Mark Creek Dam
(D310002-00)
2015 Dam Safety Review

STAGE 1:
Dam Safety Report

City of Kimberley
340 Spokane Street
Kimberley, BC V1A 2E8

06 December 2015

Northwest Hydraulic Consultants
#208 – 153 Seymour Street
Kamloops, BC V2C 2C7
Tel. 250.851.9262
Cell. 250.819.7040

Contact: Jeremy Cooke, P.Eng
Email: jcooke@nhcweb.com
06 December 2015

Mike Fox: Manager Operations & Environmental Services
City of Kimberley
340 Spokane Street
Kimberley, BC V1A 2E8

Dear Mike:

Subject: Mark Creek Dam Safety Review 2014/15: Draft Stage 1 Dam Safety Review Report

Herewith a summary of the findings of the initial stage of the Dam Safety Review (DSR) process for the audit-type DSR that was conducted on the Mark Creek Dam during 2014. A comprehensive DSR is planned as part of the second stage study.

In other words, Northwest Hydraulic Consultants Ltd. (NHC) has proposed a two-staged approach:

- Stage 1 that follows the APEGBC, Canadian Dam Association (CDA) and Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) dam safety guidelines. The intent of this stage has been to provide an initial opinion on the “health” of the dam; and to determine what detailed dam safety analyses still need to be conducted to meet the current BC Dam Safety Regulation’s requirements. This preliminary dam safety review report has been produced to document this audit-level process.

- No urgent dam safety issues were identified. However, a comprehensive-type DSR is now recommended that is focused on more detailed engineering evaluations, including areas where not enough information is available.

- The scope of work for the Stage 2 evaluation has been described in this report and will need to be discussed with yourself and the Regional MFLNRO Dam Safety Officer. A budget of $60,000 has been set out in an appendix at the end of this Stage 1 report.

- Stage 2 will involve at least a Geotechnical/Rock Mechanics Specialist and a Concrete Dam Structural Engineer. A detailed evaluation of the dam and associated safety measures will be scrutinized during this Stage in order to deliver a Comprehensive DSR.

- Based on the review of Stage 2 findings by the MFLNRO’s Dam Safety Officer, further individual studies may be required to investigate specific dam safety concerns.

If you have any questions please do not hesitate to contact me at 250.819.7040.

Sincerely,

northwest hydraulic consultants ltd.

Jeremy Cooke, P.Eng.
Senior Engineer
DAM SAFETY REVIEW ASSURANCE STATEMENT

Note: This Statement is to be read and completed in conjunction with the “APEGBC Guidelines for Legislated Dam Safety Reviews in British Columbia, July 2013 (“APEGBC Guidelines”) and is to be provided for dam safety review reports for the purposes of the British Columbia Dam Safety Regulation, B.C. Reg. 44/2000 as amended. Italicized words are defined in the APEGBC Guidelines.

To: City of Kimberley
Date: 6 December 2015

Name: Mike Fox
Address: 340 Spokane Street, Kimberley, BC, V1A 2E8

With reference to the British Columbia Dam Safety Regulation, B.C. Reg. 44/2000 as amended.

For the dam:

UTM Location): Zone 11; 569,145 m E; 5,507,514 m N

Located at (Description): 5 km upstream of Kimberley on the Mark Creek. Access through Tech-Cominco (Sullivan Mine) land

Name of dam or description: Mark Creek Dam

Dam function: Reservoir is a drinking water source for the City of Kimberley

Owned by: City of Kimberley

(the “Dam”)

Current Dam classification is:

Check one
☐ Low
☐ Significant
☐ High
☒ Very High
☐ Extreme

The undersigned hereby gives assurance that he/she is a Professional Engineer and a Qualified Professional.

I have signed, sealed and dated the attached dam safety review report on the Dam in accordance with the APEGBC Guidelines. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items (see Guideline Section 3.2):

☒ 1. Collected and reviewed available and relevant background information, documentation and data

☒ 2. Understood the current classification for the dam, including performance expectations

☒ 3. Undertaken an initial facility review
4. Reviewed and assessed the dam safety management obligations and procedures
5. Reviewed the condition of the dam
6. Interviewed operations and maintenance personnel
8. Confirmed proper functioning of flow control equipment
9. After the above, reassess the consequence classification, including the identification of required dam safety criteria
10. Carried out a dam safety analysis based on the classification in 9. above
11. Evaluated facility performance
12. Identified, characterized and determined the severity of deficiencies in the safe operation of the Dam and non-conformances in dam safety management system
13. Recommended and prioritized actions to be taken in relation to deficiencies and non-conformances
14. Prepared a dam safety review report for submittal to the Regulatory Authority by the Owner and reviewed the report with the Owner.

Based on my dam safety review, the current dam classification is:

Check one

- [ ] Appropriate
- [ ] Should be reviewed and amended

I undertook the following type of dam safety review:

Check one

- [ ] Audit (Stage 1). Have recommended a Stage 2 Comprehensive DSR Study
- [ ] Comprehensive
- [ ] Detailed design-based multi-disciplinary
- [ ] Comprehensive, detailed design and performance

I hereby give my assurance that, based on the attached dam safety review report, at this point in time:

Check one

- [ ] The Dam is reasonably safe in that the dam safety review did not reveal any unsafe or unacceptable conditions in relation to the design, construction, maintenance and operation of the Dam as set out in the attached dam safety review report
- [ ] The Dam is reasonably safe but the dam safety review did reveal non-conformances with the Dam Safety Regulations as set out in section(s) ____ of the attached dam safety review report.
☐ The Dam is reasonably safe but the dam safety review did reveal deficiencies and non-conformances as set out in the attached dam safety review report.

☐ The dam is not safe in that the dam safety review did reveal deficiencies and/or non-conformances which require urgent action as set out in section(s) ___ of the attached dam safety review report.

Jeremy Cooke, P.Eng.  06 December 2015
Name  Date

[Signature]

Suite 208 – 153 Seymour Street, Kamloops, BC V2C 2C7
Address

250-819-7040
Telephone

(Affix Professional Seal here)

If the Qualified Professional is a member of a firm, complete the following:

I am a member of the firm  Northwest Hydraulic Consultants Ltd.

and I sign this letter on behalf of the firm.
Executive Summary

The following report documents the 2015 Dam Safety Review (DSR) for the Mark Creek Dam, located 5 kilometres upstream of Kimberley, BC.

This 21.5 m high double curvature concrete arch dam is owned and operated by the City of Kimberley. The dam is rated in the “Very High” Consequence Risk Category.

Summary of Key Findings

a) This report documents the Stage 1, or Audit-level, Dam Safety Review (DSR). The main intent has been to conduct a high level review of the Mark Creek Dam (budget $23,500), so that the work associated with a more detailed Stage 2 DSR can be identified more concisely. The reason for this phased approach is to minimize expenditure of scarce City financial resources.

b) Two site visits including interviews with City Staff were conducted.

c) A large volume of data and historic records were complied and reviewed during Stage 1. A document list, including a summary of key issues was prepared. In general, it was concluded that the as-constructed dam conformed to design assumptions and industry standards. The quality of the dam and the way in which the foundations and abutments were treated have resulted in a well built and safe dam.

d) Stage 1 information gaps have been identified.

e) A brief review of the “Very High” Consequence Classification of the Mark Creek Dam has been carried out, but further assessment is required in the Stage 2 DSR. Historic dam break analyses of the old Mark Creek Dam and neighbouring Sullivan Mine tailings dams have been reviewed. A brief dam breach calculation should be conducted in Stage 2 to confirm flood wave sizes and inundation issues in Kimberley and St Mary’s.

f) Internal and external hazards and failure modes were identified at a cursory level. A preliminary Hazards and Failure Modes Matrix has been referred to in Stage 1. Stage 1 work concluded that the design, construction and subsequent performance of the dam indicate that the dam is safe. More detailed evaluation of hazards, failure modes, risks and consequences need to be conducted in Stage 2.

g) A more detailed evaluation and a Potential Failure Modes (PFM) Workshop must be held with City Staff in Stage 2.

h) No Stage 1 hydraulic assessment was conducted. It was assumed that the spillway capacity was designed to pass the Probable Maximum Flood (PMF). This will be reviewed in Stage 2.

i) The 1 in 1,000 year flood event, the PMF and the Inflow Design Flood (IDF) were reviewed. Some work will be required on this to upgrade the flood hydrology based on more recent City of Kimberley flood hydrology studies and current Climate Change considerations. It is expected that this Stage 2 work will be limited based on the fact that the original design team aimed at safely passing the PMF.
Based on the original design studies that were reviewed, freeboard for the IDF were considered adequate in line with current industry standards.

Geotechnical Engineer Mike Walsh, P.Eng. of SNT Engineering Ltd. conducted a site visit and reviewed files obtained from the MFLNRO archives in Nelson and Victoria, BC. The initial conclusion was that the dam is safe from a geotechnical perspective, but further Stage 2 analysis is required to confirm this opinion. A seismic assessment will compliment this Stage 2 work. A list of tasks is shown in an appendix to this DSR report.

A list of dam safety deficiencies and non-conformances is shown in Table E1 below.

The existing Operating, Maintenance and Surveillance procedures have been reviewed. Although appropriate, it will be necessary to update the OMS Manual in the Stage 2 DSR work. Conclusions that emanate from the PFM Workshop need to be worked into the new OMS Manual. This manual will need to be submitted to the DSO for approval and to achieve compliance with the BC Dam Safety Regulation.

A full set of dam safety surveillance tasks need to be formally identified and checklisted after the PFM Workshop.

The Emergency Preparedness Plan needs to be updated and expanded to be commensurate with a dam of this status. Stage 2 work has been identified.

There are a few minor public safety concerns at the dam that will be addressed in the Stage 2 work and incorporated into the overall Dam Safety Management System that is proposed for the Mark Creek Dam.

More formal City Staff training (Dam Operators and First Responders) will be required. This will be initiated with the PFM Workshop, which includes a site visit.

Roles, responsibilities, lines of communication and appropriate response/decision-making will be formally recorded in the updated OMS Plan and EPP.

Formal documentation of OMS activities takes place. Revised checklists will be developed as part of the PFM Workshop.

Standard dam safety evaluation criteria and expectations were documented, which resulted in a deficiency list that is aimed at complying with BC Dam Safety legislation.

**General Stage 1 Conclusions**

Stage 1 has concluded in broad terms that there is no significant deterioration in the safety or risk in the Mark Creek Dam system and its environs.

The dam is structurally safe, being operated safely and maintained in a safe condition, and surveillance is adequate to detect any developing safety problems.

Some follow-up Stage 2 work is required in order to confirm this initial assessment and maintain an acceptable level of safety risk for people, property and the environs downstream of the dam.

A focussed scope of work is proposed in Stage 2 to investigate certain components of the dam and to provide adequate motivation as to the conclusions reached in Stages 1 and 2.
The Stage 1 conclusion is as follows:

At a Stage 1, or Audit-level, the Mark Creek Dam above Kimberley, BC meets standard dam safety requirements. There are no significant, immediately actionable, dam safety concerns, and the dam is monitored on a very regular basis.

A prioritized list of dam safety expectation deficiencies, as well as non-conformances with legislation, has been provided, and should be addressed in the planned Stage 2 DSR study.

Table E1: List of deficiencies and non-conformances at MARK CREEK DAM

<table>
<thead>
<tr>
<th>#</th>
<th>Task</th>
<th>Timing/Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Obtain feedback from MFLNRO Dam Safety Officer on this Stage 1 report and mobilize Stage 2 work.</td>
<td>asap</td>
</tr>
<tr>
<td>2</td>
<td>As part of the Stage 2 DSR, conduct a 2016 review of the “Very High” consequence rating associated with the Mark Creek Dam. This will include a dam break calculation and the confirmation of existing inundation mapping below the dam.</td>
<td>Stage 2 (January 2016)</td>
</tr>
<tr>
<td>3</td>
<td>More detailed review by the Geotechnical Engineer and his preparation for the Potential Failure Modes (PFM) Workshop.</td>
<td>Stage 2 (Jan to March 2016)</td>
</tr>
<tr>
<td>4</td>
<td>More detailed review by the Structural Concrete Dam Engineer and his preparation for the PFM Workshop.</td>
<td>Stage 2 (Jan to April 2016)</td>
</tr>
<tr>
<td>5</td>
<td>More detailed identification of dam safety hazards and potential failure modes at the Mark Creek Dam, in preparation for the PFM Workshop in Kimberley. Also includes new drafts of the OMS Plan, the EPP and other dam safety management system inputs.</td>
<td>Stage 2 (Feb to March 2016)</td>
</tr>
<tr>
<td>6</td>
<td>PFM Workshop in Kimberley with City Dam Managers, Operators, First Responders, MFLRO DSO representatives and other Stage 2 team members.</td>
<td>Stage 2 (April 2016)</td>
</tr>
<tr>
<td>7</td>
<td>Conduct DSR Analysis based on the findings of the Stage 1 and Stage 2 work to date. Integrate findings of Geotechnical and Structural Engineers.</td>
<td>Stage 2 (May/June 2016)</td>
</tr>
<tr>
<td>8</td>
<td>Update the OMS Manual and the EPP based on the findings of the PFM Workshop.</td>
<td>Stage 2 (May 2016)</td>
</tr>
<tr>
<td>9</td>
<td>Brief hydraulic study of the dam spillway and stilling basin area.</td>
<td>Stage 2</td>
</tr>
<tr>
<td>10</td>
<td>Brief review of the flood hydrology, area capacity curves and freeboard</td>
<td>Stage 2</td>
</tr>
</tbody>
</table>
This Stage 1 Dam Safety Review (DSR) can be classified somewhere between an Audit- and a Comprehensive-level study.

Having said this, it is recommended that the Stage 2 DSR study be completed to investigate the safety performance of some unknown components of the dam such as the foundations and rock abutments; as well as the current condition of the concrete in the dam wall.

Based on these inputs and the rest of the work described in Table E1 above, it is believed that there will be sufficient engineering and management knowledge to complete a Comprehensive-level DSR of the Mark Creek Dam by July 2016, if work commences in January 2016.

When this draft Stage 1 Dam Safety Report has been reviewed by the City of Kimberley, it should be presented to the MFLNRO Dam Safety Officer (DSO) in Victoria, BC for acceptance of this report.

Based on the DSO’s wishes, the Stage 2 study should commence as early as possible in 2016.
Disclaimer

Northwest Hydraulic Consultants (NHC) prepared this DSR report solely for the City of Kimberley as the mark Creek Dam Owner.

Neither the Dam Owner or NHC represents, guarantees or warrants to any third party, either expressly or by implication:

a) The accuracy, completeness or usefulness of,

b) The intellectual or other property rights of any person or party in, or

c) The merchantability, safety or fitness for purposes of,

any information, product or process disclosed, described or recommended in this report.

Neither the Dam Owner or NHC accepts liability of any kind arising in any way out of the use by a third party of any information, product or process disclosed, described or recommended in this report. Nor does the Dam Owner or NHC accept any liability arising by way of reliance by a third party upon any information, statement or recommendation contained in this report. Should the third parties use or rely on any information, product or process disclosed, described or recommended in this report, they do so entirely at their own risk.

In conducting this review, NHC had to make assumptions based on opinions of others expressed in the records that were found. As some cases NHC is unable to verify some of these opinions.

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1 INTRODUCTION AND APPROACH

1.1 PROJECT BACKGROUND

The construction of the Mark Creek Dam was completed by the City of Kimberley in 1994. The dam is situated on Crown Land approximately 5 km upstream of Kimberley (Figure 1.1).

The dam is a 21.5m high double curvature concrete arch dam located at the upstream end of a canyon.

The purpose of the dam is to store water for domestic and industrial water supply for the City of Kimberley. The arch is 3m thick at its base reducing to 1.9m at its crest. The curved length of the dam crest is 55 m.

A 300 m long, 10 m earth berm was also constructed at the base of eastern slope of the reservoir, just upstream of the dam. This berm was built to add stability to the uphill slope.

Downstream impacts include the Teck-Cominco mine yard and the City of Kimberley. A dam breach flood wave would cause serious flooding of homes and businesses. Hence the “Very High” consequence classification of this dam.

The BC Dam Safety Regulation BC Reg. 44/2000 with amendments up BC Reg. 163/2011 requires that a dam safety review be conducted on a dam of this size every 10 years.

Figure 1.2: View of the Dam from about 100 m downstream (Courtesy of Mike Fox)
Figure 1.1
Mark Creek Dam Safety Review: General Locality
1.2 Business Objective

In their role of ensuring compliance with the BC Dam Regulation, the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) Dam Safety Officer in Victoria has called for the current dam safety review.

Since fairly extensive dam safety investigations are required on large dams, NHC originally proposed the following two-staged approach that fits in with limited financial resources that face smaller BC Municipalities in the current economic climate.

A Dam Safety Review (DSR) is a systematic review and evaluation of all aspects of design, construction, operation, maintenance, processes, and other systems affecting a dam’s safety, including the dam safety management system.

The level of detail in the DSR should be sufficient either to demonstrate that the dam meets dam safety requirements, or to identify areas where conformance cannot be demonstrated and future investigation or action is needed.


In other words, to reduce the risk of dam failure, legislation requires that a DSR be undertaken to determine if the dam is structurally safe, being operated safely and maintained in a safe condition, and that surveillance is adequate to detect any developing safety problems.

The current two stage Mark Creek Dam DSR will end up somewhere between the “Comprehensive DSR” and “Detailed Design-Based Multi-Disciplinary DSR” levels as described in the Association of Professional Engineers and Geoscientists of BC (APEGBC) professional practice guidelines.

1.3 Scope of Work

The overall DSR process that has been adopted is shown on APEGBC’s Figure 1.3 attached.

Stage 1

This initial stage has included running through the entire DSR process, at a cursory level, in order to determine if there are any urgent dam safety issues that need to be addressed.

Stage 1 has also involved consultation with Engineering Specialists to draft terms of reference for more detailed DSR work in Stage 2. The aim is to employ a multi-disciplinary set of Qualified Specialists in Stage 2.

In optimizing the study and minimizing the expenditure of public funds in Stage 2, it has been imperative that Stage 1 be conducted.

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1 Association of Professional Engineers and Geoscientists of BC. Professional Practice Guidelines – Legislated Dam Safety Reviews in BC. Pg.28 of V2.0 March 2014.
Figure 1: Dam Safety Review Process

1. Define roles, and responsibilities and objective of dam safety review
   - Define type of dam safety review
   - Audit Style dam safety review
   - Comprehensive Design Review

2a. Develop scope of dam safety review to meet objective
   - Issue Request for Proposals
   - Identify Concerns
   - Potential Safety Concerns

2b. Gather information
   - Information for dam safety review:
     - Dam Construction
     - Dam History
     - Design Data
     - Operation Data
     - Surveillance Data
     - Management System
     - Identified Issues
     - Joint Works Agreement

2c. Review information provided
   - Review information provided
   - Conduct Consequence Review
   - Identify functions and failure modes
   - Assess safety of dam

3a. Confirm scope and Agreement between Owner and Qualified Professional
   - May need to gather more information including field investigations
   - Extent to which this is carried out will depend on the type of dam safety review: Basic, Audit Style, Comprehensive Design Review, or Construction Phase

3b. Review information provided

3c. Conduct Consequence Review

3d. Carry out site visit and interviews

3e. Identify functions and Failure Modes

3f. Assess safety of dam
   - Analyses required and approved?
   - Documentation by Qualified Professional engineer

3g. Carry out Analyses

4. Prepare dam safety review report
   - Analyses required and approved?
   - Documentation by Qualified Professional engineer

5. Review report, prioritize deficiencies and make plans to address deficiencies
   - Next steps?
   - Fix or decommission

LEGEND
- Input into dam safety review process
- Dam safety review task by Owner
- Dam safety task by Qualified Professional
- Decision by Owner
- Documentation by Qualified Professional Engineer
- Start / End of process
1.3.1 Task 1 – Project Start-up and Initial Review of Historical Information and Data

The City’s Manager of Operations & Environmental Services (the “Client”) and the NHC Engineer (Lead Qualified Professional – the “LQP” for Stage 1) initiated this stage of the project in 2014.

The Client, who is knowledgeable in dam safety management, initially instructed his Staff to collate and provide NHC all available Mark Creek Dam and creek system documentation and data that was available at City Hall.

An initial project meeting and site visit was held in Kimberley in June 2014. The NHC also paid a visit to the MFLNRO Head Office in Victoria on the 25th of July 2014 to review files and plans in the Ministry’s archives.

In October 2014, the Geotechnical Specialists visited the MFLNRO offices in Nelson to review files and plans on the Mark Creek Dam. He also conducted a site visit to the dam during this period.

This information has been collated and reviewed, and will eventually be provided in a visual presentation that can be used in a workshop with City Operators in Stage 2.

This work has allowed the Stage 1 LQP to provide a background framework on which to conduct the initial facility review (spatial and functional model of the dam/reservoir/watershed/downstream system).

NHC also identified performance expectations as suggested by in the BC Government’s November 2012 “Dam Safety Review Guidelines”; and identified possible hazard and failure mode conditions that could act in on the Mark Creek Dam.

This information collection and review has included the overall dam safety management system employed by the City (e.g. emergency planning, operation, maintenance, surveillance, staff training, record-keeping, deficiency tracking and response).

Task 1 work was based on industry guidelines (Appendix A to this report).

A list of historic documents reviewed, including observations, is contained in Appendix B.

1.3.2 Task 2 – Detailed Site Inspections and Staff Interviews

As mentioned above two site visits to the dam were conducted during Stage 1. An initial dam safety fieldwork checklist was followed based on an outline suggested by APEGBC (Appendix C).

Staff interviews were conducted during the two site visits. The first visit also included an initial discussion with the Fire Chief regarding Emergency Preparedness. NHC was not able to witness the testing of the low-level outlet flow control equipment.

The second site visit was conducted by the Geotechnical Engineer from SNT Engineering Ltd.

1.3.3 Task 3 – DSR Evaluation

Task 3.1 – Confirm Dam Classification

NHC also conducted an overview of the “Very High” dam safety consequence rating classification that has been attributed to this dam. This work was based on the CDA’s Technical Bulletin: “Inundation, Consequences, and Classification for Dam Safety” (2007).
Task 3.2 – Stage 1 Dam Safety Assessment

Evaluation of the dam’s performance was carried out in relation to the facility condition, the applicable internal and external hazards and applicable failure modes. The Mark Creek Stage 1 process generally followed a scaled down version of safety analysis as depicted in Figure 1.4.

In summary, the two main purposes of a dam safety review are: to assess if there has been any significant deterioration in the level of safety or risk at the dam and in its environs; and to determine if the overall level of risk is being maintained within limits considered to be tolerable.

The first step is to provide an overview of the spatial and functional system associated with the Mark Creek Dam. This is expanded to identify the principal functions of each element of the dam (e.g. water retention and flow control functions).

The next step in the evaluation was to start identifying the relevant external and internal hazards or threats, and their combinations that have the potential to interfere with the safe functioning of the dam.

It was then necessary to consider: how these potential hazards act on the dam; the manner in which the dam responds to the influence of the hazards; failure modes; and the consequences of functional failure of the dam due to the hazards.

A Hazard and Failure Mode Matrix (HFMM) was utilized in this evaluation.

Stated in another way as per the Canadian Dam Association Guidelines\(^2\), the analysis also included an overview of the following:

- **Design and Construction Records**: Does the as-constructed dam conform to design assumptions and intent? Adequacy of dam and foundation materials. Only preliminary analyses were conducted in Stage 1 to identify any shortcomings. These information gaps may require more detailed analyses in Stage 2 (e.g. finite element calculations).

- **Adequacy of derived extreme events, floods, and earthquakes for which the dam was designed**, taking into account any extreme events that may have occurred since the commissioning of the dam. Only a brief review was conducted in Stage 1. Detailed updates to the flood hydrology and seismic estimates may be required in Stage 2. The relevant CDA Technical Bulletins that augment the CDA Guidelines will be used in this case. A Geotechnical Specialist was consulted.

- **Capacity of all waterways and conduits to discharge their design flows safely, pass the inflow design flood (IDF) and to draw down the reservoir in an emergency.** A dam break analysis was not conducted in Stage 1, but existing work conducted previously was reviewed. If required, more detailed analyses may be called for in Stage 2.

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\(^2\) Canadian Dam Association: Dam Safety Guidelines (2007)
Figure 3: Draft Example Dam Safety Review Process (this particular example is for water reservoir dams but the same fundamental steps apply for mining dams)

Develop spatial and functional model of the dam / reservoir system

For each element of the dam determine its principal functions:
- Water retention or
- Flow control

Analyze hazards and failure modes at detailed level

Categorize issues into “safety concern types”

Determine magnitude of the safety concern at principal functional level for concern type

Compile line item table of all functional concerns by concern type with explanations

Perform basic calculations
Finalize safety data for individual dam

Review and check all models analyses and rationale for assigned safety parameters

Safety Assessment Report

Q/A Review

Conduct Routine Surveillance

Does the dam meet all safety requirements?

Yes

Operate and maintain dam in conformance with dam safety goals; maintain emergency preparedness

Dam Safety Review

DAM SAFETY OVERSIGHT ACTIVITIES

Authority Oversight

Reservoir
Water Retention
Controlled Discharge
Generation and Control
Immediate Downstream Area

Water Retaining Subsystem

Left Abutment
Left Dam
Concrete Dam and Gate
Right Dam
Right Abutment

Foundation

Spatial Model of Earth Dam Flow Control Function (steady state condition)
• An opinion on the structural stability and seepage and erosion resistance of all water barriers and the dam’s foundations under normal and extreme loading. A more detailed seepage and rock mechanics evaluation will probably be required in Stage 2.

• Operating rules under various conditions and their conformance with design intent and criteria.

• Adequacy of design, construction, and operation to address potential failure modes.

Some of the main deliverables will be: relating the above-mentioned findings with each major component of the dam; giving a general description of the monitoring and performance of the component over the period since construction (as no formal DSR has been conducted since the dam was constructed); and noting any deficiencies and non-conformances identified during the assessment.

**Task 3.3 – Overall Operation, Maintenance and Surveillance (OMS)**

The operating, maintenance and surveillance procedures that are followed at the Mark Creek Dam were reviewed by NHC and the Geotechnical Specialist from SNT Engineering.

The following questions were considered, amongst others:

• Have adequate safe operating procedures been developed, documented and followed? Are there contingency plans for dealing with the failure of components?

• Are all facilities, needed for dam safety including precipitation and water level gauges (e.g. precipitation and flow gauging stations; and dam monitoring instrumentation), maintained in satisfactory condition in accordance with established procedures?

• Are the methods and frequency of surveillance and monitoring adequate to detect any unsafe condition in a timely manner? Have monitoring data been analyzed regularly and used to ensure prompt detection of any potentially unsafe conditions in the dam, associated water containments, or reservoir slopes?

• Are there adequate debris management procedures to ensure that debris does not block the five spillway openings at the Mark Creek Dam or reduce their discharge capacity?

• Are ice management procedures adequate to ensure that the spillways are not blocked by ice when they are needed?

• Are maintenance procedures and their frequency adequate for the dam and its components, including gates and other discharge facilities, and foundation drains?

• Are there adequate vegetation control procedures?

• Is the flow control equipment maintained in good working order and tested regularly to ensure it will function reliably when called on to operate?

• Are incidences of malfunction promptly reported, investigated, and addressed to prevent recurrence?

• Is the backup equipment that is called for in the contingency plans available and readily accessible?

• Are adequate written records kept and reviewed by Management.
Task 3.4 – Emergency Preparedness and Public Safety and Security around the Dam

The emergency preparedness protocols for the Mark Creek Dam were reviewed and briefly discussed with the City’s Fire Chief. An evaluation of public safety around the Upper Mark Creek Dam was also briefly looked at.

The current DSR will attempt to determine answers to the following questions:

- Is emergency preparedness at an appropriate level and adequately documented?
- Are the warning systems, training, and emergency response plans adequate?
- Is the frequency of testing appropriate?
- Are there processes in place for document control?
- Are findings and lessons learned from incidents or emergency drills properly documented and followed up within a reasonable time?
- How vulnerable is the dam to sabotage by disaffected persons or terrorists?

Given the significance of a dam failure of the Mark Creek Dam, the LQP has recommended that the FEMA Dam Safety Guidelines as a benchmark in reviewing the existing emergency plans. By providing this input, it will show that the City has provided additional due diligence in protecting its residents from the risk of catastrophic flooding. A workshop will need to be held with City First Responders and Dam Operators to fine tune the emergency plans. The proposed inputs have been summarized in Appendix D.

Task 3.5 – Integrated Evaluation and Stage 1 Decision-Making

The above-mentioned DSR components and other collated information were considered within the larger context of the entire Dam Management System that is employed by the City of Kimberley.

Physical and functional deficiencies, as well as non-conformances with National and BC Dam Safety Legislation, were identified at a cursory level and further Stage 2 work identified. Cost estimates for this Stage 2 work have been presented in this Stage 1 report. After discussions, the Client will make the appropriate decision regarding the scope of Stage 2 of this DSR.

1.3.4 Task 4 – Preliminary DSR Report

A first draft of the Mark Creek Dam Safety Review Report has been produced and is recorded in this document. This report is intended to provide input and guidance to the Stage 2 work.

The initial methods of analysis used or data available in the Stage 1 review may, in the opinion of the MFLNRO’s Dam Safety Officer responsible for the Mark Creek Dam, be insufficient to clearly demonstrate an acceptable level of safety for the dam, discharge facilities, or reservoir slopes; hence the need for a Stage 2 review process.

Once this draft has been reviewed by the Client and the MFLNRO Dam Safety Officer, a decision can be made as to the scope of additional work that will be required to bring the DSR up to a Comprehensive level as described in the APEGBC guidelines.

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1.4 Stage 1 Costs

Based on the budgets available to the Client, NHC worked to a Stage 1 lump sum budget of $23,500 including disbursements, travel and accommodation, but excluding GST. The Stage 2 budget will be fixed after this Stage 1 report is reviewed by the Client.

For City budgetary purposes, the additional DSR work during this second stage was estimated to cost in the order of $60,000 (Appendix L). Work will mainly be focused on specialist inputs and the proposed Potential Failure Modes Workshop. A fair amount of work has gone into preparing this Stage 1 DSR report, which can be reused in Stage 2, and consequently will save on the consulting budget.
2 THE MARK CREEK DAM SYSTEM

2.1 HISTORY

The original water storage dam was built by the Sullivan Mine on the Mark Creek in 1906. This structure was located about 2.5 km downstream of the current dam, but has subsequently been decommissioned due to stability concerns and a build up of silt in the dam’s reservoir.

The current dam was commissioned in May 1994 with the main aim of supplying water to the City of Kimberley, and the closed Sullivan Mine as required.

Proposed Work in Stage 2:

In the main Comprehensive DSR Report it is recommended that some historical background be summarized here and some archival material included in an Appendix to that report.

This is important in setting the context to the major floods that ravaged the City of Kimberley in 1916 and 1948. Although these were recognized as major flooding years in British Columbia, NHC has picked up from news reports, photographs and other historical archives that Sullivan Mine tailings dams breached during these flooding events. This has relevance when assessing dam break and downstream inundation. This should also be related to the recent dam break and inundation study for three Sullivan Mine tailings dams that was conducted in 2014 for Teck Metals by AMEC.

2.2 THE MARK CREEK WATER RESOURCES SYSTEM

The headwaters of the Mark Creek are located high in the Purcell Mountains to the north of the City of Kimberley at an elevation of around 2,300 m above mean sea level. The watershed above the dam is approx. 91 km² in extent (Figures 2.1 and 2.2).

From 2012 air photo mapping, forestry has taken place on either side of the eastern tributary of the Mark Creek. This could influence the size of peak flow events. There also seem to be a number of wetlands or marshes along this eastern tributary that could attenuate floods. This may need to be considered in Stage 2 review of the flood hydrology associated with the Mark Creek Dam.

Design studies in the early 1990’s before the dam was built indicated that the sedimentation rate into the dam’s reservoir would be lower than traditionally expected in this region. This seems to have played out as the sediment levels at the low level outlets at the dam have been noted as being low by divers that regularly service the intake screens upstream of the dam.

The dam structure itself is situated in a narrow gorge. A really good set of construction photographs is available in the MFLNRO archives in Victoria BC. A selection of photographs are shown in Appendix E). A fact sheet showing pertinent dimensions and other information regarding the dam wall can be seen on Table 3a below.

Apart from two low-level outlet pipes, there is another major pipe that releases water from behind the dam into a 4 km long, 600 mm diameter pipe that runs down the valley to the water treatment works just above the City of Kimberley. This domestic water outlet has been modified to release flows into the downstream creek to take care of environmental instream flow requirements. A study
Figure 2.1
Mark Creek Dam Safety Review:
Watershed – General Location
Figure 2.2
Mark Creek Dam Safety Review: Watershed

91 km²
conducted by Wildsight in October 2008⁴ recommended minimum and average flow rate releases to maintain the aquatic environment downstream of the dam.

The City of Kimberley is located in a fairly narrow valley. Just after the Mark Creek enters the built up area of Kimberley, it is joined by the Lois Creek and Kimberley Creeks. After running through Kimberley, the Mark Creek runs down a valley. At around 5 km downstream, the creek touches on a portion of Marysville. Just after this it enters the St Mary River, which eventually flows into the Columbia/Kootenay River system.

3 BACKGROUND REVIEW

3.1 GENERAL INFORMATION

The bulk of the historical data was collected by reviewing drawings and records held by the Dam Owners, and from the MFLNRO archives in Victoria and Nelson, BC. This collated information will be made available to the team in Stage 2.

The following table (Table 3a) provides an overview of the information collated.

Table 3a: Fact Sheet: Mark Creek Dam and Reservoir

<table>
<thead>
<tr>
<th>General</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>As the crow flies, the Mark Creek Dam is located 5 km northwest of Kimberley City Hall.</td>
</tr>
<tr>
<td>Coordinates</td>
<td>49° 42’ 36” N; 116° 02’ 33” W</td>
</tr>
<tr>
<td>Purpose</td>
<td>Storage for domestic water supplies</td>
</tr>
<tr>
<td>Status</td>
<td>In use.</td>
</tr>
<tr>
<td>Originally constructed</td>
<td>September 1993 to May 1994</td>
</tr>
<tr>
<td>Owners</td>
<td>City of Kimberley</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dam</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Dam</td>
<td>Double curvature concrete arch dam</td>
</tr>
<tr>
<td>Impounds</td>
<td>Mark Creek</td>
</tr>
<tr>
<td>Height</td>
<td>21.5 m (non-overflow crest to riverbed below outlet works)</td>
</tr>
<tr>
<td>Classification</td>
<td>Very High</td>
</tr>
<tr>
<td>Crest Length</td>
<td>55 m</td>
</tr>
<tr>
<td>Crest Width (concrete)</td>
<td>1.9 m</td>
</tr>
<tr>
<td>Base Width (concrete)</td>
<td>3.0 m</td>
</tr>
<tr>
<td>Non-overflow Crest Elevation</td>
<td>1347.5 m above sea level (amsl)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reservoir</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Creates</td>
<td>Mark Creek Dam Reservoir</td>
</tr>
<tr>
<td>Surface Area</td>
<td>Approx. 5.4 ha (13 acres) at Full Supply Level (FSL) at 1,345 m amsl</td>
</tr>
<tr>
<td>Total Storage Capacity</td>
<td>337,350 m$^3$ from 1993 design area-capacity table at FSL</td>
</tr>
<tr>
<td>Dead Storage</td>
<td>17,350 m$^3$ at Low Supply Level (LSL) at 1,335 m amsl; emergency outlet drains reservoir to around 1,000 m$^3$</td>
</tr>
<tr>
<td>Capacity left for siltation</td>
<td>Designed for 15,000 m$^3$ – volume of siltation since 1994 unknown</td>
</tr>
<tr>
<td>Live Storage Capacity</td>
<td>Design volume = 305,000 m$^3$</td>
</tr>
<tr>
<td>Operating water depth</td>
<td>10 m (between FSL and LSL)</td>
</tr>
<tr>
<td>Max. Water Depth at FSL</td>
<td>15 m just upstream of the dam wall</td>
</tr>
<tr>
<td>Reservoir Length</td>
<td>600 m</td>
</tr>
<tr>
<td>Reservoir Perimeter</td>
<td>1,400 m</td>
</tr>
</tbody>
</table>
The following are the principal functions of the Mark Creek Dam System components:

- The dam holds back a portion of the annual runoff of the upper Mark Creek watershed in its reservoir. A modern logboom has been installed about 50 m upstream of the dam to help prevent any logs or debris getting to the dam’s spillway (Figure 3.1).

- The reservoir berm on the toe of the eastern was constructed to help prevent the slope above it from slipping into the reservoir (Figure 3.1). Such a slippage could create a wave that could overtop the dam wall and potentially cause damage that could threaten the stability of the dam and its abutments.
Figure 3.1
Mark Creek Dam Safety Review: Logboom and Upstream Berm
• The double arch curvature dam was designed in such a way as to transfer any of the forces generated by the impounded water behind the dam down into the foundation and directly into the abutments.

• Water is drawn off via the water supply outlet pipe on the left flank of the dam wall. This passes through a tank system that supplies water through a 4 km long pipeline to the City’s domestic water treatment works. No details of this tank system were reviewed in Stage 1. This component, and how it ties into and affects the dam, will need to be investigated further in Stage 2 of this dam safety review. This is especially important in the context of this water line being used for hydro-electric generation at the bottom end of the water supply pipe near the water treatment works (pers comm).

• The environmental low level outlet pipe that was originally intended to release water for instream fish and other flow requirements seems to be kept closed. The upstream valve on this small pipe is operated via valve stems on the upstream face of the dam wall. It seems that environmental flows are released from the water supply pipe and tank system referred to above.

• The emergency outlet pipe that is located alongside the environmental pipe, is also operated via valve stems on the upstream side of the dam. Both the environmental and emergency low-level outlet pipes have valves on the downstream side of the wall. Unfortunately, these mechanisms seem to have been damaged by ice falling on them.

• Any excess water flows over the two outer spillway notches. Higher flow rates are also passed through the three central spillway notches, which are 0.5 m higher in elevation than the two outer notches. A limited amount of dam safety instrumentation does exist.

• The non-overflow crest, including the steel footbridges across the top of the dam, has been designed to accommodate extremely high flows up to Probable Maximum Flood (PMF) discharges. The footbridges have been sectioned off with security fencing to try to prevent unauthorised access onto the dam.

• Water flows over the spillway notches land on concrete aprons that have been placed to avoid erosion of the foundation and both rock abutments of the dam. Water falls into a stilling basin below the dam, the outlet of which forms a gauging weir to both monitor flows as well as any seepage when there is no spillway flow.

• Flows over the wall or through the low-level outlet works continue on down the Mark Creek.

### 3.2 Design and Construction History

Design reporting, design drawings and construction photographs were reviewed during Stage 1.

The initial review of these historical documents show that highly competent Dam Engineers, as well as Geotechnical and other Specialists, completed the design and construction supervision of the Mark Creek Dam in 1993 and 1994.

Documents reviewed also included weekly construction progress reports. A few minor problems in concrete grouting of contraction joints occurred due to faulty pumping equipment. The author had

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5 Personal Communication: With City of Kimberley’s Operators. A larger hydro-electric installation is being proposed at the tail end of this pipeline. Water hammer and other hydraulic effects on the dam will need to be carefully considered and taken into account in the OMS.
some unanswered questions regarding the impact of sub-zero temperatures that were experienced during the pouring and curing of the dam wall. A more detailed review of the construction processes and quality control adopted will be reviewed by a concrete Structural Engineer in Stage 2 of this DSR.

3.3 Previous Dam Safety Reporting

Daily/weekly and annual dam safety inspection reporting are conducted by the City of Kimberley Dam Operating Staff. These are meticulously recorded. The identification of hazards acting in on the dam system and a better understanding of failure modes could improve the dam inspection and surveillance process. These benefits would translate in to how the inspection reports are brought to and acted upon by City Management.

Dam safety audits have been accomplished by MFLNRO on a regular basis. These reports have been reviewed in the MFLRO archives in Victoria and Nelson, BC (File D3100002). With the exception of a few issues discussed below, the Mark Creek Dam seems to have performed well since its construction 21 years ago.

3.4 Ecological and Environmental Considerations

3.4.1 Fish and Wildlife Considerations

Although the reservoir probably contains numerous fish species, it is not an active fishing site. Screens have been placed over the water supply outlet pipe to help stop large fish from entering the downstream water supply system.

As mentioned above, normal and minimum environmental water releases through the dam have been instituted to take care of the downstream aquatic system in the Mark Creek.

3.4.2 Water Quality

Water quality in the reservoir, and how this plays in on the concrete dam and its appurtenances and rock abutments, has not been reviewed in Stage 1. This will be considered in Stage 2.

3.4.3 Recreation Considerations

Access to the dam is through a restricted area managed by Teck-Cominco. This restricts public access to a point. Hunters and quad bikers do frequent this area. No formal recreation takes place at the Mark Creek Dam. The City hosts public tours to the dam on a regular basis and uses this as a public information exercise. No public safety plan for the Mark Creek Dam was reviewed.

3.5 Flood Hydrology

A number of flood hydrology studies have been carried out on the Mark Creek before and after construction of the dam to ascertain flooding issues that could potentially affect the City of Kimberley (see Appendix B).

The flood hydrology reviewed and presented below refers to the design hydrology that was conducted as part of the dam design in the early 1990’s. Flood discharges obtained in subsequent City studies have been used as a comparison.
These more recent hydrological studies that have been carried out by the City of Kimberley have also been reviewed to better understand potential flooding and inundation downstream of the dam.

The effect of Climate Change has been looked at by the Columbia Basin Trust\(^6\).

Destructive historical flood events through Kimberley in 1916 and 1948 have also been researched by the author. Historical archives (photographs and news articles) have indicated that these serious flooding events were compounded by tailings dam failures during the high rainfall events.

Table 6.1 of the 2007 Canadian Dam Association (CDA) Dam Safety Guidelines provides the suggested Inflow Design Flood (IDF) for use in deterministic assessments (i.e. 2/3 of the way between the 1 in 1,000 flood events and the Probable Maximum Flood (PMF) for a Very High consequence dam). A stand-alone CDA Technical Bulletin entitled “Hydrotechnical Considerations for Dam Safety” was also referred to by the author.

The watershed catchment area of the Mark Creek and its tributaries above the Mark Creek Dam is 91 km\(^2\) in extent (Figure 2.2).

Watershed slopes, vegetation cover and marsh/wetland areas were some of the major consideration in reviewing peak flows. It was found that the watershed has been logged in the recent past. The longest stream run is approximately 13 km. Elevation-wise, there is a drop of around 955 m over this distance.

No flood hydrology work was conducted in Stage 1. The following instantaneous peak flows were drawn from the hydrology work conducted during the design of the dam in the early 1990’s:

- 1 in 200 \(90.5\,\text{m}^3/\text{s}\)
- 1 in 1,000 \(110\,\text{m}^3/\text{s}\)
- PMF \(338\,\text{m}^3/\text{s}\)

The OMS manual notes that the dam crest and spillway has been designed to pass the PMF without significant damage. For Stage 1 purposes, it has been assumed that the IDF = \(263\,\text{m}^3/\text{s}\). Stage 2 will review this number as well as the hydraulic capacity of the whole Mark Creek Dam spillway.

### 3.6 Earthquakes

Table 6.1 of the 2007 CDA Dam Safety Guidelines also provides the suggested Maximum Design Earthquake (MDE) in terms of the Earthquake Design Ground Motion (EDGM). The Annual Exceedance Probability (AEP) for the EDGM on a “Very High” consequence dam has been tabled as the 1 in 5,000 event.

Mike Walsh has briefly reviewed the seismic and geotechnical information available and has suggested further work during Stage 2 (see SNT Engineering Ltd. letter in Appendix F).

### 3.7 Type of Dam

This double-curvature concrete arch dam will be described in more detail in Stage 2 reporting.

\(^6\) Columbia Basin Trust – Ingrid Liepa. Adapting to Climate Change in Kimberley, BC. (June 2009)
3.8 **STABILITY CONSIDERATIONS: FOUNDATIONS AND CONSTRUCTION MATERIALS**

The strength, thickness, and inclination of strata, permeability, fracturing, and faulting are all important considerations in reviewing the safety of the dam and its foundations and abutments.

The physical and chemical makeup of dam abutments and concrete dam wall materials and how they were treated in the construction process will be reviewed in detail in Stage 2 of the DSR.

How the various dam components have weathered and their current condition will need to be understood. This information will be utilized to identify dam safety hazards and potential dam failure modes.

3.9 **SPILLWAY**

The five-notch spillway has been discussed previously in this report. The site visits showed that the concrete overflow and surrounding sections are in good condition. This will be looked at in detail by the concrete Structural Engineer in Stage 2.

Freeboard was not considered in detail in Stage 1. It was assumed that the design freeboards allowed are adequate. This will be checked in Stage 2.

A modern logboom is in place upstream of the dam. It is regularly cleared of floating logs and debris.

3.10 **OPERATIONS, MAINTENANCE AND SURVEILLANCE (OMS)**

A detailed Operation and Maintenance Manual was produced after the construction of the dam in the mid-1990’s. The latest revision that could be traced was published in August 1995.

This O&M Manual needs to be updated to bring the City of Kimberley into compliance with the BC Dam Safety Regulation.

Apart from utilizing recent Canadian Dam Association bulletins in this updating process, it is suggested that the findings of the Stage 2 hazards and failure modes\(^7\) be incorporated into manual.

3.11 **DOCUMENTATION LIST**

A list has been enclosed in Appendix B. During Stage 1, the original design and construction files at the Klohn-Crippen Berger Consulting Engineers in Calgary were not reviewed.

3.12 **INFORMATION GAPS**

These gaps have been listed in the DSR expectations checklist in Appendix G.

\(^7\) It will be recommended that a Potential Failure Modes Analysis (PFMA) be conducted in a workshop with City Staff. This will allow more focussed dam inspection to be conducted; and improve emergency planning in the event of a dam break.
3.13 Previous Dam Safety Issues

From the review of this archived material, the following previously recorded concerns were picked up regarding the safety of the Mark Creek Dam between 1994 and 2015:

a. During construction grouting operations on the 1st of April 1994, a return line on the grout pump blocked, the hose to the base of the dam ruptured, and a joint upstream face of the dam cracked adjacent to the construction joint. Although it is believed that this situation was remedied, the concrete structural engineer should as a matter of course, review the construction processes adopted on the whole dam with a view to assessing the structural integrity of the dam wall.

b. In February 1995, the Ministry of Environment’s Dam Safety Officer (DSO) expressed some concern over the gate valve stems on the upstream side of the dam sustaining ice damage. By return letter, Kloh-Crippen said they would investigate the issue. They did however note that this possible bending of the stems did not create a threat to the safety and structural integrity of the dam.

c. It was reported in April 2007 that falling ice had damaged the knife valve handles on the two small low-level outlets on the downstream toe of the dam. These have not yet been repaired. Since the upstream valves on these pipes still operate, all that is loss is redundancy, in the case where the upstream valves need to be worked on. The downstream fix should be fairly easy to achieve when there is no water cascading over the spillway.

d. During the 31st of December 2010 Ministry dam audit, small concrete surface cracks had been observed by the DSO. This audit report should be reviewed by the concrete structural engineer and the issue addressed.

e. In 2011, it was recommended that the old log boom be replaced. This was achieved using state of the art plastic booms that are still in good condition.

f. In 2014, the current LQP noted that a pinhole leak had developed in the left flank of the concrete dam wall. Although this is not serious major safety issue, it should be addressed.

g. He also noted that spillway water on the left flank is running down the joint between the dam wall and the splashpad. Although not a major issue, it should be addressed as a maintenance task in the near future.

h. These issues will be discussed in more detail in the report or in the Stage 2 DSR work. These were the main issues identified to date. Once a more detailed dam safety management system, including recording systems and task actions, it will be possible to identify a more comprehensive list of dam safety issues and concerns.
4 The Initial Dam Inspections

Both NHC and SNT Engineering Ltd. visited the dam site and environs in 2014. A photographic record is available and will be made available in Stage 2.

The main gravel access road to the site is good. It runs across Tech-Cominco land and two locked gates have to be traversed. Entry and exit also has to be reported by telephone to the Tech-Cominco security detachment in Kimberley.

In winter the last couple of hundred metres down to the dam is fairly steep and slippery. In Spring, the embankments on a portion of this road are sometimes saturated and unstable. Small mud/rock slides occur that could block a portion of the road.

At the bottom of the hill, a roadway switch backs to the right and travels up the eastern shore of the reservoir. This marks the top of the reservoir berm that was installed for stabilization of the slope above the reservoir (see photograph in Appendix E). The stability of this berm was briefly looked at by the Geotechnical Engineer from SNT Engineering, but will need to be reviewed in more detail in Stage 2.

There is no easy access to the upstream watershed, so this was not observed on the ground during the site visits.

Security fencing and public warning and problem reporting signs are all in place at the dam.

The reservoir was full during the site visits, so only the downstream abutments of the dam, the downstream concrete face, the crest/spillways, the stilling basin; the outlet pipes/valves, and downstream of the dam site were observed. The Mark Creek, as it flows through the Kimberley, was also visited.

Together with the two main Dam Operators, Chris Mummary and Wayne Murray, it was possible to gain an understanding of the current functioning of the system. Operation, Maintenance, and Surveillance(OMS) that is currently carried out at the dam was also discussed.

The Operators diligently record their visits, which occur regularly (daily during certain periods). It was noted that the Operators could improve their knowledge of how the dam was constructed, and how failure modes could take place. This would allow dam safety surveillance inspections to be more focussed. It will be suggested that a Potential Failure Modes Analysis workshop be held with City Staff to improve this knowledge, and to help update the existing OMS manual.

Pinhole seepage was observed at one spot on the concrete wall on the left flank of the dam. Although not a dam safety concern now, this will need to be investigated further in Stage 2 (Figure 4.1). The two knife-gate valves located in the middle of the wall at its downstream base have been damaged by what looks like falling ice (Figure 4.2). The sliding gates on the upstream side of these low-level pipes still operate, but there is no redundancy. The gates were not tested during the visits.
Figure 4.1
Mark Creek Dam Safety Review:
Leakage through concrete joint on left flank of dam wall
Mark Creek Dam Safety Review:
Valves at base of dam that are damaged
The Operators mentioned that divers regularly check the intake screens on the upstream side of the dam. Records were found in the City of Kimberley archives to this effect. It is suggested that the divers be contacted to obtain historic dive videos that were taken of the intake screens.

Water flowing over the far western spillway notch on the right flank of the dam lands on a splashpad that extends up the slope. Some of this water seems to be actively channelled down the joint between the pad and the wall. This could be of some concern if it erodes down to abutment rock level (Figure 4.3).

It was not possible to find any records that the survey monuments on various sides of the wall have monitored for movement since construction. This is an important monitoring activity in future as it will provide information on any displacement of deformation of the foundations or other parts of the dam structure. Although of lesser concern, the internal dam wall temperature monitoring equipment has also not been used.

No major cracking was observed on the downstream side of the concrete wall or on the crest and spillways.

Due to the water flows over the spillway, it was not possible to observe the condition of the concrete in the stilling basin.

No other significant seepage was observed through the concrete wall or natural rock abutments, but this will need to be confirmed by engineering specialists during Stage 2 of this DSR.

Other than the issues mentioned above, no other significant dam safety issue was observed. The dam is well maintained and is in good condition.

Communications are primarily by radio or cellphone. No automatic dam reservoir water level or dam break communication has been instituted. A communication cable does exist down the entire length of the water supply line from the dam to the City water treatment works downstream. This could allow for this remote communication, with automatic alarms and video feed, to be installed.

The emergency procedures associated with a dam break and normal flood events through the City was discussed with the Fire Chief. These are in place and can be improved. The upgraded dam Emergency Preparedness Plan (EPP) suggested for Stage 2 should provide clearer lines of communication.
Figure 4.3

Mark Creek Dam Safety Review:
Joint between concrete splash pad and wall
5 DAM BREAK, FLOOD ROUTING AND INUNDATION IMPACTS

No dam break or inundation mapping could be found specifically for the new Mark Creek Dam. A December 1989 dam break flood evaluation⁸ was conducted on the old Mark Creek Dam that has subsequently been decommissioned.

The study was reviewed and confirmed that a flood wave would reach the City of Kimberley within 12 to 15 minutes.

The impacts of such a “surprise” flood will need to be considered in the review of the consequence rating in Stage 2.

The Stage 2 DSR has not included a detailed dam break analysis, but just a review of the Klohn report, a more recent AMEC dam break study⁹ on the Sullivan Mine structures, and a number of flood hydrology studies through the City of Kimberley.

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⁹ AMEC. November 2014. Dam Break and Inundation Study for 3 Containment Structures, Sullivan Mine, BC
6 CONSEQUENCE RATING REVIEW

Only a cursory evaluation of the consequence rating was conducted in Stage 1.

The Canadian Dam Association’s Technical Bulletin entitled “Inundation, Consequences, and Classification for Dam Safety” was utilized as a guideline.

It was concluded that the current rating of “Very High” is appropriate.

A more detailed evaluation will need to be conducted in Stage 2.
7  **HAZARDS, FAILURE MODES AND FAILURE MECHANISM ANALYSIS**

The various hazards and failure modes that are associated with the Mark Creek Dam were identified and briefly evaluated in Stage 1.

A preliminary Hazards and Failure Mode Matrix (HFMM) has been shown on Table 7a.

It has already been recommended that a “Potential Failure Mode Analysis” (PFMA) workshop be held in Stage 2 with City Operators, Management and First Responders that are responsible for the dam.

The workshop will include:

- A thorough review of existing data and information that has been collated and reviewed in Stage 1. This will be summarized in a workshop document.
- Firsthand input from City Staff and discussions regarding the components and their functionality.
- Dam safety and failure precedents will be presented.
- As site visit – “thinking” potential failure modes and scenaria.
- Traditional engineering analyses.
- Discussion of the likelihood and potential reality of the occurrence of potential failure modes.
- Understanding of the consequences of failure.
- Discussion and ranking of PFMs.
- Informing surveillance and O & M procedures.

NHC has prepared for and would facilitate this workshop, which will inform the Stage 2 DSR work.

The benefits of this workshop will include:

- Uncovering data and information that corrects, clarifies or supplements the understanding of the dam and how it functions.
- Identifies the hazards that could play in on the dam, and the potential failure modes.
- Helps understand the consequences of each failure mode.
- Identifying risk reduction opportunities.
- Helps: develop operating and maintenance procedures; brings operating staff into the process; and educates participants on the importance of, and the reasons for, the monitoring and surveillance systems.
- Builds a team approach to the Mark Creek Dam safety process.

The following categories of hazards and failure modes were considered in the Stage 1 evaluation.
7.1 **EXTERNAL HAZARDS**

- **Meteorological Events**
  Floods larger than the Inflow Design Flood (IDF) up to the PMF level, are an external hazard to the Mark Creek; especially if the spillway becomes jammed with floating debris or ice. These overtopping flows may cause erosion of the abutments and could water to breach around the side of the dam wall.

  Other meteorological hazards such as temperature extremes, the effects of ice, lightning strikes, and windstorms, are much less significant than the flood and slope stability hazards mentioned above.

- **Seismic Events**
  Earthquakes and their influence on the dam wall, it foundation and abutments, and the upstream reservoir slopes is a hazard.

- **Reservoir Environment**
  During the original design process of the new dam, a portion of the eastern slope of the dam’s reservoir was identified as a hazard. This was counteracted by constructing the berm as shown on Figure 3.1. Slippages of this or other slopes could cause a large wave to overtop the dam and cause failure.

  Although some local activity has been noted, beaver and other burrowing animals are not overly active at the dam.

- **Terrorist Attack and Vandalism (Physical Threats)**
  Although there is a security fence at the dam wall, disaffected persons could gain access to and sabotage the dam.

7.2 **INTERNAL HAZARDS**

- **Water Barrier**
  Errors and omissions in the design of the dam, construction errors, operational and maintenance shortcomings, are all internal hazards that are considered in evaluating the components of the system that interface with the body of water.

  In this case there was a problem in the grouting of some concrete joints during construction. The effects of this and the resilience of the eventual fix needs to be assessed. Other than these and other small issues, the design and construction and OMS at the dam will need to be reviewed in Stage 2.

  Also includes new cracks in or on the surface of the concrete components of the dam, noticeable displacement between joints, significant movement of the survey monuments on the dam and abutments.
• Hydraulic Structures
  There are no control gates on the spillway. Malfunctioning or lack of access to the low-level gate valves during extreme flooding and overtopping events may present a safety issue.

• Mechanical and Electrical Systems
  There are no electrical components at the dam. The vertical mechanical sliding gates that control water flowing through the outlet pipes are in a reasonable condition and are functioning.

• Infrastructure and Plans
  The absence of “non-physical” dam safety activities necessary to support dam safety could pose a hazard to the safety of the Mark Creek Dam (e.g. planning, maintenance and implementation of all operating and safety procedures).

7.3 Failure Modes

In the workshop, Potential Failure Modes (PFM) should be identified, described and rated with regards to risk and consequences.

Describing the PFM will take three steps: identify the initiator (e.g. reservoir load; deterioration; operation malfunction; earthquake); the failure mechanism (including location and path); the resulting impact on the structure (e.g. how rapid the failure; breach characteristics).

The risk and consequences of PFM’s will categorized into one of the following: Category I: Highlighted PFM’s; Category II: PFM’s considered but not highlighted; Category III: More information or analyses are required; Category IV: PFM ruled out.

Risk reduction options will be discussed that could make the PFM less likely to occur, and that reduces potential consequences.

Some of the main components that will be considered in identifying PFMs in Stage 2 include:

• Overtopping Failure Mode
  ✓ Discharge capacity exceeded: It is the opinion of the author that the Mark Creek Dam spillway can accommodate the IDF event. Debris build up at the spillway crest may cause overtopping situations that pose a threat to the structural integrity of the dam abutments. Regular surveillance is key to ensure that these blockages do not occur, and some form of early warning system should be considered.
  ✓ Operations: During very high flow events over the spillways, easy access to the dam wall and the low level control gates at the two dams could be difficult.
  ✓ Maintenance failure: The maintenance of various components of the dam.
  ✓ Wave overtopping: Wind waves that could cause overtopping and upstream embankment slope erosion.
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✓ **Dam Safety Management function failure related to overtopping:** This refers to the oversight, verification, reporting and corrective action for hydraulic adequacy aspects of dam safety. It includes:

  - definition of dam safety requirements for hydraulic operations (operation and maintenance manuals);
  - identification and characterisation of deficiencies in hydraulic operation through routine monitoring, inspections and all surveillance activities, dam safety reviews and deficiency investigations; and
  - for hydraulic operations the planning of risk control implementation and scheduling of dam safety improvements.

- **Dam Collapse by Loss of Strength**

  ✓ **Dam Safety Management function failure related to dam collapse failure:** Similar to the overtopping section above. This relates to the OMS and Dam Safety Management System at the dam.

  ✓ **Liquefaction:** Seismically induced or static liquefaction of loose materials in the foundations and abutments.

  ✓ **Internal erosion:** The possibility of concrete scour. In other words, where water from upstream of the wall, finds its way through the wall, foundation or abutments. Also refers to water scour of the stilling pool area and rock just downstream.

  ✓ **Deformations:** Concrete wall, foundation or abutment settlement, shear or mass movement downstream.

  ✓ **Structural weakening:** Physical deterioration of any of the components of the dam. Cracking of the concrete or failure along a weak plane in the foundation or abutment bedrock.

  ✓ **Sliding and overturning stability of the concrete dam.**

These failure modes have been considered as an integrated unit. If some of these failure modes occur simultaneously, then a different more serious dam safety response may occur. This will be crossed checked against a Stage 2 version of the hazards and failure modes matrix shown on Table 7a.
<table>
<thead>
<tr>
<th>TABLE 7a: PRELIMINARY MARK CREEK DAM HFM MATRIX</th>
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<tbody>
<tr>
<td><strong>ELEMENT NO.</strong></td>
<td><strong>ELEMENT FUNCTION</strong></td>
</tr>
<tr>
<td>Inadequate installed discharge capacity</td>
<td>Meteorological inflow &gt; through dam seepage (filters/drains/pumps) to fail and reduce water tightness sufficient to cause dam collapse</td>
</tr>
<tr>
<td>Inadequate installed discharge capacity</td>
<td>Meteorological inflow &gt; through dam seepage (filters/drains/pumps) to fail and reduce water tightness sufficient to cause dam collapse</td>
</tr>
<tr>
<td>Inadequate available discharge capacity</td>
<td>Meteorological inflow &gt; through dam seepage (filters/drains/pumps) to fail and reduce water tightness sufficient to cause dam collapse</td>
</tr>
<tr>
<td>Inadequate available discharge capacity</td>
<td>Meteorological inflow &gt; through dam seepage (filters/drains/pumps) to fail and reduce water tightness sufficient to cause dam collapse</td>
</tr>
<tr>
<td>Inadequate available discharge capacity</td>
<td>Inadequate water inflow &gt; discharge capacity</td>
</tr>
<tr>
<td>Inadequate available discharge capacity</td>
<td>Inadequate water inflow &gt; discharge capacity</td>
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<tr>
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<td>Inadequate water inflow &gt; discharge capacity</td>
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<tr>
<td>Inadequate available discharge capacity</td>
<td>Inadequate water inflow &gt; discharge capacity</td>
</tr>
<tr>
<td>Systems collapse by overtopping</td>
<td>Meteorological inflow &gt; through dam seepage (filters/drains/pumps) to fail and reduce water tightness sufficient to cause dam collapse</td>
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</tr>
</tbody>
</table>
8 ASSESSMENT OF EACH COMPONENT OF THE MARK CREEK DAM

Based on the above-mentioned information and PFM analysis, the various components of the dam system will be evaluated and presented in terms of the following in Stage 2:

- General description.
- Monitoring and dam safety performance of component.
- Dam safety deficiencies and non-conformances.

These findings will be motivated in terms of statements, basic calculations and other review analyses.
9 REVIEW OF OPERATIONS, MAINTENANCE AND SURVEILLANCE (OMS)

During the Stage 1 review, the existing OMS manual was found to be detailed and appropriate for a dam of this size.

The City Staff utilize O & M forms as shown in Appendix H.

According to the BC Dam Safety Regulation, the OMS Manual has to be updated every 10 years.

Also, it is recommended that the findings of the PFM workshop be incorporated into the updated OMS Manual.

The OMS Manual needs to be submitted to the MFLNRO’s Dam Safety Office.
10 Review of Emergency Preparedness Plan (EPP)

An emergency communications plan is incorporated into the OMS Plan.

The City of Kimberley’s Fire Department also has a few pages in their emergency response manuals that deal with a potential dam break.

NHC is of the opinion that a more thorough emergency plan be developed.

During Stage 1, NHC drafted a detailed format of an EPP that can be completed in Stage 2 (Appendix D). This is based on the American FEMA guidelines\(^\text{10}\). This can be crossed checked against the EPP guidelines produced by the Canadian Dam Safety Association.

\(^{10}\) FEMA. July 2013 – FEMA 64. Federal Guidelines for Dam Safety: Emergency Action Planning for Dams
11 PUBLIC SAFETY AND SECURITY

Although the Mark Creek Dam has security fencing, it is possible for the public to access the dam wall by climbing fences. Secondly, there is access to the steep and slippery set of stairs that provides access to below the dam wall.

As such, it is recommended that the Canadian Dam Association’s bulletin\(^{11}\) on public safety be considered in Stage 2 and some recommendations made that will safeguard the City against possible litigation.

12 OVERALL DAM SAFETY MANAGEMENT SYSTEM

Even though dam safety management components in place, no formal integrated Dam Safety Management System (DSMS) was found to be in place for the Mark Creek Dam.

As a conclusion to the PFM workshop described earlier, it is recommended that the establishment of a formal DSMS for the Mark Creek Dam be planned.

Appendix J provides some input as to what would be required in such a DSMS.
13 **Owner’s Compliance with Regulatory Requirements**

The City of Kimberley has addressed the BC Dam Safety Regulation requirements as follows:

13.1 **Ongoing Requirements**

- To the best of their ability and knowledge, the City Staff carry out safe day to day operation and maintenance of the Mark Creek Dam.
- Due to domestic water quality and availability requirements, City Staff conduct daily to weekly inspections of the dam depending on the time of year.
- The Operation, Maintenance and Surveillance (OMS) plan, and the Emergency Preparedness Plan (EPP), are out of date. Upgraded versions of these plans will be conducted in Stage 2 of the DSR.
- The City commissioned the Stage 1 and Stage 2 dam safety reviews as recorded in this report. The Consultant’s Lead Qualified Professional’s takes responsibility for the delay in the production of this Stage 1 DSR Report. Stage 2 will be conducted in 2016.
- City Staff report significant findings resulting from inspections. More detail dam safety management policy decisions and lines of communication will be established in the Stage 2 DSR. The Stage 1 and Stage 2 reports will be made available to the responsible Dam Safety Officer in Victoria BC.
- The new dam safety management system to be set up in Stage 2 will outline the procedures to review the Mark Creek Dam’s consequence classification each year, as part of the annual report to the Dam Safety Officer (DSO).

13.2 **Special Requirements**

- The City is aware that it has to obtain MFLNRO DSO authorization before alternations, improvements or replacements to all or any part of their dam is conducted.
- The City is also aware that the DSO needs to be notified, and authorization obtained, before the removal, decommissioning, or abandonment of the dam.
- The City will prepare a plan in response to any safety hazard identified.
- The City will also operate the Mark Creek Dam in a manner (and initiate remedial actions) that will safeguard the public and dam in response to hazardous conditions at the dam.
- The City will obtain acceptance from the DSO for any revisions made to the OMS plan and the EPP.
- Appropriate signage is already in place that notifies passersby to report any problems at the dam to the City of Kimberley or Emergency response authorities.

13.3 **Additional Requirements**

The City is aware that dam owners must undertake the following if required by provincial authorities under the Regulation:
• Install any instrumentation necessary to adequately monitor the performance of a dam.
• Obtain further expert’s opinion on the design, construction and analysis of the dam.
• Obtain alternative opinion of an appropriate specialist such as hydraulic, hydrological, geological, geotechnical, mechanical or structural engineer or related professional on various questions, and
• Submit additional information, including recorded data, on the dam, reservoir, downstream area, or watershed upstream of the dam.

The relevant portions of this information will be presented in Stage 2.
14 KEY FINDINGS, PRIORITIZED LIST OF DEFICIENCIES AND NON-CONFORMANCES AND PROPOSED SOLUTIONS

14.1 SUMMARY OF KEY FINDINGS

a) This report documents the Stage 1, or Audit-level, Dam Safety Review (DSR). The main intent has been to conduct a high level review of the Mark Creek Dam, so that the work associated with a more detailed Stage 2 DSR can be identified more concisely. The reason for this phased approach is to minimize expenditure of scarce City/public financial resources.

b) Two site visits including interviews with City Staff were conducted.

c) A large volume of data and historic records were complied and reviewed during Stage 1. A document list, including a summary of key issues wasa prepared. In general, it was concluded that the as-constructed dam conformed to design assumptions and industry standards. The quality of the dam and the way in which the foundations and abutments were treated have resulted in a well built and safe dam.

d) Stage 1 information gaps have been identified.

e) A brief review of the “Very High” Consequence Classification of the Mark Creek Dam has been carried out, but further assessment is required in the Stage 2 DSR. Historic dam break analyses of the old Mark Creek Dam and neighbouring Sullivan Mine tailings dams have been reviewed. A brief dam breach calculation should be conducted in Stage 2 to confirm flood wave sizes and inundation issues in Kimberley and St Mary’s.

f) Internal and external hazards and failure modes were identified at a cursory level. A preliminary Hazards and Failure Modes Matrix has been referred to in Stage 1. Stage 1 work concluded that the design, construction and subsequent performance of the dam indicate that the dam is safe. More detailed evaluation of hazards, failure modes, risks and consequences need to be conducted in Stage 2.

g) A more detailed evaluation and a Potential Failure Modes (PFM) Workshop must be held with City Staff in Stage 2.

h) No Stage 1 hydraulic assessment was conducted. It was assumed that the spillway capacity was designed to pass the Probable Maximum Flood (PMF). This will be reviewed in Stage 2.

i) The 1 in 1,000 year flood event, the PMF and the Inflow Design Flood (IDF) were reviewed. Some work will be required on this to upgrade the flood hydrology based on more recent City of Kimberley flood hydrology studies and current Climate Change considerations. It is expected that this Stage 2 work will be limited based on the fact that the original design team aimed at safely passing the PMF.

j) Based on the original design studies that were reviewed, freeboard for the IDF were considered adequate in line with current industry standards.

k) Geotechnical Engineer Mike Walsh, P.Eng. of SNT Engineering Ltd. conducted a site visit and reviewed files obtained from the MFLNRO archives in Nelson and Victoria, BC. The initial conclusion was that the dam is safe from a geotechnical perspective, but further Stage 2 analysis is required to confirm this opinion. A seismic assessment will compliment this Stage 2 work. A list of task is shown in his letter in Appendix F.
l) A list of dam safety deficiencies and non-conformances is shown in Table 14a below.

m) The existing Operating, Maintenance and Surveillance procedures have been reviewed. Although appropriate, it will be necessary to update the OMS Manual in the Stage 2 DSR work. Conclusions that emanate from the PFM Workshop need to be worked into the new OMS Manual. This manual will need to be submitted to the DSO for approval and to achieve compliance with the BC Dam Safety Regulation.

n) A full set of dam safety surveillance tasks need to be formally identified and checklisted after the PFM Workshop.

o) The Emergency Preparedness Plan needs to be updated and expanded to be commensurate with a dam of this status. Stage 2 work has been identified.

p) There are a few minor public safety concerns at the dam that will be addressed in the Stage 2 work and incorporated into the overall Dam Safety Management System that is proposed for the Mark Creek Dam.

q) More formal City Staff training (Dam Operators and First Responders) will be required. This will be initiated with the PFM Workshop, which includes a site visit.

r) Roles, responsibilities, lines of communication and appropriate response/decision-making will be formally recorded in the updated OMS Plan and EPP.

s) Formal documentation of OMS activities takes place. Revised checklists will be developed as part of the PFM Workshop.

t) Standard dam safety evaluation criteria and expectations were documented, which resulted in a deficiency list that is aimed at complying with BC Dam Safety legislation.

14.2 General Stage 1 Conclusions

Stage 1 has concluded in broad terms that there is no significant deterioration in the safety or risk in the Mark Creek Dam system and its environs.

The dam is structurally safe, being operated safely and maintained in a safe condition, and surveillance is adequate to detect any developing safety problems.

Some follow-up Stage 2 work is required in order to confirm this initial assessment and maintain an acceptable level of safety risk for people, property and the environs downstream of the dam.

A focussed scope of work is proposed in Stage 2 to investigate certain components of the dam and to provide adequate motivation as to the conclusions reached in Stages 1 and 2.

The Stage 1 conclusion is as follows:

At a Stage 1, or Audit-level, the Mark Creek Dam above Kimberley, BC meets standard dam safety requirements. There are no significant, immediately actionable, dam safety concerns, and the dam is monitored on a very regular basis.

A prioritized list of dam safety expectation deficiencies, as well as non-conformances with legislation, has been provided, and should be addressed in the planned Stage 2 DSR study.
Table 14a: List of deficiencies and non-conformances at MARK CREEK DAM

<table>
<thead>
<tr>
<th>#</th>
<th>Task</th>
<th>Timing/Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Obtain feedback from MFLNRO Dam Safety Officer on this Stage 1 report and mobilize Stage 2 work (see proposed list of work Appendix L).</td>
<td>asap</td>
</tr>
<tr>
<td>2</td>
<td>As part of the Stage 2 DSR, conduct a 2016 review of the “Very High” consequence rating associated with the Mark Creek Dam. This will include a dam break calculation and the confirmation of existing inundation mapping below the dam.</td>
<td>Stage 2 (January 2016)</td>
</tr>
<tr>
<td>3</td>
<td>More detailed review by the Geotechnical Engineer as per Appendix F and his preparation for the Potential Failure Modes (PFM) Workshop.</td>
<td>Stage 2 (Jan to March 2016)</td>
</tr>
<tr>
<td>4</td>
<td>More detailed review by the Structural Concrete Dam Engineer as per Appendix K and his preparation for the PFM Workshop.</td>
<td>Stage 2 (Jan to April 2016)</td>
</tr>
<tr>
<td>5</td>
<td>More detailed identification of dam safety hazards and potential failure modes at the Mark Creek Dam, in preparation for the PFM Workshop in Kimberley. Also includes new drafts of the OMS Plan, the EPP and other dam safety management system inputs.</td>
<td>Stage 2 (Feb to March 2016)</td>
</tr>
<tr>
<td>6</td>
<td>PFM Workshop in Kimberley with City Dam Managers, Operators, First Responders, MFLRO DSO representatives and other Stage 2 team members.</td>
<td>Stage 2 (April 2016)</td>
</tr>
<tr>
<td>7</td>
<td>Conduct DSR Analysis based on the findings of the Stage 1 and Stage 2 work to date. Integrate findings of Geotechnical and Structural Engineers.</td>
<td>Stage 2 (May/June 2016)</td>
</tr>
<tr>
<td>8</td>
<td>Update the OMS Manual and the EPP based on the findings of the PFM Workshop.</td>
<td>Stage 2 (May 2016)</td>
</tr>
<tr>
<td>9</td>
<td>Brief hydraulic study of the dam spillway and stilling basin area.</td>
<td>Stage 2</td>
</tr>
<tr>
<td>10</td>
<td>Brief review of the flood hydrology, area capacity curves and freeboard</td>
<td>Stage 2</td>
</tr>
<tr>
<td>11</td>
<td>Brief evaluation of Public Safety and Security Issues as per CDA bulletin</td>
<td>Stage 2</td>
</tr>
<tr>
<td>12</td>
<td>Establish an overall Dam Safety Management System for the Mark Creek Dam, including dam safety policy development and staff training.</td>
<td>Stage 2 (May/June 2016)</td>
</tr>
<tr>
<td>13</td>
<td>Present DSR findings to City Staff</td>
<td>July 2016</td>
</tr>
<tr>
<td>14</td>
<td>Produce final Comprehensive Level DSR for the Mark Creek Dam.</td>
<td>Stage 2 (May to July 2016)</td>
</tr>
</tbody>
</table>
15 CONCLUSION

This Stage 1 Dam Safety Review (DSR) can be classified somewhere between an Audit- and a Comprehensive-level study.

Having said this, it is recommended that the Stage 2 DSR study be completed to investigate the safety performance of some unknown components of the dam such as the foundations and rock abutments; as well as the current condition of the concrete in the dam wall (Appendix L).

Based on these inputs and the rest of the work described in Table 14a above, it is believed that there will be sufficient engineering and management knowledge to complete a Comprehensive-level DSR of the Mark Creek Dam by July 2016, if work commences in January 2016.