MOKIHINUI HYDRO PROPOSAL
CONSENT APPLICATIONS
REVIEW OF ASSESSMENT OF EFFECTS OF DAM AND RESERVOIR ENGINEERING

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1.0 Introduction

1.1 Background

This report provides a review of the assessment of environmental effects (AEE) provided by Meridian Energy Ltd (Meridian) in support of resource consent applications to dam the Mokihinui River as part of the Mokihinui Hydro Proposal (MHP).

The Mokihinui Hydro Proposal includes a dam located on the Mokihinui River approximately 3km upstream from the township of Seddonville and 11km upstream from the river mouth; a new lake upstream of the dam extending to just below the Mokihinui Forks Ecological Area; a new transmission line to carry electricity from the power station to the existing Inangahua-Waimangaroa transmission line at Cedar Creek; and a new substation at Cedar Creek.

This report will provide the decision-maker with information and advice related to the dam engineering aspects of the proposal. It needs to be read in association with the review report of Mr Peter Foster in relation to dam safety issues and potential dam breach effects.

1.2 Qualifications

My name is Donald Robert Tate. I have been employed by Riley Consultants Ltd (RILEY) since 1987 and I am a Director of the company.

My academic qualification and professional memberships are:

- Bachelor of Engineering (Civil) Auckland University (1984)
- Chartered Professional Engineer
- Member of the Institution of Professional Engineers NZ
- Member of the New Zealand Geotechnical Society
- Member of the New Zealand Society on Earthquake Engineering

I am also a member and Committee Member of the New Zealand Society on Large Dams, including the Dam Safety subcommittee.

I have 23 years experience in civil and geotechnical engineering, with water retaining structures, such as dam, canals and similar structures being a specialist area of expertise.

I regularly attend conferences in New Zealand and Australia on dam engineering. I have also attended specialist courses in Australia and the United States on geotechnical aspects of dams, and safety aspects of dams respectively.

I have provided advice to various clients throughout New Zealand on safety and costing aspects of dams and other water retaining structures. Over the period of 2003 to 2006 I provided advice to Environment Canterbury (ECAN) and other regulators on safety aspects of the 50m high Opuha Dam; from review of the initial safety evaluation to completion of the major remedial works through 2005 to 2006.

1.3 Scope of Report

This report is prepared under the provisions of Section 42A of the Resource Management Act 1991 (RMA).

To carry out this review of the consent application I have considered the relevant sections of the AEE submitted by the applicant, and the technical appendix, "Mokihinui Hydro Proposal Project Engineering Description," prepared by DamWatch. I have also reviewed the responses provided by Meridian on further requests for information.

I have also taken into account issues raised by submitters in relation to the effects of dam engineering, with particular emphasis on safety aspects.

In addition, I carried out a site visit on Wednesday 5 March 2008.

The review has only considered the information that has been made available to date. It is possible that my conclusions may be altered in response to further investigation and/or new information that becomes available prior to or during the hearing of the applications.

I have liaised with Mr Peter Foster of MWH on dam engineering. Mr Foster has provided a separate report on the risk aspects of the proposal.

2.0 Submissions

A number of submitters have raised issues relating to dam engineering, including dam safety in general, and also the creation of a new hazard and the effects of dam failure. A particular focus was geological hazards ie effects of seismicity, active fault lines, geological instability, dam foundations and landsliding.

3.0 Assessment of Effects

3.1 General Description of Dam

The proposed hydropower project includes an 80 to 85M high roller compacted concrete (RCC) dam between 63 and 85MW generating capacity. The storage reservoir will impound the gorge upstream of the dam up to RL100, creating a lake extending 14km upstream of the dam. DamWatch outlines the history of previously investigated dam sites in the gorge between 1960 and 1982, and the reason for adopting the present site. Some of the key elements and features of the proposal include the following:

- The stored reservoir volume is 9.5M cubic metres at full supply level.
- RCC has been selected on the basis of reduced construction cost and duration when compared to conventional mass concrete dam construction.
- The foundations consist of granite on the right abutment and valley floor, and greywacke for the majority of the left abutment.

- The preliminary design for the spillway is a 120m wide ungated overflow spillway over the dam, with a flip bucket at RL20 on the downslope face. A plunge pool is located downstream in the river valley between abutments. The spillway crest, chute and flip buckets are constructed of conventional concrete.
- Diversion during construction is initially achieved by excavation of a channel on the left abutment, with upstream and downstream coffer dams. Subsequent stages divert the river through a box culvert within the RCC block, which is plugged at the end of construction.
- No specific low level outlet is proposed.
- Foundation works will comprise a continuous grout curtain, and drainage holes to control uplift and seepage.
- The power station is expected to have three turbines, and to be located immediately downstream of the dam on the true left riverbank. The turbines discharge to a common tailrace channel and thence the main river channel.
- Intakes are sited in the upper level of the dam, with gates and screens in the main appurtenances.

My assessment (along with that of Mr Foster) has concentrated on dam safety aspects of the proposal. Clearly, the safety of the dam for any of the loads imposed during construction and long term is a key consideration, because the effect of a dam failure is very significant (although the probability is extremely low).

3.2 Dam Safety and General Principles

DamWatch outlines the general design philosophy, including Meridian's Dam Safety Policy and Dam Safety Assurance Programme.

Reference is made to the NZSOLD New Zealand Dam Safety Guidelines (2000) and other international guidelines and standards. DamWatch states that the NZSOLD Guidelines will establish the minimum levels of accepted practice, as the Guidelines are not detailed on all specific design conditions.

It is important to consider that the process of dam design and construction relies also on precedent i.e. what has been successfully constructed before, and also observation of performance in extreme events such as earthquakes and floods.

DamWatch states that the present status of design is at a feasibility level i.e. one which identifies a "technically sound and feasible design." Both I and Mr Foster have made judgements in our reviews as to whether the information presented meets the stated criterion.
It should be noted that a building consent will be required for the dam and appurtenant structures if resource consent is gained. Mr Foster addresses this aspect in his report.

3.3 Management of Hazards and Risks

DamWatch outlines the various natural hazards and how they are addressed, and how a high level of safety can be achieved by close attention to and management of the potential hazards. DamWatch states that an essential part of the process is the identification of the potential impacts or consequences of dam failure. The DamWatch report considered that the dam has a Potential Impact Classification (PIC) of high in terms of both the NZSOLD Guidelines and the pending draft regulations for the Dam Safety Scheme of the Building Act. This assessment was primarily based on the proximity and elevation of Seddonville and other nearby residents i.e. if a breach of the dam were to occur, loss of life would be possible.

The S92 information request included that a dam breach inundation map be provided and an assessment of effects be undertaken based on the inundation event. The Applicant has undertaken this further work, documented in a report titled “Potential Failure Modes and Consequences of Failure for Input to Dam Design,” dated June 2008.

The report contains several inundation maps depicting the plan extent of flooding, and confirming the high PIC rating. However, the description of effects is not explicit and interpretation is required by the reader. For example, no velocities or depth of flooding are provided. Some other points include:

- An updated assessment of Population at Risk (PAR) is provided of 92 persons.
- The failure modes described appear realistic, but do not necessarily represent a worst case scenario of a foundation failure. (It is noted there is no ‘standard’ for dam breach assessment).
- The dam breach scenario leads to a far greater depth of flooding compared to the upper limit natural flood for a Probable Maximum Flood event without the dam.

Whilst the assessment has provided the base information requested, the assessments of effects requested is absent. In my opinion, a more explicit description of effects is required in order for submitters to be able to fully understand the implications of the technical report.

3.4 General Design Standards and Criteria

DamWatch outlines the various design criteria which are summarised in Table 1 below:

Loading Case	Event	Criteria and Value
Flood	During construction	1:5 AEP
	Maximum design flood	PMF (Probable Maximum Flood)
Earthquake	Operating basis, earthquake	1:150 AEP Either no damage or minor repairable damage
	Maximum design earthquake	Largest seismic loading possible from seismic source. AEP 1:10,000 if probabilistically derived. Some damage acceptable but reservoir must be retained

These criteria are consistent with NZSOLD Guidelines for a high PIC dam and generally accepted practice. The flood standard during construction is at the low end of a typical range. However, the RCC structure is able to withstand overtopping without failure (unlike an earth dam) and this is considered an appropriate standard, in engineering terms, provided adequate contingency measures are implemented.

It should be noted that overtopping and possible failure of the 13m high coffer dams may have detrimental environmental consequences downstream.

3.5 Geological and Geotechnical Issues

3.5.1 Dam Site Geology and Design Implications

The DamWatch report references supporting geological reports for the site (eg GNS, R Thomson Aug 2007) and two reports specifically on seismic hazard (GNS 2006 and 2007) and active faulting in the vicinity of the proposed dam.

Investigations have included geological mapping, a series of bored drill holes and seismic survey. I consider the scope of these investigations is reasonable for a feasibility stage. DamWatch concludes that the founding conditions are suitable for the proposed structure. The major factors leading to this conclusion are:

- No major faults have been identified in the foundation and known shears/faults are considered minor.
- Intact compressive strength exceeds 80MPa.
- Rock jointing is typically tight.
- The steep right abutment appears to be stable.
- The contact between greywacke and granite is inferred to be an intrusive contact (i.e. not faulted).

3.5.2 Seismic Hazard and Earthquake Design

The seismic hazard particularly related to active faulting is addressed by GNS. As summarised in the DamWatch report, the proposed site is located in an area of high seismicity. Some key points include:

- Of greatest relevance is the system of known active faults that include the Inangahua, Lyell and White Creek Faults. These are located at distances ranging 14 to 24km from the dam.
- Estimated maximum earthquake magnitudes up to M7.6 are predicted.
- The ‘possibly active’ Glasgow fault, at 1km very close to the dam, may also contribute to the shaking hazard, although to date this contribution has not been quantified.
- Site investigations to date do not find any features to indicate the potential for fault surface rupture displacement through the M11 dam site.

- The maximum design earthquake (MDE) is likely to be either the 10,000 year event or the Glasgow fault rupture scenario if further investigations indicate the fault can be classified as 'active'. The range of peak ground acceleration (PGA) for the MDE is thus in the range of 0.81 to 0.91g.

This level of earthquake shaking at MDE level is extremely high. The Operating Basis Earthquake (QBE) PGA of 0.28g is similar to that experienced in the 1987 Edgecumbe Earthquake (0.33g).

3.5.3 Reservoir Geology

Various hazards are associated with the reservoir and surrounds. This includes land sliding into the reservoir or landsliding creating a "landslide dam" upstream of the reservoir. Such an event could lead to collapse of the natural dam created and a significant flood wave into the dam reservoir. Mr Riddolls has addressed this geological natural hazard in his review report. I note that the DamWatch report includes a specific analysis of a hypothetical "landslide dam" breach upstream of the reservoir, and the assessed effects on the dam. Such a scenario occurred after the 1929 Murchison Earthquake. The analysis indicates a flood wave of similar peak flow to the PMF peak discharge, which the dam will be designed for. DamWatch outlines that the analysis is based on a 'worst case' scenario based on the 1929 event – this appears a realistic assessment of this hazard.

3.6 Dam Stability Analysis

The DamWatch report concluded that the hard rock at the dam site is suitable for the 80 to 85m high dam proposed. In the light of the high seismic loading for this site, a S92 further information request was made for:

- A preliminary stability assessment for dam blocks founded on greywacke and granite to demonstrate they meet typical international guidelines that are referenced.
- Evidence of gravity concrete dams (and RCC dams in particular) subjected to strong shaking and good performance that can be compared to the MHP.

The applicant provided further reports as follows to address these requests:

a) "Mokihinui Dam: Preliminary Stability Analysis for Conceptual Design", June 2008.

b) "Observed Performance of Concrete Dams during Earthquakes".

DamWatch outlined in the response that the earthquake performance of concrete dams has been good, with no breaches recorded due directly to seismic shaking worldwide. A number of examples are given where dams have been subjected to 0.5 to 1g with either no damage or limited damage. This includes RCC dams in China subject to the recent 2008 Wenchuan earthquake e.g. Shapei Dam, 132m high, subject to the order of 0.5 to 1g earthquake shaking. It is also stated that large RCC dams greater than 80m high have been built or planned in areas of high seismic risk – several examples are given of dams in California, Iran and China.

Whilst these observations give a degree of comfort that concrete dams have considerable history of resistance, up to, say, 0.5g shaking, the data base in the region of 0.8 to 0.9g, which is the MDE for Mokihinui is extremely small. Also, the history of performance of RCC is relatively short, especially in terms of seismic resistance at these very high levels.

The stated purpose of the preliminary stability assessment is to "provide a preliminary check that the concept dam section is in the right order to meet dam stability criteria considered acceptable in the industry." In most respects, I consider that this objective has been achieved at a feasibility level, but I do note the following points:

- Demonstration of adequate stability at the MDE level puts large demands on the strength of the RCC and foundation materials.
- Seismic tensile stresses are high and cracking/damage is an expectation at upper level events.
- No testing has yet been carried out on RCC in particular (analysis uses assumed properties) and thus the assumptions cannot yet be verified.
- More sophisticated design methods of analysis will be required in the design stage to verify adequate margins of stability (especially in the dynamic earthquake loading, and post-earthquake sliding stability). This point is acknowledged by DamWatch.

Mr Foster addresses some detailed aspects of stability analysis in his separate report.

3.7 Spillway and Plunge Pool Design

The free overflow spillway incorporates a flip bucket and plunge pool as the means of energy dissipation. The spillway is required to pass the PMF flood (preliminary value of 7200m^3/sec).

The hydrological aspects of the calculated flood flows have been addressed in a separate review report. A S92 further information request was made on the following:

a) If the PMF were to increase (in detail design) in size toward the upper bound estimates produced in the hydrology report how would the concept layout of the dam be modified to accommodate a higher flow and what effect will this have on extreme lake levels?

b) What are the potential limits of plunge pool development and could its lateral spread cause right abutment slope stability problems downstream of the dam? Will the spillway be model tested during final design and would minor adjustments to the dam be entertained to reduce the risk of erosion? It was noted that the geometry shown to create the flip bucket/plunge pool may be impractical with excessive excavation required removing toe support to the very steep right abutment slope.

The response to question a) indicated that the highest preliminary estimate of the PMF is 12,900m^3/sec. This larger flood could be passed by either accepting dam overtopping or raising the parapet walls. For the option of raising the parapet walls the resulting flood level is RL112.5. This flood level is 4.0m above the top of the wave wall at RL108.5. In my view, allowing overtopping in a PMF would not generally be considered acceptable. There are other means which could be adopted, such as widening the spillway for this scenario.

On the questions in b), the applicant responded that either physical or numerical modelling would be used in the final design of the spillway and plunge pool. With respect to the right bank there were no identified slope instability issues except for some possible minor rockfall. Lateral spreading of the plunge pool should not induce major right bank instability downstream of the dam.

In my view, these comments are reasonable; however, they do not address the primary issue raised. This is the practicality of the significant excavation required on the right bank to form the flip bucket to the plunge pool. The excavation required to form the geometry shown in the drawings would appear to require undermining of the very steep abutment slope, the effect of this on stability being the primary concern raised.

Whilst the above two aspects can be addressed in final design, there is a likelihood or possibility that any changes required may lead to a somewhat different site layout from the present preliminary design.

The preliminary design does not incorporate a low level outlet, which could rapidly lower the reservoir in an emergency or potential emergency situation as noted by DamWatch. The NZSOLD Guidelines do not explicitly require such a facility, but do state “it may be prudent depending on the dam type and hazard potential.” For the high PIC Mokihinui Dam located in an area of high seismicity and geological hazard and for an earthquake loading probably as high as any RCC dam has been designed for, I consider that the requirement for this outlet should be further evaluated by the Applicant.

3.8 Commissioning and Dam Safety Management

3.8.1 Independent Peer Review

DamWatch has outlined in the report that the NZSOLD Dam Safety Guidelines will be followed, including engaging suitable designers, peer reviewers and specialists. As there were no further details provided on the peer review process, a S92 further information request was made on this aspect. It was requested that an external peer review report or supporting statement be provided and also document how independent reviews will be carried throughout the project development to ensure the adequate safety and performance of the development. The applicant advised, in the response, that a Technical Advisory Group (TAG) has been used to conduct independent review of the engineering aspects of the proposal throughout the pre-feasibility and feasibility stages. The six experts named cover all relevant aspects and have completed three technical reviews including site visits. This degree of input would appear to meet generally accepted requirements for review up to the feasibility stage. I note, however, that no report or statement has been made available, and that such a statement or report would be desirable. In this case the very high seismic loading for a RCC dam, coupled with the significant submitter concern on dam safety and seismic issues would point further to the desirability of such information.

Any resource consent conditions should contain explicit requirements for peer review. A panel of experts is recommended, with particular expertise in:

- RCC design of the dam height envisaged, and for high seismic loading;
- Hydrology and hydraulics, for the envisaged flip bucket arrangement; and
- Geology and geotechnical aspects including seismicity.

3.8.2 Commissioning and Operation

DamWatch outlines, in broad terms, the envisaged procedures during commissioning/lake filling, and subsequent operation. Reference is made to the Meridian dam safety assurance program and NZSOLD Dam Safety Guidelines. It is important that these plans address all the hazards that have or will be identified. For example, emergency procedures or actions in the case of severe seismic shaking with potential effects on the dam, reservoir, and upstream areas of the reservoir.

3.9 Comments on Meridian Proposed Consent Conditions

Mr Foster has addressed the proposed consent conditions in his report.

4.0 Conclusions and Recommendations

1. The Applicant considers the proposed dam is one of high potential impact in terms of the New Zealand Dam Safety Guidelines. I concur with this assessment. The inundation map provided for a hypothetical dam break scenario gives a likely realistic depiction of the plan extent of flooding. However there is no explicit description or assessment of effects provided.
2. The general design standards and criteria presented appear reasonable for a high PIC dam at feasibility stage.
3. The proposed dam is located in an area of high seismic hazard. The maximum design earthquake which the dam will be designed for puts significant strength demand on the foundation and roller compacted concrete. There is only a very limited data base on RCC dams in particular subjected to this level of seismic load.
4. The PMF value is, at this stage, preliminary. There is a possibility that in the detail design phase this design value could increase requiring some amendment to the design.
5. The proposed spillway/plunge pool is considered an acceptable concept, subject to final design. The applicant states that a physical model or numerical modelling will be used in final design. I consider that the effect on right abutment stability, due to the excavation required, will require particularly close consideration.
6. Due to the high PIC and the high seismic loading for the dam, I consider it is essential that an independent panel of experts is appointed for peer review. In addition, I consider it is desirable that the applicant provides a report or statement on the peer review carried out to date, and in particular confirming that the seismic preliminary design is acceptable.
7. I consider that the requirement for a low level outlet should be further considered by the applicant.

5.0 References

- New Zealand Dam Safety Guidelines, NZSOLD New Zealand Society on Large Dams, November 2000.