MWH

Dam Safety Reviews for the Middle & Lower Chase River Dams

Prepared for: City of Nanaimo

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EXECUTIVE SUMMARY

MWH has prepared this report for the Dam Safety Reviews (DSRs) of the Middle & Lower Chase River Dams for the City of Nanaimo (the City) in accordance with the scope and budget outlined in our proposal dated March 7, 2013.

The 2013 DSRs for the Middle & Lower Chase River Dams were carried out in three phases namely:

- Phase 1 - Document Review including all pertinent documents on the dam history, construction records, where available and previous inspections and investigations
- Phase 2 – Site Visits & Detailed Work
- Phase 3 – Report Finalization

The Middle Chase River Dam is located in the southern part of the City of Nanaimo and was constructed around 1911 to provide water for coal washing in the early part of the century when coal mining was in full production in Nanaimo. The dam is 13m high and 50m long and is constructed of earth/rockfill shells on either side of a concrete core wall extending from the dam crest and keyed into bedrock. The concrete core is 0.6m thick at the crest elevation and was raised by 0.3m in 1980. The upstream shell is constructed to a slope of 1.5H to 1V and the downstream to a slope of 2H to 1V and was re-constructed in 1980 with the incorporation of a gravel filter drain to intercept seepage. Concentrated seepage was observed in 1992 and an additional gravel filter drain installed near the right abutment to intercept this. The spillway comprises a channel with concrete side walls and a natural rock base on the left side of the dam.

The Lower Chase River Dam is located downstream of the Middle Chase River Dam. Like the Middle Chase River Dam it was originally constructed in 1910 to supply water for the nearby Harewood Colliery when this was in production. It was believed that this function was finished around 1945 and now is part of the recreational area called Colliery Dam Park. The Lower Chase River Dam is an earth/rockfill structure approximately 77m long and with a maximum height of about 24m. The dam lies in a narrow steep sided ravine with both abutments founded on what is believed to be till material. Bedrock might be overlain by a veneer of till or possibly channel fill in the center of the ravine. The downstream shell was stabilized in 1980 by a compacted sand and gravel berm to a slope of 2H to 1V and the original upper slope was left at 1.5H to 1V. Drainage ditches were also formed at the abutment and a gravel filter drain to intercept seepage through the dam and abutments. A concrete wall provides the impervious barrier and also forms the front face of the dam. The top 0.6m or so of the wall is 0.3m thick and it then reportedly thickens to 1.2m. It is believed that the wall is founded on till at the base of the dam. The upstream support of the wall is believed to be by a rockfill shell. The spillway is a rectangular concrete lined channel which bifurcates into two channels upstream of the spillway structure. A double span footbridge is constructed over the channel. The spillway is a free overflow structure with the water level controlled by the spillway lip elevation. There are no offtake works from the dam; the two original low level outlet pipes passing through the body of the dam were capped in concrete, the valves removed and the control chamber backfilled in 1980.

Both Middle and Lower Chase River Dams have “Extreme” consequence categories in accordance with the 2011 BC regulations.

As part of the Dam Safety Review of the Middle and Lower Chase River Dams, Derrick Penman, Principal Hydroelectric Engineer and Masoud Mohajeri, Principal Geotechnical Engineer conducted site visits to review the dams and their associated infrastructure on July 11 and September 13, 2013.

In June 2013, MWH recommended that comprehensive probabilistic seismic hazard studies should be performed prior to or during the current Dam Safety Review studies. In lieu of this a review of past earthquake shaking in the general project site has been prepared and documented in Appendix 7.

The following is a summary of the observations made during the site visits:

Middle Chase River Dam

Because of the undercapacity of the spillway it is important that some measures be taken to eliminate the risk of blockage of the discharge channel either by cutting the trees presently leaning into the channel or providing a gabion protection around the eroded areas to prevent further undermining of the root system. This issue has been identified in previous FADSIs (MCR09-5). A new issue (MCR13-1) was raised in the Dam Issues Database to cover plotting of the dam monitoring data collected from the SCADA system so that any anomalies in dam performance could be readily identified.

Lower Chase River Dam

There was no significant leakage observed at the seepage measuring weir at the time of the visit. The upper part of the downstream slope is steep and is eroding in places causing some settlement in the crest of the dam. There is a severe crack visible on the right abutment of the footbridge and some cracking and erosion on the walls of the spillway approach channel. These issues have been reported in previous FADSIs and in the 2003 DSR. A new issue (LCR13-1) was raised in the Dam Issues Database to cover plotting of the dam monitoring data collected from the SCADA system so that any anomalies in dam performance could be readily identified.

A hazard matrix analysis was carried out based on the site inspections and the background documentation reviewed. The City's Dam Safety Issues Database was updated based on the findings of this analysis which are summarized as follows for each of the dams:

Middle Chase River Dam

1. It was concluded from the completed hazard matrix analysis and studies carried out by Klohn Crippen Berger summarized in a report in August 2013 that a risk of dam failure could result from a seismic event with 1 in 5000 annual exceedance. In the detailed design work that is to be undertaken for remedial measures to be implemented on the dam and spillway, the stability of the dam should be checked for the 1 in 10,000 annual exceedance event or MCE in accordance with the CDA Guidelines (revised in 2013). With this magnitude of earthquake a dynamic analysis should be carried out, as a conventional pseudostatic method will not be appropriate. In addition in order to determine a reasonable value for the Peak Ground Acceleration, response spectra and acceleration time histories Probabilistic Seismic Hazard Studies would have to be performed. A new issue (MCR13-2) was added in the Dam Safety Issues Database to cover this.

2. It was concluded from the completed hazard matrix analysis that a risk of dam failure would result from floods in excess of the 1 in 1000 annual exceedance event ($62m^3$/sec). Several alternatives have been put forward by Klohn Crippen Berger to increase spillway outflow capacity. It is understood that these will be considered in the remedial measures to be implemented on the dam.

3. Until the remedial measures are implemented the trees overhanging the spillway discharge channel should be removed to reduce the risk of reducing the capacity of the spillway should the root system be completely undermined and the trees fall into the channel. Alternatively some temporary protection in the form of a gabion wall should be provided to prevent further erosion (MCR09-5).
4. A diving inspection carried out by EBA Engineering Consultants as part of the field work associated with the Seismic Stability Analysis located an abandoned woodstave off-take pipe which appears to pass through the left abutment of the dam close to the spillway. This could eventually collapse and trigger settlement and internal erosion which could consequently cause leakage and dam failure.
5. There was a previous issue raised concerning the crest elevation of the dam which appeared to be lower at the left abutment and increasing towards the right. This should be a straightforward task to determine by a ground survey and should be done as soon as possible to ensure that there is the correct freeboard (MCR09-4).

Lower Chase River Dam

1. It was concluded from the completed hazard matrix analysis that a risk to dam failure would result from a severe seismic event. In the detailed design work that is to be undertaken for remedial measures to be implemented on the dam and spillway the stability of the dam should be checked for the 1 in 10,000 annual exceedance event or MCE in accordance with the CDA Guidelines (revised in 2013). With this magnitude of earthquake a dynamic analysis should be carried out, as a conventional pseudostatic method will not be sufficient. In addition in order to determine a reasonable value for the Peak Ground Acceleration, response spectra and acceleration time histories Probabilistic Seismic Hazard Studies would have to be performed. A new issue (MCR13-2) was added in the Dam Safety Issues Database to cover this.
2. It was concluded from the completed hazard matrix analysis that a risk of dam failure would result from floods in excess of 25 m^3/sec compared to the current design flood requirement of 198m^3/sec which corresponds to the PMF. As for the Middle Chase Dam several alternatives have been put forward by Klohn Crippen Berger to increase spillway outflow capacity. It is understood that these will be considered in the remedial measures to be implemented on the dam.

1. GENERAL

1.1. Purpose

MWH has prepared this report for the Dam Safety Reviews (DSRs) of the Middle and Lower Chase River Dams for the City of Nanaimo (the City) in accordance with the scope and budget outlined in our proposal dated March 7, 2013. These DSRs were carried out to meet the requirements of the BC Dam Safety Regulation 44/2000 (revised in 2011 to include amendments BC Regulation 108/2011 (June 9, 2011) and BC Regulation 163/2011 (September 12, 2011)), the APEGBC's professional practice guidelines on Legislated Dam Safety Regulations and the Canadian Dam Association (CDA) Guidelines, (2007, partly revised in 2013). Under the BC Dam Safety regulations the consequence classification rating of these dams (which is extreme) requires a DSR every 7 years. The purpose of the DSR is to determine the currency and adequacy of the dam safety management of the dams and to identify deficiencies in the safety management of the dam.

1.2. Scope

The 2013 DSRs for the two dams were carried out in three phases as outlined below. In June 2013, MWH recommended that comprehensive probabilistic seismic hazard studies should be performed prior to or during the current Dam Safety Review studies. A review of past earthquake shaking in the general project site has been prepared and documented in Appendix 7.

1.2.1. Phase 1 - Document Review

During Phase 1, performance expectations were identified, which included flood and earthquake criteria for each dam based on the BC Dam safety Regulations and 2007 CDA Guidelines. The review began by examining documents included in the following list for evidence of conformance with dam safety requirements:

- Dam Safety Management Manual
- Hazards and Failure Modes Matrix
- List of Dam Safety Expectations
- Operation, Maintenance & Surveillance (OMS) Manuals
- Emergency Plan
- Emergency Planning Guide
- Surveillance Reports and Memos
- Past Annual Inspection & Review and DSR Reports
- Past Deficiency Investigation and Capital Improvement Reports and Memos
- Current Outstanding Dam Safety Issues
- Completed Dam Safety Issues
- As built Drawings and Original Construction Documents
- Other available documents related to design, operation, maintenance, improvement, condition and performance of the dam.

The list of documents reviewed is given in Appendix 3.

1.2.2. Phase 2 - Site Visit & Detailed Work

During Phase 2, MWH determined the dam's conformance with the set of dam safety expectations, including:

- Carried out a site inspection of the dams and made a photographic record of the conditions as presented in Appendix 2.
- Evaluated, reviewed and audited City's knowledge base by meeting with City's personnel involved in dam safety management, operation, maintenance, surveillance, performance evaluation or other relevant activities.
- Identified any additional dam safety requirements to enhance risk management and to incorporate appropriate international practices.
- Reviewed the Dam Safety Issues Database and confirmed that all past recommendations and issues have been properly entered into the database and whether completed issues have been justifiably closed.
- Documented the history of the dam since the last Dam Safety Review or Annual Dam Safety Inspection referencing upgrades/rehabilitation of dam components, major studies/reports, unusual conditions, incidents, etc.
- Prepared a Hazard and Failure Mode Matrix analysis to identify potential failure modes that apply to the dam and summarized the considerations which are required for the dam safety program. The analyses were carried out on each dam based on the information gathered during the MWH field visit and background information gathered from reports and data supplied to MWH by the City. This background information has been summarized in the report for each dam to provide a basis for the assessment of the risk to the dams for each of the hazard categories identified in the matrices in Figs 2.4 and 3.3. When the hazard is related to non-conformances or deficiencies identified during this current DSR and previous inspections and reviews, the Dam Safety Issues Database reference number has been shown in parentheses.
- Summarized and prioritized dam safety deficiencies and non-conformances from a list of all potential dam safety deficiencies and documented the methodology. Reference was made to the City's Dam Safety Database in Appendix 4 for previously identified issues and non-conformances
- Prepared a draft report for the City's internal review, which in addition to addressing the foregoing requirements, included recommendations for dam safety improvements, further investigation of deficiencies and further studies to correct information gaps, and any other appropriate measures to improve dam safety. As part of the report an updated list of Dam Safety Expectations was prepared and is presented in Appendix 6.

1.2.3. Phase 3 - Report Finalization

MWH has completed the analyses and evaluations of documentation and findings and these are summarized and presented in this Final Dam Safety Report for each dam. City's review comments have been incorporated in this document.

1.3. Recent History

A DSR was last carried out for the Middle and Lower Chase River Dams by Golder Associates in 2003 and Formal Annual Inspections (FADSIs) of the dam and appurtenant structures have been carried out regularly since then. The findings of these inspections are elaborated in Sections 2.2 and 3.2 of this report.

As a result of the recommendations from these previous inspections a seismic evaluation of the dams was carried out by EBA Engineering in 2010 and a dam breach and inundation study was performed by Associated Engineering in 2012. Accordingly an "Extreme" consequence category was assigned to the dams because of the potential for loss of life in excess of 100 downstream because of inadequacy of the spillway capacity to pass the current design flood requirement (which is the PMF for this consequence category) and the structural inadequacy of the dams to resist the seismic loading from the criteria laid down by the British Columbia water Act – Dam Safety Regulation. Because of the high costs of rehabilitating the dams to be able to meet these criteria the City made a decision in October 2012 to remove the dams and return the river to a re-naturalized waterway. Criteria were established to implement this in February 2103, on the basis of which, a Construction Environmental Management Plan was prepared in June 2013.

The plan to remove the dams subsequently met with intense public opposition and the City council subsequently revoked its decision to remove the dams and re-naturalize the channel and, instead, in consultation with the Snuneymuxw First Nations (SFN), decided in May 2013 to remove the dams and replace them with new dams which would be designed to the stringent seismic and flood criteria required for its "Extreme" consequence classification.

In January 2013 the City retained Klohn Crippen Berger to conduct a study and cost estimates for the rehabilitation and replacement options. The results of this study were presented in a report entitled "Middle and Lower Colliery Dams, Conceptual Costing of Rehabilitation of and Replacement Options" dated May 1, 2013. Following discussions between the City and the SFN some further reassessment was done of the rehabilitation and replacement options to take into account SFN's concerns with respect to the impact on the fisheries habitat along the Chase River by removing and re-building the dams and it was subsequently agreed that the City would re-assess the options with the SFN's interests in mind. The scope of work for this reassessment work involved two stages as described below:

a) Short Term Mitigation

This involved investigation of three options to mitigate risks in the 2013/14 winter season:

- Lowering the water level behind the dams by pumping to control water levels up to the 1:25 year flood (21m^3/sec). The cost of this option would be high and there would be operational constraints and associated environmental risks with storage of large amounts of diesel fuel required for the pumps.
- Raising the crest height by introduction of lock block walls and hence increasing spillway capacity with the additional available head. Disadvantages to this are that the wall would impose an additional load on the dam which would cause further instability during a seismic event and any seepage from the wall could cause de-stabilization of the downstream slope of the dam.
- Lowering the spillways would lower the reservoir normal water levels by 3.0m and reduce the stored water volume by 50%. This would partially reduce the potential for loss of life downstream. There is the disadvantage that the lower spillway, which has some heritage value, would be destroyed. The seismic risk would still remain the same with the dams.

b) Long Term Mitigation

The design philosophy for the rehabilitation measures on the dams was modified to allow some limited damage to the dams but still requiring the dams to retain the reservoirs after a seismic event. The extent of rockfill on the upstream and downstream sides was sized to reduce the chance of the concrete wall and the jet grouted zones of the rockfill berm becoming unsupported due to settlement and sliding of the fill materials leading to cracking.

In August 2013 Klohn Crippen Berger prepared a report summarizing their re-assessment of options for the Middle and Lower Chase River Dams with the pros and cons of each alternative studied for both the short term and long term mitigation measures. The analyses that were carried out concluded the following:

- The existing concrete core walls and proposed jet grouted zones would crack for both the 1:5,000 and 1:10,000 seismic events;
- The 1:5,000 year seismic event (with the reservoir lowered by 3.0m) would result in deformations in the order of 25mm and 30 mm in the upstream and downstream directions at the Middle Dam respectively;
- The 1:5,000 year seismic event (with the reservoir lowered by 3.0m) would result in deformations in the order of 40mm and 30 mm in the upstream and downstream directions at the Lower Dam respectively;
- The 1:10,000 year seismic event (with the reservoir at the current elevation) would result in deformations in the order of 132mm and 68mm in the upstream and downstream directions at the Middle Dam respectively;
- The 1:10,000 year seismic event (with the reservoir at the current elevation) would result in deformations in the order of 135mm and 70mm in the upstream and downstream directions at the Lower Dam respectively;
- The seepage rates that would result from the calculated deformations and anticipated degree of cracking would be quite high;
- Klohn Crippen Berger also concluded that detailed seepage analyses and post seismic stability of the dams would have to be carried out if the City adopted the proposed rehabilitation measures. They cautioned that these analyses would be indicative only because of the variability in the quality of construction on the dams and consequently to take account of this, engineering judgment and conservative measures should be adopted in the rehabilitation of the dams.

2. MIDDLE CHASE RIVER DAM

2.1. Dam Description

The Middle Chase River Dam is located in the southern part of the City of Nanaimo and was constructed around 1911 to provide water for coal washing in the early part of the century when coal mining was in full production in Nanaimo. The location of the dam is shown in Fig. 2.1. The dam is 13m high and 50m long and is constructed of earth/rockfill shells on either side of a concrete core wall extending from the dam crest and keyed into bedrock. The concrete core is 0.6m thick at the crest elevation and was raised by 0.3m in 1980. The upstream shell is constructed to a slope of 1.5H to 1V and the downstream to a slope of 2H to 1V and was re-constructed in 1980 with the incorporation of a gravel filter drain to intercept seepage. Concentrated seepage was observed in 1992 and an additional gravel filter drain installed near the right abutment to intercept this. The spillway comprises a channel with concrete side walls and a natural rock base on the left side of the dam (see Photo MCR-01). There is a 350mm high concrete sill. There were facilities for placing stoplogs but these have now been removed. The capacity of the spillway has been determined as 62m^3/sec but no actual field measurements have been carried out to validate the flow capacity.

The layout of the Middle Chase River Dam is shown in Fig. 2.2 and a typical cross-section shown in Fig. 2.3. Salient data for the dam and appurtenant structures are given in Table 2.1.

Table 2.1 Salient data for the Middle Chase River Dam and Appurtenant Structures

Type of Dam	Concrete Core, Rock/Earthfill Dam
Maximum Height	13m
Crest Length	50m
Crest Elevation	88m
Top of Concrete Core Wall Elevation	Same as Dam Crest
Upstream Slope	1.5H:1V
Downstream Slope	2H:1V
Spillway Invert Elevation	86.041m
Low Level Outlet	N/A (the exiting woodstave LLO is abandoned and is not in service)
Spillway	Unregulated spillway designed to discharge under normal operating conditions; Concrete Channel
Hazard Rating	Extreme

2.2. Previous Dam Safety Reviews & Formal Annual Dam Safety Inspections

The last DSR was carried out for the Middle Chase River Dam in 2003 by Golder Associates and the consequence category at that time was "High". FADSIs have been ongoing regularly since 2008, with the latest in 2012, by BMA Engineering. The main recommendations made in the 2003 DSR were as follows:

- Automatic reading of the V-notch seepage weir with transfer of the readings into the City's SCADA system to give advance warning of deterioration in the dam condition. This was addressed in 2013.
- The spillway should be upgraded or the dam height increased so that a flood commensurate with the consequence classification of the dam can be safely passed (3,000 year return period event, based on High consequence category in 2003).
- Further studies should be carried out to determine whether the dam needs to be upgraded to resist a seismic event commensurate with the consequence classification of the dam. This was addressed in 2013.

As described in Section 1.3 a considerable amount of work has been carried out to determine the course of action to be taken on the Middle Chase River Dam since the 2003 DSR. The preferred option for the City was to remove the dam and re-naturalize the river. Construction procedures, appropriate erosion control measures and environmental studies were prepared to implement this option. Consequently this has precluded any upgrading measures to increase spillway capacity or improve the seismic resistance of the dam. Since the decision to remove the dam has now been reversed due to stakeholders opposition the City has recently (November 2013) appointed a consultant to review the options for upgrading the dam and spillway and prepare a detailed design for the preferred option for implementation.

Since the 30th November 2012 the Lower and Middle Chase River Dams have been equipped with automatic level monitoring. Flow sensors were also been installed on the spillways, readings from which are relayed to the SCADA system. It was reported in the 2012 FADSI that seepage flows were also relayed to the SCADA system. As of the 8th October 2013 automatic water level recording was also added to the SCADA system for the Upper Chase River Dam.

No new issues were identified by BMA Engineering in the 2012 FADSI but issues which were raised in previous FADSIs were listed. These are given below as they appear in the City's Dam Safety Issues Database presented in Appendix 4 to this report. The identification number in the database has been given for reference; the acronym identifies the dam, the number following the dam signifies the year and the number separated by a hyphen from the year identifies the issue number.

<u>MCR11-1 – Concrete Deterioration Spillway – Priority "Medium"</u>

Surface concrete deterioration was noted in many areas of the spillway including the upstream face, the side walls and the centre spillway pier but no significant displacement, settlement or cracking was noted. The issue was first recorded in 2009 (MCR09-3) and the new issue was opened in 2011 to cover inclusion in the inspection checklist.

<u>MCR11-1 – Action by the City</u>

The City monitors the deterioration in their weekly dam inspection checklist (see Appendix 6). This is only a visual check where any relative changes are in accordance with the numbering system explained in the City's Dam Applications Users Guide for the checklist (see Appendix 6).

MCR09-1 – Seepage Measuring Weir – Priority "High"

It is unclear what this issue refers to as the 2009 FADSI mentions debris presumably at the weir discharge area and visibility of the weir whereas the description in the Dam Safety issues Database in Appendix 4 clearly identifies the issue as monitoring and plotting seepage continuously with reservoir level. The latter issue has been taken to be correct.

MCR09-1 – Action by the City

The seepage weir has been recorded automatically since the 30th November 2012 and is linked to the SCADA system.

MCR09-4 – Irregularities in Crest Elevation of Dam – Priority "Medium"

The crest elevation of the dam was observed to rise towards the right abutment. The crest elevation should be checked to ensure that freeboard is adequate.

MCR09-4 – Action by the City

There is no action on this issue recorded by the City in the Dam Safety Issues Database. This issue is easily resolved by conducting a survey and should be expedited without further delay. The priority rating has been raised to "High" in this 2013 DSR. Any remedial action will depend on the results of the survey.

MCR09-5 – Erosion on Spillway Banks – Priority "High"

This issue is related to the turbulent flow in the discharge channel under even relatively small discharges. There is evidence of erosion in the banks and there are trees, undermined by erosion, overhanging the spillway channel which need to be removed.

MCR09-5 – Action by the City

There has been no action taken on this issue. Photographs MCR-04 and MCR-05 indicate the eroded area and the overhanging trees. Either the trees should be removed to avoid blockage of the channel if they were to be undermined completely and fall over in a major storm or a temporary gabion protection constructed along the eroded areas.

2.3. Consequence Classification

The Middle Chase River Dam is rated "Extreme Risk Level 1" by the Provincial Dam Safety Section – Water Management Branch in accordance with the 2011 BC Dam Safety Regulations. This consequence category was assigned to the dam following a dam breach inundation study by Associated Engineering in 2012. The study examined various dam breach scenarios at various flood frequencies and also a breach from a major seismic event. It was concluded that the number of fatalities for a dam failure resulting from a severe flood event could be in the range of 30-60. The number of casualties would depend on the timing of the dam failure after the onset of dam overtopping, the warning provided to residents prior to flooding and the amount of time available for evacuation. Economic losses would be in the range of $33.0 million to $36.0 million. The study found that the seismic induced failure could have a higher fatality rate in the range of 80 (daytime) to 150 (nighttime) because of the lack of warning to the public. The economic damages with a seismic induced failure would be in the order of $38.0 million.

The IDF for the “Extreme” category is the PMF. The PMF was determined from studies carried out in 2002 by Water Management Consultants and in 2012 by Associated Engineering to be 192m^3/sec and 198m^3/sec, respectively. The maximum capacity of the present spillway is 62m^3/sec with zero freeboard on the dam which is just below the 1000 year flood of 68m^3/sec computed by Water Management Consultants.

In accordance with the 2007 CDA Guidelines, revised in 2013, the MCE or the annual exceedance event of 1 in 10,000 should be considered. For Vancouver Island, this is a very large ground motion and in order to determine reliable values for the Peak Ground Acceleration (PGA), response spectra and acceleration time histories Probabilistic Seismic Hazard Analysis based on current seismotectonic and ground motion prediction models would have to be performed. As stated in Section 1.3 if a severe earthquake did occur the dam could sustain damage provided this did not result in excessive leakage which could lead to a complete dam failure. During its lifetime, it is estimated that the dam has experienced earthquake shaking of about 0.04g PGA or greater at least four times (Appendix 7) The largest shaking was estimated to be up to about 0.12g PGA which would be approximately equivalent to the 1 in 125 annual exceedance event.

2.4. Site Inspections

2.4.1. General

As part of the Dam Safety Review of the Middle and Lower Chase River Dams, site visits were conducted to review the dams and their associated infrastructure. Two visits were made; one visit on the 11th July by Derrick Penman Principal Hydroelectric Engineer and Masoud Mohajeri Principal Geotechnical Engineer and another more detailed inspection, on the 13th September, by Masoud Mohajeri after the Middle and Lower Chase River Dams were added to this present contract. The Watershed Inspectors, Bill Marshall and Pat Barrett were present at both visits and Scott Pamminger Water Resources Specialist and Euan Wilson, Water Resources Technologist on the second visit.

2.4.2 Observations & Findings

a) Middle Chase River Dam

The exposed concrete core wall displays some minor cracking and spalling which one would expect for a structure of this age (Photo MCR-07) but nothing evident that compromises the structural integrity of the wall. There is a seepage weir on the downstream toe of the dam adjacent to the spillway channel (Photo MCR-06), readings from which are relayed to the SCADA system. As part of the field work conducted during the seismic stability assessment of the dam carried out by EBA Engineering Consultants in 2010 a diving inspection upstream of the dam was carried out. The diver located a woodstave pipe which appeared to pass through the left abutment of the dam adjacent to the spillway in the area where the fill was not removed during the 1980 remediation work. This is obviously a cause for concern as it could collapse any time due to its deteriorated condition and cause piping due to increase seepage along the pipe triggering failure of the dam. Although seepage has been noted at this location over the years there was no sign of excessive seepage at the time of this inspection.

b) Spillway

There is some erosion visible at the base of the centre pier and the side walls of the spillway (Photos MCR-02 & MCR-03). Undercutting of the pier base is only minor at present but this should be monitored and repaired at some point as erosion will continue to occur. MCR-11 is a photograph taken (by others) during a high discharge period in winter. There are also cracks on the upstream face of the spillway and on the walls identified in previous FADSIs which should also be monitored (MCR11-1) but again do not display offsets which would indicate that there is a structural problem with the walls (Photo MCR-08). The pedestrian bridge abutment has also been eroded at the corner and should be repaired before its condition worsens (Photo MCR-08).

There is evidence of erosion taking place in unprotected areas of the spillway discharge channel which is cause for concern. There is undermining of trees along the channel's edge, causing them to lean towards the channel. In an unusual flood event these could be further destabilized and topple into the channel, causing a significant backwater. This has been previously identified as an issue with a high priority (MCR09-5) but no action has been taken by the City.

2.4.3 Summary of Observations & Findings

In general the dam and spillway appear to be performing satisfactorily. Because of the undercapacity of the spillway it is important that some measures be taken to eliminate the risk of blockage of the discharge channel either by cutting the trees presently leaning into the channel or providing a gabion protection around the eroded areas to prevent further undermining of the root system.

2.5. Operation, Maintenance & Surveillance

2.5.1. Operation

The Middle Chase reservoir is used for recreational purposes only. There is no operational offtake works and the spillway is a free overflow structure. Consequently there are no normal operation procedures for these dams.

The Chase River basin has a small catchment area of 20km^2 and responds quickly to heavy rainfall. Due to the under capacity of the spillways at each of the Middle and Lower Chase River Dams the City has procedures in place in the OMS manual to have a physical presence by the Watershed Inspectors at each of the dams to check that there is no blockage of the spillways by debris when the forecasted rainfall exceeds 25mm. Water levels are recorded on the SCADA system and monitored at the Public Works control centre as described further in Section 2.5.3.

2.5.2. Maintenance

Routine maintenance of the dam involves keeping the spillways clear of debris since there is no log boom and keeping vegetation on the downstream dam slope under control so that any signs of seepage can be monitored. The dam is inspected on a weekly basis and if there is build up of debris staff notify the Parks Department to remove it. Clearing of vegetation on the dam slopes is normally carried out in the fall.

The weekly inspection is carried out in accordance with the checklist provided in Appendix 6. Information is entered digitally into the Water Inspectors' portable lap top computer (see Appendix 6 for a sample input screen shot) from where it is transferred to the City's database on the server.

As reported in section 2.4.2 the overhanging trees in the spillway discharge channel require attention. This is highlighted in the OMS manual but action on this issue has been delayed by the City to date due to the uncertainty on the fate of the dam. Now that the removal of the dams is not proceeding some action is required on this issue.

2.5.3. Surveillance

Ultrasonic level sensor probes have been installed at the Middle Chase River Dam. This device is set up to measure reservoir levels as water enters the spillway. Using radio telemetry this data is then relayed back to the City's SCADA system in the Public Works department where a high water level alarm trigger point has been created. This SCADA data is monitored 24 hours a day 7 days a week by the City staff during normal working hours and Commissionaires and the City's on-call staff during normal working hours and on weekends. This data is collected and monitored but it should be promptly plotted also so that any anomalous behaviour is quickly identified (MCR13-01).

2.6. Hazard & Failure Mode Analysis

The hazard and failure mode analysis that has been carried out below is presented in Fig. 2.4.

2.6.1. Meteorological Events (External Hazard)

For meteorological hazards, the following failure modes <u>are not</u> considered possible for the Middle Chase River Dam:

1. <u>Management System Failure</u>

   The dam is located within the city boundary and access to the dam is just off the main road which is not likely to be blocked during a major flood event. The reservoir level is remotely monitored by SCADA 24 hours a day 7 days a week with provision for weekend monitoring (see Section 2.5.3). In the event that there is a malfunction of the SCADA system trained personnel can be dispatched to the dam within a short time period.

2. <u>Stability under Applied Loads</u>

   The downstream shell was remediated in 1980 and as part of the design of the remedial works the stability of the dam was reportedly checked and found to have an adequate factor of safety. The downstream shell was reconstructed with compacted granular fill and therefore will have enhanced the FOS from what was already acceptable.

   The upstream slope is believed to have been constructed of rockfill although to date this has not been substantiated. There are no signs such as cracking in the concrete core wall to suggest that there has been movement of the shell causing loss of support.

3. <u>Watertightness</u>

   The downstream face of the concrete core wall exposed during the 1980 remedial work appears to be in good condition with no significant cracking. There have been no seepage problems reported through the dam and in the 2003 DSR it was reported that seepage flows had in fact reduced from 1995 to 2003. It is unlikely that any minor seepage that does occur through cracking in the core wall or at the contact with the foundation could cause failure of the embankment since the downstream embankment is constructed of granular fill with a rockfill toe drain.

The following are listed as hazards and failure modes that are considered possible for the Middle Chase River Dam:

1. Inadequate Installed Discharge Capacity

   The PMF determined by Water Management Consultants is greater than the outflow capacity of the spillway which would result in overtopping of the dam (see Section 2.3 of the report). This could further be exacerbated by failure of the Reservoir No. 1 Dam upstream which may be unstable during passage of a PMF causing the release of the stored water into the Chase River.

2. Inadequate Available Discharge Capacity

   The spillway is a free overflow structure and therefore random functional failure on demand is not an issue. The discharge capacity could, however, be reduced by blockage of the crest by debris or of the discharge channel by falling trees (see Section 2.4.2 of the report).

3. Inadequate Freeboard

   An issue was raised regarding the crest elevation of the dam which appears to be lower on the left abutment. This needs to be checked by survey to ensure that the freeboard is adequate (MCR09-4).

4. Durability/Cracking – Internal Erosion

   The only mechanism that could cause cracking of the core wall from a meteorological event would be if the dam were to be overtopped and the downstream shell were to be washed out causing a differential pressure on the wall resulting in a crack or a toppling failure leading to a breach. A storm up to the 1,000 year event would be retained by the dam and is unlikely to cause cracking in the core.

2.6.2. Seismic (External Hazard)

For seismic hazards, the following failure modes are not considered possible for the Middle Chase River Dam:

1. Inadequate Installed Discharge Capacity

   It is not possible for a seismic event to cause inadequate installed discharge capacity.

2. Management System Failure

   It is unlikely that a seismic event would prevent inspection of the dam and spillway. The dam is close to the main road and even if there were to be some damage to the road system the dam is within the City limits and it could be accessible within a short time by helicopter if road access were not possible.

The following are hazard and failure modes that are considered possible for the Middle Chase River Dam:

1. Inadequate Available Discharge Capacity

   The spillway is a free overflow structure and therefore random functional failure on demand is not an issue. The discharge capacity could be reduced by blockage of the discharge channel by falling trees, collapse of spillway side walls and banks (see Section 2.4.2 of the report).

2. Inadequate Freeboard

   Recent studies have shown that slope failure of the fill could result in toppling of the concrete core wall into the reservoir with a consequent loss of freeboard and overtopping. Also if the woodstave offtake pipe is still present in the dam a severe earthquake could cause this to break and cause the crest to slough causing loss of freeboard.

3. Stability under Applied Loads

   The stability analysis of the dam has previously been carried out for a horizontal peak acceleration less than what is now required for the dam with the "Extreme" consequence rating where a seismic event with 1 in 10,000 year annual exceedance or MCE needs to be considered. Earthquake damage to the dam slopes can lead to a toppling failure of the core wall. The seismic stability of the dam and related structures needs to be re-evaluated using appropriate seismic loads. It is likely that conventional pseudostatic analysis will not indicate adequate factors of safety and a dynamic analysis approach may be required to perform a performance based assessment.

4. Watertightness

   A severe earthquake could cause cracking in the core wall and the existing buried woodstave low level outlet resulting in excessive leakage and piping which could lead to local slope failure and subsequent failure of the core wall due to lack of support as discussed in section 1.3.

5. Durability/Cracking

   The same mode of failure could occur as described above with the same consequences.

2.6.3. Reservoir Environment (External Hazard)

For reservoir environment hazards, the following are failure modes that are not considered possible for the Middle Chase River Dam:

1. Inadequate Installed Discharge Capacity
2. Inadequate Available Discharge Capacity
3. Inadequate Freeboard
4. Management System Failure
5. Stability under Applied Loads
6. Watertightness

7. Durability/Cracking

There is nothing to indicate that the reservoir rim is unstable and could cause a landslide or flood surge that could initiate any of the above failure characteristics. The topography does not indicate any unusually steep and hence potentially unstable areas. Also debris management in the dam is diligently monitored and is unlikely to be allowed to accumulate in the spillway approach area.

2.6.4. Water Barrier (Internal Hazard)

The water barrier is defined as the following:

- The main embankment dam
- The concrete core wall

The following are listed as hazard and failure modes that are not considered possible for the Middle Chase River Dam:

1. Inadequate Installed Discharge Capacity

   The design of the water barrier has no bearing on the installed discharge capacity.

2. Inadequate Available Discharge Capacity

   The design of the water barrier has no bearing on the available discharge capacity.

3. Inadequate Freeboard

   The core wall extends up to the crest of the dam on the upstream face. There is no landslide activity in the reservoir and the reservoir does not have a long fetch upstream of the dam to cause excessive wave formation and hence run-up. Although the freeboard on the dam is not conservative it appears to be adequate.

4. Management System Failure

   Reservoir levels and seepage are measured automatically and transmitted to the SCADA system which is monitored on a 24 hour 7 day a week basis (see Section 2.5.3). In addition the dam is visited on a weekly basis at which time debris accumulation water levels, seepage, etc. are visually/manually checked.

The following are listed as hazard and failure modes that are considered possible for the Middle Chase River Dam:

1. Stability under Applied Loads

   As discussed in Section 2.6.1 the embankment fill on either side of the core wall is considered stable for all loads except for the severe seismic condition which is discussed in Section 2.6.2. There was no sign of distress in the core wall when the remediation was carried out on the downstream fill section in 1980 which indicates that the embankment fills were providing adequate support for conditions experienced up to that time.

2. Watertightness

   The condition of the core wall appears adequate with no excessive seepage occurring; however, it is anticipated that the core wall will crack in a severe seismic event causing seepage as discussed in Section 2.6.2.

3. Durability/Cracking

   As discussed above if the core wall were to crack in a severe seismic event it could cause leakage and piping in the fill which could lead to partial collapses along the dam and overtopping. There could be a cascade effect where during overtopping the downstream fill is washed out and the core wall is subjected to unbalanced load and ultimately fail.

   There is also the possibility that the original woodstave pipe which was used in the offtake works is still somewhere inside the left abutment fill. Should this fail there could be a sudden collapse locally in the area causing loss of freeboard and overtopping.

2.6.5. Hydraulic Structures (Internal Hazard)

The hydraulic structures comprise the following:

- The dam
- The spillway
- Woodstave low level outlet (Abandoned)

The following are listed as hazard and failure modes that are not considered possible for the Middle Chase River Dam:

1. Management System Failure

   As discussed in Section 2.6.4 there is a good surveillance and inspection system in place for the dam and a breakdown of this leading to failure of the hydraulic structures is not considered likely.

The following are listed as hazard and failure modes that are considered possible for the Middle Chase River Dam:

1. Inadequate Installed Discharge Capacity

   The spillway is capable of handling flows only up to the 1 in 1,000 year annual exceedance. With the extreme consequence category of the dam the spillway capacity must be capable of passing the PMF (see Section 2.3).

2. Inadequate Available Discharge Capacity

   The spillway is a free overflow structure. There is no debris boom and hence vigilance must be exercised by the Watershed Inspectors to keep the approaches free of wood debris. There is the chance that the discharge channel could be blocked with falling trees (see Section 2.4.2 of the report).

3. Inadequate Freeboard

   There is inadequate freeboard to pass floods in excess of the 1 in 1000 year flood.

4. Stability under Applied Loads

   As discussed in previous sections of the report (see Sections 2.2 & 2.3) the dam is considered capable of resisting all loads with the exception of a severe seismic event when it is likely that the core wall could collapse into the reservoir which would result in overtopping of the dam and breaching.

5. Watertightness

   Watertightness could be compromised by a severe seismic event with cracking of the core wall and failure of the abandoned woodstave offtake pipe leading to seepage and piping (see Sections 2.2 & 2.3).

6. Durability/Cracking

   The same functional failure mode would apply as under Section 2.6.4 - Water Barrier.

2.6.6. Mechanical/Electrical (Internal Hazard)

None of the functional failure characteristics are considered likely under this hazard category. If the SCADA system were to malfunction the dam can be easily accessed to monitor water levels and seepage.

2.6.7. Infrastructure & Plans (Internal Hazard)

None of the functional failure characteristics are considered likely under this hazard category. The dam is located within the city boundaries and is easily accessed in an emergency. The OMS manual and EPP lay out procedures for deployment of trained observers in an emergency situation.

2.7. Dam Safety Review Findings

2.7.1. General

The requirements of the 2011 BC Dam Safety Regulations are generally being met. In accordance with the regulations surveillance is carried out on a weekly basis and FADSIs are carried out. The last DSR was done 10 years ago in 2003, the findings from which prompted a series of studies to determine flood capacity, the inundated area and population at risk in a dam breach scenario to determine the consequence category of the dam. Instrumentation has been automated and is continuously monitored. The City has also been proactive in coming up with solutions to eliminate the risk to the residents living downstream of this dam. This process is still ongoing after public opposition to dam removal has forced other solutions to be investigated and more studies to be carried out.

The following section summarizes the key findings of the hazard analysis carried out for this current DSR. This DSR confirms what is already known about the dam which is at severe flood and seismic conditions the dam would be unsafe and would pose a risk to the population living downstream.

2.7.2. Hazard Matrix Analysis

The following are the key findings of the Hazard Matrix Analysis:

1. It was concluded from the completed hazard matrix analysis that a risk to dam failure would result from a severe seismic event. In the detailed design work that is to be undertaken for remedial measures to be implemented on the dam and spillway the stability of the dam should be checked for the 1 in 10,000 annual exceedance event or MCE in

accordance with the CDA Guidelines (revised in 2013). With this magnitude of earthquake a dynamic analysis should be carried out, as a conventional pseudostatic method will not be sufficient. In addition, in order to determine a reasonable value for the Peak Ground Acceleration, response spectra and acceleration time histories Probabilistic Seismic Hazard Studies would have to be performed. A new issue (MCR13-2) has been added in the Dam Issues database in Appendix 4 to cover this.

2. It was concluded from the completed hazard matrix analysis that a risk of dam failure would result from floods in excess of the 1 in 1000 annual exceedance event. Several alternatives have been put forward by Klohn Crippen Berger to increase spillway outflow capacity. It is understood that these will be considered in the remedial measures to be implemented on the dam.

3. Until the remedial measures are implemented the trees overhanging the spillway discharge channel should be cut to reduce the risk of depleting the capacity of the spillway should the root system be completely undermined and the trees fall into the channel. Alternatively some temporary protection in the form of a gabion wall should be provided to prevent further erosion (MCR09-5).

4. There was a previous issue raised concerning the crest elevation of the dam which appeared to be lower at the left abutment and increasing towards the right. This should be a straightforward task to determine by a ground survey and should be done as soon as possible to ensure that there is the correct freeboard (MCR09-4).

2.7.3. Consequence Category

The “Extreme” consequence category is considered appropriate.

2.7.4. OMS Manual

The OMS manual was reviewed and no major issues identified. It should be mentioned in the manual that seepage and reservoir level data should be plotted on a regular basis so that any anomalies in the dam performance can be readily identified.

2.7.5. Emergency Preparedness Plan (EPP)

Because of the risk of failure of the Middle and Lower Chase River Dams in severe flood or seismic events a comprehensive EPP was prepared by the City for the Middle and Lower Chase River Dams in 2013 separate from the combined EPP which previously existed for all the dams under City’s control.

This was complemented by a Public Works Department Operations Plan for the Middle and Lower Chase River Dams which detailed the alarm levels for the automatic monitoring system for the Chase River Dams including the Upper Chase and at which stages of alarm trained observers would be dispatched to site.

Several training exercises have been undertaken in 2013. The latest full emergency training exercise was conducted on the 28th November 2013 during which about 100 emergency personnel took part to exercise the Middle and Lower Chase Dams Emergency Action Plan. The Provincial Dam Safety Branch did not attend this exercise.

3. LOWER CHASE RIVER DAM

3.1. Dam Description

The Lower Chase River Dam is located downstream of the Middle Chase River Dam. Like the Middle Chase River Dam it was originally constructed in 1910 to supply water for the nearby Harewood Colliery when this was in production. It was believed that this function was finished around 1945 and now is part of the recreational area called Colliery Dam Park. The location of the dam is given in Fig. 2.1.

The Lower Chase River Dam is an earth/rockfill structure approximately 77m long and with a maximum height of about 24m. The dam lies in a narrow steep sided ravine with both abutments founded on what is believed to be till material from a borehole that was drilled during the course of the planning of a remedial works program in 1978. The 2003 DSR by Golder Associates postulated that bedrock might be overlain by a veneer of till (or possibly channel fill) in the center of the ravine. The downstream shell was stabilized in 1980 by a compacted sand and gravel berm to a slope of 2H to 1V and the original upper slope was left at 1.5H to 1V. Drainage ditches were also formed at the abutment and a gravel filter drain to intercept seepage through the dam and abutments was added.

A concrete wall provides the impervious barrier and also forms the front face of the dam (see Photo LCR-01). The top 0.6m or so of the wall is 0.3m thick and it then reportedly thickens to 1.2m according to EBA Engineering. It is believed that the wall is founded on till at the base of the dam. The upstream support of the wall is believed to be by a rockfill shell. The plan of the dam is shown in Fig. 3.1 and a typical section in Fig 3.2.

The spillway is a rectangular concrete lined channel which bifurcates into two channels upstream of the spillway structure. A double span footbridge is constructed over the channel (see Photo LCR-02). The spillway is a free overflow structure with the water level controlled by the spillway lip elevation.

There are no offtake works from the dam; the two original low level outlet pipes passing through the body of the dam were capped in concrete, the valves removed and the control chamber backfilled.

Salient data for the dam and appurtenant structures are given in Table 3.1.

Table 3.1 Salient data for the Lower Chase River Dam and Appurtenant Structures

Type of Dam	Concrete Core, Rock/Earthfill Dam
Maximum Height	24m
Crest Length	77m
Crest Elevation	72.5-75.3m
Top of Concrete Wall Elevation	Same as Dam Crest
Upstream Slope	1.5H:1V
Downstream Slope	2h:1V
Spillway Invert Elevation	71.652m
Spillway	Unregulated spillway designed to discharge under normal operating conditions; Concrete Channel
Hazard Rating	Extreme

3.2. Previous Dam Safety Reviews & Formal Annual Dam Safety Inspections

The last DSR was carried out for the Lower Chase River Dam in 2003 by Golder Associates and FADSIs have been ongoing regularly since 2008, with the latest in 2012, by BMA Engineering. The main recommendations made in the 2003 DSR were as follows:

- Automatic reading of the V-notch seepage weir with transfer of the readings into the City's SCADA system to give advance warning of deterioration in the dam condition.
- The upstream part of the downstream slope of the dam should be reinstated to prevent the slippage that was observed during the inspections.
- The spillway should be upgraded so that a flood commensurate with the consequence classification of the dam can be safely passed (3,000 year return period event for the consequence rating at that time).
- Further studies should be carried out to determine whether the dam needs to be upgraded to resist a seismic event commensurate with the consequence classification of the dam.

As described in Section 1.3 a considerable amount of work has been carried out to determine the course of action to be taken on the Lower Chase River Dam since the 2003 DSR. The preferred option for the City was to remove the dam and re-naturalize the river. In conjunction with the Middle Chase Dam construction procedures, appropriate erosion control measures and environmental studies were prepared to implement this option. Consequently this has precluded any upgrading measures to increase spillway capacity or improve the seismic resistance of the dam. Since the decision to remove the dam has now been reversed due to stakeholders opposition, the City has recently (November 2013) appointed a consultant to review the options for upgrading the dam and spillway and prepare a detailed design for the preferred option for implementation.

Since the 30th November 2012 the Lower Chase River Dam has been equipped with automatic level monitoring. A flow sensor has also been installed on the spillway, level recordings from which are relayed to the SCADA system (see Photo LCR -10). It was reported in the 2012 FADSI that seepage flows were also relayed to the SCADA system

No new issues were identified by BMA Engineering in the 2012 FADSI but issues which were raised in previous FADSIs were listed. These are given below as they appear in the City's Dam Safety Issues Database presented in Appendix 4 to this report.

<u>LCR09-1 – Seepage Measuring Weir – Priority "High"</u>

This is the same issue recorded for the Middle Chase River Dam, where the description in the report was unclear but appears to be referring to the automation of the data collection as it appears from the Dam Safety issues Database in Appendix 4.

<u>LCR09-1 – Action by the City</u>

The seepage weir has been recorded automatically since the 30th November 2012 and is linked to the SCADA system (see Photo LCR-05).

<u>LCR09-2– Debris Collection – Priority "Very High"</u>

Some minor debris collection was noted upstream of the dam and in the spillway entrance channel. The FADSI noted the importance of debris clearing following storms.

LCR09-2- Action by the City

The issue of debris clearing was raised with the Watershed Inspectors during this current DSR and reportedly the procedures outlined in the OMS manual are followed. If there is significant accumulation of debris the Parks Department are notified to remove it.

LCR09-3 – Condition of Spillway Priority "Medium"

Significant cracking was noted in the spillway entrance bay and chutes as well as on the core wall of the dam. Monitoring was recommended.

MCR09-3 – Action by the City

The Watershed Inspectors are instructed to record this at regular intervals on annotated photographs.

LCR09-4 – Spillway Velocity Monitoring Priority "Medium"

Review of the velocities and water levels associated with the IDF were recommended to ensure that the spillway walls were of a sufficient height.

LCR09-4 – Action by the City

This issue was covered in the 2012 inundation study

LCR09-5– Spillway Chute Erosion "Medium"

It was recommended that a detailed inspection of the work carried out on the remedial works for the erosion of the rock slope below the spillway chute be carried out.

LCR09-5 – Action by the City

There has been no action by the City on this issue. Presumably this will be resolved in the measures to be undertaken to increase the spillway capacity.

LCR09-6– Potential for Erosion on Downstream Slope of Dam "High"

As noted in the 2003 DSR the upper part of the downstream slope of the dam is steep (see Photo LCR-03) and erosion is occurring. The 2009 FADSI recommended that the stability be reviewed and remedial measures carried out accordingly.

LCR09-6– Action by the City

No action has been taken by the City since this was reported. This issue will be covered in remedial measures to be undertaken in the seismic upgrade of the dam.

3.3. Consequence Classification

The Lower Chase River Dam is rated "Extreme Risk Level 1" by the Provincial Dam Safety Section, Water Management Branch in accordance with the 2011 BC Dam Safety Regulations. This consequence category was assigned to the dam following a dam breach inundation study by Associated Engineering in 2012. An outline of the results of this study has been given in Section 2.3.

The IDF for the “Extreme” category is the PMF. The PMF was determined from studies carried out in 2002 by Water Management Consultants to be $198m^3$/sec. The maximum capacity of the present spillway is $25m^3$/sec with zero freeboard on the dam and $35m^3$/sec with overtopping of the spillway chute walls which would not be acceptable. The 1 in 1000 year annual exceedance flood is $68m^3$/sec. Consequently the spillway is grossly undersized.

As discussed in section 2.3, in accordance with the 2007 CDA Guidelines, revised in 2013, the MCE or the annual exceedance event of 1 in 10,000 should be considered and Probabilistic Seismic Hazard Studies would have to be performed.

As stated in Section 1.3 if a severe earthquake did occur the dam could sustain damage provided this did not result in excessive leakage which could trigger a complete dam failure. During its lifetime the dam has sustained at least four large earthquake vibrations the biggest of which was a 0.12g PGA which would be approximately equivalent to the 1 in 125 annual exceedance event (see Appendix 7).

3.4. Site Inspections

3.4.1. General

As part of the Dam Safety Review of the Middle and Lower Chase River Dams, site visits were conducted to review the dams and their associated infrastructure. Two visits were made; one visit on the 11th July by Derrick Penman Principal Hydroelectric Engineer and Masoud Mohajeri Principal Geotechnical Engineer and another more detailed inspection, on the 13th September, by Masoud Mohajeri after the Middle and Lower Chase River Dams were added to this present contract. The Watershed Inspectors, Bill Marshall and Pat Barrett were present at both visits and Scott Pamminger Water Resources Specialist and Euan Wilson, Water Resources Technologist on the second visit.

3.4.2 Observations & Findings

a) Lower Chase River Dam

The exposed concrete core wall displays some minor cracking and spalling which one would expect for a structure of this age (Photo LCR-12) but nothing that compromises the structural integrity of the wall and it appears to be in a stable condition. There is a seepage weir on the downstream toe of the dam (Photos LCR-05, LCR-06 & LCR-07), readings from which are relayed to the SCADA system. There was minor seepage at the weir at the time of the inspection (see Photo LCR-06). The upper slope of the dam is steep and some erosion is evident (LCR- 03 & LCR-04). Some subsidence was noted in the dam crest which is likely attributed to this. There was no debris collection in the reservoir at the time of the visit (see Photo LCR-11).

b) Spillway

There is wide cracking at the abutment of the spillway footbridge (see Photo LCR-08). There is cracking also in the spillway approach walls (see Photo LCR -09). There is some minor cracking and erosion in the spillway centre pier (Photos LCR-10).

3.4.3 Summary of Observations & Findings

In general the dam and spillway appear to be performing satisfactorily. There are still outstanding issues such as the oversteep top section of the downstream slope which is eroding and causing subsidence in the crest. There is a major crack in the spillway footbridge abutment which would possibly open up further and result in a collapse of the footbridge deck in a severe seismic event.

3.5. Operation Maintenance & Surveillance

3.5.1. Operation

The Lower Chase reservoir is used for recreational purposes only. There are no operational offtake works and the spillway is a free overflow structure. Consequently there are no normal operation procedures for these dams.

The Chase River basin responds quickly to high rainfall. Due to the under capacity of the spillways at each of the Middle and Lower Chase River Dams the City has procedures in place in the OMS manual to have a physical presence by the Watershed Inspectors at each of the dams to check that there is no blockage of the spillways by debris. Reservoir levels are automatically recorded and relayed through the SCADA system where they are monitored by the Public Works Department.

3.5.2. Maintenance

Routine maintenance of the dam involves keeping the spillways clear of debris since there is no log boom and keeping vegetation on the downstream dam slope under control so that any signs of seepage can be monitored. The dam is inspected on a weekly basis and if there is build up of debris the Parks Department are notified and it is promptly removed. Clearing of vegetation is normally carried out in the fall.

The weekly inspection is carried out in accordance with the checklist provided in Appendix 6. Information is entered digitally into the lap top computer from where it is transferred to the City's database on the server.

3.5.3. Surveillance

Ultrasonic level sensor probes have been installed at the Lower Chase River Dam. This device is set up to measure reservoir levels as water enters the spillway. Using radio telemetry this data is then relayed back to the City's SCADA system in the Public Works department where a high water level alarm trigger point has been created. This SCADA data is monitored 24 hours a day 7 days a week by the City staff during normal working hours and Commissionaires and the City's on call staff during normal working hours and on weekends. This data is collected and monitored but it should be plotted also so that any anomalous behaviour is readily identified. A new issue (LCR13-01) has been added to the Dam Safety Issues Database in Appendix 4 to cover this.

3.6. Hazard & Failure Mode Analysis

The hazard and failure mode analysis that has been carried out below is presented in Fig. 3.3.

3.6.1. Meteorological Events (External Hazard)

For meteorological hazards, the following failure modes are not considered possible for the Lower Chase River Dam:

1. Inadequate Freeboard

   The core wall extends up to the crest of the dam on the upstream face. There is no landslide activity in the reservoir and the reservoir does not have a long fetch upstream of the dam to cause excessive wave formation and hence run-up. Although the freeboard on the dam is not conservative it appears to be adequate.

2. Management System Failure

   The dam is located within the city boundary and access to the dam is just off the main road which is not likely to be blocked during a major flood event. The reservoir level is remotely monitored by SCADA 24 hours a day 7 days a week with provision for weekend monitoring (see Section 3.5.3). In the event that there is a malfunction of the SCADA system trained personnel can be dispatched to the dam within a short time period.

3. Stability under Applied Loads

   The downstream shell was remediated in 1980 and as part of the design of the remedial works the stability of the dam was reportedly checked and found to have an adequate factor of safety.

   The upstream slope is believed to have been constructed of rockfill although to date this has not been substantiated. There are no signs such as cracking in the concrete wall to suggest that there has been movement of the shell causing loss of support.

4. Watertightness

   The exposed section of the concrete core wall appears to be in good condition with no significant cracking. It is unlikely that any minor seepage that does occur through cracking in the core wall or at the contact with the foundation could cause failure of the embankment since the downstream embankment is constructed of granular fill with a rockfill toe drain.

For meteorological hazards, the following failure modes are considered possible for the Lower Chase River Dam:

1. Inadequate Installed Discharge Capacity

   The PMF determined by Water Management Consultants is greater than the outflow capacity of the spillway which would result in overtopping of the dam (see Section 2.3 of the report). This could further be exacerbated by failure of the Middle Chase River Dam upstream which may be unstable during passage of a PMF causing the release of the stored water into the Chase River.

2. Inadequate Available Discharge Capacity

   The spillway is a free overflow structure and therefore random functional failure on demand is not an issue. The discharge capacity could, however, be reduced by blockage of the crest by debris since there is no log boom.

3. Durability/Cracking – Internal Erosion

The only mechanism that could cause cracking of the core wall would be if the dam were to be overtopped and the downstream shell were to be washed out causing a differential pressure on the wall causing a crack or a toppling failure leading to a breach.

3.6.2. Seismic (External Hazard)

For seismic hazards, the following failure modes are not considered possible for the Lower Chase River Dam:

1. Inadequate Installed Discharge Capacity

   It is not possible for a seismic event to cause a meteorological event.

2. Management System Failure

   It is unlikely that a seismic event would prevent inspection of the dam and spillway. The dam is close to the main road and even if there were to be some damage to the road system the dam is within the City limits and it could be accessible within a short time by helicopter if road access were not possible.

The following are hazard and failure modes that are considered possible for the Lower Chase River Dam:

1. Inadequate Available Discharge Capacity

   The spillway is a free overflow structure and therefore random functional failure on demand is not an issue. The discharge capacity could, however, be reduced by collapse of the footbridge in a severe seismic event, blocking the spillway channel.

2. Inadequate Freeboard

   Recent studies have shown that slope failure of the fill could result in toppling of the concrete core wall into the reservoir with a consequent loss of freeboard and overtopping.

3. Stability under Applied Loads

   The stability analysis of the dam has originally been carried out for a horizontal peak acceleration less than what is now required for the dam with the “Extreme” consequence rating where a seismic event with 1 in 10,000 year annual exceedance need to be considered. Earthquake damage to the dam slopes can lead to a toppling failure of the core wall. The seismic stability of the dam and related structures needs to be re-evaluated using appropriate seismic loads. It is likely that conventional pseudostatic analysis will not indicate adequate factors of safety and a dynamic analysis approach may be required to perform a performance base assessment. A new issue (LCR13-02) has been added to the Dam Issues Database in Appendix 4 to cover this.

4. Watertightness

   A severe earthquake could cause cracking in the core wall resulting in excessive leakage and piping which could lead to local slope failure and subsequent failure of the core wall due to lack of support as discussed in section 1.3.

5. Durability/Cracking

   The same mode of failure could occur as described above with the same consequences.

3.6.3. Reservoir Environment (External Hazard)

The following are listed as hazard and failure modes that are not considered possible for the Lower Chase River Dam:

1. Inadequate Installed Discharge Capacity
2. Inadequate Available Discharge Capacity
3. Inadequate Freeboard
4. Management System Failure
5. Stability under Applied Loads
6. Watertightness
7. Durability/Cracking

There is nothing to indicate that the reservoir rim is unstable and could cause a landslide or flood surge that could initiate any of the above failure characteristics. The topography does not indicate any unusually steep and hence potentially unstable areas. Also debris management in the dam is diligently monitored and hence debris accumulation is unlikely to be allowed to occur in the spillway approach area.

3.6.4. Water Barrier (Internal Hazard)

The water barrier is defined as the following:

- The main embankment dam
- The concrete core wall

The following are listed as hazard and failure modes that are not considered possible for the Lower Chase River Dam:

1. Inadequate Installed Discharge Capacity

   The design of the water barrier has no bearing on the installed discharge capacity.

2. Inadequate Available Discharge Capacity

   The design of the water barrier has no bearing on the installed discharge capacity.

3. Inadequate Freeboard

   The core wall extends up to the crest of the dam on the upstream face. There is no landslide activity in the reservoir and the reservoir does not have a long fetch upstream of the dam to cause excessive wave formation and hence run-up. Although the freeboard on the dam is not great it appears to be adequate.

4. Management System Failure

   Reservoir levels and seepage is measured automatically and transmitted to the SCADA system where it is monitored on a 24 hour 7 day a week basis (see Section 3.5.3). In addition, the dam is inspected on a weekly basis at which time debris accumulation water levels, seepage etc. are manually checked.

The following are listed as hazard and failure modes that are considered possible for the Lower Chase River Dam:

1. Stability under Applied Loads

   The embankment fill on either side of the core wall is considered stable for all loads except for the severe seismic condition which is discussed in Section 3.6.2.

2. Watertightness

   The condition of the core wall appears adequate with no excessive seepage occurring; however, it is anticipated that the core wall will crack in a severe seismic event causing seepage as discussed in Section 3.6.2.

3. Durability/Cracking

   As discussed above if the core wall were to crack in a severe seismic event it could cause leakage and piping in the fill which could lead to partial collapses along the dam and overtopping. There could be a cascade effect where during overtopping the downstream fill is washed out and the core wall is subjected to unbalanced load leading to a toppling failure.

3.6.5. Hydraulic Structures (Internal Hazard)

The hydraulic structures comprise the following:

- The dam
- The spillway

The following are listed as hazard and failure modes that are not considered possible for the Lower Chase River Dam:

1. Management System Failure

   As discussed in Section 3.6.4 there is a regular surveillance and inspection system in place for the dam and a breakdown of this leading to failure of the hydraulic structures is not considered likely.

The following are listed as hazard and failure modes that are considered possible for the Lower Chase River Dam:

2. Inadequate Installed Discharge Capacity

   With the extreme consequence category of the dam the spillway capacity must be capable of passing the PMF (see Section 3.3). The spillway can only pass 25m^3/sec with zero freeboard on the dam which is grossly undersized and in a severe flood overtopping of the embankment would occur.

3. Inadequate Available Discharge Capacity

   The spillway is a free overflow structure. There is no debris boom and hence vigilance must be exercised by the Watershed Inspectors to keep the approaches free of wood debris. There is the chance that the discharge channel could be blocked with falling trees.

4. Inadequate Freeboard

   There is inadequate freeboard to pass floods in excess of 25m^3/sec where PMF is estimated to be 198m^3/sec.

The following are listed as hazard and failure modes that are considered possible for the Lower Chase River Dam:

1. Stability under Applied Loads

   As discussed in previous sections of the report the dam is considered capable of resisting all loads with the exception of a severe seismic event when it is likely that the core wall could collapse into the reservoir which would result in overtopping of the dam leading to breaching.

2. Watertightness

   Watertightness could be compromised by a severe seismic event with cracking of the core wall leading to seepage and piping.

3. Durability/Cracking

   The same functional failure mode would apply as under Section 3.6.4 - Water Barrier.

3.6.6. Mechanical/Electrical (Internal Hazard)

None of the functional failure characteristics are considered likely under this hazard category. If the SCADA system were to malfunction the dam can be readily accessed to monitor water levels and seepage.

3.6.7. Infrastructure & Plans (Internal Hazard)

None of the functional failure characteristics are considered likely under this hazard category. The dam is located within the city boundaries and is easily accessed in an emergency. The OMS manual and EPP lay out procedures for deployment of trained observers in an emergency situation.

3.7. Dam Safety Review Findings

3.7.1. General

The requirements of the 2011 BC Dam Safety Regulations are generally being met. In accordance with the regulations surveillance is carried out on a weekly basis and FADSIs are carried out. The last DSR was done 10 years ago in 2003, the findings from which prompted a serious of studies to determine flood capacity, the inundated area and population at risk in a dam breach scenario to determine the consequence category of the dam. Instrumentation has been automated and is continuously monitored. The City has also been proactive in investigating solutions to eliminate the risk to the residents living downstream of this dam. The least cost option was to remove the dam. This process is still ongoing after public opposition to dam removal has forced other solutions to be investigated and more studies to be carried out.

The following section summarizes the key findings of the hazard analysis carried out for this current DSR. This DSR confirms what is already known about the dam which is during severe flood and seismic conditions the dam would be unsafe and would pose a risk to the population living downstream.

3.7.2. Hazard Matrix Analysis

The following are the key findings of the Hazard Matrix Analysis:

1. It was concluded from the completed hazard matrix analysis that a risk to dam failure would result from a severe seismic event. In the detailed design work that is to be undertaken for remedial measures to be implemented on the dam and spillway the stability of the dam should be checked for the 1 in 10,000 annual exceedance event or MCE in accordance with the CDA Guidelines (revised in 2013). With this magnitude of earthquake a dynamic analysis should be carried out, as a conventional pseudostatic method will not be appropriate. In addition in order to arrive at a reasonable value for the Peak Ground Acceleration (PGA) probabilistic Seismic Hazard Studies would have to be performed (LCR13-2).
2. It was concluded from the completed hazard matrix analysis that a risk of dam failure would result from floods in excess of $25m^3$/sec. Several alternatives have been put forward by Klohn Crippen Berger to increase spillway outflow capacity. It is understood that these will be considered in the remedial measures to be implemented on the dam.

3.7.3. Consequence Category

The “Extreme” consequence category is considered appropriate.

3.7.4. OMS Manual

The OMS manual was reviewed and no major issues identified. It should be mentioned in the manual that seepage and reservoir level data should be plotted on a regular basis so that any anomalies in the dam performance can be readily identified (LCR 13-1).

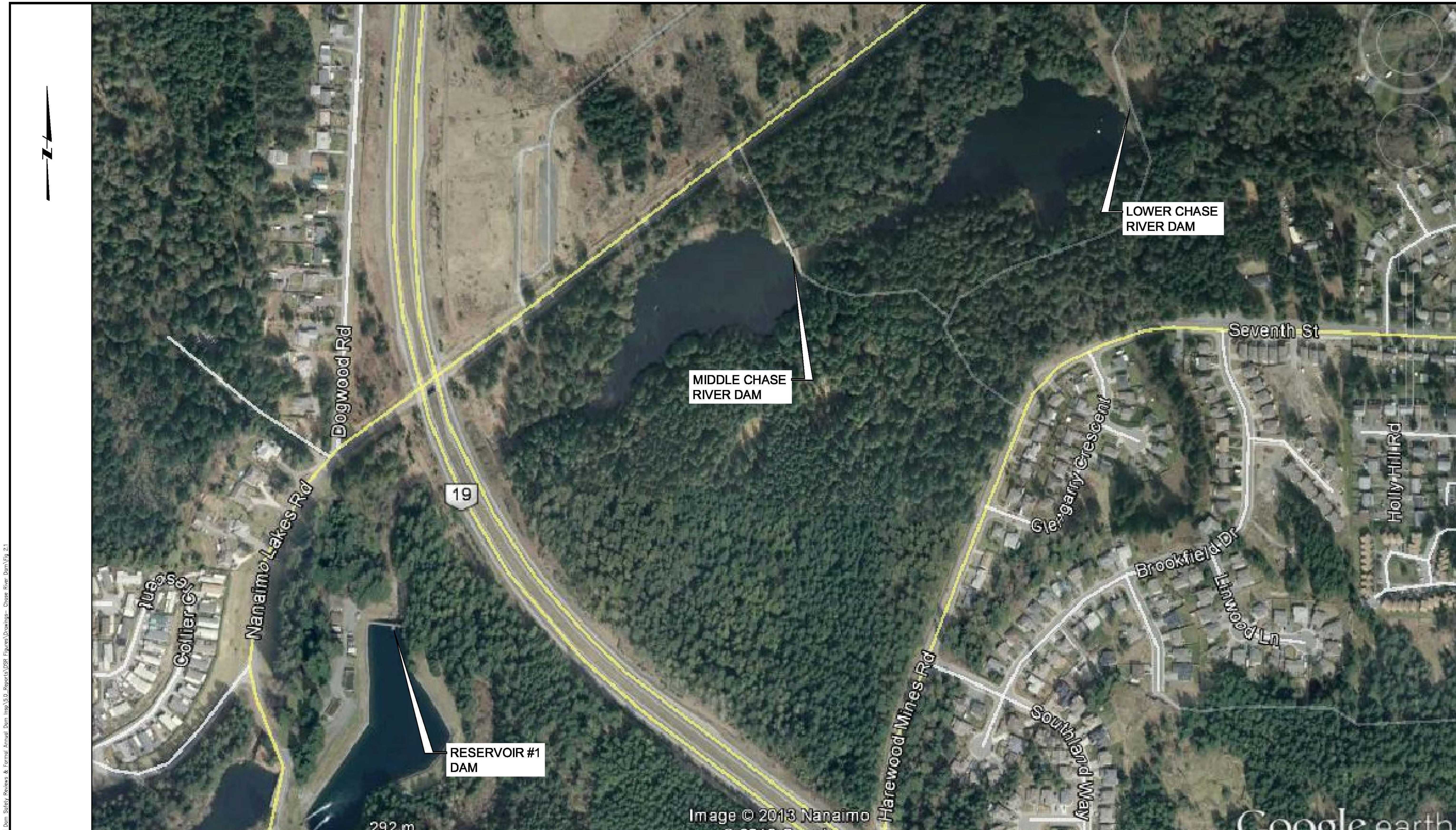
3.7.5. Emergency Preparedness Plan (EPP)

Because of the risk of failure of the Middle and Lower Chase River Dams in severe flood or seismic events a comprehensive Emergency Preparedness Plan (EPP) was prepared by the City for the Middle and Lower Chase River Dams in 2013 separate from the combined EPP which previously existed for all the dams under City’s control.

This was complemented by a Public Works Department Operations Plan for the Middle and Lower Chase River Dams which detailed the alarm levels for the automatic monitoring system for the Chase River Dams including the Upper Chase and stipulated at which stages of alarm trained observers would be dispatched to site.

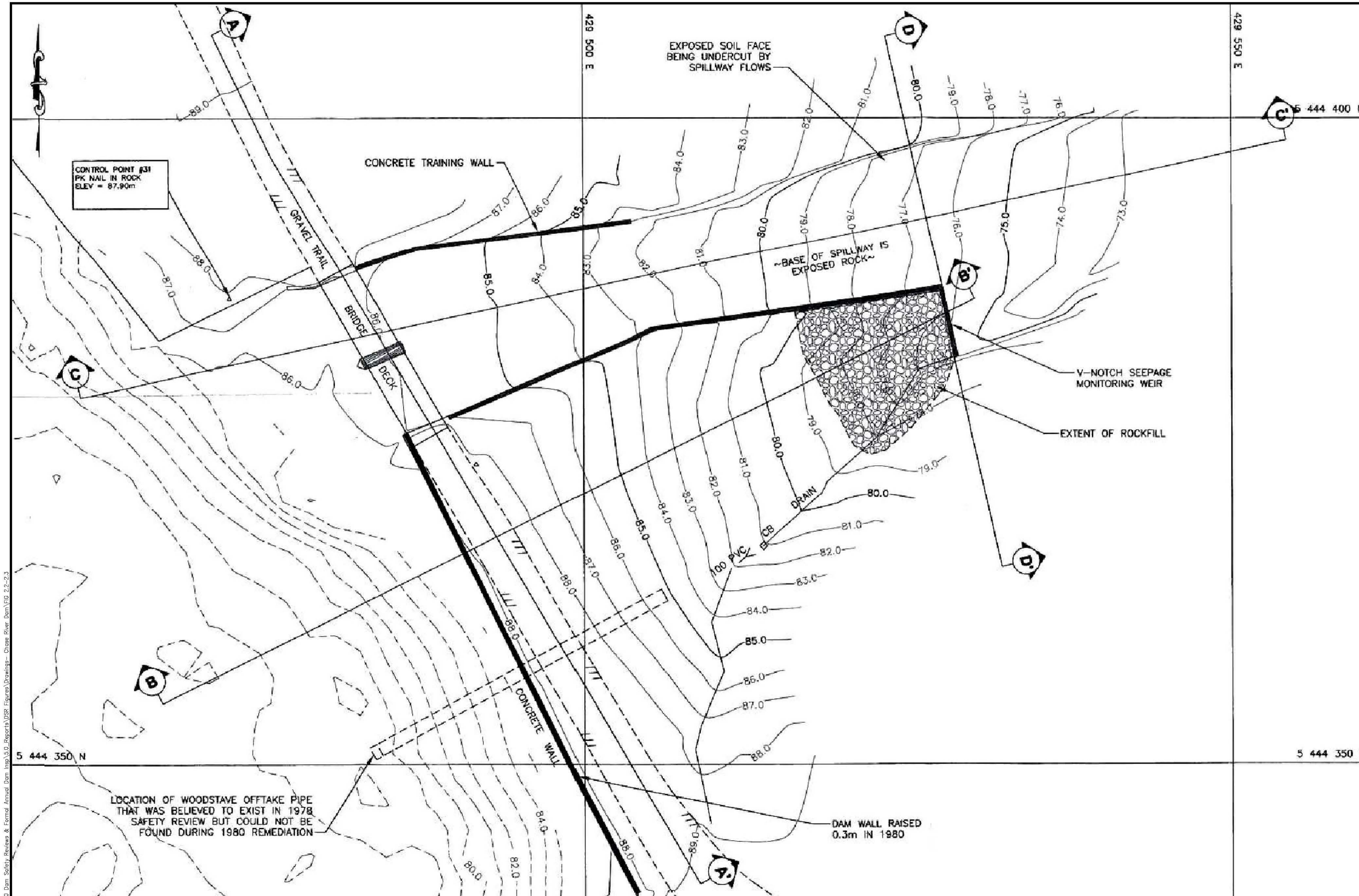
Several exercises have been held under the direction of the City's Emergency Coordination Centre/ Nanaimo Fire Rescue. This involved a unified/coordinated approach involving over 100 personnel to exercise the Middle and Lower Chase Dams Emergency Action Plan. The latest of these was held on the 28th November 2013. The Provincial Dam Safety Branch did not attend this exercise.

Appendix 1



CITY OF NANAIMO THE HARBOUR CITY	PROJECT **DAM SAFETY REVIEW FOR THE MIIDLE & LOWER CHASE DAMS**
MWH BUILDING A BETTER WORLD	TITLE LOCATION PLAN OF MIDDLE AND LOWER CHASE RIVER DAM
	PROJECT No. 25500790 — FIG. No. 2.1

\\CAVAN1S01\projects\City of Nanaimo\25500790 Dam Safety Reviews & Formal Annual Dam Insp\5.0_Reports\DSR Figures\Drawings - Chase River Dam\Fig 2.1



CITY OF NANAIMO
THE HARBOUR CITY

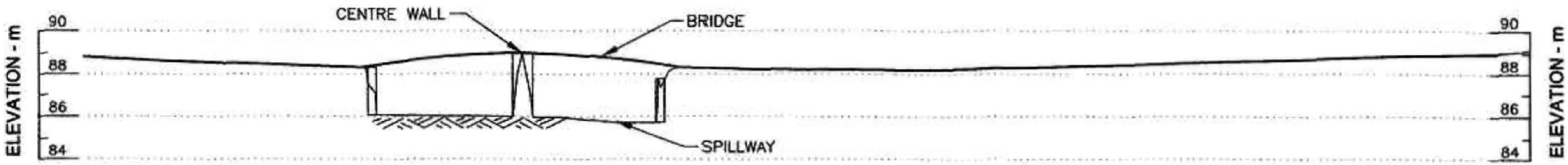
MWH
BUILDING A BETTER WORLD

PROJECT:
DAM SAFETY REVIEWS FOR THE MIDDLE & LOWER CHASE DAMS

TITLE:
LAYOUT OF THE MIDDLE CHASE DAM

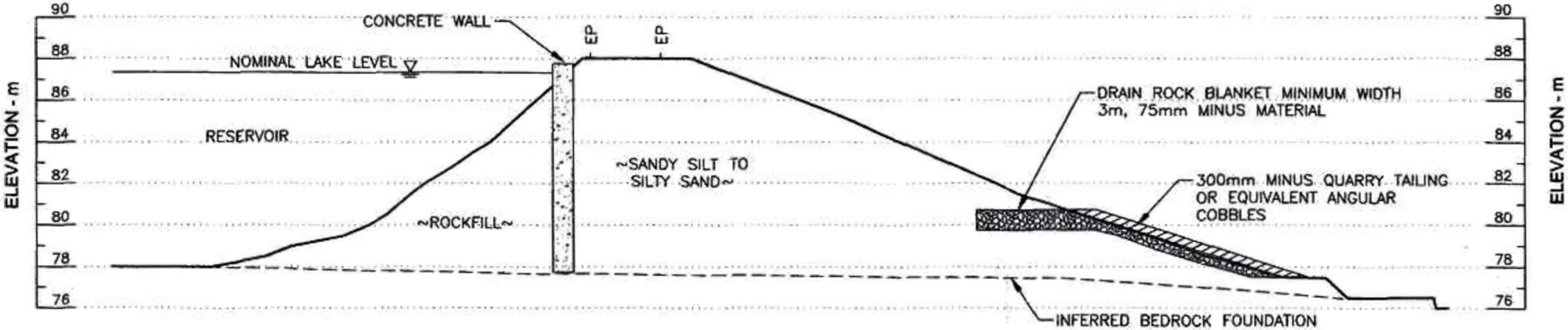
PROJECT No. 25500790

FIG. No. 2.2



A **SECTION THROUGH SPILLWAY INTAKE & CREST OF DAM**

0 2 4 6 8 10
Scale in Meters



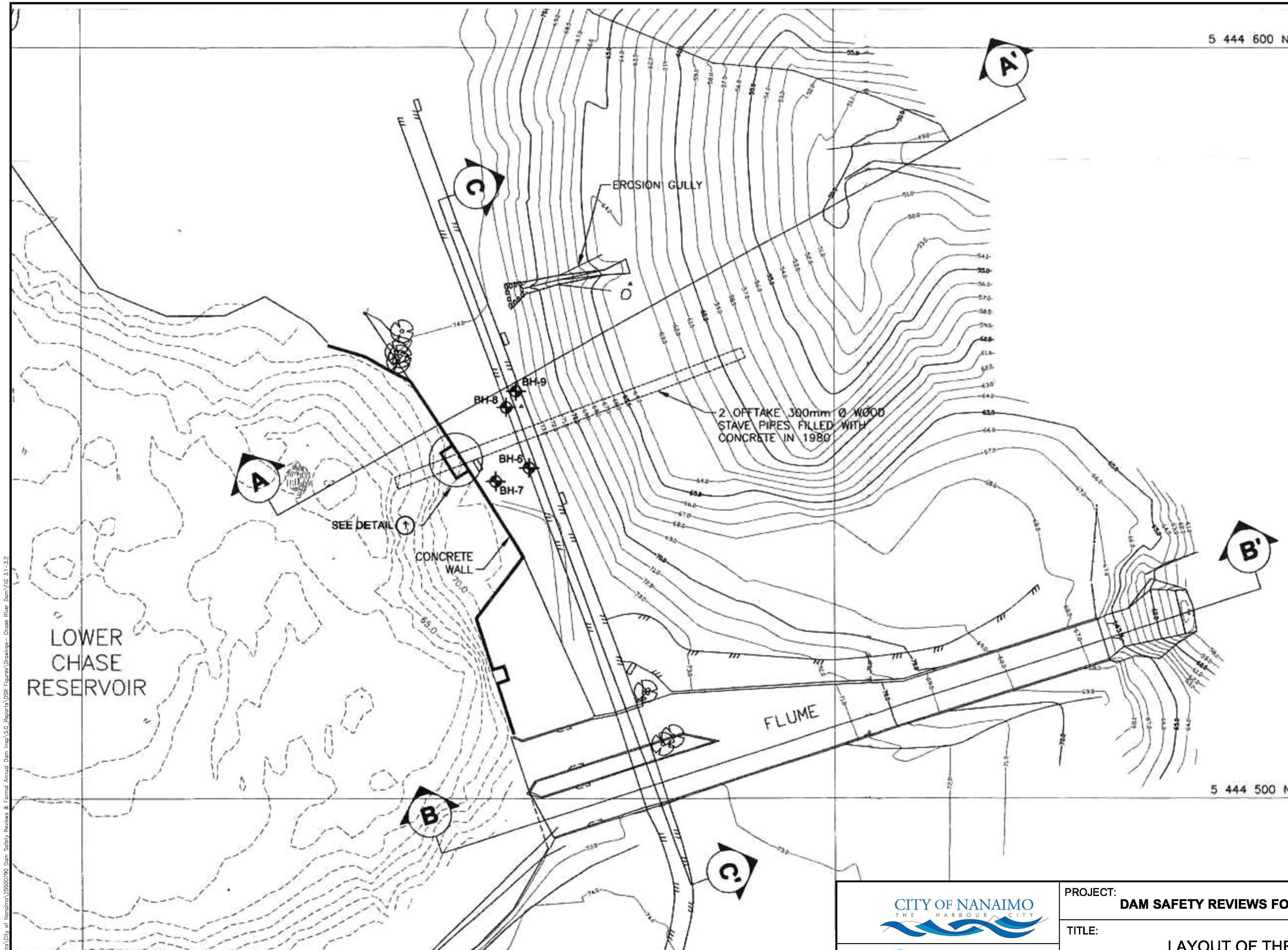
B **SECTION THROUGH DAM**

0 2 4 6 8 10
Scale in Meters

CITY OF NANAIMO THE HARBOUR CITY	PROJECT: **DAM SAFETY REVIEWS FOR THE MIDDLE & LOWER CHASE DAMS**
MWH BUILDING A BETTER WORLD	TITLE: TYPICAL CROSS SECTION OF THE MIDDLE CHASE DAM
	PROJECT No. 25500790 — FIG. No. 2.3

GLOBAL FAILURE MODES		ELEMENT AND/OR ELEMENT FUNCTION	MOST BASIC FUNCTIONAL FAILURE CHARACTERISTICS	External Hazards			Internal Hazards (Design, Construction, Maintenance, Operation)			
				Meteorological	Seismic	Reservoir Environment	Water barrier	Hydraulic struct.	Mech/elec	Infrastructure & Plans
DAM COLLAPSE BY OVERTOPPING (erosion or overturning)	Water elevation too high	Inadequate installed discharge capacity	Meteorological inflow > buffer + outflow capacity		X	X	X		X	X
		Inadequate available discharge capacity	Inadequate reservoir operation (rules not followed)			X	X		X	X
			Random functional failure on demand			X	X		X	X
			Discharge capability not maintained or retained			X	X		X	X
		Inadequate freeboard	Excessive elevation due to landslide or U/S dam			X	X		X	X
			Wind-wave dissipation inadequate			X	X		X	X
	Management System Failure	Safeguards fail to provide timely detection and correction	Operation, maintenance and surveillance fail to detect/prevent hydraulic adequacy	X	X	X	X	X	X	X
DAM COLLAPSE BY LOSS OF STRENGTH (External orinternal structural failure and weakening)			Operation, maintenance and surveillance fail to detect poor dam performance	X	X	X	X	X	X	X
	Crest elevation too low	Stability under applied loads	Mass movement (external stability:- displacement, tilting, seismic resistance)	X		X			X	X
			Loss of support (foundation or abutment failure)	X		X			X	X
		Watertightness	Seepage around interfaces (abutments, foundation, water stops)	X		X			X	X
			Through dam seepage control failure (filters, drains, pumps)	X		X			X	X
		Durability/cracking	Structural weakening (internal erosion, AAR, crushing, gradual strength loss)			X			X	X
			Instantaneous change of state (static iquefaction, hydraulic fracture, seismic cracking)			X			X	X

Figure 2.4 Hazard and Failure Mode Matrix for Middle Chase River Dam



CITY OF NANAIMO
THE HARBOUR CITY

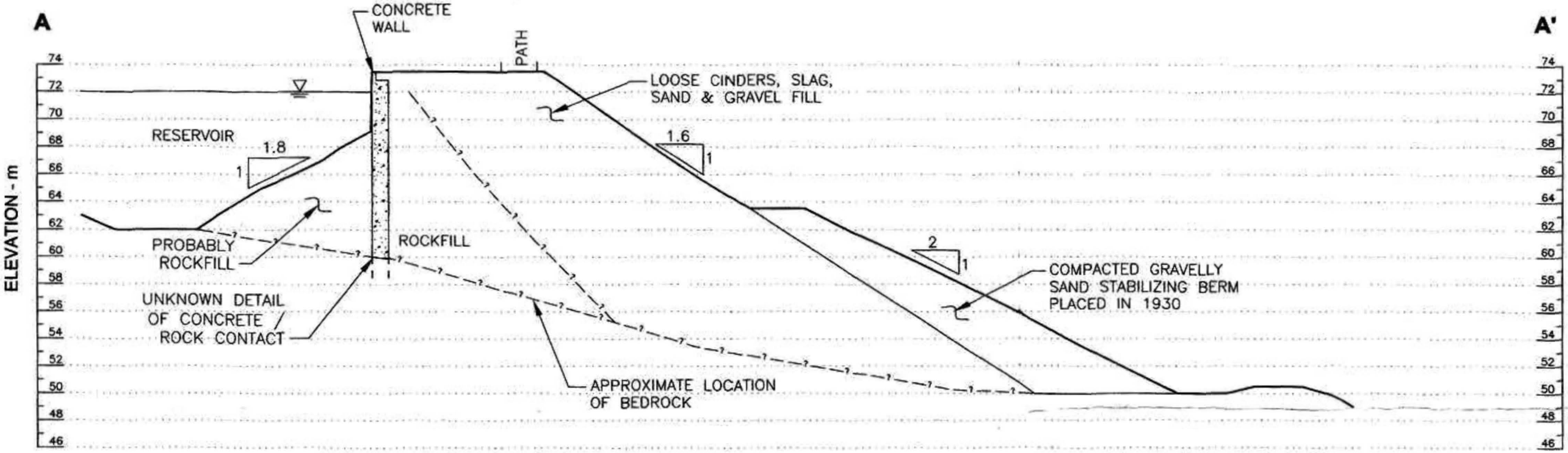
MWH
BUILDING A BETTER WORLD

PROJECT: DAM SAFETY REVIEWS FOR THE MIDDLE & LOWER CHASE DAMS

TITLE: LAYOUT OF THE LOWER CHASE DAM

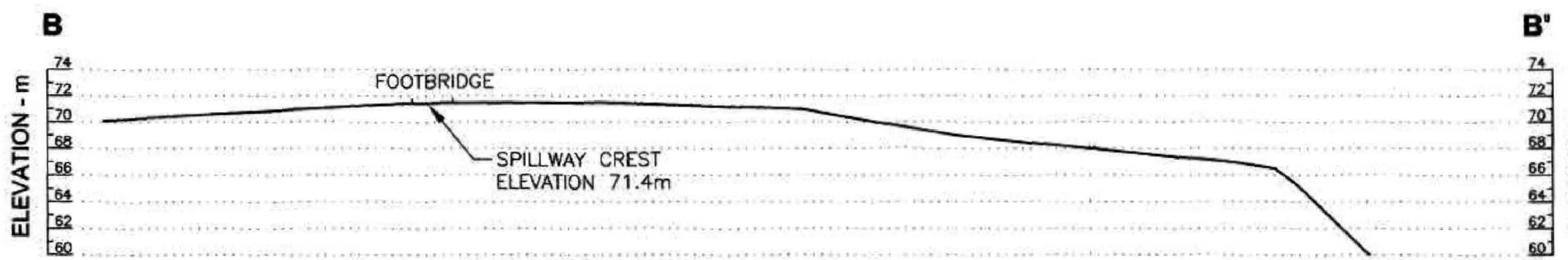
PROJECT No. 25500790

FIG. No. 3.1



A SECTION THROUGH DAM

Scale in Meters (0 – 10)



B SECTION THROUGH SPILLWAY

Scale in Meters (0, 5, 10, 15, 20, 25)

CITY OF NANAIMO — THE HARBOUR CITY	PROJECT: **DAM SAFETY REVIEWS FOR THE MIDDLE & LOWER CHASE DAMS**
MWH — BUILDING A BETTER WORLD	TITLE: TYPICAL CROSS SECTION OF THE LOWER CHASE DAM
	PROJECT No. 25500790 — FIG. No. 3.2

GLOBAL FAILURE MODES		ELEMENT AND/OR ELEMENT FUNCTION	MOST BASIC FUNCTIONAL FAILURE CHARACTERISTICS	External Hazards			Internal Hazards (Design, Construction, Maintenance, Operation)			
				Meteorological	Seismic	Reservoir Environment	Water barrier	Hydraulic struct.	Mech/elec	Infrastructure & Plans
DAM COLLAPSE BY OVERTOPPING (erosion or overturning)	**Water elevation too high**	**Inadequate installed discharge capacity**	Meteorological inflow > buffer + outflow capacity		X	X	X		X	X
		Inadequate available discharge capacity	Inadequate reservoir operation (rules not followed)			X	X		X	X
			Random functional failure on demand			X	X		X	X
			Discharge capability not maintained or retained			X	X		X	X
		Inadequate freeboard	Excessive elevation due to landslide or U/S dam	X		X	X		X	X
			Wind-wave dissipation inadequate	X		X	X		X	X
	Management System Failure	**Safeguards fail to provide timely detection and correction**	Operation, maintenance and surveillance fail to detect/prevent hydraulic adequacy	X	X	X	X	X	X	X
DAM COLLAPSE BY LOSS OF STRENGTH (External orinternal structural failure and weakening)			Operation, maintenance and surveillance fail to detect poor dam performance	X	X	X	X	X	X	X
	Crest elevation too low	**Stability under applied loads**	Mass movement (external stability:- displacement, tilting, seismic resistance)	X		X			X	X
			Loss of support (foundation or abutment failure)	X		X			X	X
		Watertightness	Seepage around interfaces (abutments, foundation, water stops)	X		X			X	X
			Through dam seepage control failure (filters, drains, pumps)	X		X			X	X
		Durability/cracking	Structural weakening (internal erosion, AAR, crushing, gradual strength loss)			X			X	X
			Instantaneous change of state (static iquefaction, hydraulic fracture, seismic cracking)			X			X	X

Figure 3.3 Hazard and Failure Mode Matrix for Lower Chase River Dam

Appendix 2

Middle Chase Dam – Spillway

<u>Photo No. MCR-01</u>

Middle Chase River Dam – Spillway Erosion in Pier on Right side

Photo No. MCR-02

Middle Chase River Dam – Spillway - Erosion in Pier in Center Pier

Photo No. MCR-03

Middle Chase River Dam – Spillway – Outlet Channel – Note Trees in Background

<u>Photo No. MCR-04</u>

Middle Chase River Dam – Close-up of Eroded Are on Left Bank of Spillway

Photo No. MCR-05

Middle Chase River Dam – Seepage Weir

Photo No. MCR-06

Middle Chase River Dam –Exposed Section of Core Wall

Photo No. MCR-07

Middle Chase River Dam - Spillway - Cracks in Spillway Wall & Bridge Abutment

<u>Photo No. MCR-08</u>

Middle Chase River Dam – Looking upstream towards Reservoir

<u>Photo No. MCR-09</u>

Middle Chase River Dam – Looking along Crest of Dam towards Spillway

Photo No. MCR-10

Middle Chase River Dam Spillway – Situation During High Discharge

<u>Photo No. MCR-11</u>

Lower Chase River Dam – Top of Concrete Core Wall

Photo No. LCR-01

Lower Chase River Dam – Footbridge over Spillway

Photo No. LCR-02

Lower Chase River Dam – Downstream Slope of Dam – Note Erosion in Steep Upper Section

<u>Photo No. LCR-03</u>

Lower Chase River Dam – Downstream Slope – Note Erosion in Steep Upper Slope

<u>Photo No. LCR-04</u>

Lower Chase River Dam – Seepage Weir Manhole

Photo No. LCR-05

Lower Chase River Dam – Close up of Seepage Weir Outlet

Photo No. LCR-06

Lower Chase River Dam – Downstream Slope Looking towards Seepage Weir

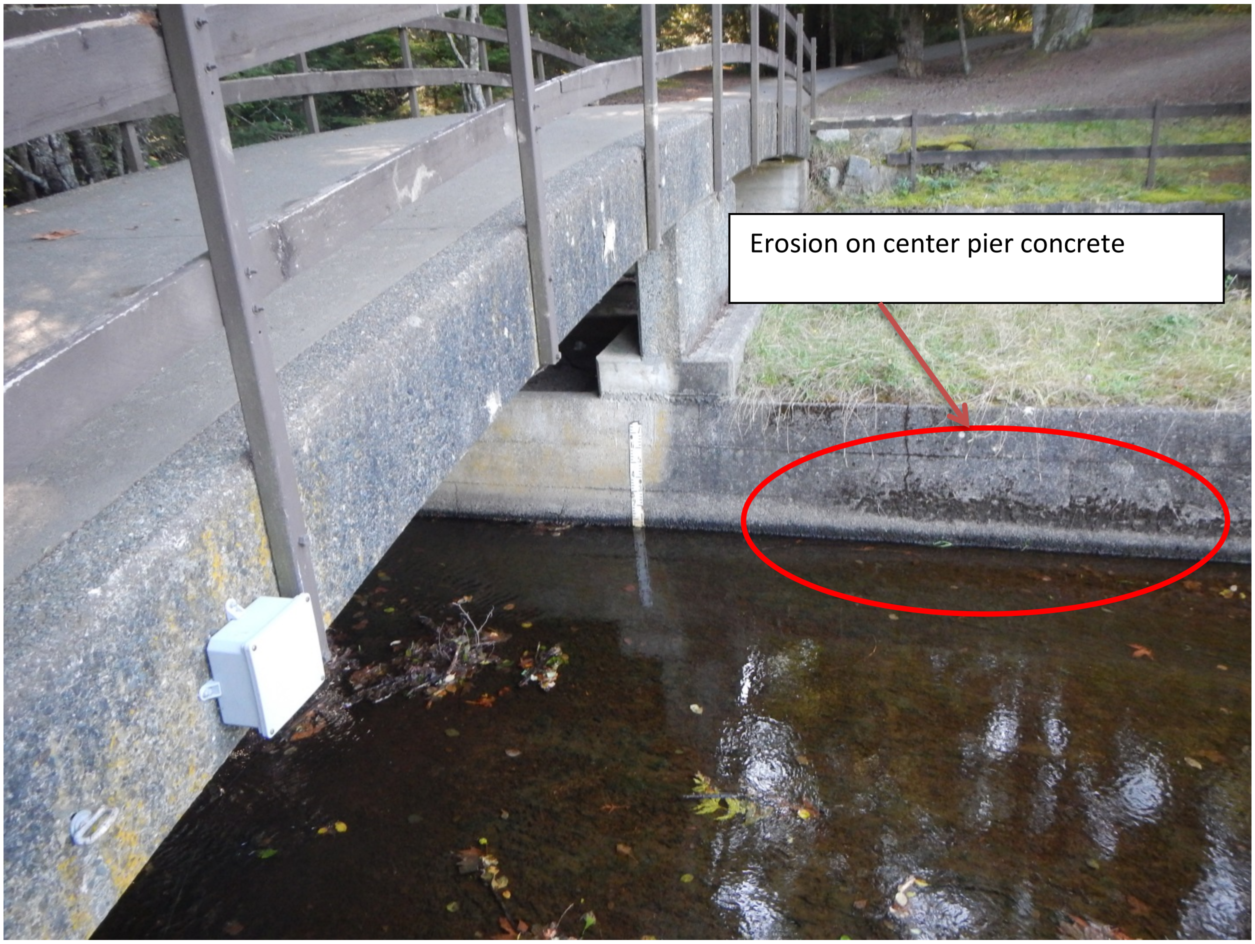
<u>Photo No. LCR-07</u>

Lower Chase River Dam – Cracking in Bridge Abutment

<u>Photo No. LCR-08</u>

Lower Chase River Dam – Cracking in Spillway Approach Walls

Photo No. LCR-09



Lower Chase River Dam – Water Level Sensor Spillway

<u>Photo No. LCR-10</u>

Lower Chase River Dam – View of Reservoir from Footbridge

<u>Photo No. LCR-11</u>

Lower Chase River Dam – Top of Concrete Core Wall showing Cracking & Spalling

<u>Photo No. LCR-12</u>

Appendix 3

List of Reference Documents

1. *Re-Assessment of Options Middle and Lower Chase Dams Nanaimo, BC- Memorandum,* Klohn Crippen Burger , August 9, 2013
2. *Removal of Middle and Lower dams Project- Chase River Re-naturalization, Preliminary Conceptual Design for Comment- Memorandum,* Klohn Crippen Burger , September 6, 2013
3. *Chase River Dam Breach Flood Inundation Study* – Associated Engineering, September, 2013
4. *Conceptual Review of Overwinter Pumping Options - Middle and Lower Chase Dam Removal Nanaimo, BC - Memorandum,* Klohn Crippen Burger, June 17, 2013
5. *Removal of Middle and Lower Chase River Dams – Environmental Management Plan*, Klohn Crippen Burger, June 10, 2013
6. *Lower Dam – Rebar Detection- Memorandum,* Klohn Crippen Burger, May 13, 2013
7. *2012 Formal Annual Dam Safety Inspections & Jump Creek Dam Inspection Monitoring* – BMA Engineering Ltd., March 31, 2013
8. *Dam Removal - Middle and Lower Chase River Dams - Design Basis Memorandum – Revision 1,* Klohn Crippen Burger, February 22, 2013
9. *2011 Formal Annual Dam Safety Inspections & Jump Creek Dam Inspection Monitoring* – BMA Engineering Ltd., January 23, 2012
10. *Seismic Hazard Assessment Middle and Lower Chase Dams* – EBA Engineering Consultants Ltd., April 14, 2010
11. *Middle Chase River Dam 2003 Dam Safety review* – Golder Associates, March 2004
12. *Lower Chase River Dam 2003 Dam Safety review* – Golder Associates, March 2004
13. *Middle and Lower Chase River Dams Spillway Hydrology Study* – Water Management Consultants, April, 2002
14. *Middle and Lower Chase River Dams* – Emergency Action Plan – Nanaimo Fire Rescue, Emergency Management Division.

Appendix 4

CITY OF NANAIMO
THE HARBOUR CITY

Formal Annual Dam Inspection and Jump Creek Dam Instrumentation Monitoring

Dam Safety Issues Tracking

Updated: December 12, 2013

File: Dam Safety Issues - outstanding items to be addressed

Dam File No.	Dam Safety Regulation ,108/2011 (Consequence Rating)
D720001-00	Extreme
D720002-00	Extreme

Legend

GEN	General Application to all dams and Dam Safety Management System
MCR	Middle Chase River Dam ~(1910) – an earth fill with concrete wall
LCR	Lower Chase River Dam ~(1910) – an earth fill with concrete wall

Issue #	Type	Reference	Key Words	Description of Issue	Status	Recommendations	Priority	City Action / Comments	Action Date
GEN11-1	NCp	BMA Engineering Ltd. 2011 Formal Inspection	Consequence	One of the more significant changes to the BC Regulation is the **requirement to annually review the consequence classification for all dams** and report any changes. In our 2010 annual inspection report, it was recommended that the consequence classification of all City dams be reviewed for consistency with current BC Regulations and this review should consider the potential for flood inundation, debris affects (GEN10-1) and potential increases in consequences over the next decade.	Annual review	BMA maintains the 2010 recommendation and suggests that this work be carried out such that inundation mapping can be easily updated with other available City data (air photographs, subdivision approvals, infrastructure upgrades, etc.) to facilitate subsequent annual reviews in a cost-effective manner.	High	New Consequence Ratings assigned by FLNRO, Dam Safety Branch, Aug. 12, 2011.	September 2014.
GEN11-2	NCp	BMA Engineering Ltd. 2011 Formal Inspection	Consequence	Another significant change in the BC Regulations includes an amended Downstream Consequence Classification Guide, Schedule 1 (BC Regs) which replaces the old 4 level consequence classification with the 5 classifications adopted by the Canadian Dam Association (CDA) in their 2007 Guidelines. This ensures that the requirements of the BC Regulations and the CDA Guidelines are consistent. As a result, most of the City's dams have had their consequence classification revised.	Ongoing	It is recommended that discussions and confirmation of Consequence Classification and all of the City's dams be carried out with the Ministry's Dam Safety Officer prior to further studies as this will be a key driver for the prioritization and design basis for any future work.	High	New Consequence Ratings assigned by FLNRO, Dam Safety Branch, Aug. 12, 2011.	April 17, 2012.
GEN11-3	NCs	BMA Engineering Ltd. 2011 Formal Inspection	Surveillance	Frequent inspections during winter storms should be considered as a high priority activity.	Ongoing	These should be carried out and a line be added to the weekly checklist to monitor debris in the spillway and around the reservoir rim.	High	City staff do increase inspections based on severity of storms.	April 17, 2012.
GEN11-4	NCp	BMA Engineering Ltd. 2011 Formal Inspection	Issue Prioritization	Although a draft prioritization of the issues is provided, it has not been discussed or agreed upon and there appears to be a lack of recognition of high priority issues.	I/P	It is recommended, therefore, that the prioritization of the City's Dam Safety issues be reviewed and consolidated such that higher ranked issues are recognized by City management. A simple prioritization of issues using the BC/CDA Consequence Classification Guide and industry standard definitions of the dam safety issues is suggested as a first step.	High	City will prioritize and work on securing necessary funding.	April 17, 2012.
GEN11-5	NCp	BMA Engineering Ltd. 2011 Formal Inspection	EPP	The amended BC Regulation now requires that dam owners update all emergency contact information in the EPP on an annual basis.	In progress		Medium	To be completed annually. Done in 2012. To be completed for 2013	2013
GEN10-1	NCp	BMA Engineering Ltd. 2010 Formal Inspection	Consequence	The consequence classification of all the City dams should be reviewed and updated, based on both potential flooding and debris affects, as recognized in the 2010 Testalinden dam failure. The consequence category should be viewed as a key driver for the prioritization of dam safety issues and the design basis for any dam safety upgrades.	I/P	Recommended the consequence classification be reviewed in detail and updated based on the 2007 CDA guidelines. The consequence classification which is determined by losses (life, economic, social, environmental, and cultural) should account for both inundation and debris affects, if these are possible. It is understood that a new flood inundation assessment is planned for the Chase River dams in 2010. It is recommended the scope of this assessment also include assessment of the potential and magnitude of debris.	High	Consequence Classification to be reviewed annually. Determine how to assess potential and magnitude of debris.	April 17, 2012
GEN10-2	NCs	BMA Engineering Ltd. 2010 Formal Inspection	Surveillance	It was observed that many of the in-town dams do not have staff gauges or other convenient means of determining lake level. It is also understood that critical water levels for response purposes have not been determined.	i/P	Recommend that staff gauges be installed at convenient locations in all reservoirs such that levels can easily be determined. Existing staff gauges should be checked against as-built data or survey information to ensure elevations are accurate and consistent at each facility. Critical lake levels should be determined and included in the OMS manuals.	Medium	Staff gauges exist at the Lower and Middle Chase Dam spillways. Critical water levels being resolved. Both the Lower and Middle Chase Dams have automated level detection on each spillway and seepage collection weir, monitored by SCADA since October 2012.	Feb. 20, 2013.

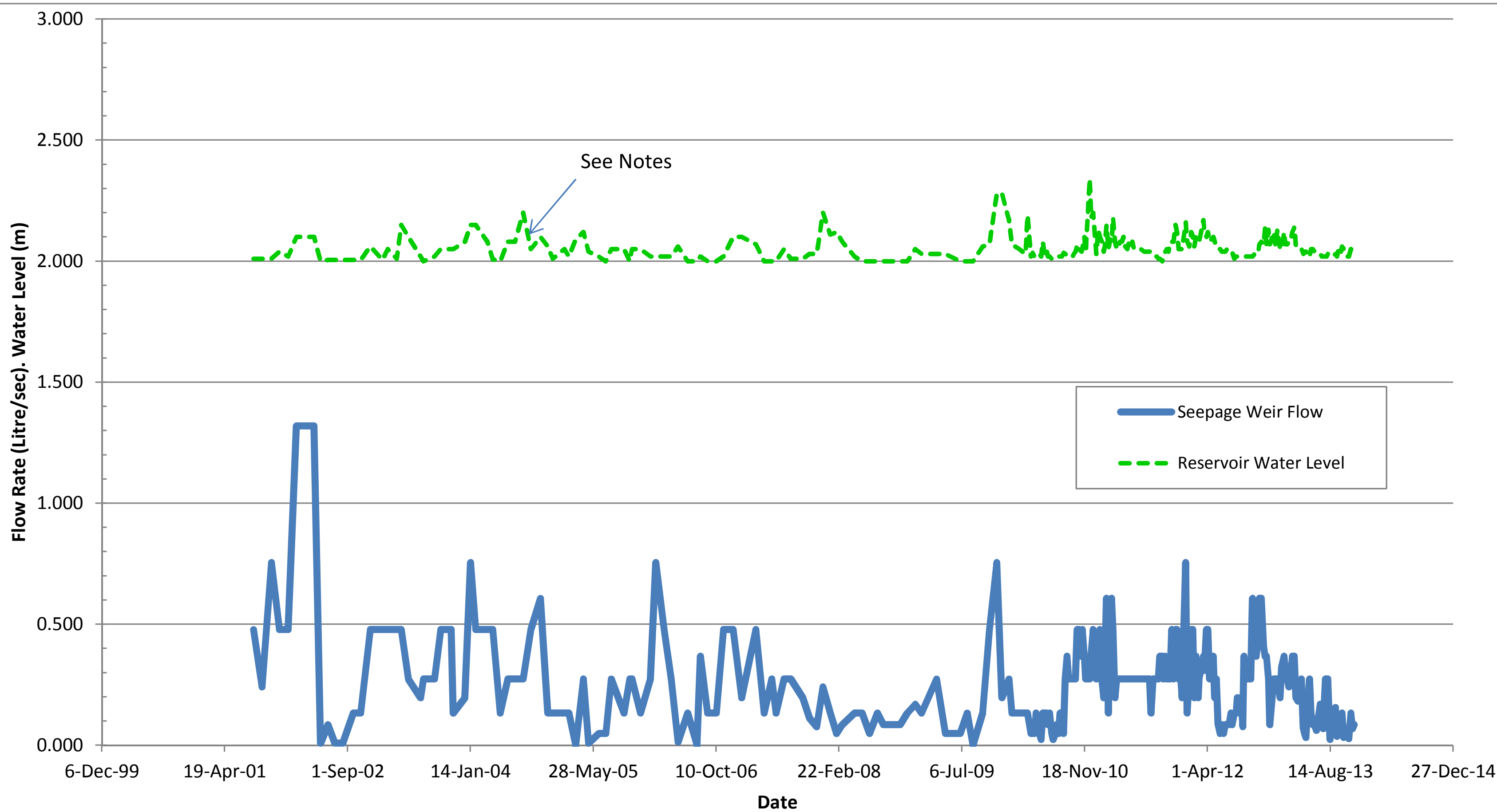
Issue #	Type	Reference	Key Words	Description of Issue	Status	Recommendations	Priority	City Action / Comments	Action Date
GEN10-3	NCs	BMA Engineering Ltd. 2010 Formal Inspection	Surveillance	It is understood that critical water levels for response purposes have not been determined.	2010	Recommend critical lake levels be determined and included in the OMS manuals.	High	Ongoing study.	Feb. 20, 2013
GEN10-4	NCs	BMA Engineering Ltd. 2010 Formal Inspection	Surveillance	Existing City checklists were utilized for the 2010 Formal Inspections. While these were satisfactory, a detailed review of the checklists should be carried out with City staff to ensure the checklists capture all appropriate observations.	Complete	This review would be best carried out in conjunction with the PBS training recommended below (GEN09-3).	Medium	City's inspectors generally, received Dam Inspection and Maintenance Training every 2 years. Last Training was April 19, 2012 - Bill Marshall, Pat Barrett, Scott P. and Euan W.	April 17, 2012.
GEN09-1	NCp	Musgrave 2009 Formal Inspection	Management	Major components of a DS Management System are in place, but formalization is not. Formalization is recommended.	Policy Provided	Review Dam Safety Management system.	Low	Completed 6th March 2013.	Feb. 20, 2013
GEN09-2	NCp	Musgrave 2009 Formal Inspection	Management	Additional operator engagement.	complete	Utilize a specifically adapted notebook computer, camera, other.	Medium	Regular recording and storing dam inspection information digitally, implemented in January 2012.	Feb. 20, 2013 and ongoing
GEN09-3	NCp	Musgrave 2009 Formal Inspection	Management	Performance based surveillance and operator training.	No Action		Medium	A more detailed level of training suggested by Bruce Musgrave tailoring failure modes to specific inspections at each dam. Not done in 2013	23-Sep-14
GEN09-4	NCp	Musgrave 2009 Formal Inspection	Management	Prioritization of Dam Safety Issues.	No Action		Medium	To be done in 2013.	April 17, 2012.
GEN09-5	NCs	Musgrave 2009 Formal Inspection	Management	Review requirements (BC Regs) for inspection frequencies and define roles and responsibilities for routine inspections of the City's in-town dams.	complete		High	City meets and in some cases exceeds expectations (i.e. Low Consequence Dams)	April 17, 2012.
GEN09-6	NCp	Musgrave 2009 Formal Inspection	EPP	Update the information in the EPP including detailed LIDAR mapping and residential listings for the inundation zones.	I/P	Similar to GEN08-7.	Very High	To be done in 2013. See GEN 11-1.	23-Sep-14
GEN08-1	NCp	EBA 2008 Formal Inspection	Consequence	Consequence update after BC Regs adopts CDA'07 Guidelines.	complete	Consequence categories have been summarized and presented in Appendix V with recent correspondence from the Province.	High	New Consequence Ratings assigned by FLNRO, Dam Safety Branch, Aug. 12, 2011. Duscussion held with Dam Safety Officers during 5 Year Audit completed in Oct. 2011	April 17, 2012.
GEN08-2	NCp	EBA 2008 Formal Inspection	OMS Update	All manuals should be updated.	Ongoing		High	City maintains a digitial record outlining when manuals need updating.	April 17, 2012.
GEN08-3	NCp	EBA 2008 Formal Inspection	Training	Staff should be familiar and trained.	Ongoing		High	As deemed necessary by supervisor.	Feb 19, 2013.
GEN08-4	NCp	EBA 2008 Formal Inspection	Log Books	All log books updated and maintained.	No action required.		Medium	Records are maintained digitally as of January 2012.	April 17, 2012.
GEN08-5	NCi	EBA 2008 Formal Inspection	EPP	Annual review and update.	Ongoing		High	Updated as required.	April 17, 2012.
GEN08-6	NCi	EBA 2008 Formal Inspection	EPP	Lessons learned from exercised included in update.			High	Updated as required.	April 17, 2012.
GEN08-7	NCi	EBA 2008 Formal Inspection	EPP	Upgrade the inundation mapping.			High	Chase Dams Flood Inundation Study complete in 2012.	April 17, 2012.
GEN08-8	NCi	EBA 2008 Formal Inspection	EPP	Dry run emergency exercises every 2 to 3 years.	Ongoing		Medium	Meeting held in January 2012 with RDN and City Emergency Program coordinators, SFN, Regional Dam Safety, City Water Supply Operations and Water Resources staff to discuss.	April 17, 2012.
GEN08-9	NCi	EBA 2008 Formal Inspection	EPP	Review OMS for consistency.			Medium	List maintained tracking needs for updates.	Feb 19, 2013.
GEN08-10	NCi	EBA 2008 Formal Inspection	Public Safety	Develop a public safety plan.			High		April 17, 2012.
GEN06-1	NCi	AMEC 2006 Formal Inspection	EPP	Mock emergency exercise be conducted to verify the state of preparation.			High	Will coordinate with City Emergency Preparedness Mgr.	April 17, 2012.
MCR13-1	NCs	MWH 2013 DSR	Surveillance	Reservoir water levels are being measured with ultrasonic level sensor probes and relayed back to City's SCADA system in Public Works department where a high water level alarm trigger point has been created but the readings were not plotted.	2013	The data collected to be plotted so that any anomalous behaviour could be identified.	Medium		
MCR13-2	NCp	MWH 2013 DSR	Earthquake	The stability of the dam should be checked for the 1 in 10,000 annual exceedance event or MCE in accordance with the CDA Guidelines (revised in 2013).	2013	It is recommended that a dynamic analysis be carried out. Bcause of the magnitude of the earthqauke a pseudostatic nalaysis would not be appropriate.	High		
MCR11-1	NCs	BMA Engineering Ltd. 2011 Formal Inspection	Surveillance	Concrete deterioration was noted in many areas including the upstream face, the center spillway pier and the spillway walls but no significant displacement, settlement or cracking was noted.	2011	It is recommended that concrete repairs be carried out in areas of deterioration and undercutting and monitoring of concrete deterioration be continued and added to the checklist.	Medium		

Issue #	Type	Reference	Key Words	Description of Issue	Status	Recommendations	Priority	City Action / Comments	Action Date
MCR09-1	NCs	Musgrave 2009 Formal Inspection	Surveillance	Weir flows are measured only 1/month with additional readings during storms.	In Progress	The seepage weir should be viewed as a KPI and read continuously along with lake level via SCADA, but initial assessment of the arrangement is recommended prior to upgrading.	High	Continuous monitoring implemented.	fall 2010
MCR09-2	NCm	Musgrave 2009 Formal Inspection	Debris	The reservoir should be checked for debris on a routine basis and debris removed when observed.	As Required	Debris management should be viewed as critical given the lack of spillway capacity.	**Very High**	Frequent storm inspections should be viewed as a Very High Priority task given no debris booms are in place.	
MCR09-3	NCs	Musgrave 2009 Formal Inspection	Surveillance	Concrete deterioration was observed on the spillway walls and U/S face. This should be carefully monitored.	No Action	**Updated**	Medium	**Status of concrete deterioration should be added to the checklist. See MCR11-1.**	
MCR09-4	NCi	Musgrave 2009 Formal Inspection	Dam	The crest area appears uneven. Actual elevations should be checked against as-built records to ensure adequate freeboard exists.	No Action		Medium		
MCR09-5	NCm	Musgrave 2009 Formal Inspection	Spillway/Veg	The height of the RHS spillway wall and erosion potential of the left side of the spillway should be reviewed. Overhanging trees which have been undermined on the left side should be removed.	No Action	Significant turbulent flow in the spillway chute even at low flows.	High		
MCR08-1	NCs	EBA 2008 Formal Inspection	OMS/ Debris	Storm Inspections - observations and measurements.	Ongoing		**Very High**	Changed to very high, see MCR09-2.	
MCR08-2	NCp	EBA 2008 Formal Inspection	OMS/ Roles	Responsibility and communication clarified with Parks.	Complete		High	Responsibilities clarified with Parks.	
MCR08-3	NCs	EBA 2008 Formal Inspection	Surveillance	Weir seepage data should be plotted when taken.		Recommend high priority. Recommend continuous data on SCADA with manual checks.	**HIGH**	Change of priority to High from Medium.	Dec '09
MCR08-4	NCp	EBA 2008 Formal Inspection	Vegetation	Health of trees on left side of spillway (arborist).			Medium		
MCR08-5	NCm	EBA 2008 Formal Inspection	Debris boom	Debris/Safety boom recommended.			Medium	Not required.	
MCR08-6	NCs	EBA 2008 Formal Inspection	Safety	Safe access to the downstream weir developed.		Similar to MCR06-3.	Medium		
MCR08-7	NCs	EBA 2008 Formal Inspection	Surveillance	Seepage from the right spillway wall should be monitored.			Medium		
MCR08-8	NCs	EBA 2008 Formal Inspection	Surveillance	Erosion on left bank of spillway should be monitored and measures implemented, if required.			Low		
MCR08-9	NCm	EBA 2008 Formal Inspection	Vegetation	Broom growing on upstream slope should be removed.			Low		
MCR08-10	NCm	EBA 2008 Formal Inspection	Maintenance	Spillway and left side intake repairs required.			Low		
MCR08-11	NCs	EBA 2008 Formal Inspection	Surveillance	Survey monuments are to be installed on the dam.		Similar to MCR06-2.	Low		
MCR06-1	NCs	AMEC 2006 Formal Inspection	Surveillance	Repair vandalized automated seepage monitoring equipment.	Complete		Medium		
MCR06-2	NCs	AMEC 2006 Formal Inspection	Surveillance	Install survey pins and monitor 2x/yr and after seismic event.			Medium		
MCR06-3	NCs	AMEC 2006 Formal Inspection	Safety	Provide safe access to the downstream toe.			Medium		
MCR03-1	NCs	Golder 2003 DSR	Surveillance	Automate reading of the V-notch weir and lake level, and incorporate into SCADA. Provide long term data storage.	Complete	Weir flow data noted as crucial validation of dam safety.	High		2012
MCR03-2	Pu	Golder 2003 DSR	IDF	Complete the Chase River hydrology and define the IDF.	Complete		Medium		
MCR03-3	Pu	Golder 2003 DSR	IDF	Rehabilitate dam and/or spillway to safely pass the IDF (1:3000 yr event).			Medium		
MCR03-4	Pu	Golder 2003 DSR	IDF	Rehabilitate lower left side of spillway chute including trees and wall.			High		
MCR03-5	Pu	Golder 2003 DSR	IDF	Insufficient freeboard under IDF (may be resolved by addressing MCR03-3).			Medium		
MCR03-6	Pd	Golder 2003 DSR	Surveillance	No peizometers exist to establish a hydraulic gradient.		No recommendation noted.	Very Low		
MCR03-7	Pq	Golder 2003 DSR	Earthquake	Provide a formal evaluation of the earthquake resistance.	Complete		Medium	Completed by EBA in 2010.	
MCR03-8	NCs	Golder 2003 DSR	Surveillance	Install settlement monitoring pins along the crest and wall and monitor 2x/yr.			Medium		
MCR03-9	Pq	Golder 2003 DSR	Earthquake	Check overturning potential of spillway walls under seismic loading.	Complete	Toppling failure of concrete core wall predicted	Low	See EBA April 2010, Seismic Hazard Assessment for Middle and Lower Chase River Dams.	April '10
MCR03-10	NCp	Golder 2003 DSR	OMS	Use of syphon for emergency reservoir evacuation should be evaluated.			Low	Evaluated	
MCR03-11	NCp	Golder 1992 DSR (Incomplete)	Debris	Install debris boom at spillway entrance.			Medium	Not required.	
MCR03-12	NCp	Golder 1992 DSR (Incomplete)	Debris	Remove dead trees from the reservoir.			Medium		
MCR03-13	NCp	Golder 1992 DSR (Incomplete)	Dam	Core the concrete wall to determine extent of deterioration.	Complete		Low		
MCR03-14	NCp	Golder 1992 DSR (Incomplete)	IDF	Extend spillway training wall on left side.			Medium		
LCR13-1	NCs	MWH 2013 DSR	Surveillance	Reservoir water levels are being measured with ultrasonic level sensor probes and relayed back to City's SCADA system in Public Works department where a high water level alarm trigger point has been created but the readings were not plotted.	2013	The data collected to be plotted so that any anomalous behaviour could be identified.	Medium		

Issue #	Type	Reference	Key Words	Description of Issue	Status	Recommendations	Priority	City Action / Comments	Action Date
LCR13-2	NCp	MWH 2013 DSR	Earthquake	The stability of the dam should be checked for the 1 in 10,000 annual exceedance event or MCE in accordance with the CDA Guidelines (revised in 2013).	2013	It is recommended that a dynamic analysis be carried out. Bcause of the magnitude of the earthqauke a pseudostatic nalaysis would not be appropriate.	High		
LCR09-1	NCs	Musgrave 2009 Formal Inspection	Surveillance	Weir flows are measured only 1/month with additional readings during storms.	In Progress	The seepage weir should be viewed as a KPI and read continuously along with lake level, but initial assessment of the weir and its general arrangement should be carried out prior to any upgrades. Similar to other previous recommendations.	High	Electronic monitoring ngoing.	
LCR09-2	NCm	Musgrave 2009 Formal Inspection	Debris	The reservoir should be checked for debris on a routine basis and debris removed when observed.	As Required	Debris management should be viewed as critical given the lack of spillway capacity. Similar to other previous issues below.	**Very High**	Frequent storm inspections should be viewed as a Very High Priority task given no debris boom is in place.	
LCR09-3	NCs	Musgrave 2009 Formal Inspection	Surveillance	Significant cracks within the spillway chute and core wall should be monitored closely.	No Action	Cause may be settlement or tree growth and root propagation. **Updated.**	Medium	**Use of anotated photographs is recommended for this purpose.**	
LCR09-4	NCi	Musgrave 2009 Formal Inspection	IDF, spillway	Review anticipated velocities and water levels associated with the IDF.	Complete		Medium	Refer to Upper Chase Dam Breach and Innundation Study 2012.	Feb 2013
LCR09-5	NCs	Musgrave 2009 Formal Inspection	Surveillance	Carry out a detailed inspection of the rock slope below the spillway chute and provide monitor points to measure potential backward erosion.	No Action	Remedial work was carried out in 1980. The condition of this work should also be inspected.	Medium		
LCR09-6	Pn	Musgrave 2009 Formal Inspection	Surveillance	The stability and potential for surface water erosion of the downstream slope should be reviewed and include the installation of movement monitoring hubs.	No Action	Installation of survey pins previously noted.	High		
LCR08-1	NCs	EBA 2008 Formal Inspection	OMS/ Debris	Storm Inspections - observations and measurements.	Ongoing		**Very High**	See LCR09-2.	
LCR08-2	NCp	EBA 2008 Formal Inspection	OMS/ Roles	Responsibility and communication clarified with Parks.	Complete		High	Responsibilities clarified with Parks.	
LCR08-3	Pu	EBA 2008 Formal Inspection	Seismic Stability	Seismic stability assessment should be carried out.	Complete		High	See EBA April 2010, Seismic Hazard Assessment for Middle and Lower Chase River Dams.	April '10
LCR08-4	NCs	EBA 2008 Formal Inspection	Surveillance	Weir seepage data should be plotted when taken.	Ongoing	Recommend high priority. Recommend continuous data on SCADA with manual checks.	***HIGH***	Completed annually.	
LCR08-5	NCs	EBA 2008 Formal Inspection	Safety	Safe access to the downstream weir developed.			Medium		
LCR08-6	NCm	EBA 2008 Formal Inspection	Vegetation	Assess health of trees on the dam crest (arborist).			Medium		
LCR08-7	NCm	EBA 2008 Formal Inspection	Vegetation	Tree branches hanging over the spillway should be removed.			Medium		
LCR08-8	NCm	EBA 2008 Formal Inspection	Debris boom	Debris/ Safety boom recommended.			Medium	Not required.	
LCR08-9	NCp	EBA 2008 Formal Inspection	Safety	Assess the need for a fence on right side of spillway.			Medium		
LCR08-10	NCs	EBA 2008 Formal Inspection	Surveillance	Monitor localized slumping and erosion on downstream crest.	Ongoing	Recommend higher priority and include on checklist.	***HIGH***	Change of priority to High from Medium.	Dec '09
LCR08-11	NCs	EBA 2008 Formal Inspection	Surveillance	Monitor localized deterioration of concrete.		Recommend higher priority and include on checklist.	***Medium***	Change of priority to Medium from Low.	Dec '09
LCR06-1	NCs	AMEC 2006 Formal Inspection	Surveillance	Install automated seepage monitoring equipment.			Medium		
LCR06-2	NCs	AMEC 2006 Formal Inspection	Surveillance	Install survey pins and monitor 2x/yr and after seismic event.			Medium		
LCR06-3	NCp	AMEC 2006 Formal Inspection	Safety	Provide safe access to the downstream toe.			Medium		
LCR06-4	NCm	AMEC 2006 Formal Inspection	Vegetation	Clear downstream slope 2x/yr, instead of once/yr.			Medium		
LCR03-1	NCs	Golder 2003 DSR	Surveillance	Automate reading of the V-notch weir and lake level, and incorporate into SCADA. Provide long term data storage.	Ongoing	Weir flow data noted as crucial validation of dam safety.	High	Vandalism issues.	
LCR03-2	Pu	Golder 2003 DSR	IDF	Complete the Chase River hydrology and define the IDF.	Complete		Medium	Refer to Chase Dam Breach and Innundation Sudy 2012.	
LCR03-3	Pu	Golder 2003 DSR	IDF	Investigate options for upgrading the spillway or providing a secondary emergency spillway.			Medium		
LCR03-4	Pu	Golder 2003 DSR	Debris	Cut down tree in the spillway island and remove vegetation, pave island surface.			High		
LCR03-5	Pu	Golder 2003 DSR	IDF	Insufficient freeboard under IDF (may be resolved by addressing LCR03-3).			Medium		
LCR03-6	NCm	Golder 2003 DSR	Dam	Upper part of D/S slope should be reconstructed.			Medium		
LCR03-6	Pd	Golder 2003 DSR	Surveillance	No peizometers exist to establish a hydraulic gradient.		No recommendation noted.	Very Low		
LCR03-7	Pu	Golder 2003 DSR	Earthquake	Provide a formal evaluation of the earthquake resistance.	Complete		Medium	See EBA April 2010, Seismic Hazard Assessment for Middle and Lower Chase River Dams.	April '10
LCR03-8	NCs	Golder 2003 DSR	Surveillance	Install settlement monitoring pins along the crest and wall and monitor 2x/yr.			Medium		
LCR03-9	Pq	Golder 2003 DSR	Earthquake	Check the stability of the foot bridge and spillway walls under seismic loading.			Low		
LCR03-10	NCp	Golder 2003 DSR	OMS	Use of syphon for emergency reservoir evacuation should be evaluated.			Low		
LCR03-11	NCp	Golder 1992 DSR (Incomplete)	Debris	Install debris boom at spillway entrance.			Medium	Not required.	

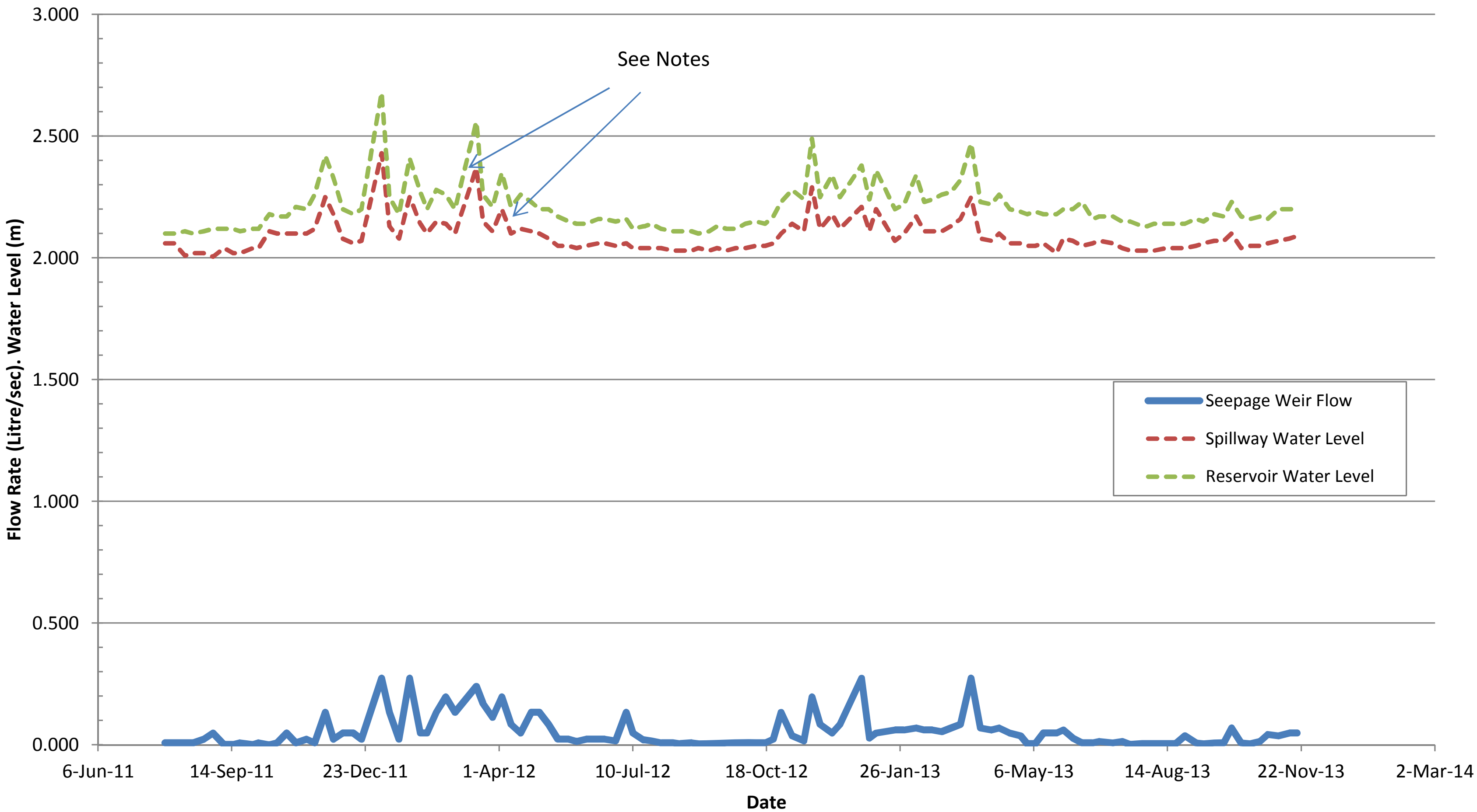
Appendix 5

Instrumentation Monitoring Summary - Middle Chase River Dams



Note: (1) to add 84.041m for elevation of water
(2) to minus 2m for water level above spillway crest level

Instrumentation Monitoring Summary - Lower Chase River Dam



Note: (1) to add 69.652m for elevation of water
(2) to minus 2m for water level above spillway crest level

Appendix 6

Jump Creek Dam - Page 1

Inspected By:

Reservoir Level: cm

Date:

Weather:

Load Last Inspection Data | Clear Inspection Data

Weekly Inspection Checklist

Feature	Concern	Rating	Comments
Reservoir	Debris		Add
	Log Boom and Anchors		Add
Dam Crest	Cracking		Add
	Erosion		Add
	Settlement		Add
Upstream Slope	Debris		Add
	Erosion		Add
	Settlement		Add
	Vegetation Growth		Add
Downstream Slope	Erosion		Add
	Seepage		Add
	Settlement		Add
	Vegetation Growth		Add
Spillway	Cracking		Add
	Debris		Add
	Movement		Add
	Spalling		Add

Jump Creek Continued...

Spillway Bridge and Gate Controls			
#1 Gate Structure	Condition		Add
#2 Gate Structure	Condition		Add
#1 Gate Cables and Sheave Assembly	Condition		Add
#2 Gate Cables and Sheave Assembly	Condition		Add
#1 Gate Seals	Condition		Add
#2 Gate Seals	Condition		Add
Paint Work	Condition		Add
Hand Rails	Condition		Add
Gate Controls - Building			
Gate Electrical Controls	Condition		Add
#1 Diesel Generator	Condition		Add
#2 Diesel Generator	Condition		Add

Weekly Inspection Checklist

Feature	Concern	Rating	Comments
Low-Level Outlet			
Gear Operator	Condition		Add
Gate Stem and Guides	Condition		Add
Gate Operation	Condition		Add
Tunnel	Condition		Add
Energy Dissipator	Condition		Add
Rectangular Weir	Condition		Add
Auxiliary Dam/Overflow Spillway			
Auxiliary Dam/Spillway	Debris		Add
	Vegetation Growth		Add
Log Boom and Anchors	Condition		Add
Upstream Slope and Groin	Condition		Add
Downstream Slope and Groin	Condition		Add
Downstream Toe and Roadway	Condition		Add

Jump Creek/South Fork Piezometers/Weir Levels

New Record | View Existing

Date:	SP7b (m):	SP12-3 (m):	Rain (mm):
Gate Level (ft):	SP9 (m):	Weir A (cm):	Discharge Gate CFS:
JC Lake Level (m):	SP10-1 (m):	Weir B (cm):	Air Temp (c):
SP1b (m):	SP10-2 (m):	Weir C (cm):	Fisheries Valve (L/s):
SP2b (m):	SP11 (m):	Weir D (cm):	SF Lake Level (m):
SP3b (m):	SP12-1 (m):	Weir E (cm):	
SP4b (m):	SP12-2 (m):	Weather:	

Submit | Cancel

Jump Creek / South Fork Reservoir Levels

New Record   View Existing

Date:		SF Reservoir Level (m):	
JC Reservoir Level (m):		Fisheries Valves (L/s):	
Gate Position (ft):		Chemainus River JC-11 (m):	
CFS:		Jump Creek JC-12 (m):	

Submit   Cancel

TR6 DAM SAFETY EXPECTATIONS

To meet the principals of the CDA Guidelines – **Middle Chase River Dam**

		Comments	Deficiency / Non-Conformance	Recommendation
1	**Dam Safety Management System**			
1.1	The Dam is classified appropriately in terms of the consequences of failure including life, environmental, cultural and third-party economic losses (Based on the BC Regulations)	Yes		
1.2	Hazards external and internal to the dam have been defined	A hazard analysis was carried out as part of this DSR		
1.3	The potential failure modes for the dam and the initial conditions downstream from the dam have been identified	This has been done as part of the hazard analysis.		
1.4	The dam system and all other components of the water barrier are defined for dam safety.	These have been defined in the hazard analysis		
1.5	The discharge characteristics for the failure modes have been estimated	These have been obtained from past studies		
1.6	The dam safety management system for the dam is in place incorporating:			
	a. policies,	In place		
	b. responsibilities,	These have been defined		
	c. plans and procedures including OMS, public safety and security,	These have been defined		
	d. documentation,	The OMS manual has been prepared		
	e. training and review,	Operator training needs to be formalized	NCp	
	f. prioritization and correction of deficiencies and non-conformances,	Generally the deficiencies and non-conformances are corrected in a reasonable time period		
	g. periodic Dam Safety Reviews	Weekly inspections are carried out. Annual reviews are carried out. This 2013 DSR is the first since 2003 and needs to be done every 7 years		The next DSR should be done in 2020
	h. supporting infrastructure	Watershed Inspectors are assigned to the dam and conduct weekly visits. A SCADA system is in place. The dams are located within the City boundaries and consequently access is good.		
1.7	Deficiencies are documented, reviewed and resolved in a timely manner. Decisions are justified and documented	In general they are resolved in a timely manner.		
1.8	Records relevant to dam safety are available including design documents, historical instrument readings, inspection and testing reports, operational records and investigation results.	Documentation is fairly complete. There are little or no construction records available for the dam. Seepage weirs are read both automatically and are read also on a weekly basis.		
1.9	Applicable regulations are met	Regulations are met.		
2	**Operation, Maintenance and Surveillance**			
2.1	Responsibilities and authorities are clearly delegated within the organization for all dam safety activities	Yes		

2.2	Requirements for the safe operation, maintenance and surveillance of the dam are documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure	In general yes		
2.3	The OMS Manual is reviewed and updated periodically when major changes to the structure, flow control equipment, operating conditions or company organizational structure and responsibilities have occurred.	The OMS manual is currently being updated.		
2.4	Documented operating procedures for the dam and flow control equipment under normal, unusual and emergency conditions exist, are consistent with the OMS Manual and are followed	The OMS manual is being followed		
	Operation			
2.5	Critical discharge facilities are able to operate under all expected conditions.	N.A.		The spillway is a free overflow structure.
a.	Flow control equipment is tested and is capable of operating as required.	N.A.		
b.	Normal and standby power sources, as well as local and remote controls, are tested.	N.A.		
c.	Testing is on a defined schedule and test results are documented and reviewed.	N.A.		
d.	Management of debris and ice is carried out to ensure operability of discharge facilities	Routine maintenance is being carried out to keep spillway clear of debris. Problem could be identified during routine maintenance or weekly inspection.		Overhanging trees in spillway requires attention.
2.6	Operating procedures take into account:			
a.	Outflow from upstream dams	Yes		
b.	Reservoir levels and rates of drawdown	Reservoir level is controlled by the free overflow spillway		
c.	Reservoir control and discharge during an emergency	N.A.		
d.	Reliable flood forecasting information	Yes, reservoir water levels are being measured with ultrasonic level sensor probes and relayed back to City's SCADA system in Public Works department. Alarm will be triggered when readings exceed high water level and corresponding reading entered into record.		
e.	Operator safety	There are good safety practices in place.		
	Maintenance			
2.7	The particular maintenance needs of critical components or subsystems, such as flow control systems, power supply, backup power, civil structures, drainage, public safety and security measures and communications and other infrastructure have been identified	Maintenance practices are good	N.A.	
2.8	Maintenance procedures are documented and followed to ensure that the dam remains in a safe and operational condition	Yes		
2.9	Maintenance activities are prioritized and carried out with due consideration to the consequences of	Yes		

	failure, public safety and security			
	Surveillance			
2.10	Documented surveillance procedures for the dam and reservoir are followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety	Seepage weirs are read manually on a weekly basis and automatically and relayed by SCADA		
2.11	The surveillance program provides regular monitoring of dam performance, as follows:			
a.	Actual and expected performance are compared to identify deviations	The Reservoir water level measurement are collected and monitored but not plotted.	NCs	These readings should be plotted so that any anomalous behaviour can be readily identified.
b.	Analysis of changes in performance, deviation from expected performance or the development of hazardous conditions	Seepage readings are measured weekly and any anomalous results would be noted; however as stated above they should be plotted monthly	NCs	
c.	Reservoir operations are confirmed to be in compliance with dam safety requirements	Yes present operation of the reservoir is safe		
d.	Confirmation that adequate maintenance is being carried out	Maintenance records are kept		
2.12	The surveillance program has adequate quality assurance to maintain the integrity of data, inspection information, dam safety recommendations, training and response to unusual conditions	Yes there are weekly checks carried out on the dam		
2.13	The frequency of inspection and monitoring activities reflects the consequences of failure, dam condition and past performance, rapidity of development of potential failure modes, access constraints due to weather or the season, regulatory requirements and security needs.	In conformance with the CDA Guidelines and BC Dam Safety Regulations		
2.14	Special inspections are undertaken following unusual events (if no unusual events then acknowledge that requirement to do so is documented in OMS).	Yes it is documented		
2.15	Training is provided so that inspectors understand the importance of their role, the value of good documentation, and the means to carry out their responsibilities effectively.	There is no formal training for operators	NCm	This needs to be initiated
2.16	Qualifications and training records of all individuals with responsibilities for dam safety activities are available and maintained	Yes		
2.17	Procedures document how often instruments are read and by whom, where the instrument readings will be stored, how they will be processed, how they will be analyzed, what threshold values or limits are acceptable for triggering follow-up actions, what the follow-up actions should be and what instrument maintenance and calibration are necessary.	Yes		
3	**Emergency Preparedness**			
3.1	An emergency management process is in place for the dam including emergency response procedures and emergency preparedness plans with a level of detail that is commensurate with the consequences of failure.	Due to the risk of failure, a comprehensive EPP is in place accompanied by a Public Works Department Operation Plan.		
3.2	The emergency response procedures outline the steps that the operations staffs is to follow in the event of an emergency at the dam.	Yes		
3.3	Documentation clearly states, in order of priority, the key roles and responsibilities, as well as the required notifications and contact information.	Yes		

3.4	The emergency response procedures cover the full range of flood management planning, normal operating procedures and surveillance procedures	Yes		
3.5	The emergency management process ensures that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.	Yes		
3.6	Roles and responsibilities of the dam owner and response agencies are defined.	Yes		
3.7	Inundation maps and critical flood information are appropriate and are available to downstream response agencies.	Yes		
3.8	Exercises are carried out regularly to test the emergency procedures.	A mock emergency exercise was planned for 26th Nov. 2013		
3.9	Staffs are adequately trained in the emergency procedures.			
3.10	Emergency plans are updated regularly and distribution is controlled so that all copies are kept up to date.	Yes		
4	**Dam Safety Review**			
4.1	A safety review of the dam ("Dam Safety Review") is carried out periodically based on the consequences of failure.	A formal annual inspection is carried out.		
5	**Dam Design and Capability**			
5.1	The MDE selected reflects current seismic understanding	No.	NCp	Appropriate seismic upgrade measures are to be carried out in consultation with stakeholders.
5.2	The IDF is based on appropriate hydrological analyses	No.	NCp	As above.
5.3	The dam is safely capable of passing flows as required for all applicable loading conditions (normal, winter, earthquake, flood)	No	NCp	Appropriate measures are to be taken to upgrade the spillway in consultation with stakeholders
5.4	The dam has adequate freeboard for all applicable operating conditions (normal, winter, earthquake, flood)	No	NCp	Recent study has shown that failure of the upstream slope could result in toppling of concrete wall into the reservoir with a consequent loss of freeboard and overtopping.
5.5	The analyses are current	See 5.3 above		
5.6	The approach and exit channels of discharge facilities are adequately protected against erosion and free of any obstructions that could adversely affect the discharge capacity of the facilities	No	NCm	See issue MCR09-5. Erosion along the left bank of the spillway channel has undermined several trees overhanging the channel. The trees need to be removed.
5.7	The dams, abutments and foundations are not subject to unacceptable deformation or overstressing	Yes	NCp	The stability of the dam has originally been carried out for a horizontal peak acceleration less than what is now required for the dam with the “Extreme” consequence. Earthquake damage to the dam slopes can lead to toppling failure of the core wall.
5.8	Adequate filter and drainage facilities are provided to intercept and control the maximum anticipated seepage and to prevent internal erosion	Yes		
5.9	Hydraulic gradients in the dams, abutments, foundations and along embedded structures are sufficiently	Yes		

	low to prevent piping and instability			
5.10	Slopes of an embankment have adequate protection against erosion, seepage, traffic, frost and burrowing animals	Yes		
5.11	Stability of reservoir slopes are evaluated under all conditions and unacceptable risk to public safety, the dam or its appurtenant structures is identified.	Needs to upgrade to provide sufficient stability in extreme seismic condition	NCp	
5.12	The need for reservoir evacuation or emergency drawdown capability as a dam safety risk control measure has been assessed.	Yes		Evaluated in 2013 studies by Klohn Crippen Berger and to be further studies currently underway by recently appointed consultant

TR6 DAM SAFETY EXPECTATIONS

To meet the principals of the CDA Guidelines – **Lower Chase River Dam**

1 Dam Safety Management System	**Comments**	**Deficiency / Non-Conformance**	**Recommendation**
1.1 The Dam is classified appropriately in terms of the consequences of failure including life, environmental, cultural and third-party economic losses (Based on the BC Regulations)	Yes		
1.2 Hazards external and internal to the dam have been defined	A hazard analysis was carried out as part of this DSR		
1.3 The potential failure modes for the dam and the initial conditions downstream from the dam have been identified	This has been done as part of the hazard analysis.		
1.4 The dam system and all other components of the water barrier are defined for dam safety.	These have been defined in the hazard analysis		
1.5 The discharge characteristics for the failure modes have been estimated	These have been obtained from past studies		
1.6 The dam safety management system for the dam is in place incorporating:			
a. policies,	In place		
b. responsibilities,	These have been defined		
c. plans and procedures including OMS, public safety and security,	These have been defined		
d. documentation,	The OMS manual has been prepared		
e. training and review,	Operator training needs to be formalized	NCp	
f. prioritization and correction of deficiencies and non-conformances,	Generally the deficiencies and non-conformances are corrected in a reasonable time period		
g. periodic Dam Safety Reviews	Weekly inspections are carried out. Annual reviews are carried out. This 2013 DSR is the first since 2003 and needs to be done every 7 years		The next DSR should be done in 2020
h. supporting infrastructure	Watershed Inspectors are assigned to the dam and conduct weekly visits. A SCADA system is in place. The dams are located within the City boundaries and consequently access is good.		
1.7 Deficiencies are documented, reviewed and resolved in a timely manner. Decisions are justified and documented	In general they are resolved in a timely manner.		
1.8 Records relevant to dam safety are available including design documents, historical instrument readings, inspection and testing reports, operational records and investigation results.	Documentation is fairly complete. There are little or no construction records available for the dam. Seepage weirs are read both automatically and are read also on a weekly basis.		
1.9 Applicable regulations are met	Regulations are met.		
2 Operation, Maintenance and Surveillance			
2.1 Responsibilities and authorities are clearly delegated within the organization for all dam safety activities	Yes		

2.2	Requirements for the safe operation, maintenance and surveillance of the dam are documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure	In general yes		
2.3	The OMS Manual is reviewed and updated periodically when major changes to the structure, flow control equipment, operating conditions or company organizational structure and responsibilities have occurred.	The OMS manual is currently being updated.		
2.4	Documented operating procedures for the dam and flow control equipment under normal, unusual and emergency conditions exist, are consistent with the OMS Manual and are followed	The OMS manual is being followed		
	Operation			
2.5	Critical discharge facilities are able to operate under all expected conditions.	N.A.		The spillway is a free overflow structure.
a.	Flow control equipment is tested and is capable of operating as required.	N.A.		
b.	Normal and standby power sources, as well as local and remote controls, are tested.	N.A.		
c.	Testing is on a defined schedule and test results are documented and reviewed.	N.A.		
d.	Management of debris and ice is carried out to ensure operability of discharge facilities	Routine maintenance is being carried out to keep spillway clear of debris. Problem could be identified during routine maintenance or weekly inspection.		Overhanging trees in spillway requires attention.
2.6	Operating procedures take into account:			
a.	Outflow from upstream dams	Yes		
b.	Reservoir levels and rates of drawdown	Reservoir level is controlled by the free overflow spillway		
c.	Reservoir control and discharge during an emergency	N.A.		
d.	Reliable flood forecasting information	Yes, reservoir water levels are being measured with ultrasonic level sensor probes and relayed back to City’s SCADA system in Public Works department. Alarm will be triggered when readings exceed high water level and corresponding reading entered into record.		
e.	Operator safety	There are good safety practices in place.		
	Maintenance			
2.7	The particular maintenance needs of critical components or subsystems, such as flow control systems, power supply, backup power, civil structures, drainage, public safety and security measures and communications and other infrastructure have been identified	Maintenance practices are good	N.A.	
2.8	Maintenance procedures are documented and followed to ensure that the dam remains in a safe and operational condition	Yes		
2.9	Maintenance activities are prioritized and carried out with due consideration to the consequences of	Yes		

	failure, public safety and security			
	Surveillance			
2.10	Documented surveillance procedures for the dam and reservoir are followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety	Seepage weirs are read manually on a weekly basis and automatically and relayed by SCADA		
2.11	The surveillance program provides regular monitoring of dam performance, as follows:			
a.	Actual and expected performance are compared to identify deviations	The Reservoir water level measurement are collected and monitored but not plotted.	NCs	These readings should be plotted so that any anomalous behaviour can be readily identified.
b.	Analysis of changes in performance, deviation from expected performance or the development of hazardous conditions	Seepage readings are measured weekly and any anomalous results would be noted; however as stated above they should be plotted monthly	NCs	
c.	Reservoir operations are confirmed to be in compliance with dam safety requirements	Yes present operation of the reservoir is safe		
d.	Confirmation that adequate maintenance is being carried out	Maintenance records are kept		
2.12	The surveillance program has adequate quality assurance to maintain the integrity of data, inspection information, dam safety recommendations, training and response to unusual conditions	Yes there are weekly checks carried out on the dam		
2.13	The frequency of inspection and monitoring activities reflects the consequences of failure, dam condition and past performance, rapidity of development of potential failure modes, access constraints due to weather or the season, regulatory requirements and security needs.	In conformance with the CDA Guidelines and BC Dam Safety Regulations		
2.14	Special inspections are undertaken following unusual events (if no unusual events then acknowledge that requirement to do so is documented in OMS).	Yes it is documented		
2.15	Training is provided so that inspectors understand the importance of their role, the value of good documentation, and the means to carry out their responsibilities effectively.	There is no formal training for operators		This needs to be initiated
2.16	Qualifications and training records of all individuals with responsibilities for dam safety activities are available and maintained	Yes		
2.17	Procedures document how often instruments are read and by whom, where the instrument readings will be stored, how they will be processed, how they will be analyzed, what threshold values or limits are acceptable for triggering follow-up actions, what the follow-up actions should be and what instrument maintenance and calibration are necessary.	Yes		
3	**Emergency Preparedness**			
3.1	An emergency management process is in place for the dam including emergency response procedures and emergency preparedness plans with a level of detail that is commensurate with the consequences of failure.	Due to the risk of failure, a comprehensive EPP is in place accompanied by a Public Works Department Operation Plan.		
3.2	The emergency response procedures outline the steps that the operations staffs is to follow in the event of an emergency at the dam.	Yes		
3.3	Documentation clearly states, in order of priority, the key roles and responsibilities, as well as the required notifications and contact information.	Yes		

3.4	The emergency response procedures cover the full range of flood management planning, normal operating procedures and surveillance procedures	Yes		
3.5	The emergency management process ensures that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.	Yes		
3.6	Roles and responsibilities of the dam owner and response agencies are defined.	Yes		
3.7	Inundation maps and critical flood information are appropriate and are available to downstream response agencies.	Yes		
3.8	Exercises are carried out regularly to test the emergency procedures.	A mock emergency exercise was planned for 26th Nov. 2013		
3.9	Staffs are adequately trained in the emergency procedures.			
3.10	Emergency plans are updated regularly and distribution is controlled so that all copies are kept up to date.	Yes		
4	**Dam Safety Review**			
4.1	A safety review of the dam ("Dam Safety Review") is carried out periodically based on the consequences of failure.	A formal annual inspection is carried out.		
5	**Dam Design and Capability**			
5.1	The MDE selected reflects current seismic understanding	No.	NCp	Appropriate seismic upgrade measures are to be carried out in consultation with stakeholders.
5.2	The IDF is based on appropriate hydrological analyses	No.	NCp	As above.
5.3	The dam is safely capable of passing flows as required for all applicable loading conditions (normal, winter, earthquake, flood)	No	NCp	Appropriate measures are to be taken to upgrade the spillway in consultation with stakeholders
5.4	The dam has adequate freeboard for all applicable operating conditions (normal, winter, earthquake, flood)	No	NCm	Recent study has shown that failure of the upstream slope could result in toppling of concrete wall into the reservoir with a consequent loss of freeboard and overtopping.
5.5	The analyses are current	See 5.3 above		
5.6	The approach and exit channels of discharge facilities are adequately protected against erosion and free of any obstructions that could adversely affect the discharge capacity of the facilities	Yes		
5.7	The dams, abutments and foundations are not subject to unacceptable deformation or overstressing	No	NCp	The stability of the dam has originally been carried out for a horizontal peak acceleration less than what is now required for the dam with the “Extreme” consequence. Earthquake damage to the dam slopes can lead to toppling failure of the core wall.
5.8	Adequate filter and drainage facilities are provided to intercept and control the maximum anticipated seepage and to prevent internal erosion	Yes		
5.9	Hydraulic gradients in the dams, abutments, foundations and along embedded structures are sufficiently low to prevent piping and instability	Yes		

5.10	Slopes of an embankment have adequate protection against erosion, seepage, traffic, frost and burrowing animals	No	NCm	See issue LCR09-6. As noted in Golder 20003 DSR, downstream slope of dam is steep and erosion is occurring. 2009 FADSI recommended stability to be reviewed and remedial measures carried out.
5.11	Stability of reservoir slopes are evaluated under all conditions and unacceptable risk to public safety, the dam or its appurtenant structures is identified.	Needs to upgraded to provide sufficient stability in extreme seismic condition	NCp	
5.12	The need for reservoir evacuation or emergency drawdown capability as a dam safety risk control measure has been assessed.	Yes		Evaluated in 2013 studies by Klohn Crippen Berger and to be further studies currently underway by recently appointed consultant

Appendix 7

MWH
BUILDING A BETTER WORLD

MEMORANDUM

TO: *Project Files* DATE: *04 December, 2013*

cc:

FROM: *John Young*

SUBJECT: Middle and Lower Chase Dams Safety Assessment
Record of Past Earthquake Shaking

1) Introduction

As a supplement to the safety assessment of the Middle and Lower Chase dams, an assessment has been carried out to determine if the dams have been subjected to significant earthquake shaking during the past century. The purpose of this study is to determine to what degree dam stability has been tested by actual earthquake ground motions. It should be noted that this study is an assessment of actual history and is not intended to be the basis of a seismic hazard study for future seismicity.

The middle and Lower Chase Dams were commissioned in approximately 1911. To determine the levels of past ground shaking the following work has been done:

- Compile data on all earthquakes larger than Magnitude 3.5 that have occurred within a 200 km radius of the Upper and Lower Chase dams.
- Compute the peak ground acceleration at the site using well known attenuation relationships.

2) Earthquake Records

The study compiled records of 61 earthquakes that occurred between 1912 and 2009 within a 200 km radius of the project site. Earthquake images are shown on the Google Earth image in Figure 2.1. This period covers the operation life of the Central and Lower Chase River dams. The earthquake records are from the following sources:

- 1985 to 2009: National Research Council of Canada
- 1974to 1984: US Geological Survey
- 1912 to 1949: National Research Council of Canada, “Important Canadian Earthquakes” file

It should be pointed out that the data has not been messaged or culled in any way. Because the data comes from three data bases, there may be some gaps and omissions in the record. No data on smaller earthquakes (< M4.0) was found in publicly accessible databases for the period prior to 1972. The database would need further work if it was to be used in a site specific probabilistic seismic hazard assessment (PSHA). However no important earthquakes have been omitted and the record is sufficient for the overall purposes of this review.

Data for the earthquake are presented on Table A1 and A2 in Appendix A. The distribution of earthquake magnitudes for this period is summarized as follows:

- M 3.5 to M 3.9: 28 events
- M 4.0 to M 4.9: 25 events
- M5.0 to M 5.9: 6 Events
- M6.0 to M6.9: 1 event
- > M7.0: 1 event

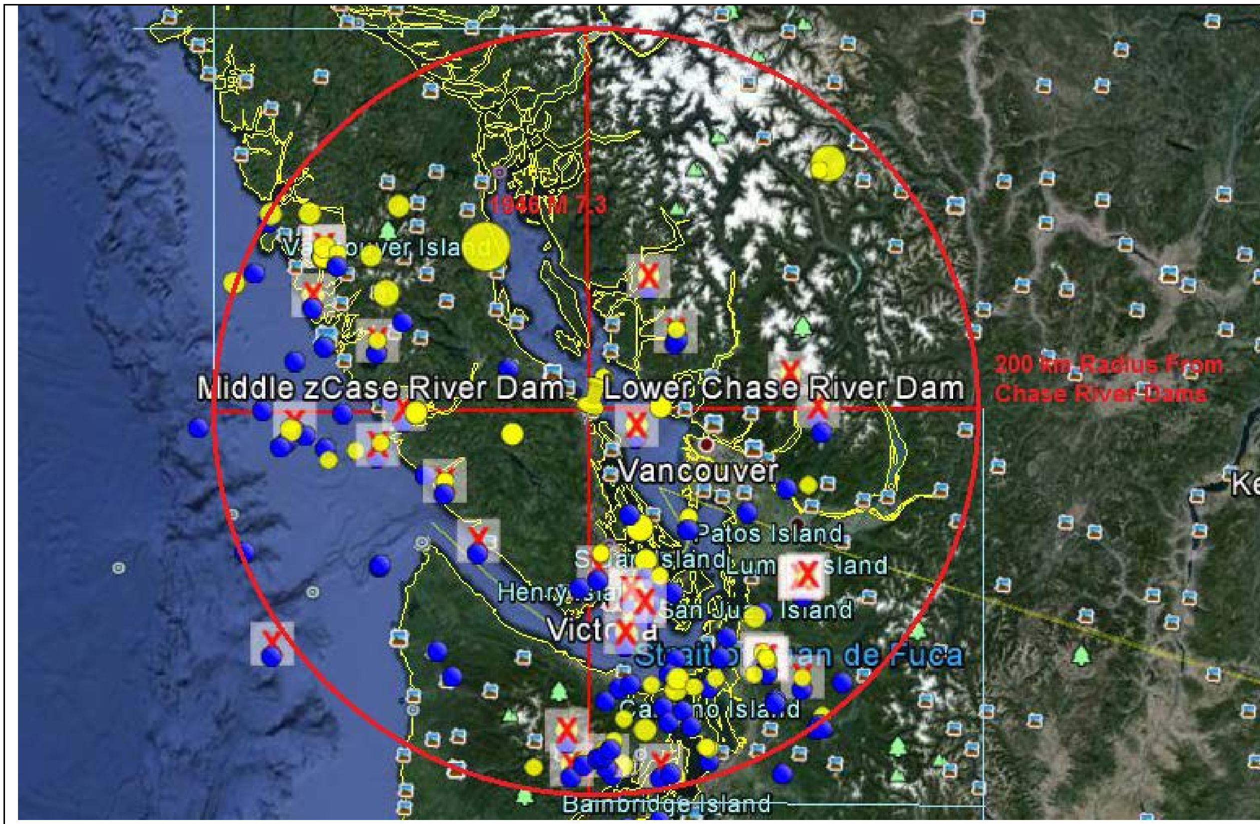


Fig. 2.1: Google Earth Image showing historical earthquake epicentres located with 200 km of the Chase River damsites.

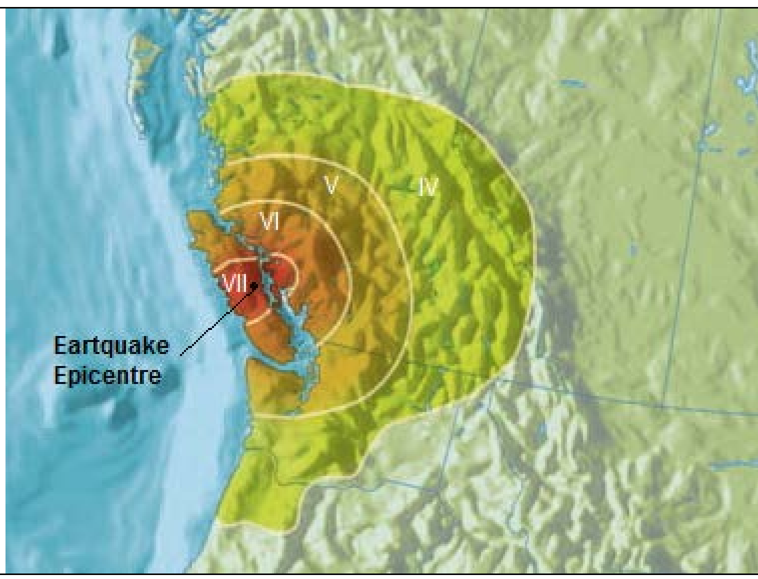


Figure 2.2: Modified Mercalli Intensity map showing intensity of shaking associated with an earthquake (magnitude 7.3) that occurred at 10:15 A.M. on June 23, 1946. The epicentre was in central Vancouver Island, near the communities of Courtenay and Campbell River. (Department of Natural Resources Canada)

The largest earthquake in this post 1911 data set is the M 7.3 event which occurred on the east side Vancouver Island, approximately 100 km north northwest of Nanaimo on June 23, 1946. The epicenter was located in the Forbidden Plateau, west of Campbell River. Ground shaking from this event caused 2 fatalities. Extensive damage occurred throughout central area of Vancouver Island (see Figure 2. 2) and in areas of the British Columbia mainland. Some damages were reported in Vancouver and as far away as Seattle, Washington.

Several other significant earthquakes of M 4.5 to M 5.5 occurred within 200 km of the dams during their operation life. Shaking from events smaller than M5.5 would have been widely felt, but relatively little damage would have happened.

The largest historical earthquake on record in the study area is the Magnitude 9 Cascadia Earthquake which occurred on January 26, 1700. This event was centered in the subduction zone off the west coast of Vancouver Island. It is estimated that this earthquake was caused by a 1000 km long fault rupture. The epicenter location is unknown but has been assumed by the Geological Survey of Canada to have been approximately at the intersection of the Canada / USA border, southwest of Vancouver Island. The assumed epicentre is located approximately 100 km south-southeast of the Chase River dams. The Cascadia Earthquake would have caused severe ground shaking throughout Vancouver Island in much of the west coast of British Columbia and the state of Washington. All seismic hazard studies of the British Columbia area assume that further events of similar magnitude can occur in in the offshore subduction zone. Postulated similar subduction zone earthquakes are controlling factors for the NRCC building code seismic hazard criteria for the Nanaimo area.

3) Computed Peak Ground Acceleration (PGA) Values

A preliminary screening of the site peak ground acceleration (PGA) ground motions is presented on Tables A1 and A2 of Appendix A. Two attenuation formulas are used on these tables; the 1993 Campbell formula for rock foundations, the 1997 Campbell relationship for soft ground and the 1991Youngs soft ground formula for subduction zone interface earthquakes. The Campbell relationships are appropriate for relatively shallow crustal earthquakes but it underestimates the PGA of deeper subduction zone events. The Youngs formula, which is not suitable for shallow crustal events, is appropriate for subduction zone events.

It can be seen on Tables A1 and A2 that most of the earthquakes are too small and/or too distant from the site to produce significant PGA values. These tables do show, however that a number of the historical earthquakes could have produced significant ground motions in the area of interest. Table 3.1 below lists a total of 7 earthquakes that could have theoretically produced PGA values greater than 0.01 g at the Chase River dams. The epicentres of these M 4.6 to M 7.3 events were located within 167 km of the Chase River Dams. This table also shows a PGA values computed by Campbell (93 and 97) for crustal earthquakes and the Youngs et al (97) subduction zone relationships (the 1997 Youngs et al relationship is more accurate than the 1991 Youngs relationship used on Table A1 an A2). The following assumptions were made:

- It is assumed that the two Chase River damsites have bedrock foundations.
- Both the mean/median and 84^{th} percentile values are shown in Table 3.1and it is assumed that realistic PGA values fall within the ranges shown for each event.
- The Campbell attenuation relationships are appropriate for crustal earthquakes.
- The Youngs attenuation relationship, which computes higher PGA values than the Campbell formulas, is appropriate for subduction zone earthquakes. It should be noted that the Youngs relationship has a large degree of scatter and the 84^{th} percentile PGA values are more than twice the mean values.
- For this assessment, it is assumed that earthquakes with a focal depth of 50 km or more may be subduction zone earthquakes. This provides an upper bound PGA's caused by these events, as shown on Table 3.1. It is also assumed that all earthquakes that are shallower than 50 km are crustal events.

Table 3.1: Significant earthquake and computed PGA at Chase River damsites. PGA values shown are for bedrock foundations.

Date	Latitude	Longitude	Magnitude		Depth (km)	Distance (R, km)	Horizontal PGA (g)			
							Campbell, rock (93)		Youngs et al subduction, rock	
							Mean	84th percentile	Median	84th percentile
6/7/2001	48.49	-124.38	4.9	Mw	35	79.5	0.006	0.010	na	na
6/24/1997	49.24	-123.62	4.6	ML	4.6	26.5	0.023	0.045	na	na
11/29/1979	49.39	-123.96	3.8	mb	69	26.5	0.015	0.025	0.04	0.11
5/16/1976	48.80	-123.36	5.1	mb	62	59.0	0.015	0.025	0.04	0.09
11/30/1975	49.36	-123.51	4.7	mb	32	40.2	0.016	0.032	na	Na
23/06/1946	49.76	-125.34	7.3	Ms	50	100.0	0.023	0.038	0.07	0.14
23/01/1920	48.60	-123.00	5.5	ML	50	93.3	0.007	0.011	0.02	0.04

The assessment on Table 3.1 indicates that the Chase River dams have experienced some level of ground shaking (>0.04g) at least three times since they were commissioned in 1911. These are for the deeper earthquakes that are assumed to be subduction zone events and the PGA values are computed by the Youngs et al relationship. Horizontal PGA values were in the range of 0.04g to 0.11g in during the 1976 (mb 5.1) and 1979 (mb 3.8) earthquakes. The destructive 1946 M 7.3 earthquake triggered a horizontal PGA that was at least 0.07g and may have been as high as 0.14g.

4) Conclusions

The Middle and Lower Chase River dams have been subjected to earthquake vibrations since their commissioning in 1911. The sites experienced peak ground accelerations (PGA) of approximately 0.04 to 0.12g on a few occasions and maybe more than 0.2g during the large 1946 earthquake. A maximum PGA of 0.04g is approximately equivalent to approximately the 1/40 to 1/50 year ground motion of the NRC building code seismic hazard for the site. A 0.12g PGA would be approximately equivalent to the NRC 1/125 year event.

Submitted by

John Young
Principal Geotechnical Engineer

Historical earthquake data from GSC and USGS files

All earthquakes occur with a 200 km radius of the Middle Chase Dam

(N49.150 N and -123.962 W)

Table A1: GSC (NRC) Earthquake Data

Earthquake Description							PGA (g)		
Date	Lat.	Long	Depth	Magnitude		R (km)	Youngs (97) Soil	Campbell (93) (Rock Foundation)	Campbell (97) Soil Foundation (M>4, R < 100 km)
1/30/2009	47.803	-122.671	70.9	4.6	Mw	177.6	0.003	0.001	
11/27/2007	47.765	-123.037	54.5	3.5	ML	168.6		0.005	
7/4/2006	48.328	-123.204	46.2	4	Mw	107.1		0.003	
1/15/2006	48.565	-123.533	44.4	3.6	ML	72.3		0.004	
11/23/2005	48.854	-122.146	1	4.4	Mw	136.6		0.002	
3/8/2004	49.35	-123.977	1	3.1	Mw	22.3		0.019	
3/17/2004	48.439	-122.267	1	4.2	Mw	147.3		0.001	
4/25/2003	47.67	-123.25	51.3	4.6	Mw	172.9	0.003	0.001	
9/21/2002	48.49	-123.151	26.2	4.3	Mw	94.5		0.004	0.007
6/7/2001	48.49	-124.378	35	4.9	Mw	79.5	0.017	0.010	0.015
4/7/2001	48.691	-124.74	32.1	3.8	ML	76.5		0.004	0.007
8/1/2000	49.493	-126.133	41.3	5.2	Mw	162.1	0.005	0.002	
8/1/2000	49.492	-126.133	41.3	5.2	Mw	162.0	0.005	0.002	
6/29/2000	48.468	-123.146	25.9	3.6	ML	96.6		0.002	
12/25/1999	48.688	-125.865	30.8	5	Mw	148.4	0.005	0.003	
12/11/1999	48.521	-123.272	53	4.9	Mw	86.4	0.014	0.008	0.014
12/11/1999	48.521	-123.272	53	3.9	ML	86.4		0.004	0.007
5/8/1999	49.264	-126.076	33.4	3.8	ML	154.3		0.002	
6/24/1997	49.237	-123.621	4.6	4.6	ML	26.6	0.054	0.045	0.058
2/22/1996	49.897	-123.902	2	4	ML	83.3	0.004	0.004	0.007
11/20/1994	49.18	-125.535	38.2	3.8	ML	114.5		0.002	
2/19/1991	49.696	-122.725	5.2	3.9	ML	108.2		0.002	
4/14/1990	48.822	-122.188	3.6	4	ML	134.6		0.001	
4/14/1990	48.825	-122.191	2	4.9	ML	134.3		0.003	
4/3/1990	48.836	-122.175	1.7	3.8	ML	135.1		0.001	
4/2/1990	48.832	-122.188	0.8	4.4	ML	134.3		0.001	
10/24/1989	48.931	-125.19	36.9	3.9	ML	92.9		0.005	0.006
3/6/1989	48.429	-122.231	2	4	ML	150.2		0.001	
3/5/1989	47.813	-123.357	46	4.6	MB	155.4		0.001	
2/14/1989	48.429	-122.228	1	3.6	ML	150.4		0.001	
2/6/1989	48.418	-122.214	0	3.5	ML	151.9		0.000	
11/22/1988	47.704	-125.455	59.9	3.5	ML	195.1		0.000	
4/8/1987	49.703	-123.589	3.3	3.9	ML	67.2		0.006	
9/6/1986	48.736	-125.27	33.1	3.5	ML	106.2		0.002	
7/10/1986	49.597	-122.462	4.9	3.5	ML	119.6		0.001	

Table A2: Mixed USGS and GSC Earthquake Data

Earthquake Description							PGA (g)		
Date	Lat.	Long	Depth	Magnitude		R (km)	Youngs (97) Soil	Campbell (93) 84th percentile, Rock	Campbell (97) Soil Foundation (M>4, R < 100 km)
8/28/1983	47.934	-122.854	51.3	4.2	mb	158.1		0.001	
2/5/1983	48.673	-125.397	33	3.6	ml	117.6		0.002	
2/24/1982	49.18	-126.63	18	4.9	mb	194.2		0.002	
11/12/1981	47.95	-122.42	27.5	3.9	ml	175.4		0.001	
6/8/1980	47.95	-123.017	51	3.5	ml	150.6		0.001	
3/7/1980	49.79	-125.741	44	4.9	mb	147.1		0.001	
11/29/1979	49.388	-123.955	69	3.8	mb	26.5	0.050	0.025	0.036
11/26/1979	48.59	-122.398	21	4.1	mb	130.4		0.002	
11/15/1979	49.24	-122.345	15	3.6	ml	118.0		0.001	
11/9/1979	49.002	-124.415	28	4.3	mb	36.9	0.048	0.024	0.031
3/12/1979	48.202	-122.761	26	3.8	mb	137.6		0.001	
8/23/1978	48.379	-123.2	17	3.5	ml	102.4		0.000	
8/19/1978	48.629	-123.55	32	3.5	ml	65.4		0.004	
11/17/1976	49.532	-125.797	10	4.2	mb	139.7		0.002	
9/2/1976	48.205	-122.761	24	4.3	mb	137.3		0.002	
8/12/1976	50.62	-123.01	18	3.8	ml	177.3		0.001	
5/16/1976	48.8	-123.356	62	5.1	mb	59.0	0.056	0.025	0.038
4/25/1976	49.538	-126.574	33	4.3	mb	194.3		0.001	
1/18/1976	48.587	-125.551	10	3.9	ml	132.1		0.000	
11/30/1975	49.355	-123.506	32	4.7	mb	40.2	0.050	0.032	0.043
11/29/1975	49.606	-126.316	33	4	mb	178.0		0.001	
3/31/1975	49.397	-125.599	33	5.3	mb	122.0		0.005	
5/16/1974	48.139	-122.918	54	3.8	mb	136.2		0.001	
06/231946	49.76	-125.34	x	7.3	Ms	100.0	0.090	0.038	0.075
01/23/1920	48.6	-123	50+/- 20 km	5.5	OT	93.3		0.011	0.020
12/061918	49.44	-126.22	15	6.9	OT	167.1	0.032	0.009	

LEGEND:

The Richter local magnitude (ML)
Moment magnitude (Mw)
Surface wave magnitude (Ms)
Body wave magnitude (mb)