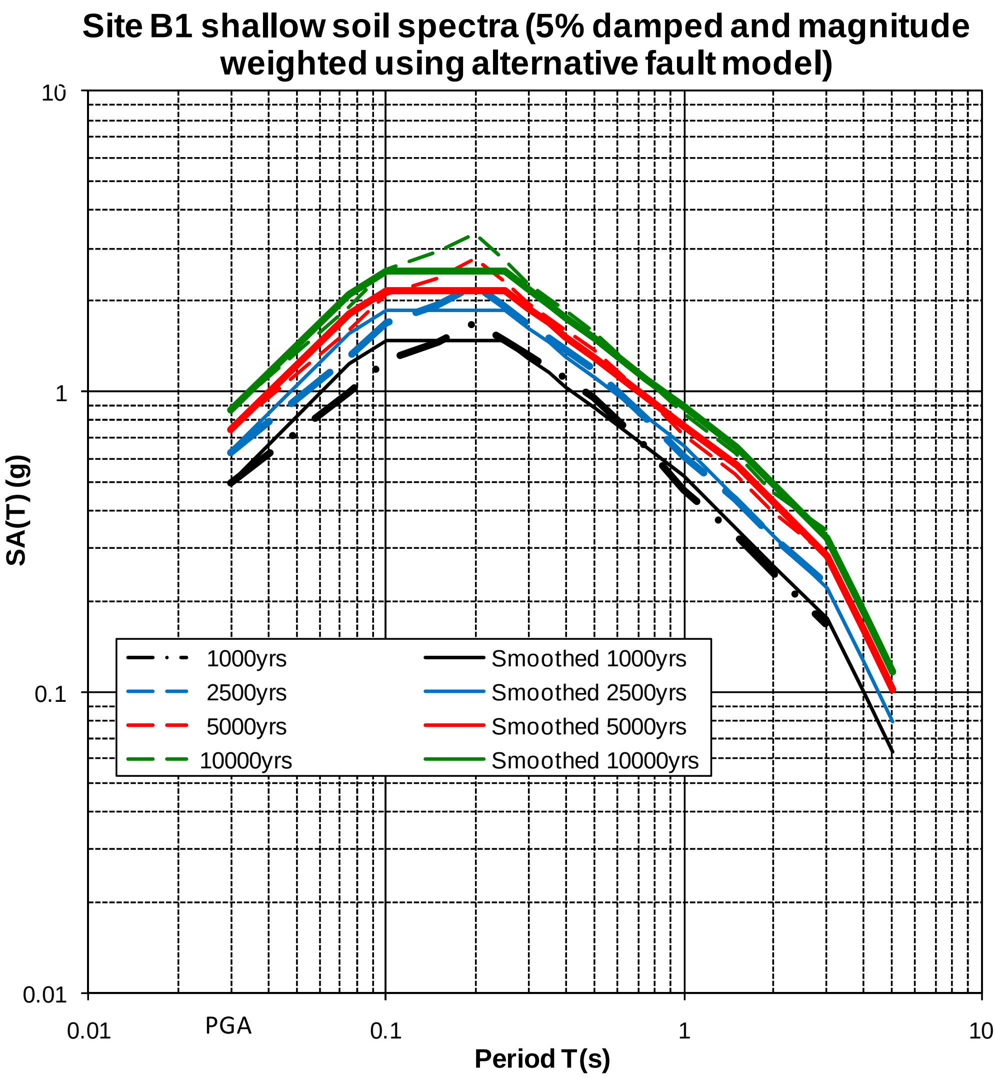

Figure 11 Raw and smoothed magnitude weighted spectra for site B1 (shallow soil) using the alternative fault model.

In the standard model, magnitude 7.5 earthquakes on the Mohaka Fault about 12 km from the site are the source of the strongest potential motions at Site B1 (see deaggregation results in Section 5). However, the alternative model leads to significant changes in the response spectra from scenario earthquakes. At all periods, the largest scenario spectrum at either the 50- or 84-percentile level is for a scenario earthquake from the Ruataniwha Fault at a distance of 4.6 km. This fault has a reverse focal mechanism with an expected magnitude of 7.1 and an average recurrence interval of 12,000 years. Figure 12 compares the raw and smoothed median and 84-percentile spectra for this scenario earthquake, together with the raw and smoothed hazard spectra for a return period of 10,000 years.

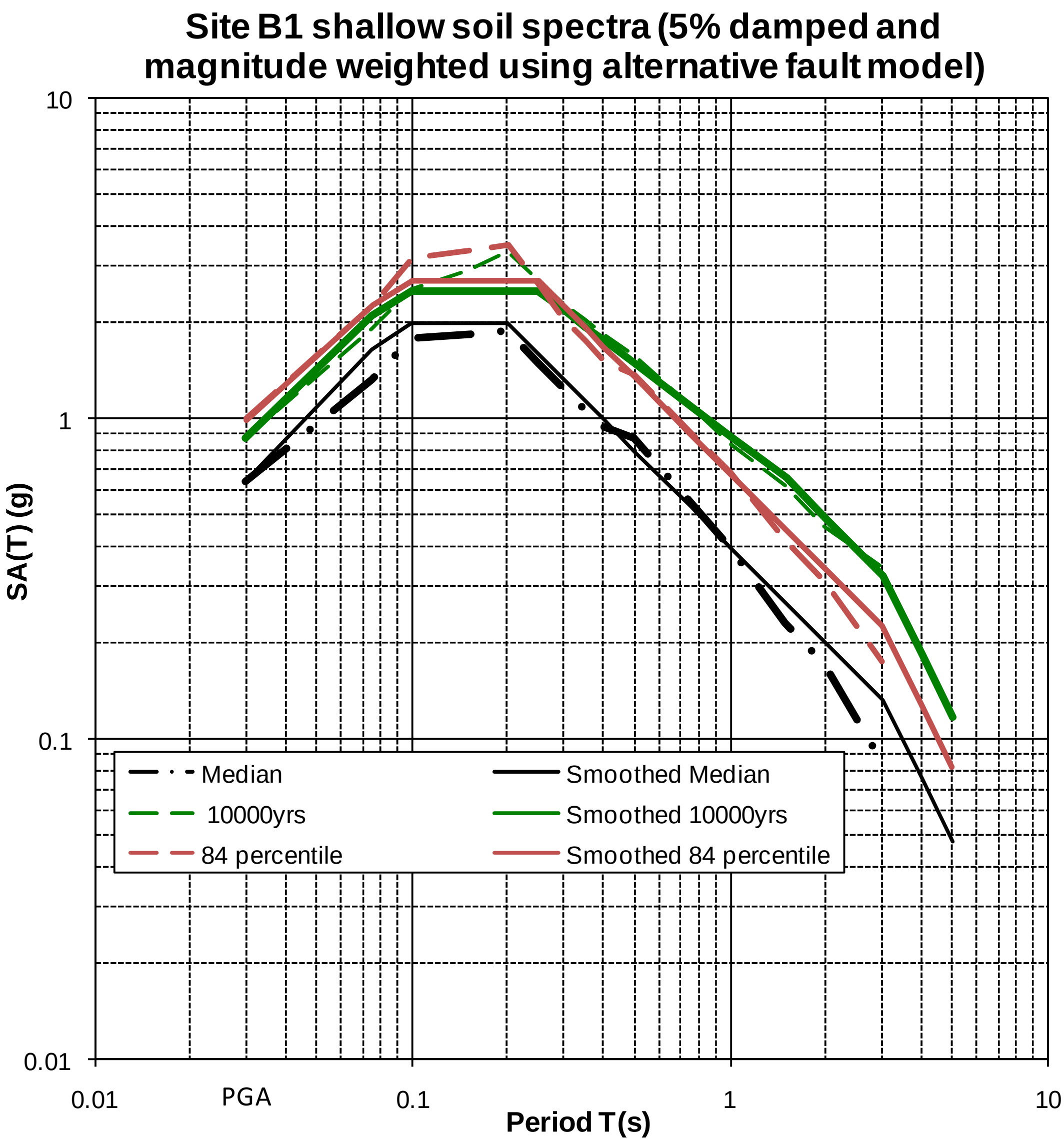

Figure 12 Raw and smoothed magnitude-weighted spectra, for a scenario earthquake from the modified Ruataniwha Fault model (median and 84-percentile) and for a return period of 10,000 years for site B1 (shallow soil) using the alternative model.

Figure 13 shows the smoothed hazard spectra computed from the alternative model for 4 return periods of 1000, 2500, 5000 and 10,000 years, together with the smoothed median and 84-percentile spectra for a scenario earthquake from the modified version of the Ruataniwha Fault used in the alternative fault model. In the alternative fault model, the reverse-mechanism Ruataniwha Fault has an expected magnitude of 7.1 at a distance of 4.6 km from the site, compared with a magnitude of 6.6 and distance of 17 km for its shorter representation in the standard model. In the alternative model, the Ruataniwha Fault replaces the Mohaka South Fault as the source with the strongest 50- and 84-percentile spectra at site B1. It also has the largest contribution to the annual rate of exceedance for PGA and for spectral accelerations for periods up to 0.2s, although the strike-slip Mohaka fault remains a larger contributor for spectral periods over 0.2s. Figures 12 and 13 show that the spectra for the reverse-mechanism Ruataniwha Fault reduce more rapidly with spectral period beyond 0.25s than the hazard spectra, unlike the strike-slip Mohaka South Fault (Figure 11). In the attenuation model used for the present study, a reverse fault produces higher spectral accelerations than a strike-slip fault at short periods (by a factor of about 1.3), but has accelerations similar to or less than those from a strike-slip fault at the same distance at spectral periods over 1.0s. These characteristics of the reverse fault lead to rapid decrease in the median and 84-percentile smoothed spectra in Figure 13. The 84-percentile spectrum at periods less than 0.3 s are slightly higher than the smoothed hazard spectrum for a 10,000-year return period, and decrease to those for 2500-year return period over 1 s spectral period. The 50-percentile spectrum decreases from near the 2500-year spectrum at short periods to weaker than the 1000-year spectrum for periods longer than 0.35 s. Given the long average recurrence interval of 12,000 years for the Ruataniwha Fault in the alternative model, we recommend the 10,000-year spectrum rather than the 84-percentile Ruataniwha Fault spectrum for the MDE spectrum for site B1.

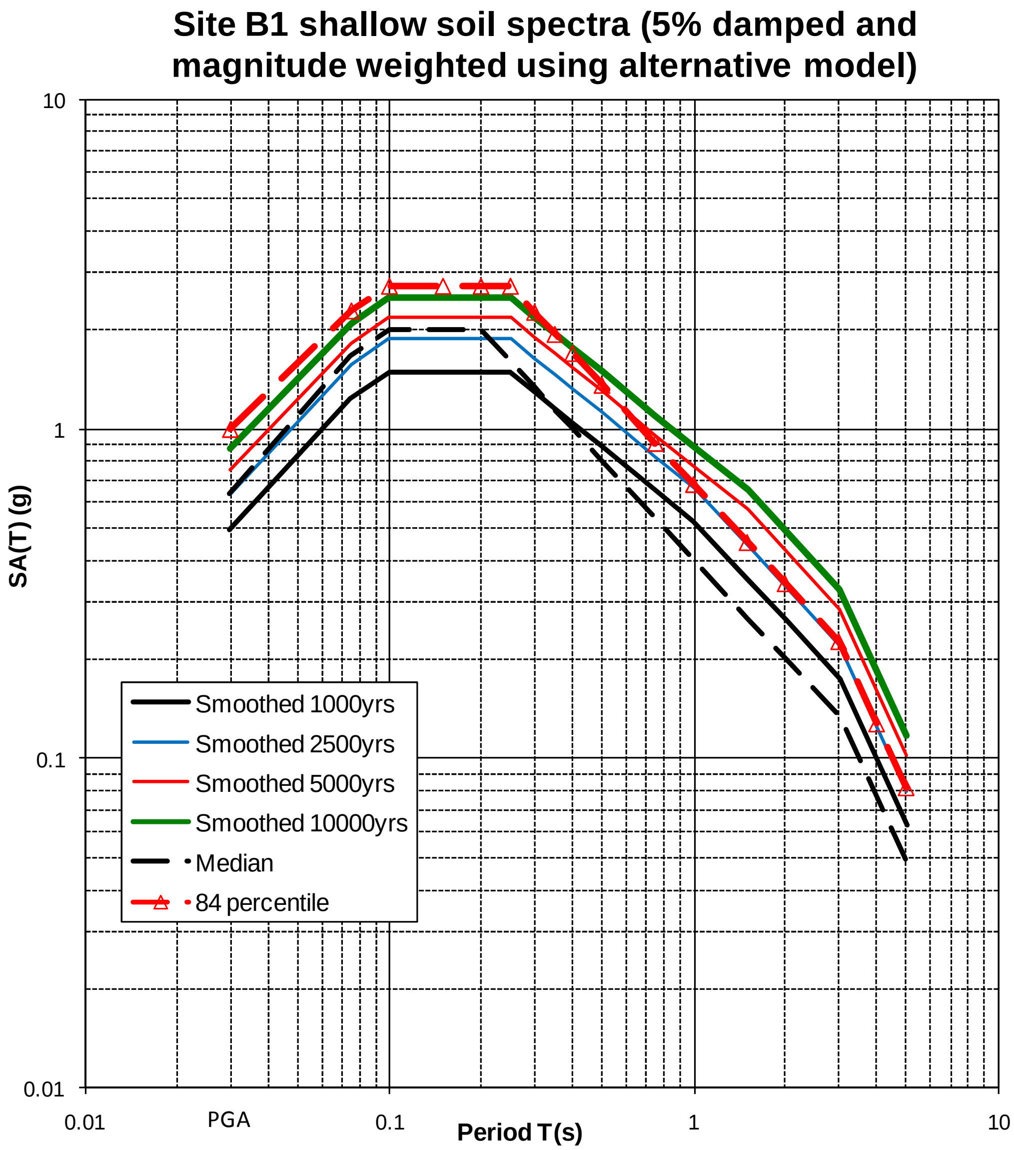

Figure 13 The smoothed hazard spectra at Site B1 (shallow soil) for the alternative model, for 4 return periods (1000, 2500, 5000 and 10000 years), and the median and the 84-percentile spectra for a scenario earthquake from the modified Ruataniwha Fault used in the alternative fault model. PGA is plotted at 0.03 s.

For site B1, the closest fault is the modified Ruataniwha Fault at a distance of 4.6 km and the next closest fault is the Mohaka South fault. Because near-fault factors apply only to the spectra over 0.7s and the long-period hazard spectra for a 10,000-year return period are dominated by the contribution from the Mohaka South fault, we recommend the near-fault term derived for the Mohaka South fault for site B1. Figure 14 shows the near-fault factors for site B1 established for five rupture-initiation scenarios of the Mohaka South fault, with rupture initiating at the southern end (the worst scenario), southern quarter-point, centre, northern quarter-point and the northern end, together with the 84-percentile factors estimated across all full-fault rupture-initiation scenarios. Figure 14 also shows the average near-fault factors of the five rupture-initiation scenarios and the NZS1170.50 code near-fault factors at a distance of 12.2km. At site B1, four of the five rupture-initiation scenarios produce a set of near-fault factors less than 1.0, and the average near-fault factors of the five rupture scenarios are also less than 1.0. The 84-percentile near-fault factors are also very close to 1.0. The code near-fault factors at this location reach at maximum of just over 1.3 at long-period. We recommend that the near-fault factor for Site B1 be taken as 1.0.

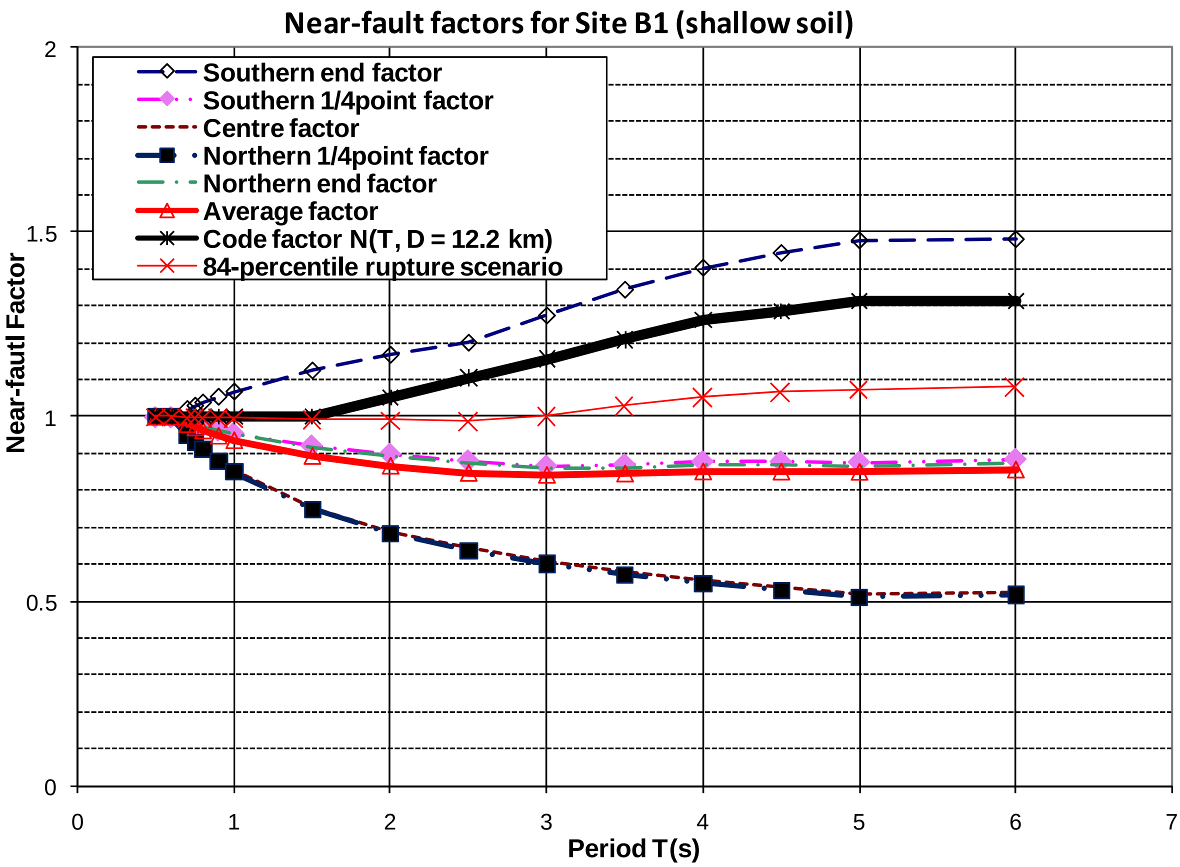

Figure 14 Near-fault factors for Site B1 for five rupture scenarios, of the Mohaka South fault, for rupture initiating at the southern end, southern quarter-point, centre, northern quarter-point, and northern end. The 84-percentile, average and code near-fault factors at a distance of 12.2km are also presented. Given that the average factors (thick red line) are less than 1.0, and the 84-percentile factors (thin red line) exceed 1.0 only modestly, near-fault factors are recommended as 1.0 rather than the NZS1170 code values (thick black line).

In summary, we recommend the smoothed 10,000-year spectrum with near-fault factors of 1.0 to represent MDE motions for Site B1. The equations for the smoothed 10,000-year spectrum for site B1 (shallow soil) are presented in Section 4.2, with the parameter values corresponding to the recommended alternative fault model listed in Table 3.

4.5 Recommended smoothed spectra for Sites A1 and B1

The recommended smoothed MDE spectra for Sites A1 and B1 are listed in Table 5, which is also given as Table ES2 in the Executive Summary. The equations and parameters for constructing the smoothed spectra without near-fault factors are presented in Section 4.2. For Site A1 where the recommended spectra include near-fault factors, the smoothed spectra given by the equations of section 4.2 require multiplication by the 84-percentile near-fault factors of Table 4.

Table 5 Recommended design spectra (g) for MCE motions, with the values without near-fault factor presented in brackets for Site A1.

Spectral period (s)	Site A1 (weak rock)[1]	Site B1 (shallow soil)[2]
0.03	0.75	0.87
0.075	1.96	2.09
0.1	2.36	2.50
0.15	2.36	2.50
0.2	2.36	2.50
0.25	2.03	2.50
0.3	1.80	2.18
0.35	1.62	1.94
0.4	1.48	1.76
0.5	1.28	1.49
0.75	1.00 (0.97)	1.10
1	0.85 (0.80)	0.88
1.5	0.68 (0.61)	0.65
2	0.57 (0.46)	0.49
3	0.46 (0.31)	0.33
4	0.30 (0.17)	0.18
5	0.20 (0.11)	0.12

1 84-percentile spectrum for Mw 7.5 Mohaka South fault earthquake at 1.5km distance
2 10,000-year spectrum

4.6 Contour maps of 10,000-year hazard parameters

As well as developing MDE spectra for sites A1 and B1, the brief required a map with contours of the 10,000-year hazard in terms of a parameter that can be used to scale the spectrum for the representative site for other locations in the eastern region. In developing the smoothed spectra in section 4.2, two parameters were used, with the parameters depending on site class: rock spectra were generated from the magnitude-weighted rock PGA and the 5% damped rock response spectrum acceleration at 1.5s, SA_{rock} (1.5s); shallow-soil spectra were generated from the magnitude-weighted shallow-soil PGA and the 5% damped shallow-soil response spectrum acceleration at 0.75s, $SA_{shallowsoil}$ (0.75s). The 10,000-year values of these parameters are presented in the maps of Figures 15 to 20.

4.6.1 Rock sites

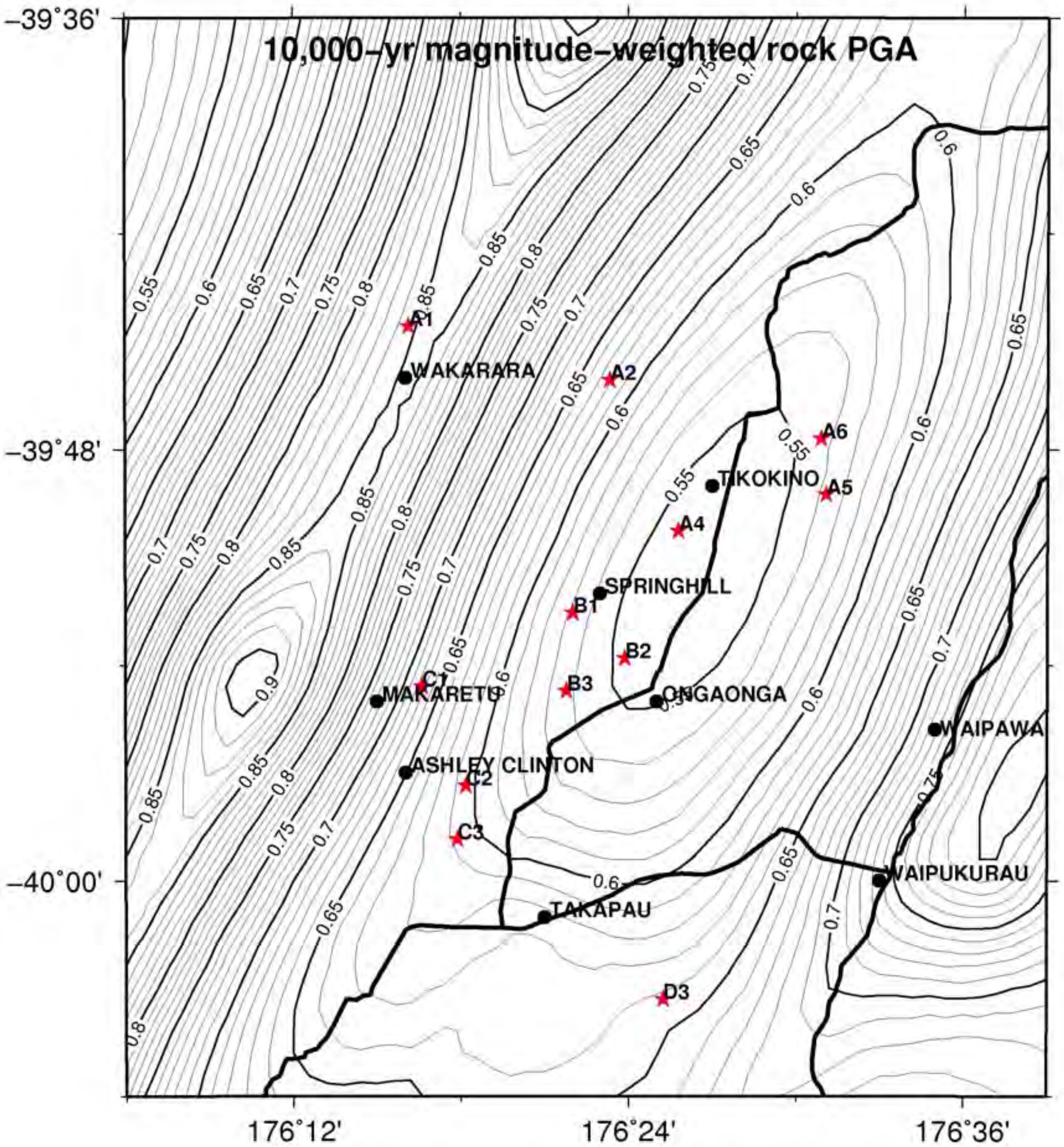

Figure 15 Contours of magnitude-weighted PGA (g) for rock site conditions with a return period of 10,000 years, using the standard fault model. Site locations are marked by red stars. A deterministic limit of 0.75g rock PGA is recommended, based on the 84-percentile PGA estimated for location A1 in a magnitude 7.5 earthquake on the adjacent Mohaka South fault.

Figure 15 shows the contours of magnitude-weighted peak ground accelerations (PGA) (10,000-year return period) for class B (rock site) and Figure 16 presents the contours of magnitude-weighted rock site acceleration spectra at 1.5 s period. These maps can be used together with the equations in section 4.2 to generate the 10,000-year rock spectra for sites other than A1. For site A1, the MDE spectrum was limited to less than the 10,000-year spectrum by the 84-percentile motions for a magnitude 7.5 earthquake on the nearby Mohaka South Fault. The resulting MDE motions corresponded closely to the 5000-year motions, and were defined by a magnitude-weighted rock PGA of 0.75 g and SA_{rock}(1.5s)=0.61 g (excluding near-fault factor). In the contour maps, it is recommended that the 10,000-year values also be capped by these parameter values.

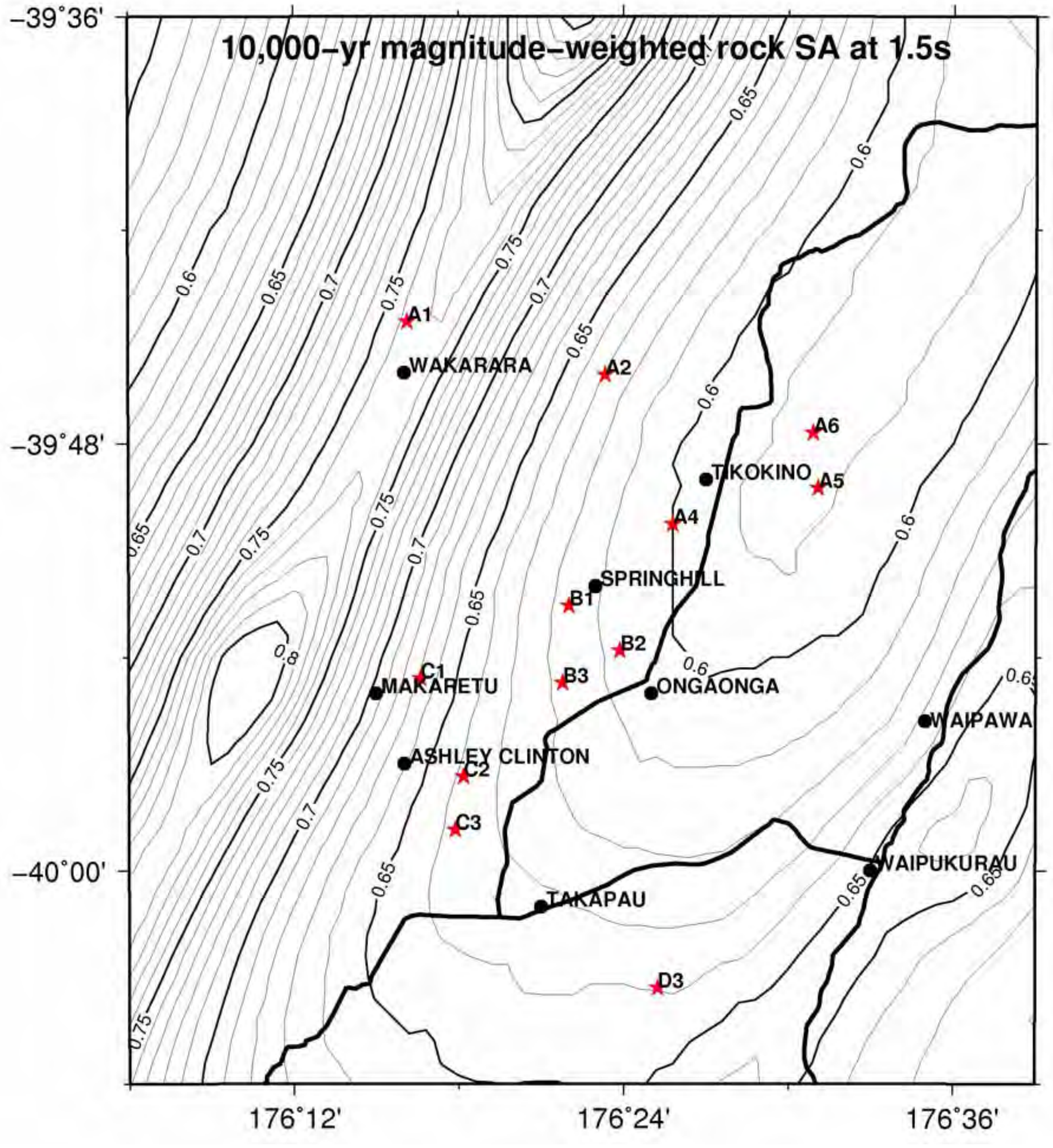

Figure 16 Contours of magnitude-weighted SA (g) at 1.5s period for rock site conditions with a return period of 10,000 years, using the standard fault model. Site locations are marked by red stars. A deterministic limit of 0.61g rock spectrum (excluding near-fault factors) is recommended, based on the 84-percentile PGA estimated for location A1 in a magnitude 7.5 earthquake on the adjacent Mohaka South fault.

To illustrate the effect of the modified fault parameters, Figure 15 presents the contours of 10,000-year magnitude-weighted PGAs for rock site conditions using the standard fault model while Figure 17 shows the same contours for PGAs derived by using the alternative fault model. At sites A1 and A2, the rock PGAs from the standard and the alternative fault models are nearly identical. For other sites, the alternative fault model enhances the hazard PGA with the largest increase being just over 10% for sites A5, A6 and B2.

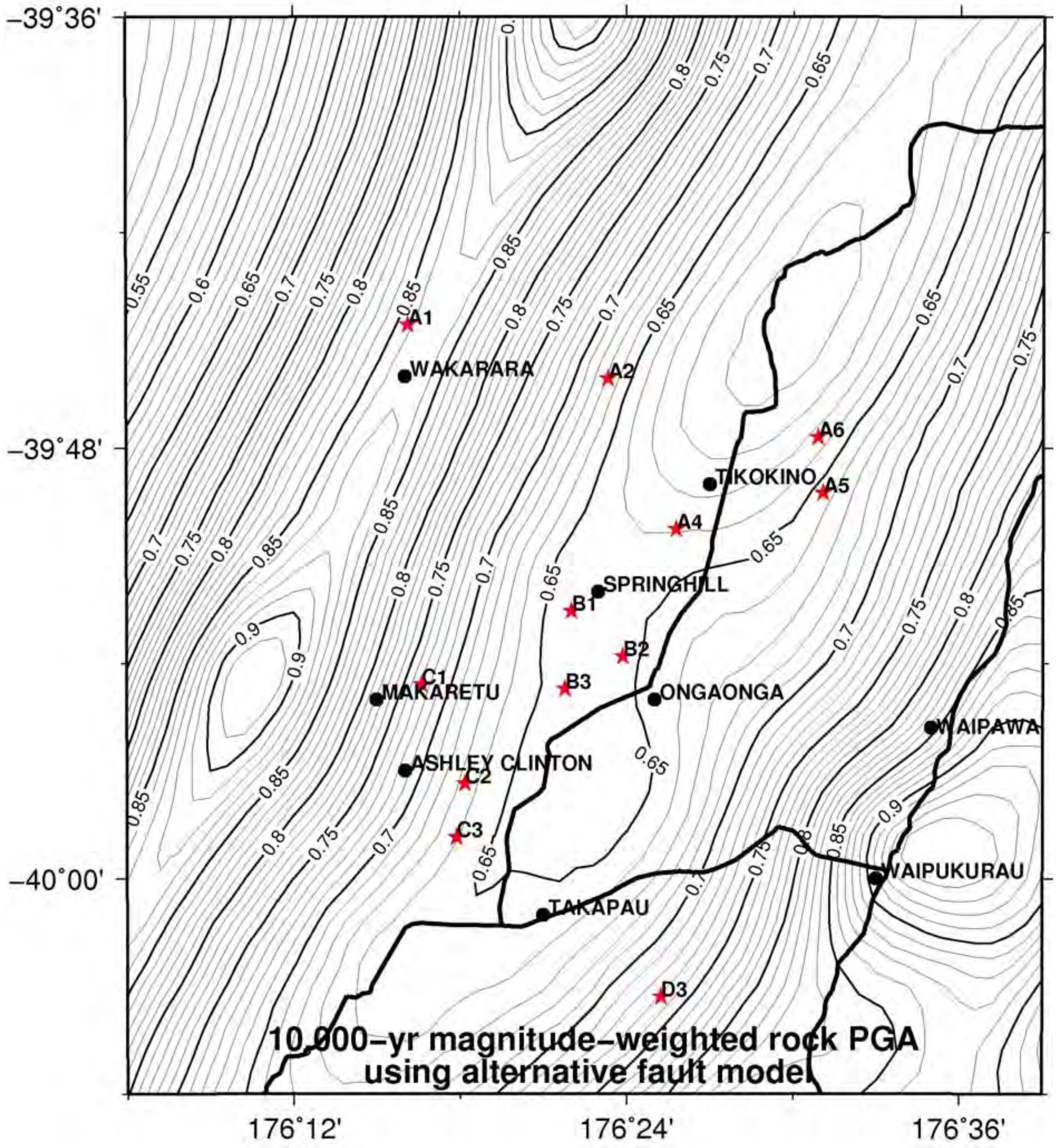

Figure 17 Contours of magnitude-weighted PGA (g) for rock site with a return period of 10,000 years, using the alternative fault model. Site locations are marked by red stars.

4.6.2 Soil sites

Figures 18 and 19 present the contours of magnitude-weighted PGA and acceleration spectra at 0.75s for a return period of 10,000 years for shallow soil site conditions. The alternative fault model was used, consistent with the model used for the recommended smoothed spectra for Site B1. These maps and the recommended spectra may be used to estimate the spectra for the other sites. Again, it is recommended that the 10,000-year values should be capped by values corresponding to 84-percentile Mohaka South Fault motions at location A1. For shallow soil site conditions, these are a magnitude-weighted shallow-soil PGA of 1.0g and $SA_{shallowsoil}(0.75s)=1.1g$.

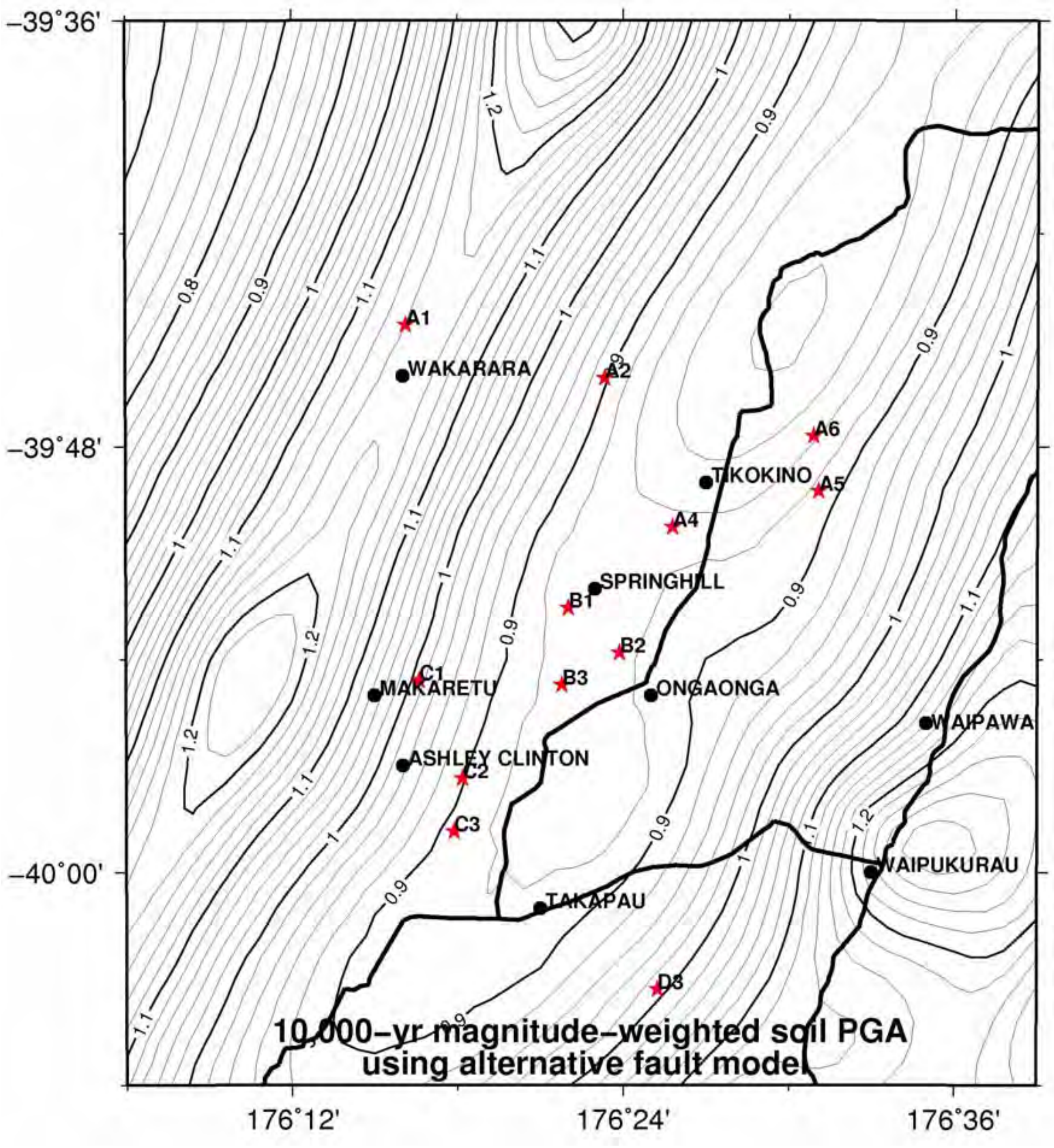

Figure 18 Contours of magnitude-weighted PGA (g) for shallow-soil site conditions using the alternative fault model. Site locations are marked by red stars. A deterministic limit of 1.0g shallow-soil PGA is recommended, based on the 84-percentile PGA estimated for location A1 in a magnitude 7.5 earthquake on the adjacent Mohaka South fault.

To demonstrate the effect of the changes in the fault parameters, Figure 18 shows the contours of the magnitude-weighted PGA for a return period of 10,000 years derived by using the alternative fault model and Figure 20 shows those derived from the standard fault model. The differences are typically less than 10%.

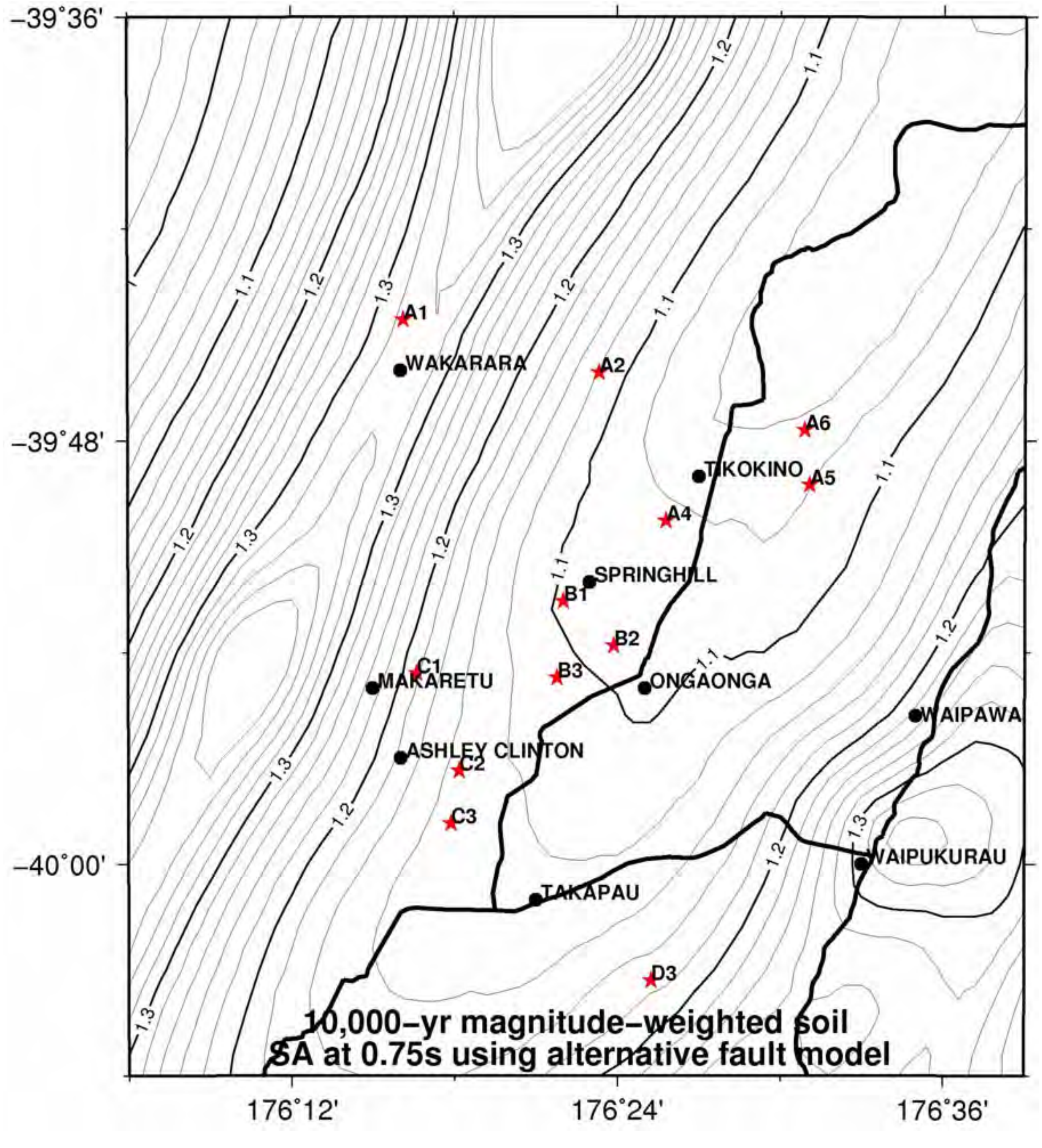

Figure 19 Contours of 5% damped acceleration response spectra (g) at 0.75 s spectral periods for shallow soil sites using the alternative fault model. Site locations are marked by red stars.

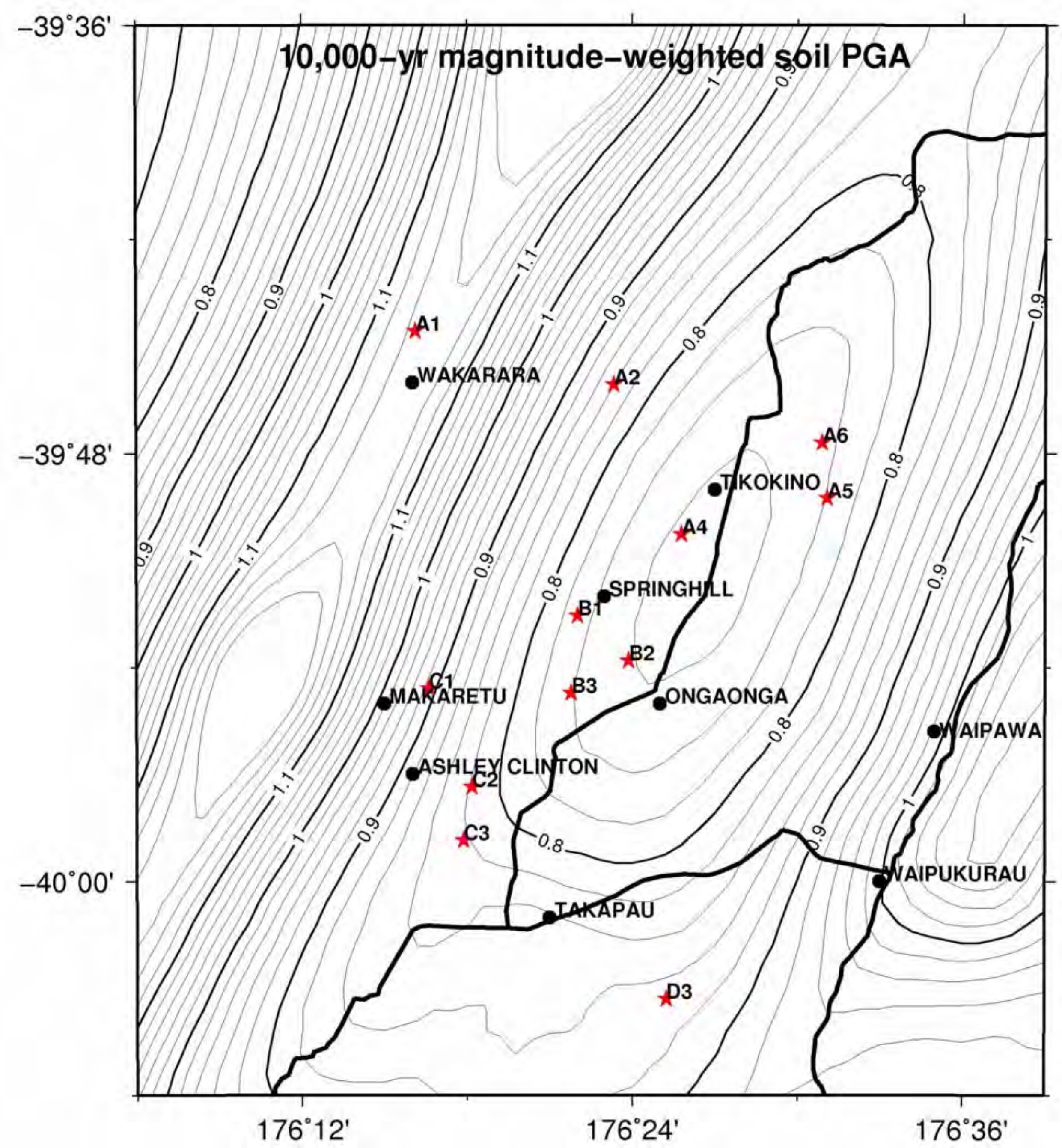

Figure 20 Contours of magnitude-weighted PGA (g) for shallow soil site with a return period of 10,000 years, using the standard fault model. Site locations are marked by red stars. A deterministic limit of 1.0g shallow-soil PGA is recommended, based on the 84-percentile PGA estimated for location A1 in a magnitude 7.5 earthquake on the adjacent Mohaka South fault.

Note that the effect of near-fault factors is not included in the contour maps presented here. The mapped contours are appropriate to use for a preliminary assessment of the 10,000-year spectrum at any site in the location, but it is recommended that the location-specific near-fault factors should be estimated for any sites that are selected for development.

We recommend that a site-specific study be carried out when the final locations of the water retention embankment sites are determined.

5.0 DEAGGREGATION OF THE HAZARD

Figures 21 and 22 show the deaggregation results for PGA and spectra at 1 s period at site A1 with a return period of 5000 years. The deaggregations for site A1 are presented for this return period rather 5000 years because the "deterministic" 84-percentile spectrum for rupture of the Mohaka South fault that is recommended as the MDE spectrum for site A1 corresponds approximately to the 5000-year spectrum. For all spectral periods, the largest contribution rate to the annual probability of exceedance is from the Mohaka South fault source and the second largest contribution is from the Ruahine Central fault source.

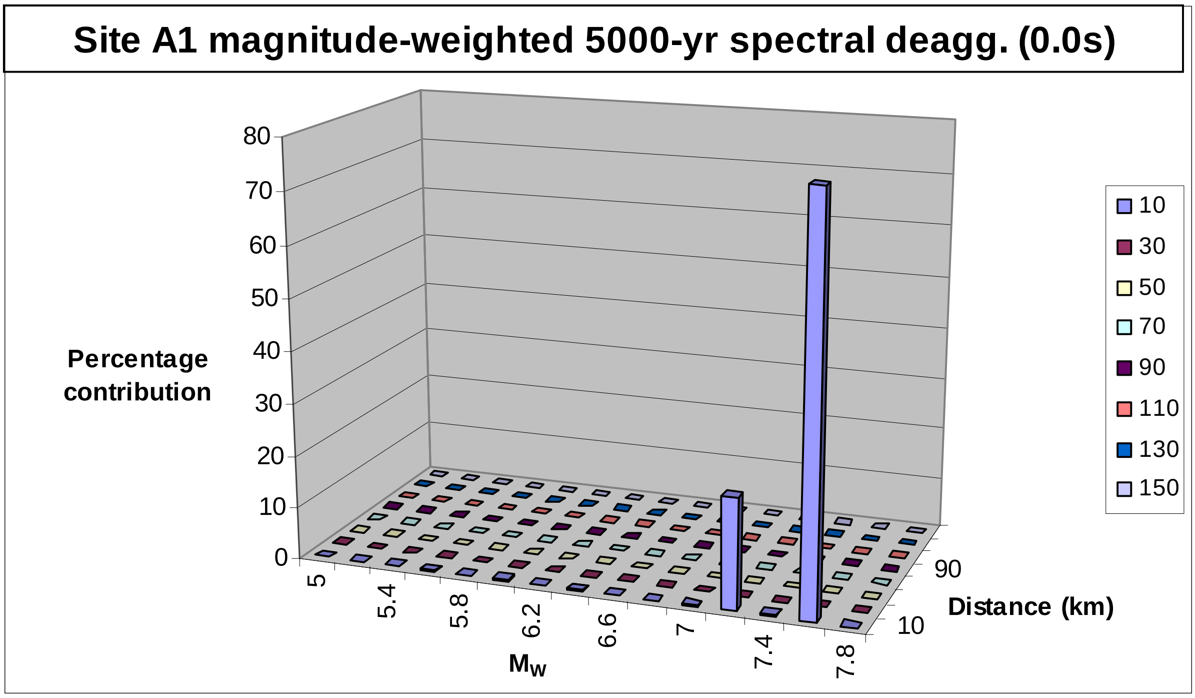

Figure 21 Percentage contribution to exceedance rate of the 5000-yr PGA for Site A1 as a function of magnitude (M) and distance (in km, with Legend) using the standard fault model.

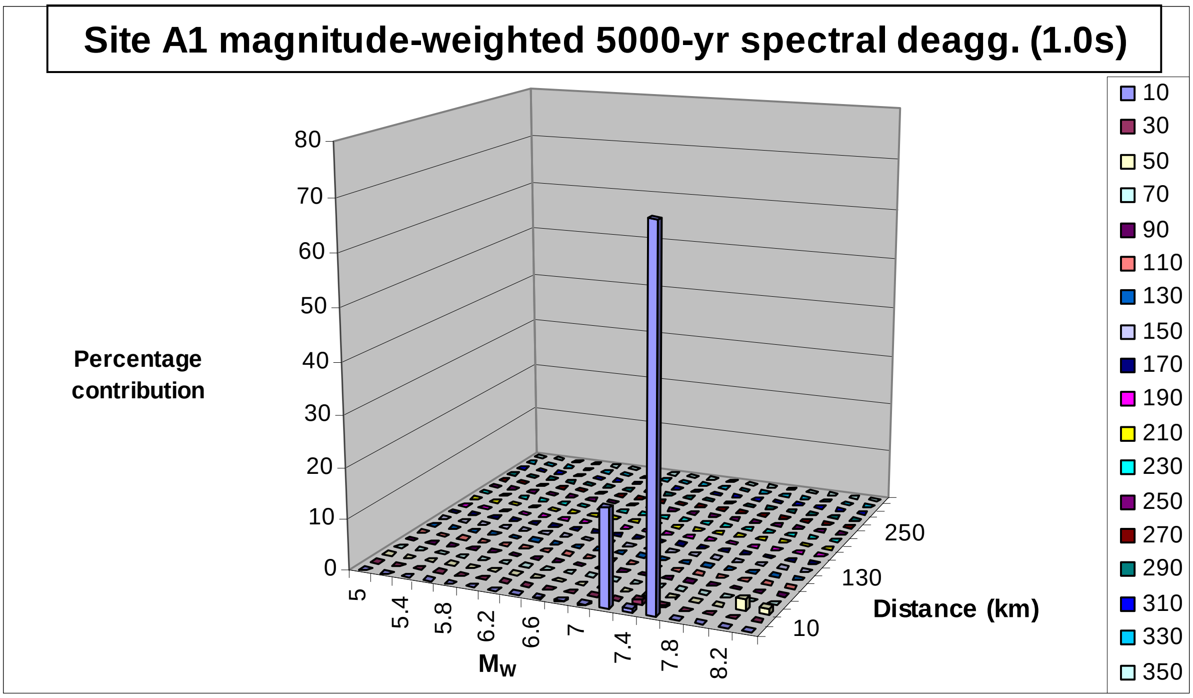

Figure 22 Percentage contribution to exceedance rate for spectrum at 1 s spectral period with a return period of 5000 years for Site A1, as a function of magnitude (M) and distance (in km, with Legend) using the standard fault model.

Figures 23 and 24 present the deaggregation results for PGA and spectra at 1s at site B1 with a return period of 10,000 years using the alternative fault model. For PGA, the largest hazard contribution is the combined contribution from the modified Ruataniwha Fault, the Wakarara Fault, the Poukawa Fault and the Tukituki Fault (all have a modelled magnitude of 7.1). The largest contribution of a single fault is from the Mohaka South Fault and the next largest contribution is from the modified Ruataniwha Fault. For spectra at 1 s period, Mohaka South Fault still makes the largest contribution, larger than the combined contribution from the group of faults with an expected magnitude of 7.1. Contributions from Hikurangi subduction earthquakes make the next two largest contributions.

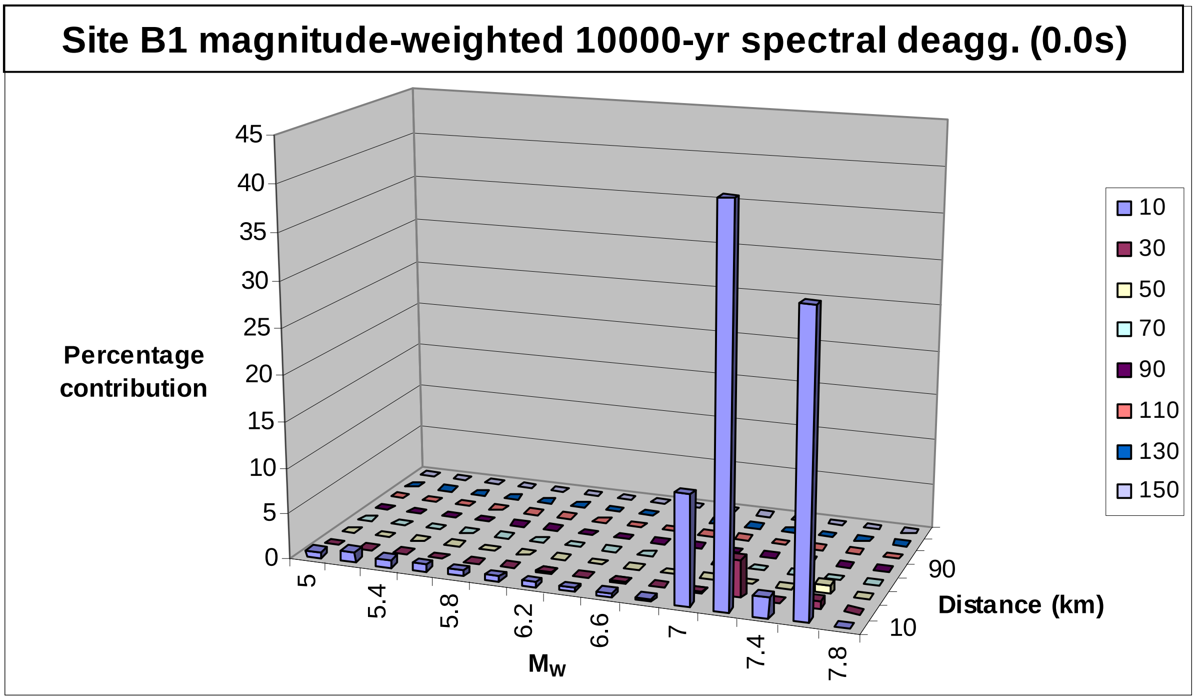

Figure 23 Percentage contribution to exceedance rate for PGA with a return period of 10,000 years for Site B1as a function of magnitude (M) and distance (in km, with Legend, using the alternative fault model. The largest contribution is the combined contribution from the modified Ruataniwha Fault, the Wakarara Fault, the Poukawa Fault and the Tukituki Fault (all have an expected magnitude of 7.1)

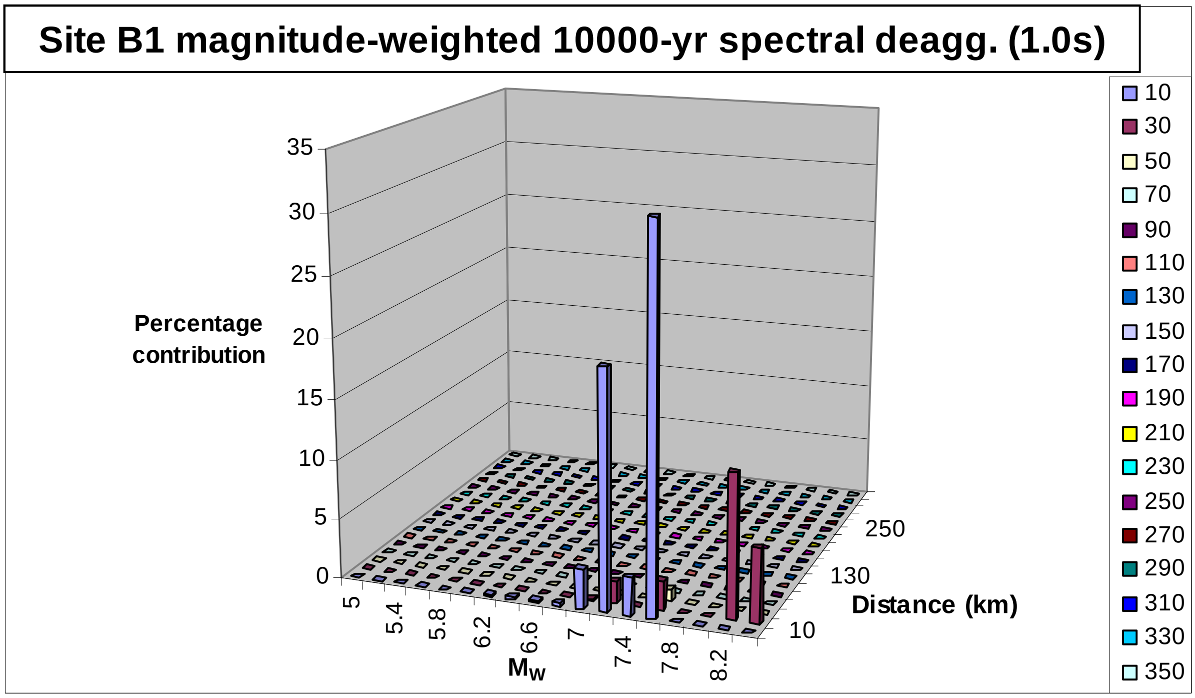

Figure 24 Percentage contribution to exceedance rate for Spectra with a return period of 10,000 years for Site B1, as a function of magnitude (M) and distance (in km, with Legend, using the alternative fault model.

6.0 CONCLUSIONS AND RECOMMENDATIONS

- A geological and spectral assessment project has been undertaken to assess the hazards of surface faulting and seismic shaking for a number of possible water retention embankments and related infrastructure in Central Hawke's Bay.
- Active fault mapping in a GIS and field reconnaissance have confirmed many active faults, including a number of new or recently identified faults. The latter include the Te Heka, Wakarara, Rangefront, Ruataniwha and Takapau faults, which are all reverse faults.
- The most active faults in the area are the strike-slip Mohaka and Ruahine faults, oblique-slip Oruawharo fault, and the reverse-slip Poukawa Fault Zone. Field reconnaissance has contributed to the derivation of fault slip rates and single-event displacements for many of these faults. These have been used to design a series of new fault sources for an alternative source model (c.f. the standard 2010 model) for the New Zealand National Seismic Hazard model.
- The characterisation of the faults in this report in terms of their location, geometry and activity level is sufficient for determination of spectra, but not sufficiently detailed to address fault-avoidance or deformation issues. In future, analysis of available LiDAR imagery may help in the identification and location of active fault traces.
- Some of the potential embankment, pipe, race and reservoir locations are within 200 m of active fault traces. These include embankment A5, and races or pipes related with embankments B3 and C1.
- It is recommended that site-specific investigations focused on fault location and/or deformation characterisation should be undertaken if major parts of the scheme are to avoid crossing active fault/fold deformations or be designed with sufficient resilience to be able to accommodate tectonic deformations that may impact on the scheme with a high likelihood of occurrence.
- Due to the density of faults within the Ohara Depression between the Mohaka and Ruahine faults, it is recommended that detailed geological investigations are undertaken in the vicinity of site A1.
- Maximum Design Earthquake (MDE) motions have been estimated in terms of horizontal-component acceleration response spectra with 5% damping for two client-defined locations that are significant to the proposed Central Hawke's Bay Water Augmentation Scheme.
- The spectra were developed using GNS Science's 2010 National Seismic Hazard Model, and secondly by developing an alternative fault model that considers more current knowledge about the active faults in the central Hawke's Bay area.
- The alternative fault model was based on existing information and a field reconnaissance to perform a reassessment of the active faulting in the central Hawke's Bay area, including defining best-estimate rupture lengths and slip-rates, and hence earthquake magnitudes and recurrence intervals associated with surface rupture of faults in the region.
- The results are presented in terms of plots of smoothed 5% damped spectra for return periods ranging from 1000 years to 10,000 years for NZS1170 Class B Rock, and Class

C Shallow Soil site conditions. The strongest 50- and 84-percentile spectra were also determined for the various fault-rupture scenarios affecting each location.

- For Site A1, we recommend the 84-percentile spectrum of a magnitude M 7.5 scenario earthquake from the Mohaka South fault at a distance of 1.5 km, with 84-percentile near-fault factors, as the MDE spectrum (Figure ES3 and Table ES2).
- For Site B1, we recommend the 10,000-year smoothed hazard spectrum using the alternative model, with the near-fault factors taken as 1.0, as the MDE spectrum (Figure ES3 and Table ES2).
- We presented contour maps for the 10,000-year values of PGA and the 5% damped response spectral acceleration at 1.5 s period for rock and PGA and the response spectral acceleration at 0.75 s for shallow soil conditions. These maps can be used together with the equations in Section 4.2 to generate 10,000-year spectra (excluding near-fault factors) at any location in the region of interest.
- The MDE spectra should be capped by the smoothed 84-percentile Mohaka South spectrum at site A1 for the relevant site class; the 10,000-year spectra at some locations will exceed these values.
- The effect of near-fault factors is not included in the contour maps presented in this report. We recommend that a site specific study be carried out when the final location of the dam sites are determined.
- Deaggregation results show that the largest hazard contribution is from the Mohaka Fault at the two sites evaluated in the present study.

7.0 ACKNOWLEDGEMENTS

This report has been reviewed by Drs. Nicola Litchfield and Rob Buxton of GNS Science. Russ Van Dissen contributed to the discussions leading to the modified fault model used in this study. Julie Lee is thanked for help preparing the fault maps and discussions about active faulting and folding in the region. The farmers of Central Hawke's Bay are thanked for their cheery hospitality in the field.

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