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LAKE GERALDINE DAM

SAFETY REVIEW

Iqaluit, Nunavut

Final Report

PREPARED FOR:

THE CITY OF IQALUIT

PREPARED BY:

CONCENTRIC ASSOCIATES INTERNATIONAL INCORPORATED

CONCENTRIC REFERENCE NUMBER:

13-5021-B

DATE:

March 27, 2014

EXECUTIVE SUMMARY

The City Of Iqaluit retained Concentric Associates International Incorporated (Concentric), in May 2013, to prepare a Dam Safety Review (DSR) for the Lake Geraldine Dam.

The DSR was conducted during the period July through August 2013, in general accordance with the Dam Safety Guidelines, (*DSG2007*) prepared by the Canadian Dam Association.

As a result of the DSR, the following observations, conclusions and recommendations have been made regarding Lake Geraldine Dam:

1. In accordance with Section 2 of the DSG, the dam classification is Very High (Consequence). This classification requires a DSR every five (5) years.

2. The design review for the dam structure has been based on visual information obtained on site and design documentation provided by the design engineer Trow Associates (Trow, now exp.).

3. A remote surveillance camera is recommended.

4. The Permanent Record File (PRF), Logbook, and Operations, Maintenance and Surveillance (OMS) Manual require updating for 2014.

5. As indicated in the 2012 DSI, the Emergency Preparedness Plan (EPP) has reportedly been completed. The City had this document prepared by others. This document should be included in the PRF, and any incompleteness resolved.

6. A Dam Safety Inspection (DSI) is required in 2014.

7. A new DSR will be required in 2018.

8. Consideration should be given to implementing a pore-water pressure monitoring program leading up to the next DSR in 2018.

9. A Seismic Hazard Assessment (SHA) is recommended prior to the next DSR in 2018.

10. An underwater survey is recommended for 2014.

11. It is recommended that ballast and rip-rap be supplemented at the south end of the north berm (where the berm abuts the concrete dam structure).

12. Insufficient data exists on the berm construction. In conjunction with Item 8., above, invasive/material testing and independent analysis should be conducted leading up to the 2018 DSR.

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1. INTRODUCTION & SCOPE OF WORK

Significant modifications to the Lake Geraldine Dam in 2005 triggered the requirement for a Dam Safety Review (DSR) in 2006, in accordance with the Canadian Dam Association publication, Dam Safety Guidelines (DSG), published in 1999. Since the 2006 DSR, no significant modifications have been made. The current DSR (2013) has been prepared because of the requirement of the 1999 DSG to conduct a DSR every seven (7) years.

The 1999 DSG has since been superseded by the 2007 DSG. The DSG applies, in general, to those structures that are at least 2.5 meters in height, and which have at least 30,000 cubic meters of storage capacity. The Lake Geraldine Dam exceeds these minimums.

The DSG document is far reaching in terms of applicability and requirements for conformance. This is understandable as the type and complexity of structures that fall under the jurisdiction of the document varies considerably, from relatively small and simple berms or dikes to massive and complex dams associated with hydroelectric generating facilities, irrigation, flood control, etc.

The DSG requires that all structures exceeding the height and volume minimums described above be classified according to their "consequence category", that is, the consequence of dam failure in terms of incremental loss of life, environmental and cultural values, and infrastructure and economics. The category assigned may range from Low to Extreme. The consequence category dictates the requirement and frequency of Dam Safety Reviews.

A Dam Safety Review (DSR) is a formal review process, conducted at regular intervals, that involves completion of items in accordance with the Dam Safety Guidelines. The DSR forms part of the record documentation of history, condition, repairs, alterations, monitoring, operating, safety and emergency procedures.

The frequency of DSR's varies depending on potential consequences of dam failure, the presence of changes in external hazards, the result of surveillance, and the demonstrated performance. For dam structures where there are significant implications for population at risk, loss of life, incremental environmental and cultural values, and infrastructure and economical losses, the frequency of DSR's will increase.

It is required in the DSG document that in the interval between DSR's, a Dam Safety Inspection (DSI) be performed on an annual basis. The DSI comprises a visual inspection to identify any changes in condition, or any observed concerns. The results of the DSI are incorporated into the DSR documentation. A DSI may trigger repairs, or changes in standard operating procedures.

The level of detail required to conduct a DSR is influenced by several factors as follows:

- Basis of previous assessments
- Complexity of the dam

- Continuity of surveillance and records
- Internal and external hazards
- Operating history
- Dam performance and age
- Need for public protection during operation

A summary of the methodology to complete the work is presented below:

1. Acquisition and assembly of chronological documentation, including but not limited to:
   - Design Documents
   - Repair Specifications
   - Past Condition Assessment Reports, including past DSI`s and DSR`s.
   - Records of Alteration
2. Review of all available record documentation.
3. Perform a site inspection to assess the current condition of the structures. No invasive work was performed; the condition assessment was visual in nature.
4. Interview maintenance and management personnel as required and appropriate.
5. Review the DSR requirements.
6. Prepare the draft DSR report, complete with record documentation.
7. Submit the final DSR report.

2. HISTORY & BACKGROUND

In the following chronological summary (Section 2.2), record documents have been referenced. After each reference, a number appears in parenthesis. That number corresponds to tabulated record document numbers in Section 2.4, where details are provided on the document source.

2.1 Reservoir

The City of Iqaluit derives its water supply from Lake Geraldine, which is retained by a structure consisting of a cast in place concrete gravity dam incorporating a spillway section and a cast in place concrete cut-off wall and berm. All concrete structures are reported to be founded on rock, and engage rock at their abutments.

Lake Geraldine is a natural body of water in an irregularly shaped basin. It is fed by rainfall and snow/ice melt from a watershed with an area of approximately 385 hectares.

2.2 History

In the late 1950's, the demand for a reliable year round source of water resulted in the construction of a cast in place concrete gravity dam, and a section of earth berm with a central cast in place concrete cut off wall. The project was designed and built by the Department Of National Defense. According to the literature, the original construction took place circa 1958.

Since that time, as the City has grown and water demands have risen, the dam has been raised four times to increase the storage capacity.

The first height increase of 0.3m reportedly took place in 1979. This involved a concrete extension, which was dowelled into the existing structure.

The second construction took place in 1985, and increased the height of the spillway structure by approximately 1.15m. The berm portion was widened and heightened as well to accommodate the increased storage capacity. Again, the extension was constructed of concrete dowelled into the existing structure, and incorporated a steel formwork frame over the spillway section.

The third extension was done in 1995, and increased the height of the gravity dam structure by a further 1.5m of concrete, with a corresponding increase in berm geometry. Based on analysis done prior to the extension, it was determined that the gravity dam would not have an adequate factor of safety against overturning if the extension was simply "dowelled-in" as before. The 1995 alteration therefore included an extensive rock-anchoring program for the gravity dam portion to provide the required stability to the structure.

The latest extension was completed in two phases over 2005/06. Additional rock anchors were installed thought the gravity dam in 2005 in preparation for a further height extension of 2m in 2006. The existing berms were enlarged and the existing cut-of-walls were extended in height. A new berm and cut off wall were installed to the south of the existing dam structures.

In the time span of the available historical data, which extends back to 1984, there have been numerous events relating to the safety and serviceability of the dam structures.

- In November 1984 joint and patch repairs were made to localized areas on the upstream side of the spillway structure by diving contractors. Reporting was minimal.
- In June 1990 an inspection report (4) of the structure by diving contractors was made following construction blasting. The 1984 repair areas were also assessed. The 1984 repairs were noted to have generally deteriorated. No conclusions were made. Reporting was minimal.
- In June 1990 a visual inspection report (5) was prepared for the City by an engineering consultant, as a result of the construction blast. No significant damage was noted, and no recommendations were made for repair.
- In July 1990 a dam inspection and stability report (6, 7) was conducted for the City by an engineering consultant. Recommendations were made regarding repair of leaking joints, and provisions to increase stability should the dam be raised in the future.
- In September 1990, a diving contractor performed crack repairs and prepared an inspection report (8). Repair material used was oakum. These repairs appeared to generally address areas observed in the June 1990 diving inspection. Reporting was minimal.
- In October 1997 a visual inspection report (11) was prepared for the City by an engineering consultant. Leaking cracks were identified; however, these were not viewed as being structurally significant. It was recommended that leaking cracks be chemically grouted. This work was not done.
- In June 1998, a study (12) was prepared for the Department Of Public Works by an engineering consultant to assess the hydrological impact of a dam failure on a proposed downstream hospital site.
- A diving inspection was reportedly carried out in 1999. A report was not submitted. A video record was provided. The video provides images of the water intake, but no record of the condition of the dam.
- In 2001, a DSR (13) was conducted for the Lake Geraldine Dam and Sewage Lagoon.
- In 2002, the dam was visually assessed, a diving inspection performed, and a DSI (14) was prepared, which cited the need for grouting repairs to actively leaking cracks.
- In 2003, grouting repairs were undertaken (15), primarily to seal actively leaking cracks, in particular, a larger flow crack on the south transition of spillway and gravity sections. A DSI report (16) was prepared.
- A geotechnical report was completed in 2005 prior to the vertical expansion (17).

- A DSI report (20, 21) was prepared in 2005 and 2006.
- A DSR (22) was conducted in 2006 because of the modifications (vertical extension) to the Lake Geraldine Dam in 2005 and 2006
- No DSI's were conducted in 2007 or 2008.
- DSI's (26, 28, 31, and 32) were conducted in 2009, 2010, 2011 and 2012.
- An Underwater Survey (27) was conducted in 2010.
- An Inundation Study for the Emergency Preparedness Plan was conducted in 2011/2012.
- Grouting repairs (30) were completed in 2011.
- Repairs to the North Berm (33) were conducted in 2012 due to the washout event of 2010.
- In August 2012, Concentric provided periodic monitoring of water accumulation areas on both sides of the vehicle access ramp. These areas were initially identified in 2010.
- In 2011 and 2012, Concentric investigated the suspect areas and conducted limited invasive openings to determine if a source was the 2006 cut-off wall interface. These investigations were inconclusive.
- In August 2012 monitoring confirmed little or no water accumulation in summer months. The water accumulations were most evident in late winter and early spring.
- In June 2013, Concentric prepared a scope of work for a proposed 12 month monitoring term, commencing August, 2013.

2.3 Description of Structure

The dam is comprised of a concrete section (incorporating a concrete spillway) and earth berms to the north and south. The 15.3m wide spillway has an upper elevation of 111.33m (the new operating level of the reservoir) while the concrete sections on either side of the spillway have an elevation of 112.28 m. At the operating level of the reservoir, the dam has approximately 0.95 m of freeboard. The southern section of the concrete dam extends approximately 39.1 m to the south rock abutment. The northern section of the concrete dam extends 13.3 m to the north of the spillway section, where it joins the earth berm. The north berm extends approximately 135 m to the north rock abutment. A new earth berm (approximately 68.5m long) was installed in a valley to the south of the existing structures in 2006. The berm sections of the dam incorporate a concrete cutoff which is reportedly founded in rock and has an upper elevation of 112.30 m (approximately 0.97m of freeboard). The concrete section of the dam is also reportedly founded in rock.

2.4 Relevant Record Documents

The following documentation has been utilized in the preparation of this report. Other record documentation was provided but not directly applicable to the DSR.

TABLE I
RELEVANT RECORD DOCUMENTATION
LAKE GERALDINE DAM

No.	Date	Description	Author
1	December 1957	Water Storage Dam at Lake Geraldine (3 Drawings)	DND
2	August 1984	Lake Geraldine Water Supply Report	OMM
3	January 1985	Water Supply Improvement Report	OMM
4	June 1990	General Diving Report	Arctic Divers
5	June 1990	Dam Inspection for Blast Damage	Hardy BBT
6	July 1990	Dam Inspection & Leakage Repair	Acres
7	July 1990	Dam Stability	Acres
8	Sept. 1990	Diving Report	Arctic Divers
9	Feb. 1995	Lake Geraldine Storage Report	OMM
10	June 1995	Lake Geraldine Storage Design Drawings & Specifications	OMM
11	October 1997	Dam Inspection	Trow
12	June 1998	Dam Failure Study	EBA
13	March 2001	Dam Safety Review	Trow
14	October 2002	Dam Safety Inspection	Trow
15	August 2003	Lake Geraldine Dam Repairs 2003	Dillon
16	2003	Dam Safety Inspection	Concentric
17	March 2005	Geotechnical Investigation	Trow
18	May 2005	Lake Geraldine Dam Rock Anchors 2005 (Specifications and 4 Drawings)	Trow
19	February 2006	Lake Geraldine Dam Earth and Concrete Work 2006 (Specifications and 11 Drawings)	Trow
20	2005	Dam Safety Inspection	Concentric
21	2006	Dam Safety Inspection	Concentric
22	Dec. 2006	Dam Safety Review	Concentric
23	2007	Permanent Record File (PRF)	Concentric
24	2007	Operations, Maintenance, and Surveillance (OMS) Manual	Concentric
25	2007	Logbook	Concentric
26	Oct. 2009	Dam Safety Inspection	Concentric
27	Aug. 2010	Underwater Survey	Concentric
28	Nov. 2010	Dam Safety Inspection	Concentric
29	Feb. 2011	Permanent Record File Update	Concentric
30	Aug. 2011	Grouting Repairs	Concentric
31	Sept. 2011	Dam Safety Inspection	Concentric
32	July 2012	Dam Safety Inspection	Concentric
33	Sept. 2012	North Berm Repairs	Concentric
34	2012	Emergency Preparedness Plan (EPP)	Others
35	2013	DSI and DSR	Concentric

3. COMMENTARY ON DAM SAFETY REVIEW REQUIREMENTS

According to the Dam Safety Guidelines, the document applies to those structures that are at least 2.5 meters in height, and which have at least 30,000 cubic meters of storage capacity. The Lake Geraldine Dam exceeds these minimums.

The document requires a systematic review, which includes the following items. For each item, the applicable Section number from the Dam Safety Guidelines is shown in parenthesis.

1. Dam Classification (DSG Section 2)
2. Site Inspection (DSG Section 5)
3. Analysis and Assessment: (DSG Section 6)
   - 3.1. Hydrotechnical (DSG Section 6.4)
   - 3.2. Seismic (DSG Section 6.5)
   - 3.3. Geotechnical (DSG Section 6.6)
   - 3.4. Structural (DSG Section 6.7)
   - 3.5. Mechanical and Electrical (DSG Section 6.8)
   - 3.6. Other Considerations (DSG Section 6.9)
4. Operation & Testing (DSG Section 3)
5. Maintenance (DSG Section 3)
6. Surveillance & Monitoring (DSG Section 3)
7. Emergency Preparedness (DSG Section 4)
8. Compliance With Previous Reviews (DSG Section 5)

4. LAKE GERALDINE DAM DSR

4.1 Dam Classification (DSG Section 2)

Based on the Dam Safety Guidelines, and the dam structure itself, the Lake Geraldine Dam has a "Very High" Dam Consequence Class for the two categories considered under the dam classification: *The Population at Risk and The Incremental Losses (of Life, of Environmental and Cultural Values and of Infrastructure and Economics*).

The "Very High" dam consequence class is assigned by the DSG, in the case of population at risk if the population at risk is ordinarily located in the dam-breach inundation zone (permanent residents).

In the case of incremental losses, a "Very High" dam consequence class is assigned for the three sub-categories as follows:

a) Incremental Loss of Life: if the loss of life is fewer than 100 persons.

b) Incremental Losses in Environmental and Cultural Values: if there is significant loss or deterioration of critical fish or wildlife habitat, but the restoration or compensation for the loss is possible but impractical.

c) Incremental Losses in Infrastructure and Economics: if there are very high economic losses affecting important infrastructure or services (e.g., Highway, industrial facilities, storage facilities for dangerous substances).

In the case of the Lake Geraldine Dam, both a) and c) are deemed to apply.

Under the guidelines it is required to have a Dam Safety Review every five (5) years for those structures with a "Very High" dam consequence class.

4.2 Site Inspection (DSG Section 5)

A visual site inspection of the dam structures was performed in August 2013. The inspection was non-invasive in nature, and did not include an underwater assessment.

A summary of observed conditions is as follows:

- The visible portions of the concrete structures are generally in good condition.
- There was no evidence of distress or overstressing of any portion of the visible concrete structures.
- The north and central berms appeared to be in a stable condition. Slopes of 2H:1V appeared to be maintained on the down stream rip-rap and in the up stream rock fill.
- The reservoir level was slightly below the top of the spillway.

- The reservoir level has reached the south berm.
- No significant changes were noted in the general condition of the concrete and earthworks portions of the dam. Seepage/leakage was observed to be occurring at the same locations as previously identified. Overall the magnitude of seepage/leakage was observed to be slightly reduced.
- Additional ballast/rip-rap is recommended at the south end of the north berm.
- The north berm in the vicinity of the ramp access did not exhibit visible leakage.

4.3 Analysis and Assessment (DSG Section 6)

The intent is to determine if the existing dam configuration satisfies performance criteria given in the DSG for safety and serviceability, in response to likely loads impinging on the structure. We have followed the format in the DSG document for convenience and clarity.

4.3.1 Hydrotechnical (DSG Section 6.4)

According to the DSG, dams shall be designed or evaluated for a maximum flood termed the Inflow Design Flood (IDF). The IDF is selected on the basis of the Potential Consequences of Failure and the Probable Maximum Flood (PMF). The PMF is defined as the most severe flood that may reasonably be expected to occur at a particular location. For a dam with a High Consequence Category, the DSG requires an IDF with an Annual Exceedance Probability (AEP) of 1/3 between 1/1000 year flood and the PMF.

The contributory area for the reservoir is essentially the water shed of the Sylvia Grinnel River. As the 2006 dam rising has not intersected additional drainage areas we deem the inflow characteristics on the reservoir and dam structure to be unchanged. The spillway characteristics (freeboard and width) have also been maintained with the new dam structure. As climate data has not indicated a significant change in rain and snow events, the statistical flood analysis carried out with the 2001 DSR and the Inundation Study conducted in 2011/2012 by others, are considered to be still valid and the dam is considered to meet the requirements of the DSG.

4.3.2 Seismic (DSG Section 6.5)

According to the DSG, dams shall be designed to withstand the Earthquake Design Ground Motion (EDGM). For a dam with a Very High Consequence Category, the DSG requires evaluation of a 1/5000 year EDGM. The DSG requires that the EDGM be justified to demonstrate conformance to societal norms of acceptable risk. Justification can be provided with the help of failure modes analysis focused on the particular modes that can contribute to failure initiated by a seismic event. If the justification cannot be provided then the EDGM should be 1/10,000 year.

The 2007 DSGs recommend that the seismic loading for evaluating existing dams be determined by the Earthquake Design Ground Motion (EDGM).

Establishing the EDGM is based on site characterization through a Seismic Hazard Assessment (SHA), which includes a statistical analysis of historic earthquakes for the site and region. This information is not readily available. For this reason, we have relied on the previous DSR for seismic compliance.

It is recommended that the next DSR (2018) include a SHA and allow for the significant time/research commitment to gather and analyze available seismic data, and develop a site appropriate EDGM.

4.3.3 Geotechnical (DSG Section 6.6)

Section 6.6 of the DSG presents Geotechnical considerations for proposed dams, as well as for several configurations of existing dams. The overall dam system includes the dam berm and appurtenant structures, their foundations, abutments, and the reservoir rim.

Concrete Gravity Dam Portion

For dams on rock foundations the DSG indicates that geotechnical investigations and design should be sufficient to ensure that *foundation stability*, *shear strength parameters* and *seepage and drainage* issues are identified and addressed.

Our review of the present dam configuration indicates that *seepage and drainage* are not presently areas of concern.

Information on the record drawings indicates that a peak angle of internal friction of 40 degrees has been used with respect to design of the gravity portion of the dam against sliding.

The designer, Trow (now exp.), has confirmed that the internal friction angle used was supplied by the geotechnical consultant (also Trow, now exp.), and satisfies the requirements for shear strength and foundation stability.

Berm Dam Portion

Under the 2007 DSG, several engineering analyses need to be performed to demonstrate that the dam, the foundation and the abutments will remain stable under all hazards and loading conditions.

Geotechnical hazards include the following:

- Overtopping,
- Surface erosion,
- Slope instability,
- Static and dynamic liquefaction,
- Seepage, and
- Deformation.

The raising of the reservoir in 2005/2006 entailed increasing the height of the north berm and installation of a new south berm. The general design/construction methodology was to leave the existing berm structures in place, extend the height of the existing cutoff wall and install the new materials over the existing berm materials. The cutoff wall for the new south berm has also been extended into rock while the new berm is founded on the native overburden. Cutoffs are installed to reduce seepage and uplift in the down stream berm structure. Where suitable soils are available, an earth core may be more durable than a concrete core. The concrete cutoff is deemed to be a necessity of cost and the scarcity of appropriate materials.

Overtopping:

Overtopping as a result of exceeding the reservoir capacity is the most common mode of failure for embankment dams. Although this is generally considered a hydrotechnical storage or discharge capacity issue, settlement of the dam crest can be a contributing factor. Once overtopping occurs, the uncontrolled flow may cause the dam to breach, depending on the erodibility of the materials exposed along the flow path. The rate of breaching is also dependent on this erodibility.

In 2010, the Lake Geraldine Dam had an overtopping incident along the north berm. The dam was already at capacity and strong waves caused by high winds started to overtop the berm. This wave action caused the roadbed to be scoured down to the cut off wall in some sections of the berm. This action eroded the granular material from the upper berm and displaced it farther down the slope. Such erosion of the granular material can be rapid, and over a sustained period of time could lead to localized or complete failure of the berm.

In September of 2012, the North Berm was repaired and enhanced as a result of the overtopping incident of 2010. The current configuration is deemed to meet the requirements of the DSG.

Surface Erosion:

Both upstream and downstream berm slopes are faced in rock. The requirements of the DSG are therefore deemed to be met.

Slope Instability:

The dam berm and abutment slopes should be adequately stable to withstand all foreseeable loading conditions. The current DSG states that a limit equilibrium analysis should be sufficient to verify the stability of the slopes under normal operating conditions, and considers acceptance criteria based on factors of safety.

The configuration of the berm portion of the dam has been substantially modified. At present the available information is considered to be too limited to perform a comprehensive review. Independent material testing and design analysis will have to be performed to complete this section for the next DSR (2018).

The current configuration has remained stable, by inspection, since the vertical extension of 2005/2006.

Static and Dynamic Liquefaction:

Berm failures due to earthquake excitation can be classified into two groups. One is damages caused by liquefaction or softening of sand foundation and the other is sliding and cracking of berm body resting on hard foundations. In the former case, high excess pore-water pressure is generated during earthquakes by the application of cyclic shear stresses, and large deformation as well as vertical displacement develops in the foundation. These deformations may lead to catastrophic damages due to overtopping.

No materials identified in the geotechnical investigation appear to be susceptible to liquefaction. The requirements of the DSG are therefore deemed to be met.

Seepage:

Seepage is controlled by the concrete cutoff wall; however, no consideration has been made for the monitoring of hydraulic gradients across the berm. Steady state seepage is more constant in an earth core dam and will not be significantly impacted by movement and shifting materials. Filter and drainage requirements become less critical for a concrete cutoff wall, however, monitoring of the hydraulic gradient is important. Installation of piezometers in the down stream berm would allow monitoring of the operational pore-water pressure and infer the condition of the concrete cutoff wall. Information would be used to: verify seepage rates through the berm; verify slope stability calculations; and locate problem areas along the length of the dam. It was identified in the 2005 geotechnical investigation that, within the north berm, a section of the original cutoff wall may not have been founded in rock. Although we can infer that the dam has performed adequately regardless of this condition, the raising of the reservoir would effectively increase: the head of water on the upstream face of the cutoff; the seepage rates across the discontinuity; and the piping and uplift forces acting on the downstream berm structure. Although the geotechnical investigation recommended that this section of the cutoff be grouted to rock, we have no record that this repair was done as part of the 2005/2006 vertical expansion. Given the assumption that the concrete cutoff wall is intact and founded in rock, we deem the requirements of the DSG to be met. This assumption may be confirmed through the installation of proper monitoring instrumentation.

Deformation:

The DSG recommends that the state of deformation and distribution of pore-water pressures in the entire continuum of the dam system should be evaluated for different stages:

- During construction and immediately after construction
- During impoundment and transient seepage.
- After full reservoir level has been reached and steady-state seepage has developed

- During long term consolidation and creep
- Under transient loading, such as rapid or sudden reservoir drawdown, floods and earthquakes.

Evaluating most of the above stages is unrealistic or impossible at this point. Consideration should be given to implementing a pore-water pressure monitoring program leading up to the next DSR in 2018, in conjunction with the seepage monitoring, above.

Geotechnical Loading conditions include the following:

- End of construction
- Rapid drawdown,
- Reservoir surcharge,
- Wind and wave action,
- Steady-state seepage, and
- Earthquakes.

End of Construction, and Rapid Drawdown:

Marginal drawdown capabilities exist via the pump housing for the existing water supply system. It was noted in the previous DSR that during the operation of the reservoir at the design head, it may be prudent to drawdown the reservoir under extreme ice load conditions. It is currently unknown whether the drawdown capabilities of the pump house have ever been established. Rapid drawdown capabilities; therefore, cannot be said to exist.

Reservoir Surcharge, Wind and Wave Action:

For berm dams, the maximum reservoir level, including the effects of wind should be at or below the top of the impervious core, unless it can be demonstrated that for the duration of the reservoir surcharge, no damage would be incurred.

The Lake Geraldine Dam is compliant with this criteria.

Steady-state seepage:

As previously stated in the report, our review of the present dam configuration indicates that seepage is not presently a concern.

Earthquakes:

Refer to Section 4.3.2 of this DSR.

4.3.4 Structural (DSG Section 6.7)

Where the berm structures predominantly fall under Section 6.6 of the DSG, Section 6.7 outlines the requirements for concrete structures. The DSG states that the assessment of existing structures should be carried out using a full range of normal to extreme load cases consistent with the site conditions, consequences of failure, applicable regulations, and current good practice in the industry.

The DSG provide review performance categories for the assessment of existing structures: *Adequacy of Structure and Foundations, Acceptance Criteria for Assessment of Stability, Determination of Loads, Load Combinations, and Design.*

In being provided with the tender drawings and specifications, we deem there to be sufficient documentation to complete a basic review of the design. Our review of the drawings indicates general conformance with accepted principles of engineered design.

Adequacy of Structure and Foundations:

The structure was visually inspected on site. At the time of our visit, we did not observe any conditions that would adversely affect the structural adequacy and/or performance. The concrete structure is generally considered to be relatively new with no deficiencies noted.

Acceptance Criteria for Assessment of Stability:

This category is evaluated based on commonly accepted Normal Compression Strength Values and Sliding Factors. In general, the level information and documents leads us to the following conclusions:

- One of the requirement for a Usual Load Combination (explained later in this section) is that the Sliding Safety Factor (taking into account friction only) be grater or equal to 1.5. This value is deemed to be met. (2007 DSG, Table 6-4, pg. 73).
- Concrete Strength values are within acceptable limits.

Determination of Loads:

The loads under consideration are listed as follows:

- Dead loads (D).
- Normal headwater level (H).
- Headwater level due to Inflow Design Flood (H_F).
- Internal water pressure and foundation uplift forces (U).
- Static and dynamic thrust created by an ice sheet (I).

Loads associated with the Earthquake Design Ground Motion (Q) are not listed on the drawings. Rock anchors (herein denoted as R) are not listed in the DSG but considered in this DSR. Vertical and Horizontal loading due to soil backfill, including potential effects of liquefaction, as well as loads from silt deposited against the structure are not deemed to be an issue given the past history and construction of the dam. Temperature-induced loads are generally not considered for gravity dams.

Load combinations:

Of the load combinations listed in the DSG (pg. 73) the three which are most relevant to the dam rising are:

- *Usual Loading:* D+H+I+U+R
- *Extreme Flood Loading*: D+H_F+U+R
- *Extreme Earthquake Loading:* D+H+Q+U+R

The Unusual Loading and Post Earthquake Loading cases were not considered applicable.

Design and Analysis:

Static Analyses for gravity dams are normally based on "rigid body" limit equilibrium method and linear elastic finite element analysis.

The two first load combinations listed above can be treated as static load cases because of the relatively sustained nature of the loads involved. On the third load case, the DSG suggests that the effect of ice on the structure should be given special consideration. However, under the assumption that Ice has no (or little) impact on the flood and earthquake loading cases, the Usual Loading case governs.

Given the prescribed loading, the dam should be designed to resist and prevent:

- Sliding at the dam-foundation interface, within the dam and at any plane in the foundation.
- Overturning
- Overstressing of the concrete dam or foundation
- Excessive seepage through the foundation or joints in the concrete dam.

Given the above, we undertook a rigid body analysis of the dam structure utilizing 2 dimensional models of the dam at select locations. In general, our analysis revealed the following:

- The loads listed on the structural drawings appear to be realistic.
- The original rock anchors (1995) do not appear to have been utilized in the resistance calculations.

- The free body diagrams indicated on the drawings appear to represent the worst case (highest head) for both the spillway and the typical gravity dam sections.
- To accurately determine the factor of safety against sliding (sliding factor), the angle of internal friction, angle of sliding friction (or coefficient of friction) and estimate-able anchor tensions would have to be known. Given the information provided, the lowest limit on the sliding factor would be approximately 1.6.
- Provided the full service load of the rock anchors is mobilized, analyzing the dam at the critical sections indicated that the minimum factor of safety against overturning is approximately 1.5
- Pressures at the toe of the dam are highly dependant on the tension in the rock anchors. Without additional information regarding the installation and pre loading of the rock anchors it is not possible to determine toe pressures.
- Negative pressures are indicated in the heel of the dam.
- Seepage is not currently considered to be an issue.

4.3.5 Mechanical and Electrical (DSG Section 6.8)

Mechanical and electrical equipment at dams consists of the flow control equipment, auxiliary equipment, power supplies, and control systems which are relevant to more complex structures.

4.3.6 Other Considerations (DSG Section 6.9)

When dam improvements are performed, project specifications should be strictly adhered to. This section of the DSG refers to all the factors that must be assessed should an improvement to the dam be completed.

No major improvements have been implemented on the dam since the last DSR; therefore, this section of the DSG is deemed to be met.

4.4 Operation, Maintenance and Surveillance (DSG Section 3)

In 2007, a Permanent Record File (PRF) was created. The file contains the following:

- Annual Updates Pages (PRF).
- Chronological history and Background of the structure.
- Operation, Maintenance and Surveillance Manual (OMS).
- Permanent Log Book (PLB).
- All Dam Safety Inspections and Dam Safety Reviews.
- As-built drawings from original construction and all subsequent construction phases.

Given the 2005/2006 vertical expansion, additional design and construction related documents should be part of the permanent file. These documents have recently been supplied by Trow (now exp.).

As with the previous DSG the following files should be included in the PRF:

- Instructions given by regulatory agencies, dam designer or other authority, and the record of compliance and details of any remedial action.
- Readings on any instrumentation and summary reports of dam performance.

4.5 Emergency Preparedness (DSG Section 4)

"ERPs (Emergency Response Plans) and EPP (Emergency Preparedness Plans) should be in place for all dams where live is at risk or if implementation of emergency procedures could significantly reduce the consequence of failure. Consequences are normally evaluated on the basis of dam-breach analysis and inundation mapping. The level of detail required in any ERP or EPP should be commensurate with the consequence of failure." (2007 DSG pg. 39)

Emergency plans should be in place for the full life cycle of the dam, including the construction phase of a new dam, especially where significant cofferdams are requires. For a new dam, the final plans should be in place prior to first filling of the reservoir." (2007 DSG pg. 39)

The EPP should include the following:

- Emergency Identification and Evaluation.
- Preventative and Remedial Action.
- Notification Procedure
- Site Access
- Communication Systems, Equipment, and Materials.
- Inundation Maps.
- Warning Systems.
- Additional Information.

According to the City, the Emergency Preparedness Plan has been completed. This should be verified, and the document included in the PDF.

5. SUMMARY RECOMMENDATIONS & REQUIRED ACTION

Based on our inspection, review, and analyses, we summarize the results of the DSR as follows:

1. In accordance with Section 2 of the 2007 DSG, the potential consequence of failure of the Lake Geraldine Dam was assessed. We conclude that it operates under a "Very High" dam consequence class, with a DSR required every five (5) years.
2. The design review for the dam structure has been based on visual information obtained on site and tender documents provided by the design engineer Trow (now exp.).
3. The addition of a remote surveillance camera is recommended.
4. The Permanent Record File, Logbook, and Operation and Surveillance manual require updating for 2014.
5. The Emergency Preparedness Plan (EPP) reportedly prepared by others for the City should be reviewed and any incomplete items resolved, and the document added to the PDF.
6. A Dam Safety Inspection (DSI) is required in 2014.
7. A new DSR will be required in 2018.
8. Consideration should be given to implementing a pore-water pressure monitoring program leading up to the next DSR in 2018, to assist with seepage and deformation assessments.
9. It is recommended that a Seismic Hazard Assessment (SHA) be conducted prior to the next DSR (2018).
10. An underwater inspection of the submerged structures should be conducted in 2014.
11. It is recommended that supplementary ballast and rip-rap be installed at the south end of the north berm.
12. Insufficient data exists on the berm construction. In conjunction with Item 8., above, invasive/material testing and independent analysis should be conducted leading up to the 2018 DSR.

Should there be any questions, please contact the undersigned.

Yours sincerely,

Concentric Associates International Incorporated

Elizabeth Bran, P. Eng.

Allan Murray, P. Eng.
President

APPENDIX A

Site Photographs

Photo 1: Overview of Dam Spillway and Wingwalls.

Photo 2: Spillway – Note minimal leakage.

Photo 3: North Side of Ramp Access – Note no leakage.

Photo 4: South Side of Ramp Access – Note no leakage.

Photo 5: Overview – North Berm – Looking north.

Photo 6: Overview – North Berm – Looking south.

Photo 7: North Berm at Wingwall – Supplementary ballast and riprap required.

Photo 8: Overview – South Berm.