Annex C

Dam Safety -

- **Project Failure**
- **Response to CSR Recommendations**

C.1 Dam breach during construction project

Originally a community project, the scheme initially suffered a disaster during construction of the dam. By 6th February 1997 the dam was about 29m high – the final height of the dam would be 50m – and was retaining a lake of ~13 million m^3. Until now an emergency channel had been provided by the contractors to protect the dam works in case of heavy rainfall into the catchment area whilst the dam was vulnerable to flood damage. The contractors building the dam decided at this point that they could complete the dam to its full height within two weeks, so decided that it was unnecessary to maintain an emergency channel especially, as by this stage the penstock ('conduit') had been installed enabling a flow of <40m^3/s safely past the dam site. The contractors took the view that this penstock flow plus the flood attenuation provided by partially completed dam complied with the requirements for a 1/10 year flood management plan during the construction phase. Also it was summer-time, so heavy rainfall during this two-week period was perceived to be unlikely.

The decision back-fired when unforeseen heavy rains breached the true left side of the partially completed earth dam, removing about one third of the dam near the left abutment. The resultant flood flow, estimated at <2,000m^3/s, from release of water from behind the partially completed dam lasted only ten – fifteen minutes, but caused damage to third party farmland, some loss of livestock, flooded one home, but there was no loss of life. The insurance costs were ~$8 million NZD to rebuild the dam and ~$4million costs incurred in compensation payments.

Why did the dam fail during construction? As always there are two sides to the root cause of any disaster. **The basic facts are that any dam is very much more vulnerable to damage from flooding, whilst under construction, than at any other time, due to lower crest levels, limited capacity to manage flood flows and the limited flood flow attenuation provided by the lake being impounded by the dam.**

In the case of Opuha dam, the spillway had nearly been completed and its crest level exceeded that of the partially built dam at that time, so the spillway offered no protection to the works during the flood. The fact the dam was little more than half height meant the lake impounded by the dam reduced the lake's ability to attenuate the effects of catchment flows into the lake. The monitoring of inflows into the catchment area – a feature of any commissioned dam – were not yet installed, so information as to total catchment inflows were not available to those managing the emergency situation in February, 1997.

The dam breach was caused by an event with an estimated average return period of 30 -35 years. The completed dam can spill 1/200 year flood from the service spillway alone, and, ignoring the large lake area and the storage capacity it now provides, the service slipway and the auxiliary slipways can safely pass the estimated 1/2,000 year flood flows. The service spillway alone would have safely handled the inflows of February 6th 1997 had the project been completed by that time.

Despite its unfortunate construction phase, the completed dam has proven to be "immensely successful" for all involved. *"The reliable water supply from Lake Opuha is vitally important for the regional economy"*[5]. Evidence of the success of the scheme is evident that in its history to date there have only been two occasions when water restrictions were deemed to be necessary, and on both occasions the restrictions lasted less than one week. The reliability of water supply from the dam has, therefore, been in excess of 99%.

[5] Tony McCormick, CEO, OWL

C.2 Dam Safety Report

A summary of the conclusions reached during the completion of the DSR is provided below.

- We understand that a dam safety assurance programme for Opuha Dam will be developed before the Building (Dam Safety) Regulations come into effect, and that the programme will include appropriate dam surveillance and monitoring procedures.
- The dam surveillance and monitoring procedures, dated November 2011, are well documented but require revision to better reflect the existing structure for the operation of the facility, management responsibilities and personnel contact details.
- Two members of Opuha Water's staff have had training in dam safety surveillance. Although we understand that additional training is planned, we believe that the current personnel do not have an appropriate level of training for completing routine monitoring and surveillance activities at Opuha Dam.
- Tonkin & Taylor is retained by Opuha Water to complete intermediate dam safety reviews based on NZSOLD's Dam Safety Guidelines. Each review includes a site inspection, a review of surveillance data, and the completion of an annual dam safety report. We offer the following summary comments on the 2007, 2008, 2009, 2010 and 2011 intermediate dam safety review reports:
  - They are well compiled and provide a very clear picture of existing conditions and data records. However, future reports should be expanded to include an interpretation of the data records……..
  - The safety of the main dam is dependent on the reliable operation of the spillway gates and the by-pass valve. As such, we believe that future reports should also include a summary description of the gates and valve, including their dam safety functions and associated control and communication systems……..
  - The main dam has been classified as a "high" potential impact classification (PIC) dam. While the PIC for the main dam will need to be determined in accordance with the procedures included in the Building (Sam Safety) Regulations before the regulations come into effect, the "high" PIC classification is considered appropriate.
  - The minimum flood safety evaluation guideline for the main dam is that the spillway facilities should be capable of safely passing the Probable Maximum Flood (PMF). We understand that the PMF inflow estimate was determined using the generalised PMP methodology for New Zealand developed between 1992 and 1994 and, as such, the estimate reflects current practice.
  - Existing PMF routing analyses result in a peak reservoir level close to the crest of the main dam. Accordingly, we believe that the assumptions incorporated in the existing PMF inflow estimate should be reviewed and, if changes in the assumptions result in a revised PMF estimate, the resulting PMF inflow should be routed through the reservoir to determine the peak reservoir level and the peak discharges through the service and auxiliary spillways.
  - Industry practice for the seismic safety evaluation of a dam is that it should safely withstand the effects of a Safety Evaluation Earthquake (SEE) without an uncontrolled release of the reservoir. For a "high" PIC dam, the SEE should be equivalent to the Maximum Credible Earthquake, or the 1 in 10,000 year event if probabilistically derived.
  - A review of seismic hazards by Geological and Nuclear Sciences (GNS) in 2004 derived a peak ground acceleration of 0.54g for the estimated 1 in 10,000 year event at the dam site. Existing seismic stability analyses demonstrate that, at maximum normal operation level, the existing freeboard is more than sufficient to safely accommodate the estimated deformation of the dam.
  - The review of seismic hazards by GNS highlighted the presence of the Opuha Fault immediately downstream of the dam. The activity and significance of the fault are presently unknown and the seismic hazard review assumed that the fault had a very low rupture recurrence interval. However, the fault's location and attitude suggest that the issue should be discussed with GNS to determine whether further study is necessary to establish the fault's significance to the safety of the dam.

- Although the risk of its occurrence is considered to be very low, the more likely potential failure modes for the main dam are:
  - *A failure of the dam by internal erosion, initiated by the loss of fines from the seepage control zone, overloading of the chimney drain by increased seepage flows through the seepage control zone, and unravelling of the dam toe.* While the dam incorporates features which encourage the development of high seepage flows at the dam toe, the completed toe remediation works have strengthened the toe area and we consider that seepage flows sufficient to initiate unravelling of the dam toe are very unlikely to occur.
  - *A failure of the dam by internal erosion, initiated by the development of preferential seepage and erosion through the dam, along an existing defect, or along a transverse crack through the embankment.* While the dam incorporates a number of features which could encourage the development of preferential seepage and erosion, we consider that preferential seepage flows sufficient to initiate internal erosion and dam failure are very unlikely occur.
  - *A failure of the dam by internal erosion, initiated by the loss of fines from the seepage control zone and blockage of the base drainage system.* Any blockage of the drainage system would result in seepage discharges from the relief well and provide early warning of a developing dam safety deficiency. As such, we consider that a blocked drainage system is very unlikely to initiate a dam failure.
  - *A failure of the dam by overtopping during an extreme flood event, initiated by:*
    - *a flood that exceeded the combined discharge capacity of the spillway facilities; or*
    - *a failure of the auxiliary spillways to operate as intended; or*
    - *a failure of the spillway gates to lower during a large flood event.*

    Safety margins during the discharge of the PMF are small; however, given the low probability of the PMF, we consider that an overtopping failure is very unlikely to occur.
- The only potential failure mode that has not been addressed by the completed remedial works is an overtopping failure of the main dam during an extreme flood event. Such a failure could be initiated by erosion of the material overlying the seepage control zone at the crest of the dam, a flood that exceeded the combined discharge capacity of the spillway facilities, a failure of the auxiliary spillways to operate as intended, or a failure of the spillway gates to lower during a large flood event.
- While visual surveillance is included in the routine surveillance and monitoring programme for the main dam, the monitoring database includes no provision for the recording of routine visual observations. Visual observations are important as they are frequently the first signs of abnormalities or reductions in structure performance……..
- The small number of piezometers and the lack of any operational piezometers in the seepage control zone (Zone A) provide a very limited picture of seepage conditions within the dam upstream of the chimney drain. Given that the erosion of fines from the seepage control zone (Zone A) is associated with two of the more likely potential failure modes for the dam, some monitoring of seepage conditions within the seepage control zone appears to be warranted.
- Although the drainage discharges from the chimney drain are high for a 50m high embankment dam, the recorded data and lack of any observed turbidity in the drain discharges indicate reasonably stable seepage conditions. In addition, the base flow data for drains D7 to D10 does not indicate the development of any significant blockages in the drainage system.
- The seepage discharges from the chimney drain sumps and base drainage zone must, in some cases, be close to the capacity of the drainage outlets. Any large increases in seepage could result in increased water levels within the chimney drain and, if the Zone A materials immediately downstream of the chimney drain and above the base drainage layer incorporate permeable zones, some saturation of the downstream shoulder.
- The civil works and recently completed remedial works for the main dam look robust and have been well designed and constructed. However, it should be remembered that while the remedial works have resulted in significant improvements in dam safety, the temporary spillway benches beneath the seepage control zone on the left abutment, the right abutment interface between the seepage control zone and the service spillway, the erodibility of the seepage control zone, and the incompatibility between the seepage control zone and the

chimney drain represent risks to the long-term safe performance of the dam. Ongoing dam safety is very dependent on effective surveillance and monitoring, and a prompt response to any identified change in dam behaviour.

- We believe that the plant items critical to the safety of the main dam are:
  - The service spillway gates including their operating equipment and power supplies. Gate lowering is important during large flood events.
  - The bypass valve including its operating equipment and power supplies. Valve operation is important for lowering the pond level in response to a dam safety emergency.
  - The control and communication systems necessary for operation of the above facilities. The performance reliability of these systems is critical for an automatic and remotely controlled facility.
- The spillway gates are in good working order, but their control appears to be unreliable. An investigation has identified some problem areas in the gate control system, but has not covered all possible causes of unreliable gate operation (eg wrong control settings).
- The bypass valve is in very good working condition and is inherently secure given its location and robustness. However, some additional security would minimise the potential for damage by intruders or vandals.
- The only source of ac power supply for spillway gate and bypass valve operation is from a 33/0.4kV, 100kVA transformer mounted on a pole and connected by drop fuses to the first span of the 33kV line. A single source of power supply is not in line with current best practice.
- NZSOLD's Dam Safety Guidelines outline a number of Owner responsibilities relating to the development, content, distribution, maintenance and testing of emergency action plans. The current Emergency Action Plan (EAP) addresses most of the generic points included in the Guidelines; however, it would be enhanced by expanding the existing content to include:
  - The location where an emergency response would be coordinated
  - Procedures for inspection during and following a large flood event
  - Procedures for inspection following a large earthquake.
- While the existing EAP provides a framework for the management of a dam safety emergency, some urgency should be given to completing and issuing the proposed revised document. In addition, the effectiveness of the existing emergency procedures would be enhanced by the completion of regular emergency training exercises.

Our detailed report includes recommendations to address the above points and a number of additional observations made during the completion of the DSR. We understand that Opuha Water will consider our recommendations and initiate appropriate action.

"Five yearly Dam Safety Reviews are a component of Opuha Water's Dam surveillance and monitoring plan. In completing the Dam Safety Review we have applied dam safety criteria generally recognised by the New Zealand Committee on Large Dams (NZSOLD) and the Australian National Committee on Large Dams (ANCOLD) and the International Committee on Large Dams (ICOLD) as being current best practice. A summary of the conclusions reached during the completion of the Dam Safety Review is provided below."

C.3 Response to recommendaions from CSR follows

OPUHA WATER LTD
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Not Yet Actioned
Actioned (Pending)
Completed

COMPREHENSIVE DAM SAFETY REVIEW 2012 RECOMMENDATIONS

ACTION LIST

Table 1: Dam Safety Recommendations

	Recommendation	Reason or Purpose	Priority Rating[1]	Report Ref.	OWL Response	Completion Date
1	Develop a dam safety assurance programme that meets the requirements of the Building (Dam Safety) Regulations	A dam safety assurance programme is a requirement of the Building (Dam Safety) Regulations which come into effect in July 2014.	MP	2.1 & 2.3	Our current Dam Safety Assurance Programme meets current NZSOLD Guideline requirements and will be expanded for new Regulations. Revision will include provision for the investigation, assessment and resolution of any dam safety deficiencies and procedures for the inspection and testing of plant critical to the safety of the dam. Note we are already underway with implementation of the critical plant/systems testing as a result of the CSR recommendations.	June 2014
2	Revise and re-issue the existing Dam Surveillance and Monitoring Plan.	The existing plan requires revision to better reflect the existing management structure, management responsibilities and personnel contact details.	HP	2.1 & 2.3	Completed	June 2012
3	Initiate a dam safety assurance training programme for appropriate Opuha Water personnel.	The current personnel do not have an appropriate level of training for completing routine monitoring and surveillance activities at Opuha Dam.	HP	2.2 & 2.3	Course scheduled for mid-November 2012. All Opuha operations personnel will complete the course.	November 2012
4	Install a diesel generator to provide a second source of ac power supply.	To avoid a blackout that could occur through outages of the 33kV line or the 33/0.4kV transformer. A single power supply is also inconsistent with current industry practice and NZSOLD's Dam Safety Guidelines (E.4.2).	MP	3.3.3 & 7.3.5	Complete	March 2013
5	Complete the current studies programme and any necessary remedial works to restore the functionality and reliability of the service spillway gates.	Reliable operation of the gates is essential to the safety of the dam and the security of the re-regulation pond overflow embankment.	MP	4.2, 5.2, 5.5, 7.3.4 & 7.3 8.	Refurbishment work completed October 2012. Some final testing and tuning being completed with opportunity of high lake level – October 2012.	October 2012

	Recommendation	Reason or Purpose	Priority Rating[1]	Report Ref.	OWL Response	Completion Date
6	Complete a review of the assumptions incorporated in the existing PMF estimate for the catchment and, if changes in the assumptions result in a revised PMF estimate, complete a series of routing studies to determine peak reservoir levels and spillway discharges during the PMF.	A number of large flood events have occurred since the PMF was derived and existing routing studies indicate little freeboard to the crest of the dam during the discharge of the PMF.	LP	4.2, 6.3.1 & 6.7.2.1.	Study to be scoped with T&T	June 2013
7	Complete an internal inspection of the low level conduit within the next two years and record the results of the inspection.	An internal inspection has not been completed since initial commissioning.	MP	5.2 & 5.5	This work has been included in the annual maintenance plan for the last two years but requires a low lake level to undertake the diving. Planned for autumn 2013. Currently on track for inspection starting 3rd June 2013.	June 2013
8	Complete an internal inspection of the low level conduit every five years, and following a large earthquake, and record the results of the inspections.	The low level conduit and its internal steel liner are critical to the ongoing safety of the dam.	LP	5.2 & 5.5	This will be scheduled on a five yearly basis.	Oct 2012
9	Expand future annual safety inspection reports to include summary descriptions of plant critical to dam safety and their dam safety functions, a comparison of planned and actual maintenance and testing activities, and comment on the adequacy of the completed maintenance and testing activities.	Ongoing dam safety is dependent on the reliable operation of the service spillway gates and bypass valve.	MP	5.3 & 5.5	This additional scope has been included in the most recent Annual Safety Inspection (April 2013).	April 2013
10	Expand future annual safety inspection reports to include comment on the performance of the main dam, and a brief compliance section reporting compliance/non-compliance against the recommendations included in NZSOLD's Dam Safety Guidelines.	Existing reports do not fully address the intent of NZSOLD's Dam Safety Guidelines.	MP	5.4 & 5.5	This additional scope has been included in the most recent Annual Safety Inspection (April 2013).	April 2013

	Recommendation	Reason or Purpose	Priority Rating[1]	Report Ref.	OWL Response	Completion Date
11	Determine the PICs for the main dam and re-regulation embankments, in accordance with the Building (Dam Safety) Regulations, and document the results.	The Building (Dam Safety) Regulations require all dams to be classified according to their potential effects on people, property and the environment.	MP	6.2	Existing classification appears appropriate (main dam is already "high") but will be checked and documented as required by new Building Regulations Letter rec'd 25th January 2013 from T&T	January 2013
12	Discuss the Opuha Fault with GNS to determine if any work should be completed to better understand the significance of the fault to the safety of the dam.	The fault is located immediately downstream of the dam and its activity is unknown.	LP	6.3.2	Discuss with GNS. Often sufficient assurance is available from existing knowledge and a specific study is unwarranted. Letter rec'd from T&T 20th December 2012	December 2012
13	Check the elevation of the right hand end of the closure embankment and, if low, restore it to its design elevation.	Crest level appeared to be low. Possibly caused by traffic along farm road.	MP	6.4	Survey completed October 2012 identified low area as suggested as well at other end against structure. Remedial work completed January 2013.	January 2013
14	Complete a Failure Modes and Effects Analysis (FMEA) before the next CSR.	Present day practice for "high" or "medium" PIC dams is to complete an FMEA.	LP	6.5	This will be coordinated after upgrade of the DSW spillway project.	December 2013
15	Complete a thorough review of piezometer and observation well alert levels and piezometer trigger levels.	Alert and trigger levels should reflect current trends and expected dam performance.	HP	6.6	T&T to complete review once maintenance and upgrade of piezometers is completed.. Curren	July 2013
16	Review the reliability of the existing piezometers and consider installing additional instrumentation to monitor seepage conditions within the seepage control zone (Zone A).	Unusual piezometric pressures have been recorded at a number of piezometers and no effective instrumentation is in place to identify a change in seepage behaviour within the seepage control zone (Zone A).	LP	6.6	Installing new piezometers is not feasible so alternative pressure or level monitoring would be required. Scope of options to be completed by T&T. Physical inspection and maintenance of existing piezometers has been carried out March 2013. Some components require replacement and are currently being sourced.	May 2013
17	Review the ability of the dam to safely withstand the PMF and, if necessary, initiate appropriate remedial works.	The dam may be overtopped and could fail during the PMF.	LP	6.7.2.1	Dependent on the outcome of PMF review (Item 6 above).	June 2013
18	Establish and implement a program for the inspection and testing of plant critical to dam safety.	Current practices are inconsistent with the recommendations included in NZSOLD's Dam Safety Guidelines.	MP	8.3	TrustPower requested to complete a test and inspection programme.	November 2012

	Recommendation	Reason or Purpose	Priority Rating[1]	Report Ref.	OWL Response	Completion Date
19	Review and re-issue the EAP.	The existing EAP is out of date	HP	9.2 & 9.5	Finalising revisions to EAP June 2013.	June 2013
20	Undertake and document regular exercises to test emergency procedures and provide emergency personnel with appropriate training.	Regular training exercises will ensure that personnel are aware of their responsibilities and are familiar with all emergency procedures.	HP	9.4 & 9.5	Will be implemented once EAP revision completed and communicated.	August 2013

Table 2: Asset Management Recommendations

	Recommendation	Reason or Purpose	Report ref.	OWL Response	Completion Date
1	Provide improved access along the top of the left hand wall of the service spillway for piezometer and deformation observations.	Existing access is difficult and is resulting in damage to the downstream slope of the embankment.	4.2	Modifications planned for December 2012. Steps and hand rail to be installed. Completed Feb 2013	February 2013
2	Develop a more effective system for the reporting of recommendations in annual safety inspection reports.	All recommendations since 2007 appear to have been tracked; however, the number of recommendations included in the later reports is a little overwhelming.	5.5	Discussed with T&T. Quarterly internal reviews initiated.	October 2012
3	Install an intruder detection/alarm at the spillway gatehouse.	To reduce/manage the risk of intrusion and vandalism.	7.3.2 & 7.3.8	Scope work and evaluate benefit. No history of forced entry. Cameras now operational and provide surveillance capability.	July 2013
4	Install a lockable and removable means for preventing unauthorised access to the bypass valve platform.	To minimise the risk of intruders and vandals reaching the valve platform and interfering with the hydraulic flexible hoses or the valve position transducer.	7.4.2 & 7.4.8	Lockable gate to be installed on top of ladder.	February 2013
5	Install an intruder detection/alarm at the re-regulation gatehouse.	To reduce/manage the risk of intrusion and vandalism.	7.5.2	Scope work and evaluate benefit. No history of forced entry. Cameras now operational and provide surveillance capability.	July 2013
6	Install a log boom across the front of the radial gate outlet structure.	To improve public safety.	7.5.2	Log/trash booms required for both main dam and DSW. Design required because of large level range.	Sept 2013
7	Secure the two 12V batteries contained in the cabinet located in the re-regulation pond gatehouse.	The two batteries contained in the cabinet were not securely clamped and could be damaged during an earthquake.	7.5.5	Brackets to be fitted.	July 2013

	Recommendation	Reason or Purpose	Report ref.	OWL Response	Completion Date
8	Review the adequacy of in-house and contract operation resources, and enhance the resources to address any identified deficiencies.	Existing resource levels for the safe operation of Opuha dam appear to be limited.	8.1	Current in-house resources, in conjunction with contractors (TrustPower and Siebers) considered adequate for safe operation. Additional training provided to Operations & Asset Manager July 2012.	July 2012
9	Ensure in-house and contractor staff with responsibilities for operation of Opuha dam are properly trained and their competencies are assessed and documented.	Prevailing industry standard and practice, and a safety requirement.	8.2	Dam Surveillance and Monitoring Course completed November 2012. All Opuha operations personnel completed the course.	November 2012
10	Prepare flap gate operating procedures and include a copy of the procedures in the spillway gatehouse.	Current practices are inconsistent with the recommendations included in NZSOLD's Dam Safety Guidelines.	8.2	Procedures being revised following refurbishment and testing of gate controls Sept-Oct 2012.	May 2013