REPORT

August 29, 2014

COLLIERY DAMS, NANAIMO, BC

Report on Dam Remediation Options

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Executive Summary

This report presents work carried out by Golder, and its sub-consultants, in relation to the development of remediation options for the Lower Dam, as part of Golder's role as the technical advisor to the Colliery Dam Technical Committee (TC). The design development and option selection was carried out within the TC framework and was primarily carried out in the course of a number of TC meetings, at which time Golder presented technical findings. This report describes the various TC meetings and provides a summary of key decisions made during the meetings. The options were developed and selected based on the TCs objective of:

"Development of an environmentally minimally invasive, cost- and time-effective solution while satisfying required safety standards - i.e. a solution that addresses:

- *The safety of downstream residents and workers;*
- *Dam Safety Section requirements;*
- *The respective objectives of the City, Snuneymuxw First Nation, the Colliery Dam Park Preservation Society and the community;*
- *Environmental concerns, including fisheries habitat and ecology;*
- *Cost-effectiveness; and,*
- *Having a timely permanent solution in place by no later than 2015 and ideally in 2014."*

The process undertaken to design and select a remediation option of the Lower Dam is novel for a number of reasons:

- The application of the risk assessment (or risk-informed) method of dam safety assessment is new and has not been applied previously in BC. Therefore, the Dam Safety Section of the Province of BC (DSS) was included in many of the meetings in order for them to understand the risk assessment process, as well as the proposed remediation options.
- The use of the Technical Committee approach in dam safety assessment projects is not common. This process provided an effective means of gaining comprehensive input on the relative merits of the various options, but also required additional effort in responding to questions and concerns and explaining technical concepts.

A key project challenge was the tight timeframe, as there was a strong preference to carry out the options assessment and selection as well as detailed design and construction of the dam remediation in 2014.

The development of the options described in this report has been based on the findings of the risk assessment which, in turn, is based upon various investigations and dam safety analyses which are described in separate reports and include:

- Site investigation. A site investigation was carried out to assess the condition of the Lower Dam. Among other things, this investigation determined the concrete core and foundations of the Lower Dam to be in good condition.
- Risk assessment and technical analyses. A quantitative risk analysis and supporting technical analyses were carried out to assess dam performance and assess life safety and financial risks. These analyses determined that, due to various characteristics related to the dam, the risk due to earthquake hazards is low, but the risk due to flood events is significant. Based on these findings, remediation of the dam to improve its seismic resistance is not required (although additional surveillance is required, as discussed in the report), however remediation of the dam to improve its flood routing capacity is required.

The report summarizes a number of remediation options which were considered which would improve the flood routing characteristics of the dam. This “long list” of options was eventually reduced to two options by the TC. These options are; the Labyrinth Weir option; and the Dam Hardening option. The TC has been unable to select a single preferred option to be taken forward.

Recommendations are provided for further work prior to proceeding to construction. The timing and sequencing of this work is dependent upon further decisions with respect to a contracting strategy and timing for the work.

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by the City of Nanaimo (CON) to be the technical advisor to the Colliery Dam Technical Committee (TC). The Colliery Dam Technical Committee's mandate is to identify an environmentally minimally invasive, cost- and time-effective remediation solution for the Colliery Dam system that meets safety standards and the respective objectives of the CON, Snuneymuxw First Nation (SFN), the Colliery Dam Park Preservation Society (CDPPS) and the community.

This report presents work carried out by Golder, and its sub-consultants, with regard to the development of remediation options for the Lower Dam, as part of Golder's role as the technical advisor to the Colliery Dam TC. This report presents, in summary form, the background to the selection of the remediation options that have arisen from the TC. In particular, this report presents the list of options that were considered by the TC and the relative merits of those that were carried forward and those that were dropped from further consideration. As the TC process revolved around a series of TC meetings, at which time Golder presented technical findings, this report describes the various TC meetings and provides a summary of key decisions made during the meetings. In order to reflect the nature of the decision making process, information presented in this report represents that which was presented at the respective TC meetings – no additional analysis or assessment has been carried out subsequent to the meetings. The Dam Safety Section of the Ministry of Forests Lands and Natural Resource Operations of the Province of BC (DSS) was in attendance at a number of these meetings, and their input assisted in guiding the development of the remediation strategy for the dams.

This report is not a design report, and therefore design calculations and findings related to the remediation options are not provided in the report, however, an introductory discussion of the design basis is provided as this is necessary in order to understand the motivation behind the selection of the remediation options.

The selection of the remediation options was based on the results of site investigations, hydrology studies, seismic, structural and geotechnical studies and a risk assessment, all of which are referenced herein, but not repeated in this report. For a more complete understanding of the remediation options, the reader is referred to these reports prepared by Golder

This report focuses on remediation options for the Lower Dam only. The work conducted for this project, in particular the risk assessment determined that the Middle and Lower Dams, given their proximity, act as a system, with the Lower Dam controlling downstream consequences. For this reason, it was determined that the remediation of the Lower Dam will provide the greatest reduction in risk to those living downstream of the dams, and remediation of this dam should be given the highest priority. The remediation requirements for the Middle Dam, if any, will be addressed separately, at a later date.

The process undertaken to design and select a remediation option of the Lower Dam is novel for a number of reasons:

- The application of the risk assessment (or risk-informed) method of dam safety assessment is new and has not been applied previously in BC. Therefore, DSS were included in many of the meetings in order for them to gain an appreciation of the risk assessment process, as well as the proposed remediation options; and,

- The use of the Technical Committee approach in developing dam remediation options is uncommon. This process provided an effective means of gaining comprehensive input on the relative merits of the various options, but also required additional effort in responding to questions and concerns and explaining technical concepts. For this reason, this report contains a section outlining the TC process.

A key project challenge was the tight timeframe, as there was a strong preference to carry out the options assessment and selection as well as detailed design and construction of the dam remediation in 2014.

The assessment provided herein included input from Herold Engineering Ltd (Herold) for structural design of the spillway. Associated Engineering Ltd (Associated) provided input to the breach scenarios used in the risk assessment, while EQ-Tec Engineering Ltd (EQ-Tec) provided structural engineering services for the seismic analysis of the dams.

This report should be read in conjunction with the *"Important Information and Limitations of This Report"* which is included following the text of this report. The reader's attention is specifically drawn to this information, as it is essential that it is followed for the proper use and interpretation of this report.

2.0 PROJECT BACKGROUND

2.1 Technical Committee

The dam remediation options have been developed and presented to the Technical Committee (TC) over several meetings which occurred between December 2013 and June 2014. This section has been prepared to summarize the various meetings which took place during the course of the development of the options, and to summarize some of the key issues and key decision points for these meetings. Due to the iterative process of the development of the options during the TC meetings, some understanding of the TC meeting content is important in order to understand the nature of the option selection.

The focus of many of the meetings was to inform the parties of the progress of the design and obtain input as the design progressed. This served as a means to expedite the remediation option development by eliminating the need for detailed reporting, commenting and review. As indicated earlier, there was a strong desire to for the dam remediation to be implemented in 2014. As a result of this requirement the design process became critical as timing was limited.

This section summarizes the key TC meetings which were attended in person by Golder personnel and during which the remediation options were presented, as well as other important project meetings outside of the TC process which involved key technical discussions which impacted the remediation design.

TC Meeting December 5, 2013

A start-up meeting was held which included:

- Introduction of participants;
- Review of TC tasks and process;
- Discuss of expectations; and,
- Discussion of actions and next steps, including recommendations for ongoing technical work.
  - The application of the risk assessment for the project;
  - Review of available documents; and,
  - The inclusion of DSS at select TC meetings.

Specifically the objectives of the TC were defined as follows

> *"Development of an environmentally minimally invasive, cost and time-effective solution while satisfying required safety standards" - i.e. a solution that addresses:*
>
> - *The safety of downstream residents and workers;*
> - *Dam Safety Section requirements;*

- *The respective objectives of the City, Snuneymuxw First Nation, the Colliery Dam Park Preservation Society and the community;*
- *Environmental concerns, including fisheries habitat and ecology;*
- *Cost-effectiveness; and,*
- *Having a timely permanent solution in place by no later than 2015 and ideally in 2014."*

TC Meeting December 13, 2014

At this meeting, which was also attended, in part, by DSS representatives, key discussion items included:

- Golder provided presentations which addressed;
  - The scope of the risk assessment;
    - The concept of risk was introduced as well as the CDA Guidelines (2013 addendum) proposing the use of risk assessments in dam safety; and,
    - A detailed risk presentation was made to explain the risk analysis model that would be followed considering incremental safety risk, financial, loss of life and the environment;
  - The findings of a preliminary review of previous project reports; and,
  - An initial outline of remediation options;
- The concept of focusing remediation efforts on the Lower Dam was outlined;
- On being asked, DSS. stated that although the application of risk assessment to dam safety was new, the approach was acceptable to them;
- The schedule determined that it was necessary to establish and evaluate the remediation design options concurrent with the risk assessment; and,
- Discussion of actions and next steps.

TC Meeting January 21 and 22, 2014

This meeting which was also attended, in part, by DSS representatives was held to present the following:

- Update of Golder review of information on the dams (a list of the documents is included in the references);
  - Unknowns and uncertainties with respect to design and construction of the dams were explained to the committee;
  - Recommendations for field investigations were outlined; and,

  - An assessment of previous technical studies was provided as well as recommendations for additional technical studies.
- An overview of the risk assessment process, specific to the Colliery Dams, was provided;
- Several potential remediation options for overtopping resistance were presented; and,
- Discussion of actions and next steps, including:
  - The site investigation work at the Lower Dam to establish the soil conditions and identify the condition of the concrete core;
  - Carry out a hydrology and hydraulics analysis;
  - Carry out the risk assessment; and,
  - Development of four alternative options for consideration at the next meeting.

TC Meeting March 4, 2014

This meeting which was also attended, in part, by DSS representatives was held to present the following:

- Four remediation options were presented for the Lower Dam along with preliminary construction estimates;
  - Following review of the Lower Dam remediation options, 2 options were selected to be taken forward for further assessment.
- An update on the risk assessment was provided. The preliminary results were based on the Phase 1 risk assessment (*i.e.* does not consider potential failure of the Lower Dam), and included preliminary risk input parameters;
- An update on the findings of the recently completed site investigation was provided; and,
- An update on the hydrology and hydraulics analysis was provided. Discussion of actions and next steps, including:
  - Further development of the risk assessment, including conducting a risk assessment workshop;
  - Carry out dam stability studies (seismic deformation analysis (FLAC)) based on geotechnical parameters for the fills in the Lower Dam which were collected during the site investigation; and,
  - Further development of the two shortlisted options.

Meeting April 4, 2014 – Risk Workshop (not a TC meeting)

The primary purpose of the risk workshop, was to review and seek input and consensus on the following; the structure of the risk model; the risk model input parameters; and the risk model outputs. As a technical workshop, the risk workshop was attended by key technical specialists, including; seismic specialists (Golder);

hydraulic modelling specialists (Associated); hydrology and hydraulics specialists (Golder); and geotechnical and dam safety specialists (Golder). The meeting was also attended by DSS representatives and TC representatives (not the full TC). The workshop included:

- An update on the risk assessment - these results were based on the Phase 2 risk assessment (which incorporates the two preferred Lower Dam remediation options);
- Detailed review of the risk model, risk inputs and outputs;
- A presentation on the hydraulic (inundation) modelling was provided (Associated Engineering); and,
- A presentation of the hydrology and hydraulic inputs to the risk assessment was summarized.

Meeting April 24, 2014 – Meeting at DSS (not a TC meeting)

This meeting, which was also attended by representatives of the TC (not the full TC) and DSS, included a discussion of:

- Risk assessment model – revisions and comments following the April 4 risk workshop; and,
- A presentation on the dam safety analysis and the dam classification.

TC Meeting May 12, 2014.

Meeting held to discuss the following; progress of the development of the remediation options; recent results arising from the seismic analyses of the dams; and review of ongoing discussions with DSS on the Dam Classification.

Meeting May 15, 2014 – Meeting at DSS (not a TC meeting)

This meeting, which was also attended by representatives of the TC (not the full TC), DSS and seismic specialists (Golder and EQ-Tec) was to summarize the results of the seismic analyses of the dams.

TC Meeting May 20 and 21, 2014

This meeting which was also attended, in part, by DSS representatives was held to present the following:

- Lower Dam remediation options. The two shortlisted remediation options for the Lower Dam were presented for consideration by the TC. The TC was unable to reach consensus on a favoured option;
- Middle Dam. It was accepted that the remediation of the Lower Dam is a higher priority. Remediation of the Middle Dam, if required, will be addressed at a later date, following completion of the Lower Dam remediation; and,

- Lower Dam Remediation timing. It was accepted that completion of the Lower Dam remediation in 2014 was extremely challenging and would likely add to costs. Deferral of this work until 2015 was accepted, providing that adequate controls remain in place.

Meeting June 27, 2014

Meeting held to attempt to reach an agreement on the options that are presently on the table. An agreement to select a single preferred option to be taken forward was not achieved and the meeting ended.

2.2 Dam Condition and Site Information

2.2.1 General

Golder carried out a review and re-evaluated available information provided by the CON. Based on the review as well as discussions and correspondence with the CON and anecdotal information from local residents, an interpretation of the Middle and Lower Dams original design and construction, previous mitigation and existing stratigraphy was developed. This process identified several uncertainties in both the Middle and Lower dams. This section of report focuses on the conditions, uncertainties and information requirements for the Lower Dam.

2.2.2 Background

The dams were constructed in the early 20th century to provide coal washing water during the coal mining era of Nanaimo. Middle and Lower Chase Dams are 13 and 23.5 m high and 50 and 77 m long, respectively. The dams appear to have been engineered structures when constructed over one hundred years ago, but no records of their design and construction are available.

Both dams consist of a central concrete core wall buttressed by variable rock fill slopes constructed upstream and downstream of the concrete wall. The upstream slopes are underwater and survey attempts to determine the condition and configuration of the fill on either dam have been unsuccessful due to heavy siltation. It is our understanding based on historical maps that a railway track was constructed over the Lower Dam around 1918. Coal waste (cinders and slag fill) appeared to have been added to the downstream shell to permit crossing at an orientation not parallel to concrete wall.

2.2.3 Lower Dam Uncertainties

Based on the review and re-evaluation of the available information, uncertainties for the Lower Dam are outlined below:

- The presence and condition of the fill on the downstream side of the concrete core wall - both the rockfill and cinder and slag fill composition, location and conditions were uncertain. (The condition of the compacted berm was known due to 1980 as-built reports (Willis Cunliffe and Tait, 1980));
- Groundwater conditions (groundwater levels) in the dam;
- The condition and effectiveness of the concrete core;

- The concrete core wall thickness at depth (does the concrete core wall get thicker at depth);
- The concrete core reinforcement – possible presence and spacing; and,
- The concrete core condition - previous project reports had indicated the concrete was likely to be of poor quality (*i.e.* contains honeycombing and weak spots potentially from weak filler material). The presence of cold joints and what is the condition and spacing.

In order to address these uncertainties related to the condition of the Lower Dam, which will in turn assist in evaluating the stability of the dam, a geophysical, geotechnical, environmental, structural and hydrogeological investigation was carried out between January and April, 2014 (Golder 2014a).

2.2.4 Geotechnical Investigations

Sonic Drilling in Downstream Dam Face

A geotechnical drilling investigation was carried out on the Lower Dam crest in February 2014, consisting of three sonic holes (SH14-04 to SH14-06), as shown on Figure 2. The purpose of the investigation was to:

- Observe the soil/fill material in the downstream shell and develop a profile of internal layering;
- Collect soil samples for environmental contaminant testing for characterization of the coal waste used for fills;
- Collect soil samples for laboratory testing of properties including grain size distribution, plasticity and moisture content;
- Profile underlying foundation (bedrock or till interface);
- Identify "water table," and possible variations in water saturation; and,
- Provide a hole for estimating the p and s wave velocities in the fill material in a separate (later) geophysical survey.

These boreholes (SH14-04, 05 and 06) were drilled between February 11 and 14, 2014, and were drilled through the full depth of the dam and into the dam foundation. The holes were continuously sampled, to provide information on the dam zonation and foundation conditions.

Following completion of SH14-04, a standpipe piezometer was installed and screened in rockfill. A 76 mm PVC pipe was installed in SH14-05 upon completion to facilitate down hole geophysics testing. SH14-06 was backfilled in accordance with the BC Groundwater Protection Act (BCGPA) regulations. Ground water not encountered in any of the holes during the drilling.

Laboratory classification tests were performed on selected soil samples obtained from the investigation. The samples were selected from the continuous cores retrieved from the drilling. The classification tests included sieve distribution analyses and a determination of specific gravity. Classification testing was carried out by ALS Laboratories. The testing information collected was used in the dam stability analysis and in developing the design options.

Test Pitting

Due to access, budget and time restraints, a test pit investigation program was considered optimal for collecting information on the properties of the dam fills on the downstream face, near the existing spillway and on the dam crest.

A total of eleven test pits were put down on April 1 and 2, 2014 at selected accessible areas within the site. The test pits were excavated by hand using a shovel and spade to depths between 0.3 and 1.5 m below the existing ground surface. The test pits were backfilled upon completion.

Diamond Drilling in Concrete Core Wall

A diamond drilling investigation was carried out in the Lower Dam concrete core, with the purpose of

- Observation of the condition of the concrete core and confirm the possible presence and condition of reinforcement;
- Collection of concrete core samples for evaluation of the concrete conditions and possible further laboratory strength testing for assessing the core wall condition and the response to earthquake induced deformations; and,
- To provide a hole for delineating the variation in thickness of the concrete core wall at depth and possibly detect reinforcement near the core holes in a separate geophysical survey.

Concrete and bedrock coring was carried out using a diamond drilling rig on February 11 to 14, 2014. Two core holes (CH14-02 and CH14-03) were drilled into the concrete core of the Lower Dam. A third planned core hole (CH14-01) was not completed due to time constraints.

The full thickness of the wall was exposed 0.6 to 0.7 m below ground surface to ensure each hole was centered on the wall before drilling. A Risk Management Plan (RMP) was prepared to address dam safety concerns and is discussed in the investigations report (Golder 2014a). It was not necessary to implement the RMP during the course of the drilling.

Core hole CH14-02 was drilled on Feb 11 and 12, 2014 in the center of the concrete core. Core hole CH14-03 was drilled on Feb 13 and 14, 2014 at the South end of the concrete core. The holes were continuously sampled through the full depth of the concrete core and into the bedrock foundation of the dam. The core from both holes was observed to be in good condition and generally uniform with no signs of deterioration, voids, alkali aggregate reaction, or honeycombing. Construction joints were present but were generally tight and in good condition. The core recovery was very high (average 96%).

In both core holes, the bedrock encountered was good quality conglomerate in the foundation. The bedrock/concrete contact in both core holes was very good, indicating that careful construction controls must have been in place. Reinforcement was intersected in both boreholes, with the 3/4" square twist bars indicating no sign of carbonation or deterioration. Water tests were carried out in the core holes and the concrete was found to be of low permeability, indicating that it is functioning as intended.

Laboratory testing on selected concrete samples was carried out. A total of five Unconfined Compressive Strength (UCS), two direct tensile strengths, two modulus of elasticity and two Poisson's ratio tests were carried out on concrete samples. The UCS of the concrete cores tested ranged from 24.8 to 56.3 MPa.

The above information indicated that the Lower Dam concrete core wall consisted of good quality steel re-inforced concrete, which appeared to have been well constructed and keyed into good quality bedrock.

Geophysical Investigations

A geophysical investigation consisting of Ground Penetrating Radar (GPR), Multichannel Analysis of Surface Waves (MASW), seismic refraction and downhole surveys (optical and acoustic televiewers and downhole GPR for CH14-02 and CH14-03, and downhole shear wave testing in SH14-05)) was carried out in January through March, 2014. The intent was to:

- Profile the internal layering of the material on the dams' downstream face;
- Identify the "water table" and other possible variations in water saturation, within the dams; and,
- Profile the underlying foundation and whether the foundation is glacial till or bedrock.

On the Lower Dam, highlights of the information gained from the surface geophysical investigation include:

- Corroborated bedrock depths and internal layering from the boreholes;
- Confirmed the location of the buried original concrete core-wall – the original concrete core-wall appears to continue towards the spillway at the same orientation as the exposed portion. The top of the buried core-wall is estimated to be at approximately 0.8 – 1 m depth below present ground surface; and,
- The borehole televiewer and GPR investigation confirmed the presence of rebar throughout the core, as well as identified fractures in the bedrock and provided an in-situ characterization of the concrete in support of the geotechnical core logs and other geotechnical information.

Interpreted Dam Section

The collected information was used to develop the geotechnical profile of the dam (see Figure 2), and provided the necessary parameters for dam stability analysis and modelling, which was, in turn used to characterize dam safety, and in particular, address the seismic stability and seismic risks associated with the dam.

2.3 Geo-Environmental Conditions

2.3.1 Purpose and Approach

The purpose of the geo-environmental assessment was to obtain environmental information with respect to the chemical quality of various media (*i.e.,* soil, water, sediment, soil vapour) at the Lower Dam, in order to assess, on a preliminary basis, the potential issues with respect to remediation of the dam structure. A detailed discussion of the scope and findings of this investigation is provided in Appendix A and in the investigation report (Golder 2014a).

2.3.2 Implications for Design and Construction

The subsurface investigation of the Lower Dam has identified the presence of fill (coal slag) containing chemical concentrations exceeding the applicable land use standards. Sediment downstream of the dam (but inferred to be associated with the dam fill material) may also contain chemical concentrations exceeding the provincial standards. The full extent of this coal slag fill has not yet been determined.

As the full extent of historical slag fill is currently unknown, there is considered a potential that dam remediation work may encounter such material. Therefore, as part of the remedial planning effort, consideration and allowance for the handling, characterization and disposition of soil would be prudent. In addition, the removal and handling of contaminated soil (*i.e.,* work falling under the definition of "remediation" under the Contaminated Sites Regulation) would require regulatory notification.

Depending on the location and type of construction contemplated, the following general issues (amongst others) may need to be addressed:

- The potential for encountering contaminated soil;
- The need to dispose of or deal with contaminated soil;
- The potential to expose contaminated soil to receptors;
- The potential for erosion of contaminated soil and migration to downstream locations;
- Regulatory notification requirements and documentation;
- Leach-ability and erode-ability of stabilized and/or treated soil;
- Risks associated with contamination remaining following construction; and
- Regulatory and public (stakeholder) acceptance.

2.3.3 Summary and Further Work Needed

The results of investigations and analyses conducted to date and the interpretation of conditions and recommendations for further work, are summarized in the following sub-sections.

2.3.3.1 Initial Investigation Program

- The Lower Colliery Dam contains cinder, ash and slag fill on the downstream face;
- The slag fill is estimated to be up to 7 metres, or more, in thickness on the downstream face;
- The slag fill contains metals concentrations (specifically barium and arsenic) that exceed both the CSR PL and CSR IL soil standards;
- The slag fill contains hydrocarbon concentrations (extractable petroleum hydrocarbon (LEPH and/or HEPH) and selected polycyclic aromatic hydrocarbon (PAH) constituents) that exceed the CSR PL soil standards;
- Test results obtained, to date, do not indicate that the slag fill would be classified as a Hazardous Waste, under the HWR; and,
- Synthetic Precipitation Leaching Procedure (SPLP) testing suggests that the leachate generated through contact between the slag fill and precipitation would likely not result in water concentrations exceeding either the CSR AW (freshwater) standards or the BCWQ guidelines for freshwater.

2.3.3.2 Supplementary Investigation Program

- Exceedances of the CSR PL soil standards were only identified in two of the eleven shallow soil samples collected and analysed as part of the supplementary sampling program. With the exception of one sample (containing arsenic), the constituent concentration exceedances were observed to be dissimilar to that exhibited by the slag fill material. In addition, the shallow soils appeared to lack visual evidence of slag fill. This suggests that the shallow soils at the dam site may consist of different material, or have been modified (though erosion, leaching, soil redistribution, etc.);
- Water samples collected from the Site were not found to contain chemical concentrations (total, dissolved metals and hydrocarbons) that exceeded the inferred applicable CSR standards (AW freshwater, DW) or the BCWQ guidelines; with the exception of total iron in one downstream water sample;
- Sediment samples collected from the Site were found to contain selected constituent concentrations exceeding the CSR sensitive site standards, but not the CSR typical site standards; and,
- No vapour concentrations were found to exceed the inferred applicable CSR soil vapour standards, upon application of permitted attenuation factors.

2.3.3.3 General Comments and Observations

The near surface soils at the Site do not appear to consist of the same material as the underlying slag fill. The surficial soils contain certain exceedances of the inferred applicable soil standards. However, when applying only the standards associated with the site-specific factors of “intake of contaminated soil” and “toxicity to soil invertebrates and plants” (which are applicable at all sites, and are the more relevant factors with respect to evaluation of direct contact exposure), no exceedances are identified, with the exception of nickel (that has a generic numerical standard).

Potential exceedances of the sensitive site standards for sediment were identified, but it is considered unlikely that such standards would apply at this Site.

Both surface water and soil vapour conditions do not appear to have been detrimentally-impacted by the presence of slag fill material.

2.3.3.4 Recommendations for Further Environmental Work

As exceedances of the inferred applicable CSR soil standards have been detected, future dam remediation activities involving the slag fill soils will likely require regulatory notification and, possibly, permitting. Such materials would also need to be appropriately handled during construction work.

In-situ management of contaminated soil, or other material, would typically include an assessment of risk to human health or the environment, resulting from these materials remaining in-place. Also, given the accessibility of the Site to potential receptors (human, terrestrial, avian, aquatic, etc.), potential exposure to the identified soil contaminants is considered possible, and the risk associated with such exposure should be evaluated.

It is recommended that a preliminary risk assessment be conducted, based on existing conditions, to help make sure that no sensitive receptors have been missed, that critical pathways have been evaluated, and to verify that no unacceptable risk is incurred as a result of in-situ management. If issues are identified through such an assessment, a plan for risk mitigation may then be developed.

3.0 RISK ASSESSMENT AND DAM SAFETY SUMMARY

3.1 General

This section provides a summary of the key findings of the various technical studies that have been carried out and which form the basis for the development of the remediation requirements.

3.2 Summary of Analyses Undertaken

A risk assessment has been carried out which is central to the dam safety assessment (Golder 2014d). This approach was adopted as it provides a means to better understand dam safety risks and to comparatively evaluate various remediation options. The risk assessment provides a means to more thoroughly assess potential failure mode probabilities and consequences. Further, the risk assessment can be used to determine conformance with dam safety guidelines, based on the most recent revision of the Canadian Dam Safety Guidelines (CDA, 2013), which provides criteria to be used when carrying out a risk-informed dam safety assessment. While the CDA Guidelines do not form part of the BC Dam Safety Regulation, they are considered in the application of the Regulations. The adoption of the risk assessment approach was undertaken in collaboration with the TC and DSS.

Central to the risk assessment was the identification of valid potential "failure modes" for the dams and considered potential failure modes that lead to downstream inundation and thus consequences. Dam failure modes that result in a slow release of water from the reservoir and no downstream flooding (and thus no consequences) were not considered. The failure modes of interest were breaches caused by either storm events, seismic events, or a broad category of "other" events, and included the cascading effects of a Middle Dam failure on the Lower Dam.

The key inputs to the risk assessment were developed with a combination of traditional deterministic analysis and, where necessary, subjective assessments based on input from specialists. These include:

- A site investigation to evaluate the current condition of the Lower Dam (Golder 2014a);
- Studies which assessed the stability of the Lower Dam, in particular during strong earthquake shaking (Golder 2014b). These analyses included dynamic soil structure interaction analyses (FLAC analyses); structural assessment of the performance of the concrete core of the dam and post seismic evaluations of the stability of the dam (SEEP/W and SLOPE/W);
- Hydrological and hydraulic studies were undertaken to evaluate potential storm events and return periods and to evaluate the hydraulic capacity of the existing spillways and other key hydraulic structures on the Chase River system (Golder 2014c);
- An assessment of the probability of dam breach, and the dam breach parameters (rate of breach and extent of breach) due to dam overtopping (Golder 2014c); and
- Dam Breach analyses were carried out to determine downstream flooding extents as a basis for evaluating consequences of dam failure (AE 2014 and Golder 2014c).

3.3 Key Findings

The risk assessment and the supporting technical studies has led to an increased understanding of the key dam safety risks for the Lower Dam:

- Reservoir Size. Due to the relatively small size of the reservoirs, the dam breach development duration (i.e., the time it takes for the dam to fail completely) is a key determinant of the extent of flooding and thus of consequences/risk. Simply stated, if the dam failure is relatively slow, it was found that there was insufficient storage in the reservoirs to cause significant downstream flooding. In general, it was found that the extent of flooding was related to the rate of breach, such that more severe flooding occurred for the very fast breach scenarios (*i.e.*, assuming the dams failed in 10 to 20 minutes – which represents the lower limit of the range of breach times considered possible for these dams), while much less severe flooding occurred for the slower assumed breach times.
- Seismic Risk. The keys findings of the geotechnical and structural seismic analyses and risk assessment of the Lower Dam are:
  - The Lower Dam is very unlikely to fail in a rapid manner that will cause downstream flooding. Therefore the seismic risk of the dam is considered to be low in comparison to the risk to the dams due to a storm event. It is noted that the seismic risk due to the cascading effect of a Middle Dam failure would be mitigated by remediation of the Lower Dam to increase flood routing capacity, if this remediation was not in place the seismic risk to the Lower Dam would be increased as it could be overtopped and fail in the absence of increased spillway capacity or overtopping protection; and,
  - The Lower Dam would be very badly damaged by a large earthquake and, although not analyzed, would likely be highly susceptible to more severe damage and possibly rapid failure in the event of earthquake aftershocks. Following an earthquake an assessment of the dam would need to be promptly conducted and recommendations for evacuation of downstream residents and remediation or removal of the dam made at that time.
- Dam safety risk due to storm events. The key findings of the hydrology and hydraulic analyses and risk assessment of the Lower Dam are:
  - The Lower Dam spillway is significantly undersized, and it has been determined that storms larger than a 25 year return period could exceed the capacity of the spillway and lead to overtopping of the dam;
  - As an earthen dam, the Lower Dam is vulnerable to failure (breach) in the event of an overtopping event. It is considered to be more resistant than the Middle Dam, primarily due to part of the dam being constructed of rockfill and the relatively thicker concrete core on the Lower Dam, however a significant portion of the Lower Dam is composed of highly erodible sand and silt; and,
  - Lower Dam breaching can have significant consequences.

The risk assessment considered the residual risk associated with the Lower Dam remediated to increase flood routing capacity, by either: 1) an enlarged spillway (Labyrinth Option); or 2) dam crest and downstream face hardened to resist overtopping (Hardened Option). These results can be used to evaluate conformance of the remediation options to the criteria presented in the CDA Guidelines (CDA 2013). The key findings are:

- ***Financial impacts*** – each of the dam remediation options have low damage costs (<$20,000 per year);
- ***Individual safety criteria*** - both dam remediation options meet CDA criteria (<10^{-4} chance of fatality per year); and,
- ***Societal safety criteria*** - both dam remediation options have risk levels that are between the CDA "Acceptable" and "Unacceptable" regions, and are therefore in the "As Low As Reasonably Practicable" (ALARP) region of the criteria (see Figure 3). The CDA Guidelines describe the ALARP principle as "… based on the duty to reduce risks to life to the point where further risk reduction is impracticable or requires action that is grossly disproportionate in time, trouble and effort to the reduction in risk achieved…".

While the CDA Guidelines do not form part of the BC Dam Safety Regulation, they do inform current industry practice and therefore are considered as part of the evaluation of dam remediation options.

The recommended remediation requirements for the Lower Dam are presented in the next section of the report.

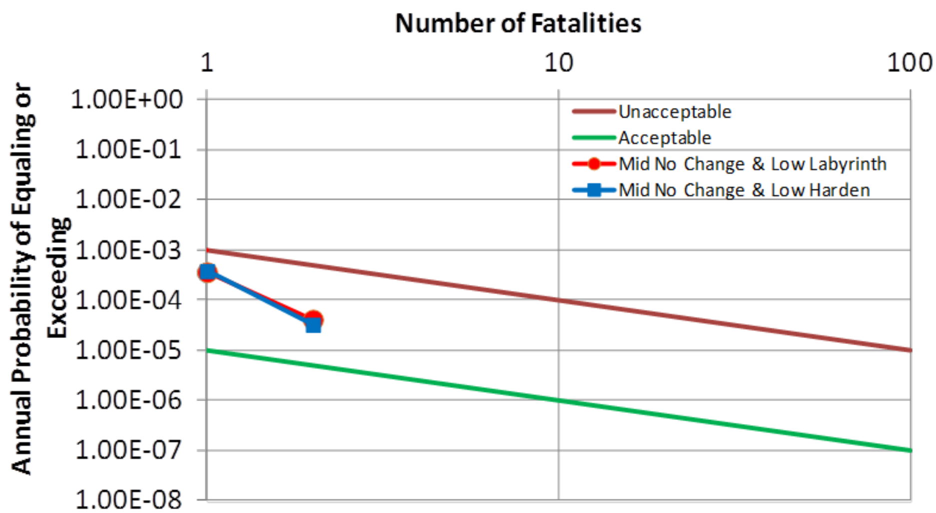

Figure 3: Incremental Societal Safety Risks for each Lower Dam Remediation Option (Golder 2014d)

4.0 DAM CLASSIFICATION AND REMEDIATION REQUIREMENTS

Through the course of the TC meetings and discussions with DSS, it has been determined that the dam remediation requirements for the Lower Dam are to be based on the findings of the risk assessment, together with consideration of the "traditional standards-based" requirements as presented in the CDA Guidelines. The standards based requirements are, in turn, based on the consequence classification of the dams.

Based on information developed during the course of the risk assessment and the dam stability analyses, the consequence classification of the dams has been re-assessed by DSS (this re-assessment is subject to review of the final Golder reports). As a result of the re-assessment, the consequence category has been reduced from Extreme to High and Very High for the Middle and Lower Dams respectively.

Based on the above classification, and the risk assessment findings discussed in the previous section, the recommended dam remediation requirements for the Lower Dam are outlined below:

- Remediation requirements to address earthquake risks. The risk assessment and the related dam stability studies have determined that the risk of sudden collapse of the dam which would cause downstream flooding is extremely low. The dam will be badly damaged during an earthquake, and the risk due to aftershocks may be significant. Based on these considerations, remediation works on the dam to improve stability are not recommended, however it is recommended to carry out the following additional measures to improve dam surveillance and dam safety management:
  - Install instrumentation in the dam to enable assessment of the dam following on earthquake to determine the condition of the core and to provide a means to determine if additional measures are required. Such instrumentation could be installed in the two core holes in the dam, one of which is in the maximum dam section. These holes extend the full depth of the dam and into the foundations and therefore are a good location to monitor the condition of the dam;
  - In the event of a severe earthquake and resulting damage to the core, measures should be in place to lower the reservoir level and/or evacuate downstream populations; and,
  - These measures should be included in dam safety documentation (Operations, Maintenance and Surveillance (OMS) Plan, and the Emergency Preparedness Plan (EPP)).
- Remediation requirements to address flood risks (including flooding due to upstream dam collapse). As indicated in previous sections, the risk of dam collapse due to flood events is significant and must be addressed by dam remediation to improve flood routing characteristics of the dam. The required flood routing capacity is given by the Table 6.1CDA Guidelines, and is based on the Consequence Classification of the dam. For a Very High consequence dam, the dam must be able to pass a flood at least the equivalent of 2/3 of the way between a 1000 year and a PMF flood; and,
- Remediation to address "other risks". These risks, which were quantified in the risk assessment (Golder 2014d) include risks to the dam arising out of other causes (piping, etc.). These risks can be adequately addressed without dam remediation, for example through regular dam safety reviews, as required by the Regulations.

Specific recommendations to address the remediation requirements for flood routing capacity are discussed in the next section of this report.

5.0 REMEDIATION OPTIONS – LOWER DAM

5.1 General

This section of the report presents the remediation options which were developed for the Lower Dam during the TC meetings. The report is structured using the same sequence of options development and assessment as applied during the TC meetings. To capture the sequence of assessment and shortlisting of options, the options are discussed in this report as they were presented to the TC. Those options that were selected for the final shortlist, would therefore have been discussed at more than one stage of development, as a result the evolving design concepts, and cost estimates, are presented in this report.

Due to time constraints, the development of the remediation options was carried out concurrently with the site investigation (Golder 2014a), the risk assessment (including the dam safety analyses, (Golder 2014 b, c and d) and the dam re-classification. This parallel sequence of events required some assumptions during the options development, including the use of the design criteria for the previous dam classification (since the dam was not re-classified until later in the options development), as well as certain assumptions of how the risk assessment may be applied (since, for DSS, this was the first application of the risk assessment process for dam safety analysis in BC).

While the risk assessment is geared towards addressing the dam safety risks, options assessment was based on satisfying the remaining objectives of the Technical Committee, namely:

- The safety of downstream residents and workers;
- Dam Safety Section requirements;
- The respective objectives of the CON, Snuneymuxw First Nation, the Colliery Dam Park Preservation Society and the community;
- Environmental concerns, including fisheries habitat and ecology;
- Cost-effectiveness; and,
- Having a timely permanent solution in place by no later than 2015 and ideally in 2014.

In order to reflect the nature of the decision making process, information presented in this section of the report represents that which was presented at the respective TC meetings – no additional analysis or assessment has been carried out subsequent to the meetings.

5.2 Available Options and Initial Screening Process

A "long list" of available options was developed by Golder for the Lower Dam and presented to the TC at the January 21, 2014 meeting. The options fall under two broad categories:

- Allow overtopping of the dam (reinforce the downstream face of dam): This option involves strengthening of the crest and downstream face of the dam to resist the erosion forces which can cause dam breach in the event of the overtopping of an unprotected dam; and,

- Increase spillway capacity, with or without the use of entrance structures to maintain the reservoir level at its current elevation.

The options considered under both categories are discussed below.

5.2.1 Overtopping of the Dam

Options to strengthen the dam to allow overtopping (for long return period storm events) are gaining increased usage internationally in dam safety upgrades as an alternative to constructing larger spillways or increasing reservoir storage by raising the dam crest. Overtopping protection systems have been the subject of a recently issued technical manual from the Federal Emergency Management Agency (FEMA), which was issued in May 2014. This manual, which was developed by FEMA in conjunction with the US Bureau of Reclamation (USBR), is considered to represent the current practice in the design of overtopping protection and was therefore the principal reference in developing the options for the Lower Dam. The technical manual discusses best practices for design, construction, problem identification and evaluation, inspection, maintenance, renovation, and repair.

Information issued by the International Commission on Large Dams (ICOLD) was also considered during the screening process and is discussed further below.

There are various methods to strengthen the downstream face of the dam to provide resistance to the scour and erosion resulting from overflow floods where spillway capacity is exceeded. The initial list of options (below) were considered for the Lower Dam remediation considering the criteria given above and the overriding requirements to ensure public safety and provide a long term solution for the dam. Due to time constraints, this list of initial options was developed in conjunction with a preliminary flow and scour analysis.

A summary of the options initially considered for the dam is discussed below and schematics and photographs of the initial options are shown in Figure 4 (Sheets 1 and 2). Reasoning for choosing to carry forward or eliminate an option at this stage during the screening process is discussed following the list of options.

Roller Compacted Concrete (RCC) and Soil Cement (SC)

The term RCC is defined by FEMA (2014) as:

"…combines a mix of sand, gravel, and cement, while soil cement is formed by creating a mix of soil and cement." RCC differs from SC in that it may have coarse aggregate, higher strength properties, and higher abrasion resistance. In order to achieve greater compressive strengths for more rigid and durable protection, RCC typically requires a higher cement content.

RCC was initially used for backfill, sub-base and concrete pavement construction and has been used in dam construction since the early 1960s. A general concept schematic of RCC is shown in Figure 4.1.

Both RCC and SC are typically placed in lifts, and rolled with earth moving equipment. Protection using SC was initially not carried forward to the screened options as it was thought that a more cost effective option could be feasible. Upon further analysis work, the SC was considered more feasible construction-wise and also resulted in a better product (with superior quality control) and was therefore brought forward to the shortlist for preliminary design.

Conventional/Mass Concrete Slabs

Conventional or mass concrete slabs can be used as the flow surface for overtopping flows. A continuously reinforced concrete slab (CRCS) installed over a filtered drainage layer allows high velocity flows along the downstream face of the dam while protecting the underlying embankment from erosion. Guide walls can be used to contain the flows and protect the abutments. A general concept schematic of mass concrete slabs is shown in Figure 4.2.

Precast Concrete Blocks

Precast concrete blocks are referred to as articulating concrete blocks (ACBs) when they are used as a matrix of individual concrete blocks over earth material to provide a hard surface for flow to pass safely over without eroding the underlying surface and with specific hydraulic performance characteristics. The main types of ACBs include:

- Cable tied: The concrete blocks are tied together with cables into large mattresses (usually at the factory) and delivered to the site for installation with a crane. Cast in place, fabric formed, cable reinforced, concrete mattresses referred to as articulating block mats are another similar system. A general concept schematic of hydraulic forces on a typical cable-tied ACB system is shown in Figure 4.3;
- Interlocking: The concrete blocks are individually formed and generally hand placed onsite in an interlocking pattern;
- Overlapping: For stability purposes, the concrete blocks are tapered (wedge shaped) or the slabs are overlapped and are also staggered and interlocked; and,
- Butt-jointed: The concrete blocks are also referred to as cinder blocks and are hand placed with butt joints on the earth surface for erosion control.

Gabions

Gabions are constructed from a hexagonal mesh comprised of heavily galvanized steel wire woven into rectangular baskets or mattresses and filled with rock. The porous baskets can be placed side by side to provide overtopping protection by relying on the interlocking of the individual rocks and the weight to resist hydraulic and earth forces. The modular design generally provides protection with a smaller footprint and with finer rocks than loose riprap. Gabions have the option of being vegetated. An example photograph showing the installation of gabions is shown in Figure 4.4.

Vegetative cover, reinforced and artificial turf

Well maintained vegetative cover on the downstream face of dams can protect against normal weathering and erosion due to rainfall by reducing the velocities and shear stresses at the embankment boundary as well as reinforcing the underlying soil with plant roots. This system is intended for fairly low velocities and flows and will not protect against large overtopping events and will only delay failure. This form of protection can be somewhat improved with the use of turf reinforcement mats.

A general concept schematic of vegetative cover with mat and mesh reinforcement is shown in Figure 4.5.

Rockfill and reinforced rockfill

Rockfill can be used for protection on the downstream face of the dam by slowing down erosion which will delay failure during an overtopping event. Mesh and anchor bars can be used to reinforce the rockfill by holding the rock particles in place. A general concept schematic of reinforced rock fill is shown in Figure 4.6.

RipRap

Riprap comprises large, uniform size rock fragments that can protect against the initiation of erosion on the downstream face of the dam during an overtopping event. An example photograph of rip rap lining a channel is shown in Figure 4.7.

Geomembranes and Geocells and fabric formed concrete

A geomembrane is defined by FEMA (2013) as, "an impermeable synthetic liner or barrier made from relatively thin, continuous polymeric sheets." The geomembrane provides an impermeable surface for flows during an overtopping event and should be installed with a granular soil cover.

Geocells, also known as cellular confinement systems, are typically light weight, honeycomb-like mats made from high-density polyethylene (HDPE) strips and filled with a variety of fill materials. Concrete fill in the geocell can be used to prevent erosion on the downstream face of the dam during an overtopping event.

Fabric-formed concrete can provide erosion protection to the downstream face of the dam and reduce flow velocities. Deeply patterned surfaces can be implemented into the fabric forms to create hydraulic resistance.

A general concept schematic of geomembranes, geocells and fabric formed concrete is shown in Figure 4.8.

Open stone asphalt

Open stone asphalt is a bituminous mix comprising uniform sized crushed stone covered in sand resin. It is durable, erosion resistant (suitable for low velocity flows) and maintenance free. An example photograph showing the installation of open stone asphalt is shown in Figure 4.9.

Soil Stabilization

Stabilization involves hardening the downstream shell material of the dam to provide erosion protection during and overtopping event. The hardening is accomplished by soil mixing the in-situ material with a binder mix, such as cement. A general concept schematic showing mass stabilization with the propriety system ALLU is shown in Figure 4.10.

5.2.1.1 Selection of Overtopping Option

Golder considered FEMA and ICOLD guidelines when selecting an overtopping option to carry forward to the shortlisted options. It is important to note the category the Lower Dam falls into (*i.e.* Large or Small dam) when considering an appropriate overtopping protection system.

Large dams are defined by ICOLD as any dam with "Maximum height (H), measured from deepest foundation level to highest structure crest level, more than 15 m. "

FEMA (2014) referenced this definition and states that "If large dams are defined as those having a height of greater than 50 feet, only RCC, CRCS, and reinforced rockfill have been considered or used for overtopping protection of large embankment dams. Most laboratory testing of overtopping protection systems has been limited to a drop height of 50 feet or less." The Lower Dam is 23.5 m high (as measured from crest to downstream toe) and hence by definition, falls into the Large Dam category.

When considering the three remaining FEMA endorsed options: RCC (or SC), CRCS and reinforced rockfill, Golder considered several factors including the maximum head over the dam crest, the flow velocities across the downstream face, erosion potential, aesthetics, and durability and in one case, economics.

Due to poor supportability of the loose cinders and slag fill surface which might settle or move with time, construction difficulties of forming and placement of concrete on a steep surface, cost and time limitations, CRCS was not carried forward as an overtopping protection system.

FEMA (2014) also summarizes design parameters, including flow velocity, that may represent practical upper limits for their applications. As there is no information on flow velocity for reinforced rockfill noted by FEMA, detailed testing would be required to confirm that the estimated flow velocity during a design event for the Lower Dam could be met. Further, the long term durability of the steel reinforcement would not be assured. Therefore, reinforced rockfill was not carried forward as an overtopping protection system.

Open stone asphalt is not discussed in FEMA, however, there are precedence cases in Europe for this technique being used in spillways for moderate flows and velocities. This option would require detailed scaled model testing to ensure it would meet the durability and flow requirements given the incline of the slope. Therefore, open stone asphalt was not carried forward as an overtopping protection option.

Soil stabilization is also not discussed in FEMA and there are no precedence cases for this technique. This option was initially considered during the screened assessment. After further work, soil stabilization with ALLU (insitu soil mixing) was not considered feasible for construction as this slope was considered too steep for this option. Also, from a quality control perspective, the final protection would be less assured than with more conventional methods of mixing. Therefore, it was not carried forward as an overtopping protection option to the shortlist for preliminary design.

5.2.2 Spillway

A spillway's function is to provide the controlled release of flows from a reservoir past the dam. Mitigation options to increase spillway capacity included enlarging the existing spillway, developing a swale (an auxiliary spillway) or constructing a new spillway structure.

5.3 Screened Options

Based on the above potential options and the specific design requirements stated above, a reduced list of four mitigation concepts were developed which optimized flood criteria, robustness of design, environmental issues, impact to the park, constructability, and conventional precedence. The four options include:

- Option 1: Enlarge Existing Spillway with construction of new spillway slab and walls, as shown in Figure 5. The existing spillway remains in place and is widened to the south. It is a typical broad crested weir design with a total spillway area of ~4000m^2;
- Option 2: Swale (auxiliary spillway) excavated to allow flood waters to pass around the dam and discharge into an adjacent creek on the right (southern) abutment, as shown in Figure 6. The existing spillway would remain in place, largely unaltered. The swale invert would be higher than the existing spillway invert, so that it would only be activated in extreme storm events, with a ~90 m wide crest width and ~5:1 landscaped slopes;
- Option 3: Labyrinth Spillway, as shown in Figure 7. A labyrinth spillway is a particular form of spillway which optimizes the flow by providing a 'zig-zag' entrance wall that increases the entrance sill to the spillway chute. The provision of the zig-zag wall allows the construction of a smaller structure than would be necessary for a conventional uncontrolled spillway. Originally a ~20 m wide chute with 3 m high walls was considered at the location of the existing spillway to meet the initial capacity requirements; and,
- Option 4: Dam Hardening with downstream soil /slope hardening using soil cement (SC) (a form of Roller Compacted Concrete (RCC)), as shown in Figure 8.

In order to provide a consistent basis for comparison, the screened option assessment was based on a hydraulic capacity of 175 m^3/s. At the time this work was undertaken, the dams were both assigned a consequence classification of Extreme, and therefore a conservative flow requirement, slightly greater than the regulatory requirement (PMF), was selected. As noted in Section 4.0, the hazard classification for the Lower Dam was later reduced to Very High.

Each of the options given above were established considering precedence (as recommended by ICOLD (2012)) and long term performance with minimal maintenance (FEMA, ICOLD).

These four options were evaluated in further detail and were presented at the March 4, 2014 TC meeting, with a view to select a preferred option(s) to be taken forward to further assessment. The general advantages and disadvantages are presented in Table 1 which was used as a basis for discussion at the March 4 TC meeting.

Table 1: Advantages and Disadvantages for 4 Screened Options

Option Name	Advantage	Disadvantage	Initial Cost Estimate (see Note)
Enlarge Existing Spillway	■ Does not require specialist contractor ■ Minimum maintenance after design event	■ Loss of ~3200m^2 of habitat permanently (total spillway area ~4000 m^2) ■ Does not address contaminated soil ■ Requires long bridge	$2,589,000

Option Name	Advantage	Disadvantage	Initial Cost Estimate (see Note)
Swale	■ Area could be landscaped with grass, possibly 'designed' tree growth (aesthetics, habitat) ■ Does not require specialist contractor	■ Loss of ~10100m^2 of habitat – requires temporary removal of vegetation and soil ■ Does not address contaminated soil ■ Maintenance required after design event	$1,345,000
Labyrinth Spillway	■ Minimum maintenance after design event ■ Small footprint (aesthetics) ■ Does not require specialist contractor	■ Loss of ~850m^2 of habitat permanently ■ Does not address contaminated soil ■ Requires bridge	$2,592,000
Dam Hardening	■ Area can be reseeded for grass growth (aesthetics) ■ Addresses contaminated soil	■ Loss of ~3000m^2 of habitat ■ Requires specialist contractor ■ Maintenance required after design event ■ Requires raising section of trail (considered required at the screening design stage) ■ Possible armouring required on existing spillway	$1,487,000

Note. These costs appearing in this table were initial cost estimates, which reflected the conceptual nature of the design and cost estimating at the time of the March 4 TC meeting. The costs increased as further design work and additional analysis was undertaken as shown later in this report. The costs provided in this table did not include contingency, owner's costs, design and resident engineer's costs, or costs for ancillary works (replacement bridge, landscaping, etc.).

5.4 Shortlisted Options

Based on the preceding discussion and review of the screened options for the remediation, the TC opted to carry two shortlisted options further in design, namely, the Labyrinth Spillway option and the Dam Hardening option. Both the swale and enlarged spillway were eliminated by the TC.

5.4.1 Design Requirements

This section presents the design philosophy (as expressed as design requirements, or design objectives) that was the basis for development of the remediation options.

The primary means of preventing and mitigating any long term degradation or failure which would increase the risk to the performance of the remediation is to adopt a "defence in depth" design (ICOLD). This approach means that several safe guards are worked into the design and hence, several levels of protection would have to fail before negatively impacting the public, property or the environment. Consequently 'safety by design' (SbD) *(reducing safety and environmental risks by identifying and designing out or mitigating hazards during the design)* was applied, where conservatism (by reasonable safety margins) and practical redundancy were inherently incorporated into the two shortlisted remediation options.

The two options (Labyrinth Spillway and Dam Hardening) were carried forward to the preliminary design stage based on the following design requirements:

- Safety concerns to be addressed;
- Dam remediation criteria must conform to the CDA Guidelines design criteria (Table 6-1) for the Very High Classification;
- International guidelines for spillways, dam design, overtopping and remediation such as FEMA, CDA, ICOLD, ASDSO should be adopted; and,
- Remediation to be technically appropriate for the conditions considering:
  - Long term and durable design (100+ years) and assurity of any remediation design;
  - Appropriate remediation design to address the loose and erodible soil fill materials which comprise the downstream dam embankment;
  - Safely passing the design floods in overtopping remediation, a robust scour protection must be capable of resisting the design flood levels;
  - Adequate design of spillway slabs and walls for maximum design earthquake (MDE) conditions. Remediation works must survive and be operable under MDE conditions; and,
  - Any overtopping remediation must channel all the flood water over the dam in a controlled manner and prevent random uncontrolled spilling over the abutments.

With respect to overtopping protection (dam hardening), this design is used infrequently, and has never been applied on a dam in BC. Therefore, for dam hardening, there is expected to be a need to demonstrate precedence, or acceptance under international dam design guidelines (e.g. FEMA guidelines) in order to demonstrate acceptability.

5.4.2 Construction Requirements

In addition to the preceding design requirements, there are a number of requirements which must be addressed in the construction of any dam remediation work.

- Remediation works to by minimally invasive to the park and environmentally sensitive to park ambiance;

- Remediation works are to ensure that existing water levels in the lakes are maintained and the reservoir levels not lowered permanently;
- Minimal tree or vegetation removal;
- Water release to be provided for downstream fish habitat;
- Cost effective remediation solution consistent with design requirements;
- Work to be carried out with adequate controls to prevent adverse environmental impacts (e.g. controls to prevent sediment run-off);
- Soil testing to detect contamination of excavated materials to be carried out and excavation soils accommodated as appropriate and required by legislation;
- Construction access roads for equipment to be minimally invasive to the park; and,
- Provision of adequate remediation construction sequencing (cofferdam, pumps etc.) to ensure worker safety and protect the works from sudden storm events.

5.4.3 Description of Shortlisted Options

Following selection of the two shortlisted options (the Labyrinth Spillway option and the Dam Hardening option), Golder carried out further design, analysis and cost estimating in order to facilitate the selection of a single final option to be carried forward to final design and construction. This section outlines the details of the two options and presents the constructability issues used to develop preliminary construction cost estimates. This section reflects the information on these options which was presented to the TC at the May 20 meeting.

5.4.3.1 Labyrinth Spillway Option

As indicated previously, the labyrinth spillway is considered to be the least intrusive spillway option to accommodate the design floods. This design includes a less conventional weir design which allows a smaller footprint. As the risk assessment and shortlisted designs were being carried out simultaneously, two labyrinth sizes were considered; a labyrinth spillway with an 18 m wide entrance was designed with a 175 m^3/s capacity and a 12 m wide entrance was designed with a 143 m^3/s capacity (equivalent to the requirements for a Very High dam classification).

The design for the 12 m wide labyrinth spillway is shown on Figure 9. Design details for the 18 m wide labyrinth spillway are not provided in this report. Details of the 12 m wide structure are as follows:

- The spillway entrance is 12 m wide tapering to 8 m wide. The walls and base slab are cast-in place concrete;
- The labyrinth weir height is 3 m, comprised of 4 zig zag walls. Three of the zig zag walls are comprised of 12 pre-cast concrete panels and 1 wall is comprised of 5 pre-cast concrete stop logs. Stop logs enable controlled draw down of the reservoir following a seismic event (or they can be useful for repairs, etc.);

- A low level Outlet (LLO) gate is provided for dry season fish water releases, if required;
- The total wall height is 5 m at spillway entrance tapering to ~3 m high further down the spillway;
- There is no information on the conditions that will comprise the foundation of the structure – particularly beneath the zig zag weir. For the purposes of the cost estimate, the excavation has been assumed to be half in rock and half in soil. Based on available information, any rock that is encountered is expected to be relatively weak and can be mechanically excavated ("ripped"), rather than excavated by drilling and blasting;
- To construct the spillway there will be a permanent loss of ~230 m^2 of habitat including the existing spillway footprint;
- During construction, approximately 1600 m^2 of habitat (including existing spillway) will be impacted (as noted later in this report, there are options to reduce this impacted area);
- A grout or concrete seal is required at the spillway entrance and drainage along the channel base has been accounted for in the design; and,
- Heavily reinforced concrete walls and foundation are required in order to withstand the design seismic event (MDE).

5.4.3.2 Construction Sequence of Labyrinth Spillway

Construction costs for the 12 m wide labyrinth spillway are based on the following sequence considering a construction period extending from July to mid-October. A diversion will be provided to prevent base flows and small storm events from entering into the works. The diversion is impractical for large storm events and hence, is one of the reasons that construction should finish as early in the fall as possible. Floods in excess of the diversion capacity will be routed through construction works. Extension of construction into late fall is to be avoided, due to the potential for increased precipitation and storm events which could exceed the capacity of the diversion system. The excavation plan, dewatering concept and site access for construction are shown in Figure 10. It is noted that this figure represents the construction sequence and construction footprint used in developing the cost estimate, and that alternative approaches (which could result in a smaller construction footprint) are available. As an example, instead of the large open excavation shown in the figure, a smaller excavation footprint could be achieved using steeper excavation slopes (using excavation shoring).

- Construction would commence with mobilization, set up of site access and then implementation of the water management plan discussed in the points below;
  - The Lower Dam reservoir level will be drawn down 5 m using two 450 mm siphons located on the south side of the existing spillway;
  - The Middle Dam reservoir level will also be drawn down 5 m using two 450 mm siphons placed on the invert of the spillway. The reason for lowering the Middle reservoir, is to provide additional storage capacity in the event of a summer storm, so, in essence, the Middle Dam serves as "protection" to the inundation of the Lower Dam works due to a storm;

  - A cofferdam has been assumed for the Lower Dam, 1 m below the dam crest; and,
  - This water management plan represents the basis for costing – alternative approaches are available, potentially including options which would avoid impacting the Middle Dam reservoir, utilizing a higher capacity siphon system.
- Construct the labyrinth zig zag wall once the diversion has been implemented; and,
- Sectional demolition and removal of the existing spillway structure and construction of the new spillway walls starting from downstream and working upstream towards the reservoir. The sectional construction of the spillway will reduce the period when spillway through-capacity will not be maintained to pass any storms which exceed the diversion capacity.

Environmental controls would be in place when this work is carried out, including methods to limit impacts on fish populations in the reservoir, and methods to limit impacts on terrestrial habitat.

5.4.3.3 Dam Hardening Option

Overtopping protection is a requirement to ensure that the scouring effects of overflows from flood events over the dam are adequately resisted to prevent loss of embankment fills. For this option, the design shown on Figure 11 has been prepared. Specifically the design features are as follows:

- The loose material on the downstream face will be removed in strips from surface up to 3 m deep. The material will be taken to the soil/ cement mixing plant for mixing in a controlled manner then replaced on the downstream face, on a compacted subgrade;
- Since this option results in a modification to the dam structure, it was analyzed (for earthquake resistance) as part of the dam stability analysis (Golder 2014b). It was found that the dam hardening, improved the dam performance during an earthquake, by significantly reducing dam deformations, while not impacting the performance of the dam core in an earthquake;
- The removal, mixing and replacement of material has been designed to provide a “re-shaped” dam surface, which is required for two main reasons;
  - The non-level crest will concentrate flow over the center of dam and is designed to prevent turbulence and potential increased scour on the downstream face; and,
  - The re-graded downstream face is bowl shaped to prevent flows from impacting the abutments and thereby undermining the dam to minimize convergence and provide uniformity to flow.
- Modifications to the existing spillway is required to confine design storm flows and to prevent overtopping of the spillway during a design storm event berms up to 1.5 m high, which have been assumed to be made of soil/ cement, are constructed along portions of the north and south sides of the existing spillway to confine flows in the spillway.

5.4.3.4 Construction Sequence of Dam Hardening

Construction costs for the dam hardening option are based on the following sequence. Similar to the labyrinth weir, the works should be constructed prior to the onset of the wetter fall season, as moisture control during placement of the soil-cement is of particular importance. The excavation plan and site access during construction is shown in Figure 12. The construction sequence is as follows:

- Mobilize and set up site including soil/cement mixing plant;
- The dam crest is partially excavated and used as a working pad;
- Low impact access roads will needed to access the downstream dam face;
- ‘Hardening” is accomplished by first excavating soil in strips from surface down to 3 m depth. The material is then transported to the mixing plant on site and the soil cement mix then replaced and compacted to the design grades on the downstream face. Berms up to 1.5 m high made of soil/ cement mix are constructed along portions of the north and south sides of the existing spillway; and,
- Erosion control blankets and vegetative cover would then be placed on the dam face and the site and access roads re-landscaped.

Environmental controls would be in place when this work is carried out, including methods to limit impacts on fish populations in the reservoir, and methods to limit impacts on terrestrial habitat.

5.4.4 Cost Estimates

Cost estimates presented in this section are based on the designs and construction sequences presented above, and, where uncertainties still exist, also include certain assumptions regarding site conditions, as indicated later in this section. Also, these cost estimates include additional project costs (contingency, owner’s costs, design and resident engineer’s costs, and costs for ancillary works (replacement bridge, landscaping, etc.), and therefore cannot be compared to the costs presented in the previous sections of this report.

The “Base Costs” provided in these tables have been developed using full, “resource based” (or bottom-up) cost estimating, which includes contractor mark-ups and is therefore intended to reflect potential contractor bid costs.

5.4.4.1 Labyrinth Cost Estimate

The cost estimate for this option is provided in Table 2 below.

Table 2: Labyrinth Cost Estimate

Item		Estimate ($)
1.	Base Cost	5.4
2.	Other items	0.3*
3.	Contingency (~10%)	0.6**
4.	Design, RE	0.6

Item		Estimate ($)
5.	CM	0.6
6.	Owners Costs	0.6
TOTAL		$8.1M

The cost estimate for the labyrinth includes several assumptions in addition to those previously described:

- "Other items" – includes allowances for those items which are required, but were not estimated in detail - these include a new pedestrian bridge and landscaping;
- Contingencies are normally applied to reflect potential additional costs which are due to uncertainties such as ground conditions, incomplete design, etc. The contingency for the labyrinth is lower than shown for the hardening option because of lower risks and potential opportunities as summarized below;
  - A number of potential methods to "value engineer", or optimize the labyrinth design are available - including less expensive means to construct the spillway walls and foundations (*e.g.* MSE walls), and the potential to reduce or eliminate the cofferdam. These could reduce the "base cost" significantly; and,
  - The design for the labyrinth is considered to be less sensitive to changes in site conditions. The hardening option will result in modifications to the dam and must not adversely affect its long term performance. Since there are no design drawings or as-built reports for this dam (with the exception of the works carried out on the downstream toe), the uncertainties in the construction of the downstream shell of the dam are significant and may impact design and construction of any overtopping design.
- The design, resident engineer and construction management costs are preliminary allowances based on conventional practice, rather that cost estimates developed specifically for this project;

Two size options of the Labyrinth Weir were designed and costed. It was found that there was limited increased cost to increase the size and capacity of the spillway.

5.4.4.2 Dam Hardening Cost Estimate

The cost estimate for this option is provided in Table 3 below.

Table 3: Dam Hardening Cost Estimate

Item		Estimate (M$)
1.	Base Cost	3.2
2.	Other items	0.7*
3.	Contingency (~30%)	1.2**
4.	Design, RE	0.8
5.	CM	0.8
6.	Owners Costs	0.6
	TOTAL	**$7.3M**

The cost estimate for the labyrinth includes several assumptions in addition to those previously described:

- "Other items" – includes allowances for those items which are required, but were not estimated in detail - these include a new pedestrian bridge, a permanent siphon, landscaping and seismic drains (should further design indicate these to be required);
- The contingency for this option is greater than shown for the labyrinth option because of greater risks as discussed above;
- The design, resident engineer and construction management costs are preliminary allowances based on conventional practice, rather that cost estimates developed specifically for this project. The allowances are greater that for the labyrinth weir due to the greater complexity of the option, and the increased level of construction controls that are anticipated; and,
- Some allowances have been included in developing the construction quantities for this option:
  - Over 1,000 m3 fill material will have to be imported, for re-grading and berm construction;
  - 500 m3 of excavated material will be unsuitable for re-use in the dam fills and will need to be disposed off site in a licensed landfill;
  - About 8,000 m3 of material will be processed onsite and placed on the dam;
  - About 400 m3 of material will be required for the berms along the spillway; and,
  - Erosion control and vegetative mats will be placed on all re-graded surfaces.

5.4.5 Comparison of Options

These options were presented at the May 20, 2014 TC meeting, with a view to select a preferred option to be taken forward to final design and construction. The general advantages and disadvantages are presented in Table 4, where (+) and (-) denote advantages and disadvantages, respectively.

Table 4: Advantages and Disadvantages of Shortlisted Options

	Dam Hardening (soil cement)	Labyrinth Spillway
Environmental	(-) Larger construction footprint (-) Larger area(s) of disturbance for construction, hauling, stockpiling, and staging	(-) Requires reducing the water level in the one, or possibly both, reservoirs during construction (-) Removal of heritage spillway
Design and construction	(-) Sampling and testing for soil cement mix design not yet undertaken (-) High level of engineering inspection required (-) Not a typical armoring solution (-) Existing spillway lifespan in question (-) Construction risk – materials in dam not fully defined – possible effect on schedule and cost; risk of inclement weather	(+) Ability to incorporate some drawdown (-) Construction risk of being flooded
Design Reliability (life safety risk)	(-) Slightly higher risk of failure (risk assessment)	

	Dam Hardening (soil cement)	Labyrinth Spillway
Maintenance	(-) After flood or seismic event some damage to be expected and maintenance probably required	
Construction Cost	(+) Potentially lower cost	
Schedule	(-) Risk reduction would require the work to be carried out during periods of low precipitation and runoff	(+) Work could probably be carried out during most inclement weather conditions provided standard construction procedures followed.

Following discussion of these two options at the May 20 and May 21 TC meetings, the TC was unable to develop a single preferred option to be taken forward.

5.5 Further Work

Depending upon the contracting strategy selected by the CON and the timing of the construction work, the following elements of additional work are anticipated:

- Detailed design and optimization. As stated previously, there are various anticipated elements of the design which could be improved through optimization, with corresponding decreases in cost or environmental intrusion;
- Site investigations. The investigations to date have provided information necessary to undertake preliminary designs of remediation options for the Lower Dam. In order to complete a detailed design, further geotechnical investigation work is required which would include:
  - Additional drilling into the downstream face of the dam to better delineate the material (particularly the cinder and slag fill); and,
  - Drilling along the foundation of the proposed spillway to identify soil conditions and the depth and quality of bedrock.
- Other assessments. Additional assessments such as geo-environmental assessment (as described earlier in this report) will be required as the project proceeds.

6.0 CLOSURE

We trust that the information provided herein meets your present requirements. Should you have any questions regarding the above, please do not hesitate to contact us.

GOLDER ASSOCIATES LTD.

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IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder can not be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

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Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

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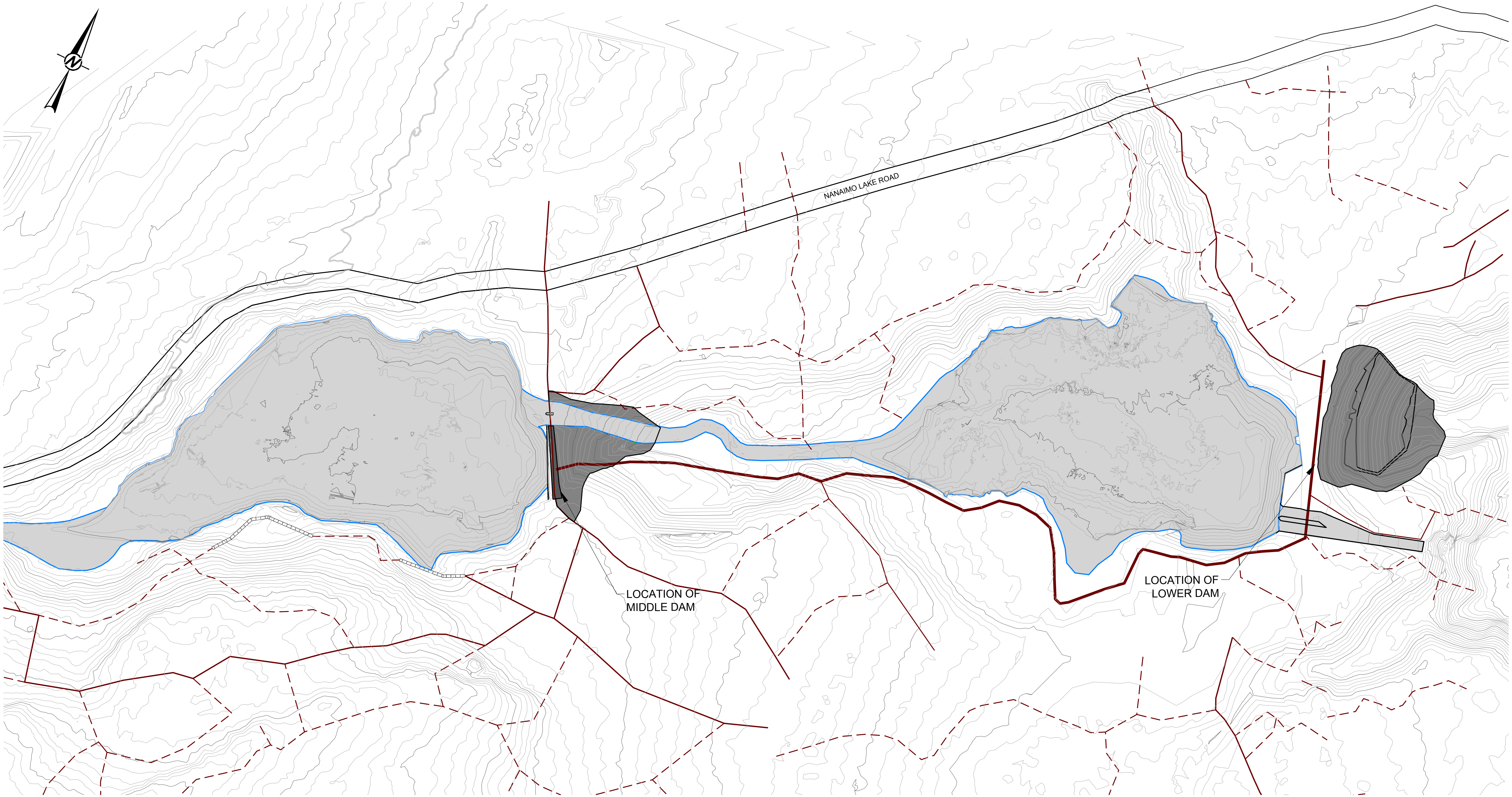


LEGEND

- NORMAL OPERATING LEVEL OF RESERVOIR
- MAJOR TRAILS
- MINOR TRAILS
- MAIN PAVED PATHWAYS

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC DATA FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
3. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMSW, N 13101249, APRIL 14, 2014. (EBA 2010)

0 20 40 60

SCALE

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

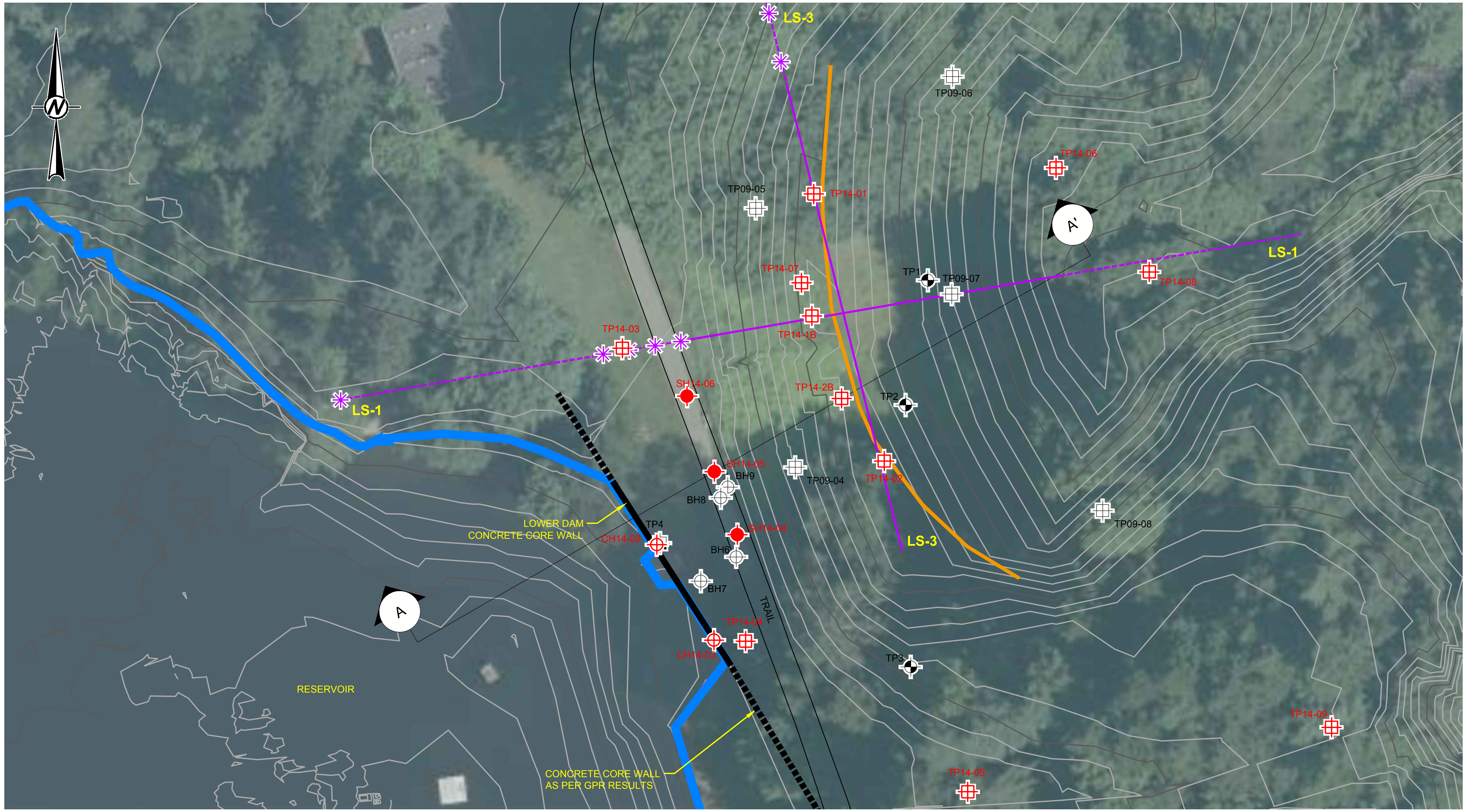
TITLE

MIDDLE AND LOWER DAM PLAN

Golder Associates

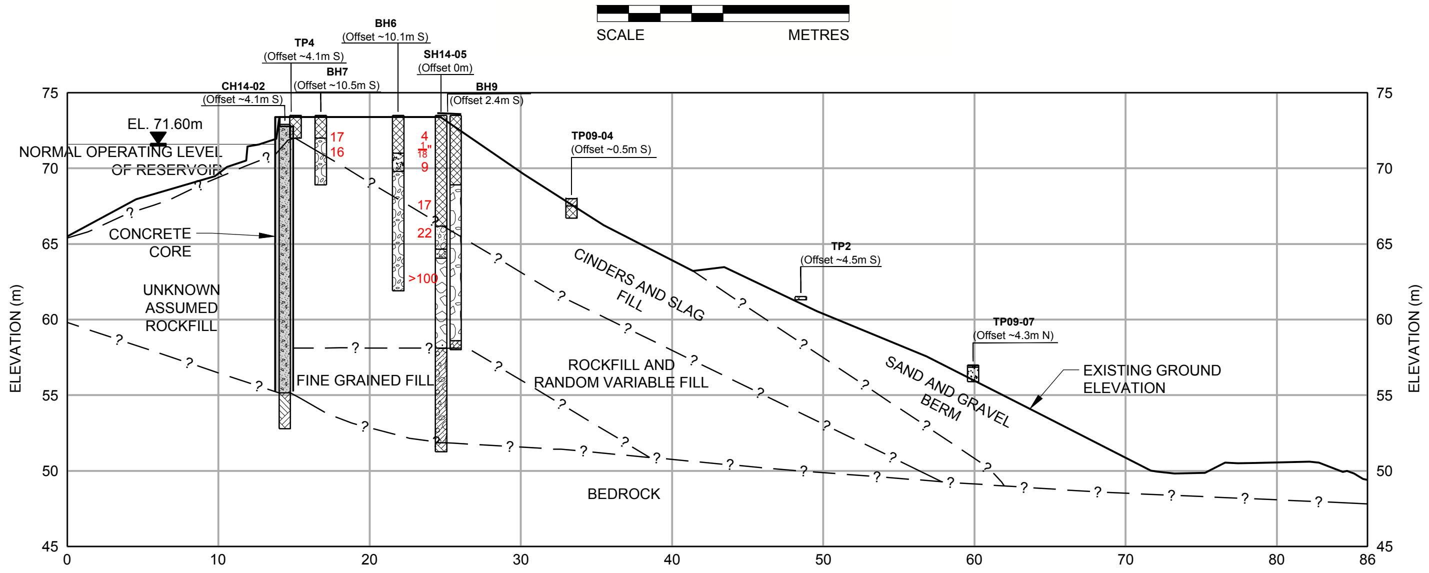
PROJECT No.		13-1447-0516/2200	FILE No.	1314470516_2200-09
DESIGN	J.G.	2014-08-18	SCALE	AS SHOWN
CADD	M.R.	2014-08-21	FIGURE	1
CHECK	J.G.	2014-08-29		
REVIEW	B.D.	2014-08-29		

M:\Active\Year 2013\1447\13-1447-0516 (Chase Dams - City Of Nanaimo)\DRAFTING\2200\PRODUCTION\Design Report\1314470516_2200-09.dwg | Layout: Layout1-ANSI_B_FIGURE_LANDSCAPE | Modified: matrobertson 08/22/2014 3:08 PM | Plotted: matrobertson 08/28/2014



PLAN

0 10 20
SCALE METRES



A DAM CROSS-SECTION

0 10 20
SCALE METRES

LEGEND

- NORMAL OPERATING LEVEL OF RESERVOIR
- 1978 BOREHOLE (GOLDER)
- 1978 TEST PIT PUT DOWN BY EXCAVATOR (GOLDER)
- 1978 TEST PIT PUT DOWN BY HAND (GOLDER)
- 2009 TEST PIT (EBA)
- 2014 SONIC HOLE (GOLDER)
- 2014 COREHOLE (GOLDER)
- 2014 TEST PIT (GOLDER)
- GROUND PENETRATING RADAR LINES
- SEISMIC LINE (DASHED TO OFF-END SHOT POINTS)
- SEISMIC SHOT POINTS OFF-END (OFF-END OF RECORDING ARRAY)
- OUTLINE OF WALL, 1.2m IN THICKNESS, AT 0.6m BELOW GROUND SURFACE

NOTE

1. DAM ZONATION IS INFERRED BASED ON AVAILABLE GEOTECHNICAL INFORMATION.

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

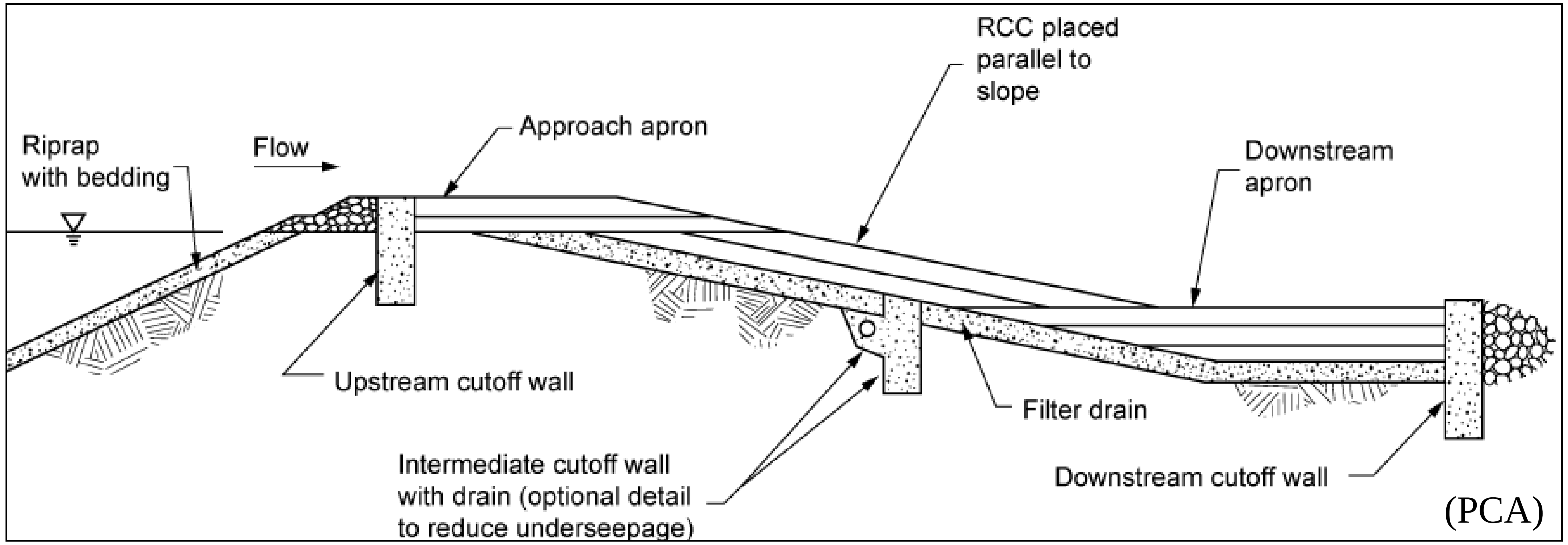
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

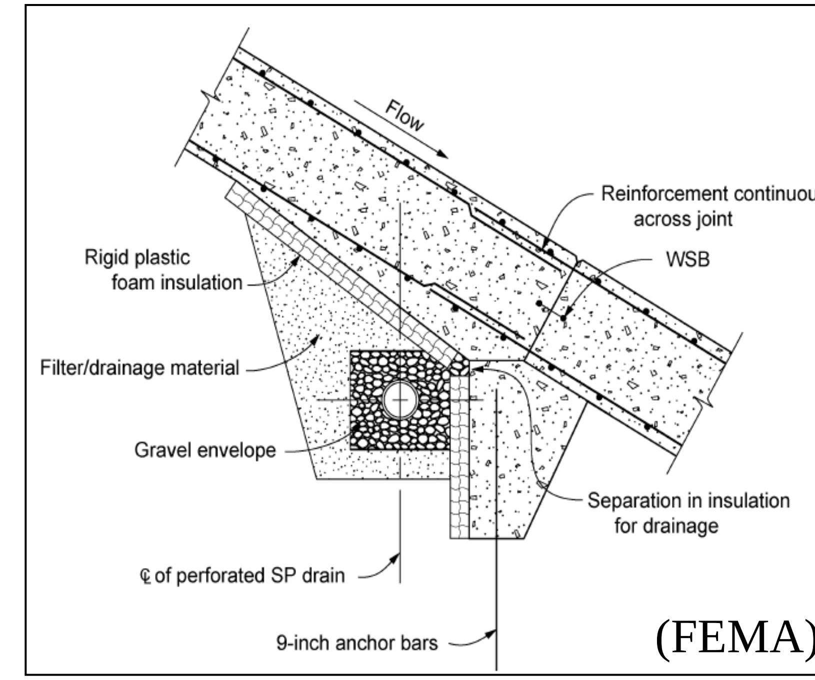
PLAN AND SECTION
LOWER DAM

PROJECT No.	13-1447-0516/2200		FILE No.	1314470516_2200-10
DESIGN	J.G.	2014-08-18	SCALE	AS SHOWN
CADD	M.R.	2014-08-20	FIGURE	
CHECK	J.G.	2014-08-29		2
REVIEW	B.D.	2014-08-29		

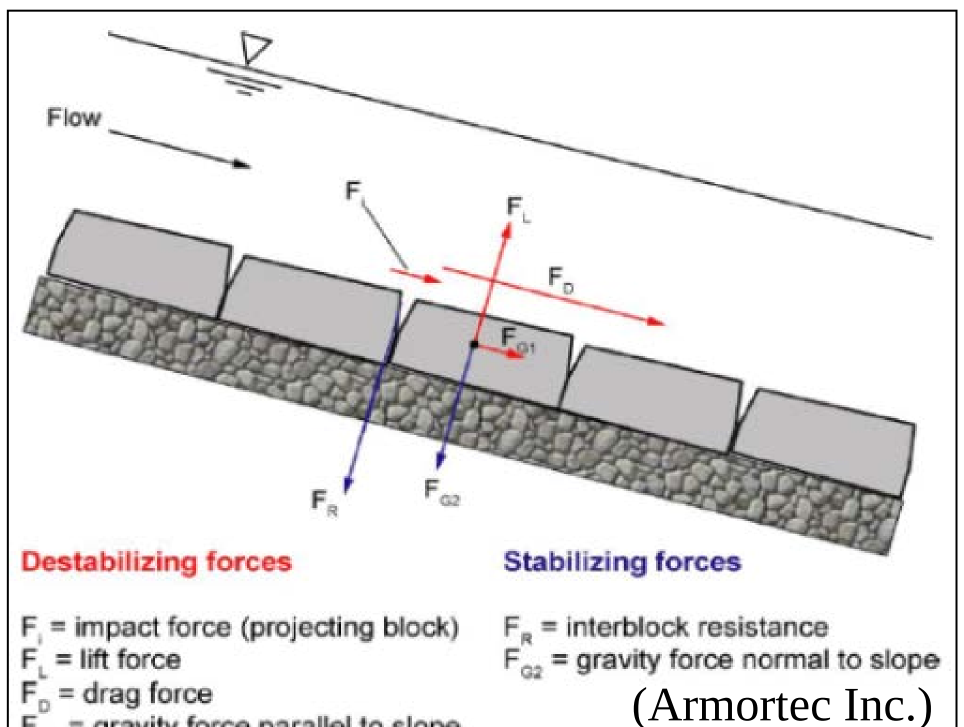
Golder Associates



1. Roller Compacted Concrete

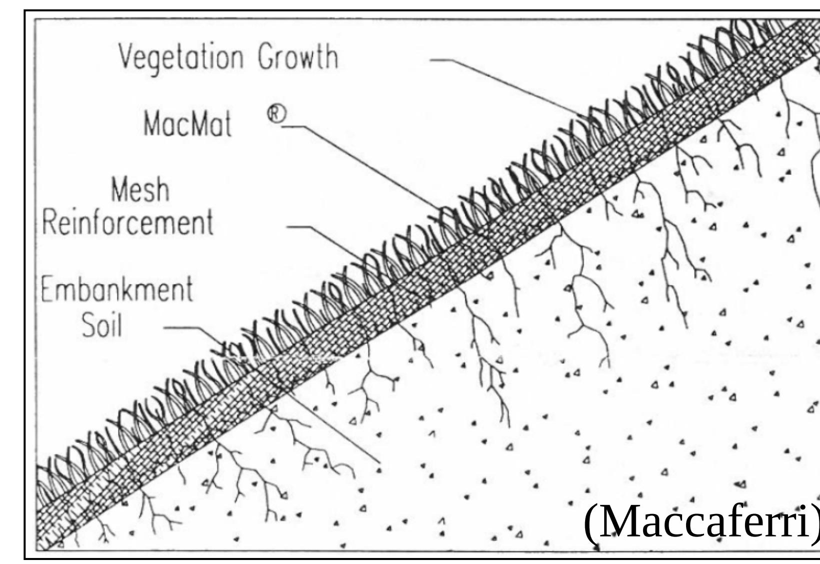


2. Mass Concrete Slab



3. Precast Concrete Blocks

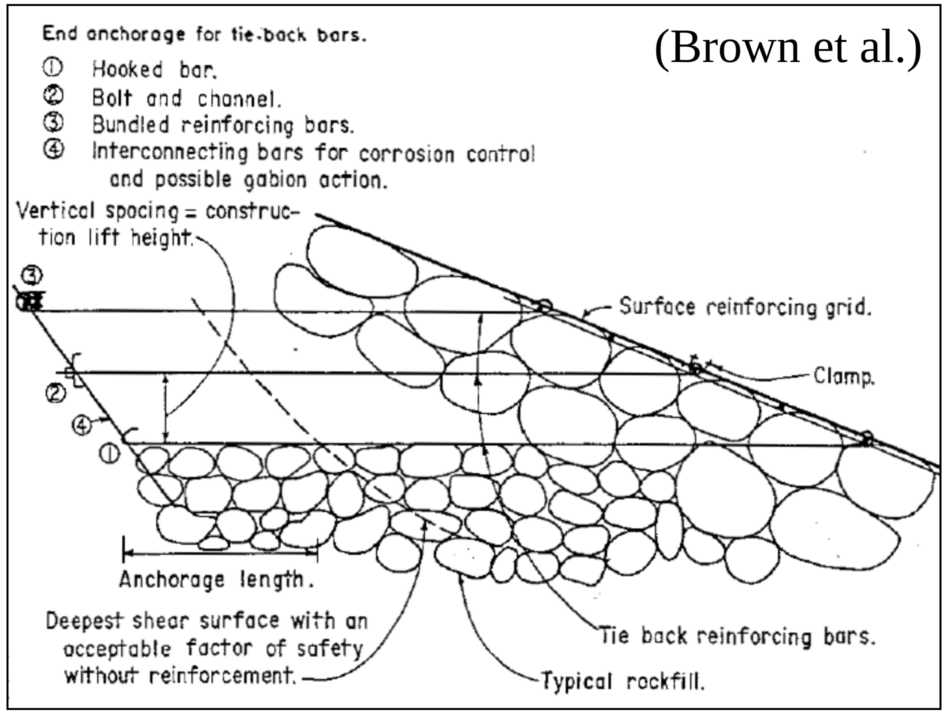
4. Gabions



5. Vegetative Cover

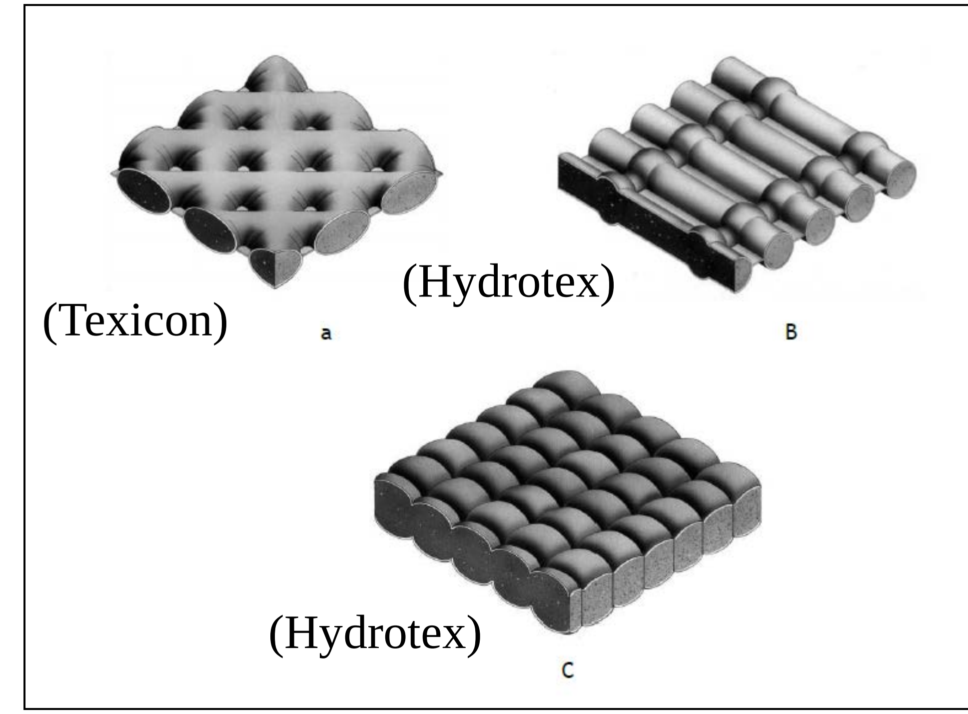
PROJECT	CITY OF NANAIMO COLLIERY DAMS NANAIMO, B.C.
TITLE	OVERTOPPING PROTECTION SYSTEMS – SCREENING OPTIONS SHEET 1

Golder Associates	PROJECT No. 13-1447-0516			PHASE No. 2200	
	DESIGN	RE	13JAN14	SCALE: NTS	REV. 1
	CADD	--	--	FIGURE 4 (1/2)	
	CHECK	JG	15JAN14		
	REVIEW				



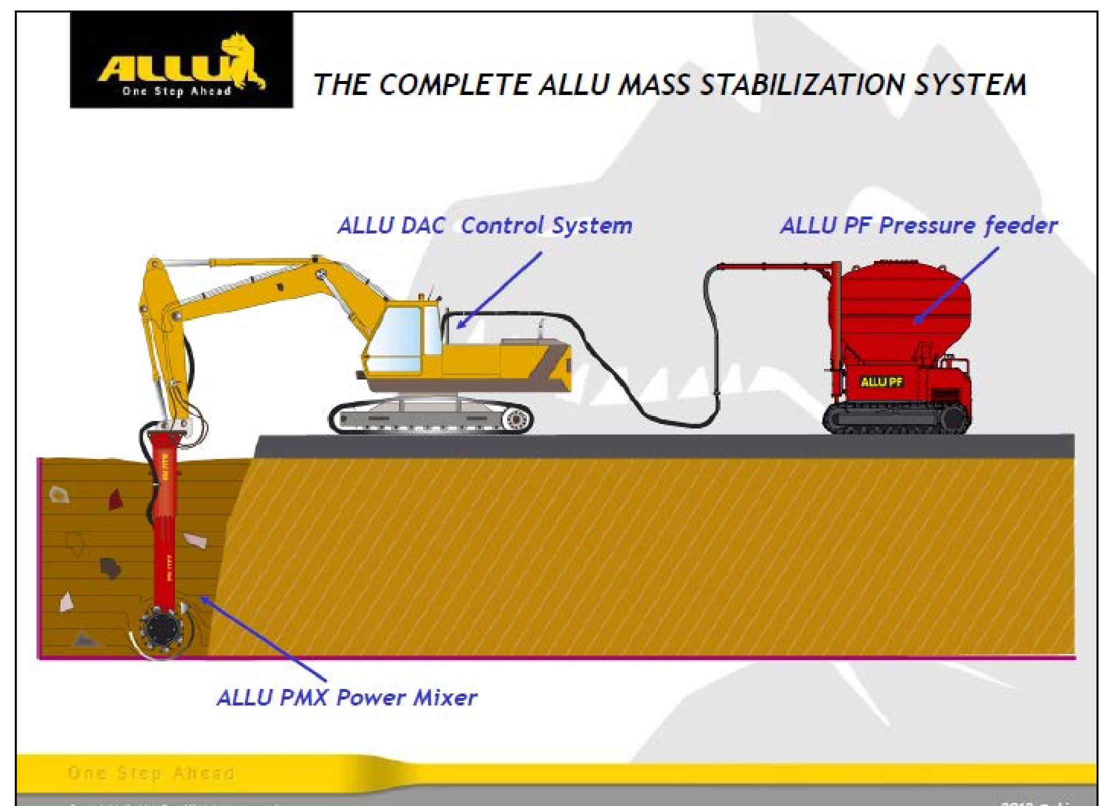
6. Reinforced Rock Fill

7. Riprap



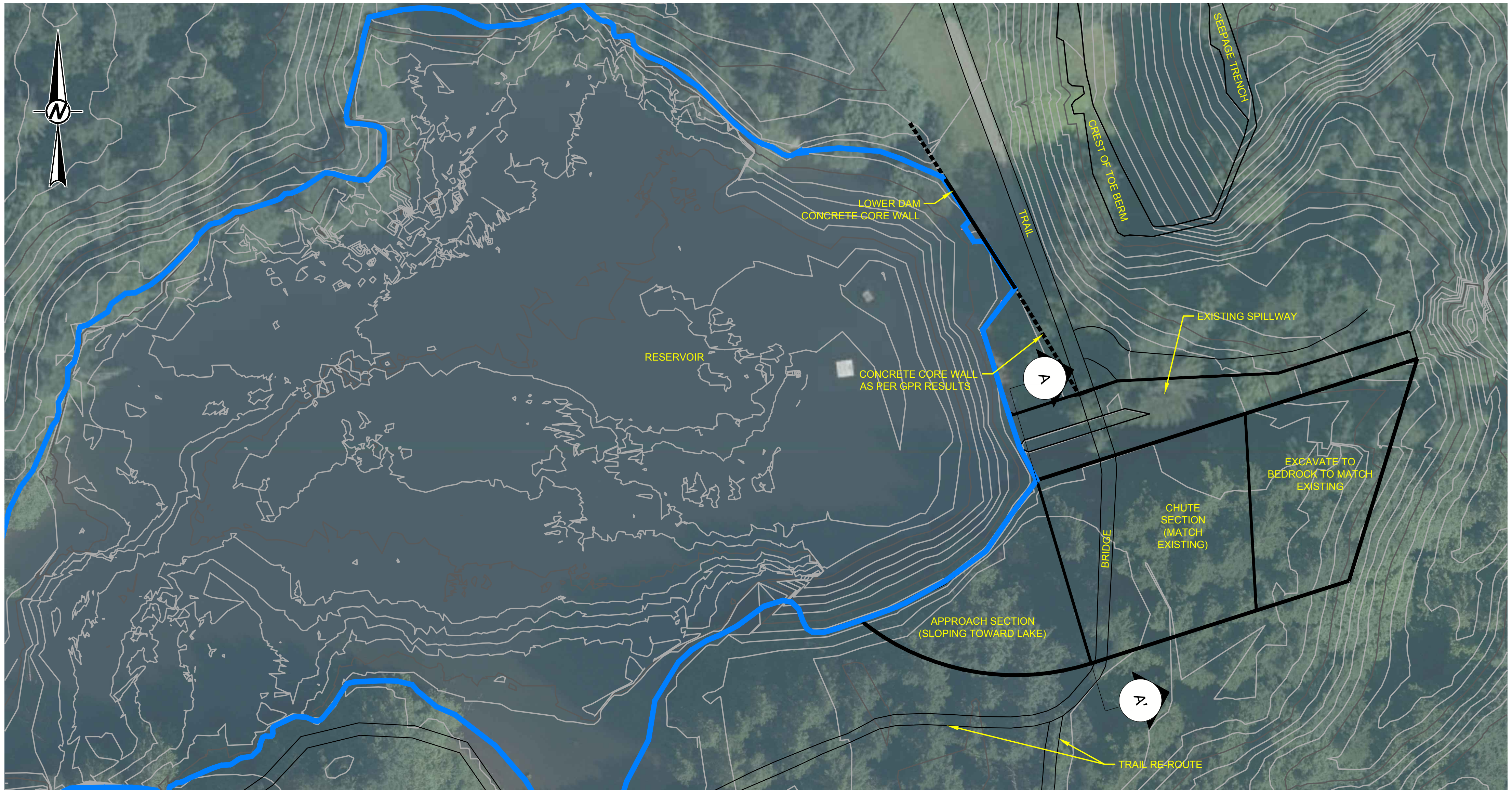
8. Fabric Formed Concrete - (a) Filter Point™ fabric form pumped with concrete; (b) Filter Band™ fabric form pumped with concrete; (c) Uniform Section™ fabric.

9. Open Stone Asphalt



10. Soil Stabilization

PROJECT	CITY OF NANAIMO COLLIERY DAMS NANAIMO, B.C.			
TITLE	OVERTOPPING PROTECTION SYSTEMS – SCREENING OPTIONS SHEET 2			
Golder Associates	PROJECT No. 13-1447-0516		PHASE No. 2200	
	DESIGN	RE	13JAN14	SCALE: NTS	REV. 1
	CADD	--	--	FIGURE 4 (2/2)
	CHECK	JG	15JAN14	
	REVIEW			



PLAN

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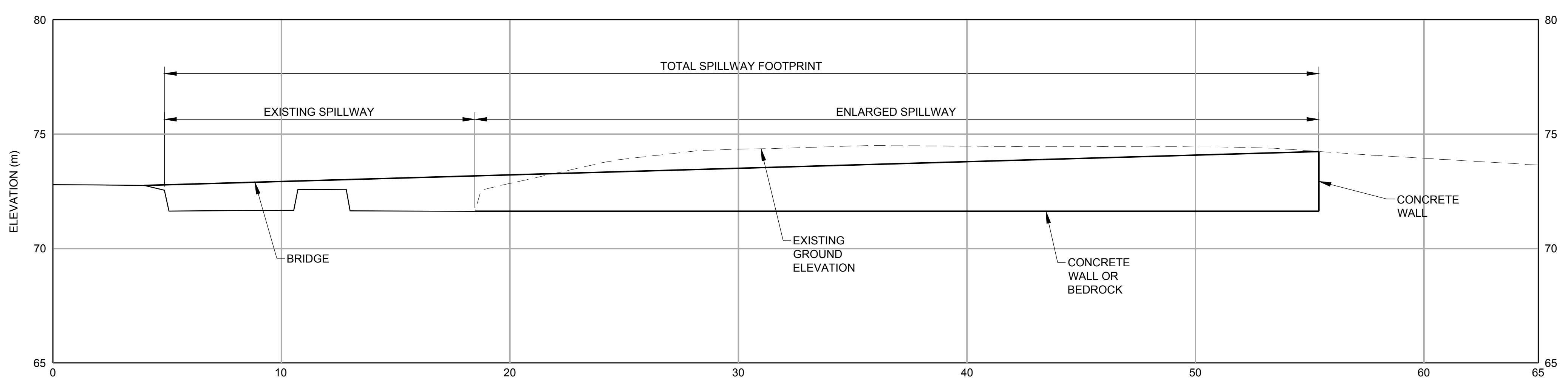
SCALE METRES



A SPILLWAY CROSS-SECTION

0 5 10
SCALE METRES

LEGEND

NORMAL OPERATING LEVEL OF RESERVOIR

ENLARGED SPILLWAY FOOTPRINT

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

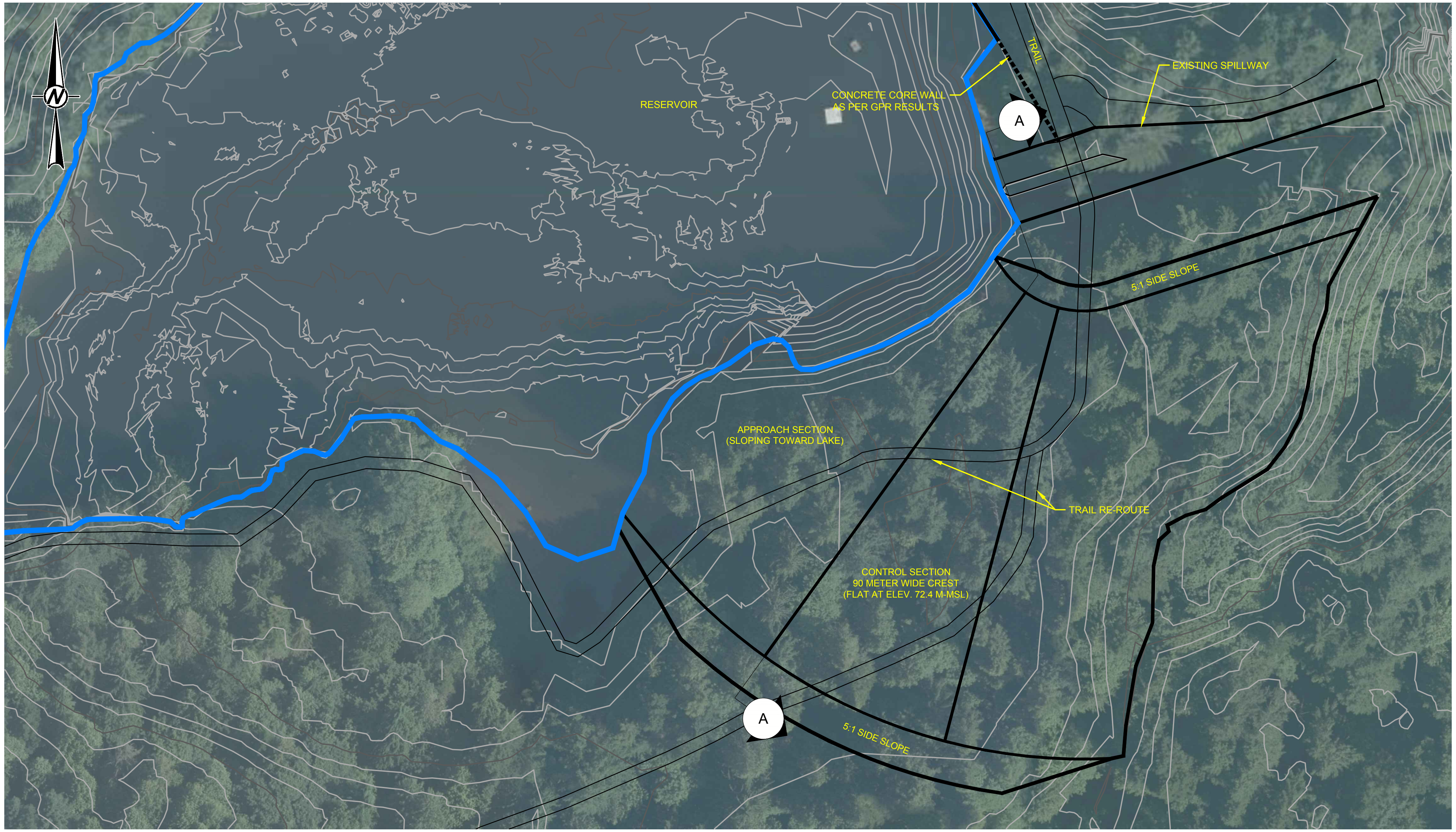
TITLE

OPTION 1 - ENLARGED SPILLWAY

PROJECT No.	13-1447-0516/2200	
DESIGN	J.G.	2014-08-01
CADD	M.R.	2014-08-07
CHECK	J.G.	2014-08-29
REVIEW	B.D.	2014-08-29

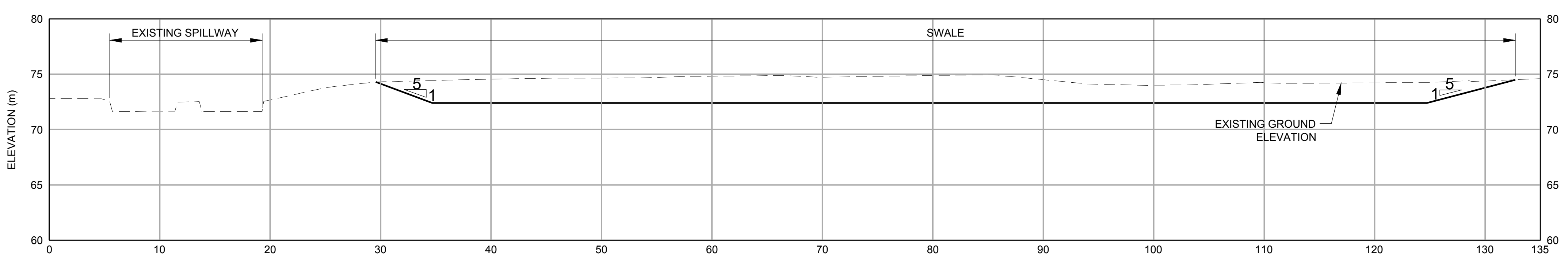
FILE No. 1314470516_2200-01
SCALE AS SHOWN
FIGURE 5

Golder Associates



PLAN

SCALE 0 25 50 METRES



A SWALE CROSS-SECTION

SCALE 0 10 20 METRES

LEGEND

- NORMAL OPERATING LEVEL OF RESERVOIR
- ENLARGED SPILLWAY FOOTPRINT

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

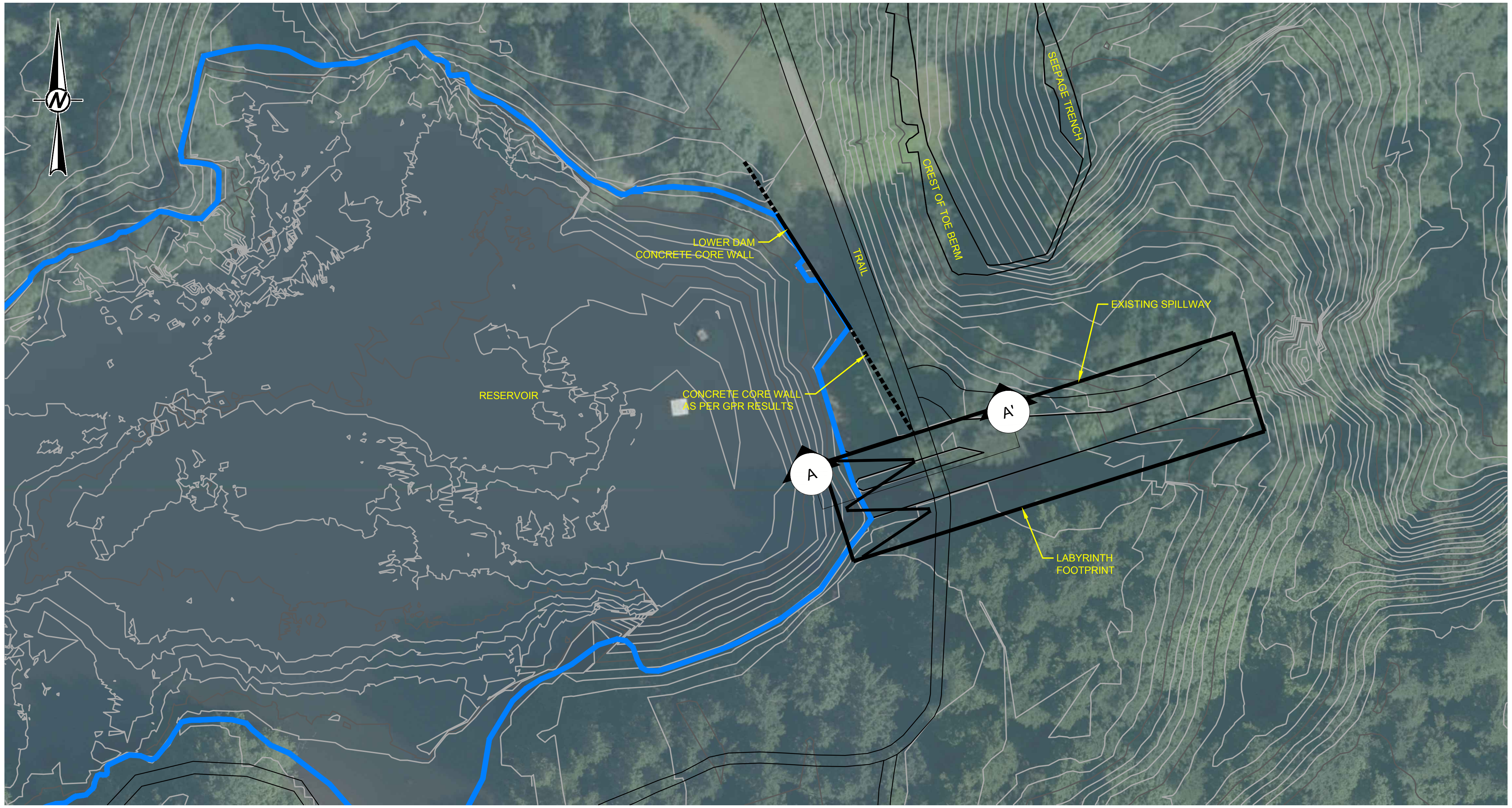
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

OPTION 2 - SWALE (AUXILLIARY SPILLWAY)

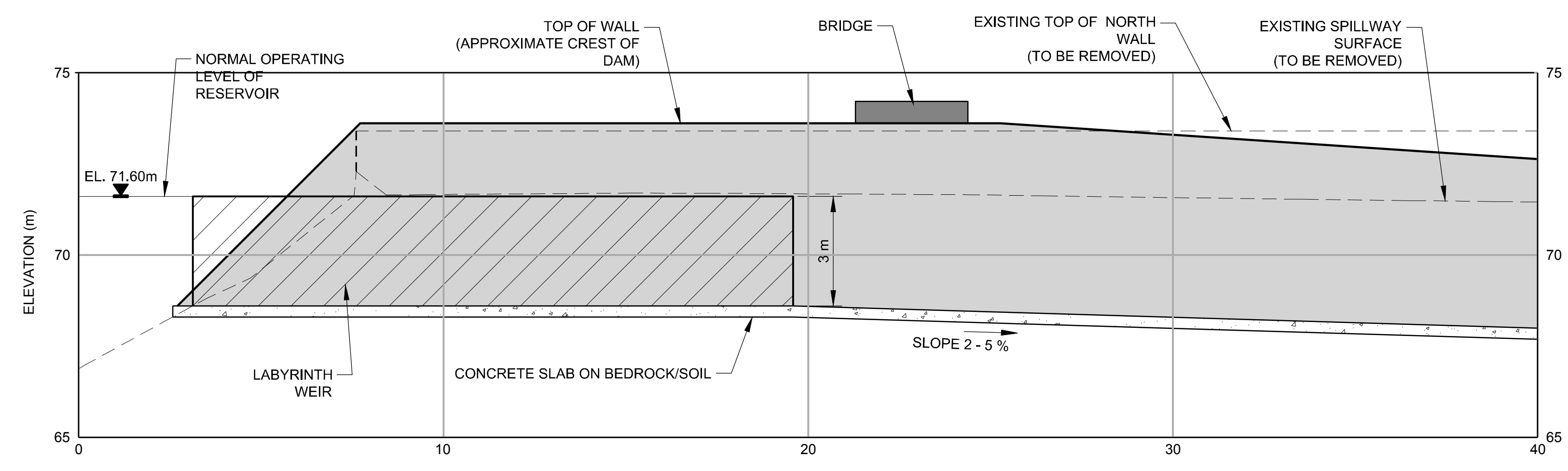
Golder Associates

PROJECT No.	13-1447-0516/2200		FILE No.	1314470516_2200-02
DESIGN	J.G.	2014-08-01	SCALE	AS SHOWN
CADD	M.R.	2014-08-07	FIGURE	
CHECK	J.G.	2014-08-29		6
REVIEW	B.D.	2014-08-29		



PLAN

0 25 50
SCALE METRES



A SPILLWAY CROSS-SECTION

0 5 10
SCALE METRES

LEGEND

NORMAL OPERATING LEVEL OF RESERVOIR

ENLARGED SPILLWAY FOOTPRINT

NOTE

1. THIS FIGURE REPRESENTS THE CONCEPTUAL ARRANGEMENT FOR THE OPTION, WHICH WAS FURTHER DEVELOPED AND IS SHOWN AS A SUBSEQUENT FIGURE IN THIS REPORT.

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

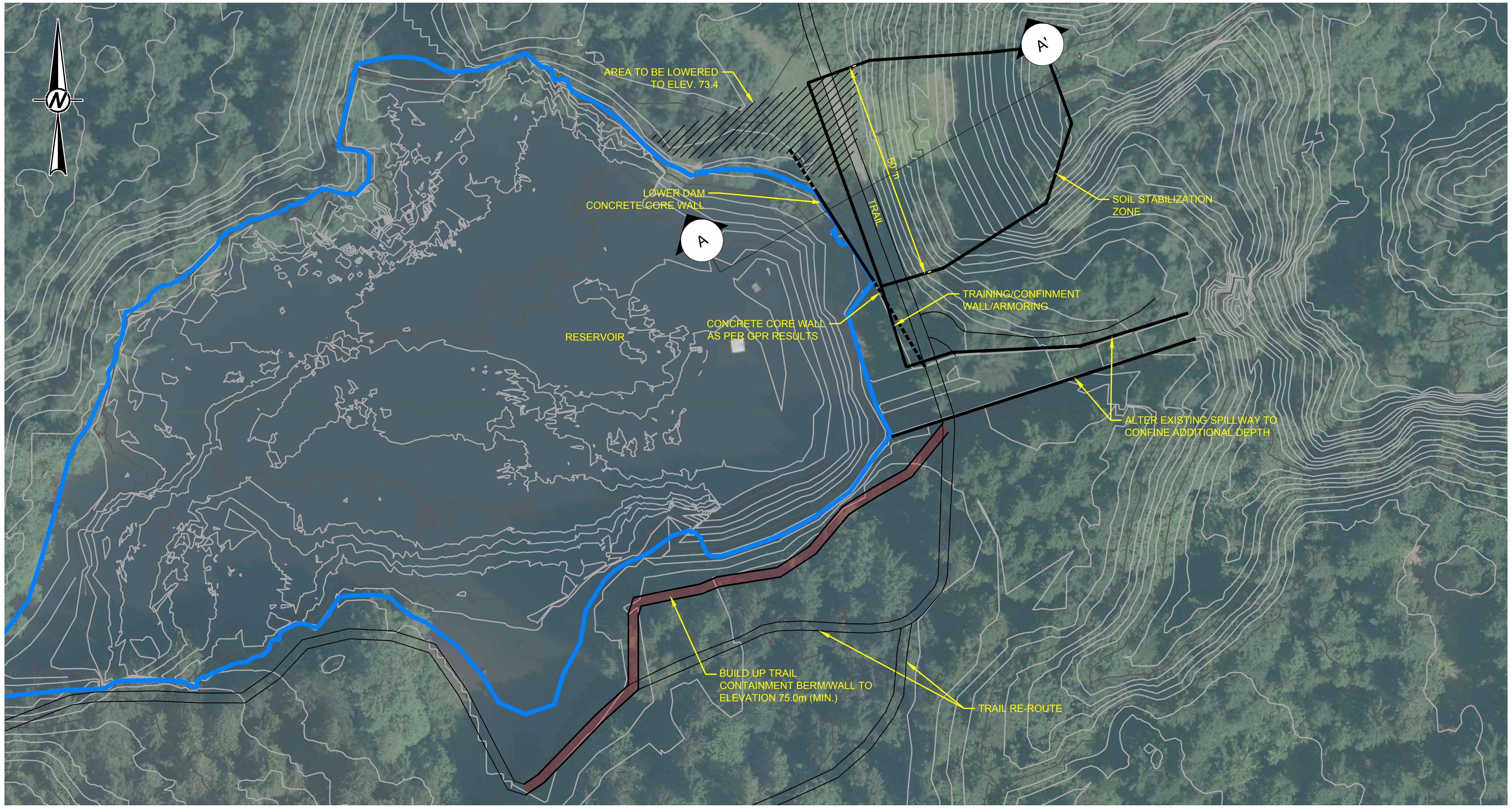
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

OPTION 3 - LABYRINTH WEIR

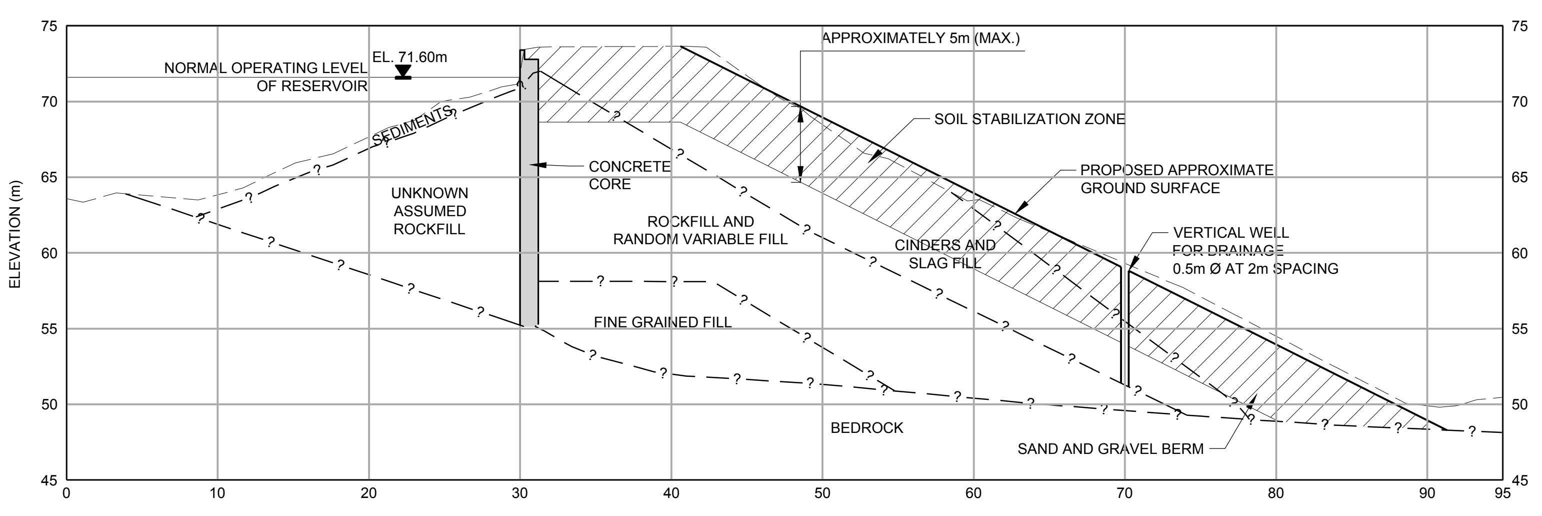
PROJECT No.	13-1447-0516/2200		FILE No.	1314470516_2200-03
DESIGN	J.G.	2014-08-01	SCALE	AS SHOWN
CADD	M.R.	2014-08-07	FIGURE	7
CHECK	J.G.	2014-08-29		
REVIEW	B.D.	2013-08-29		

Golder Associates



PLAN

0 25 50
SCALE METRES



A DAM CROSS-SECTION

0 10 20
SCALE METRES

LEGEND

- NORMAL OPERATING LEVEL OF RESERVOIR
- ENLARGED SPILLWAY FOOTPRINT

NOTE

1. THIS FIGURE REPRESENTS THE CONCEPTUAL ARRANGEMENT FOR THE OPTION, WHICH WAS FURTHER DEVELOPED AND IS SHOWN AS A SUBSEQUENT FIGURE IN THIS REPORT.

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

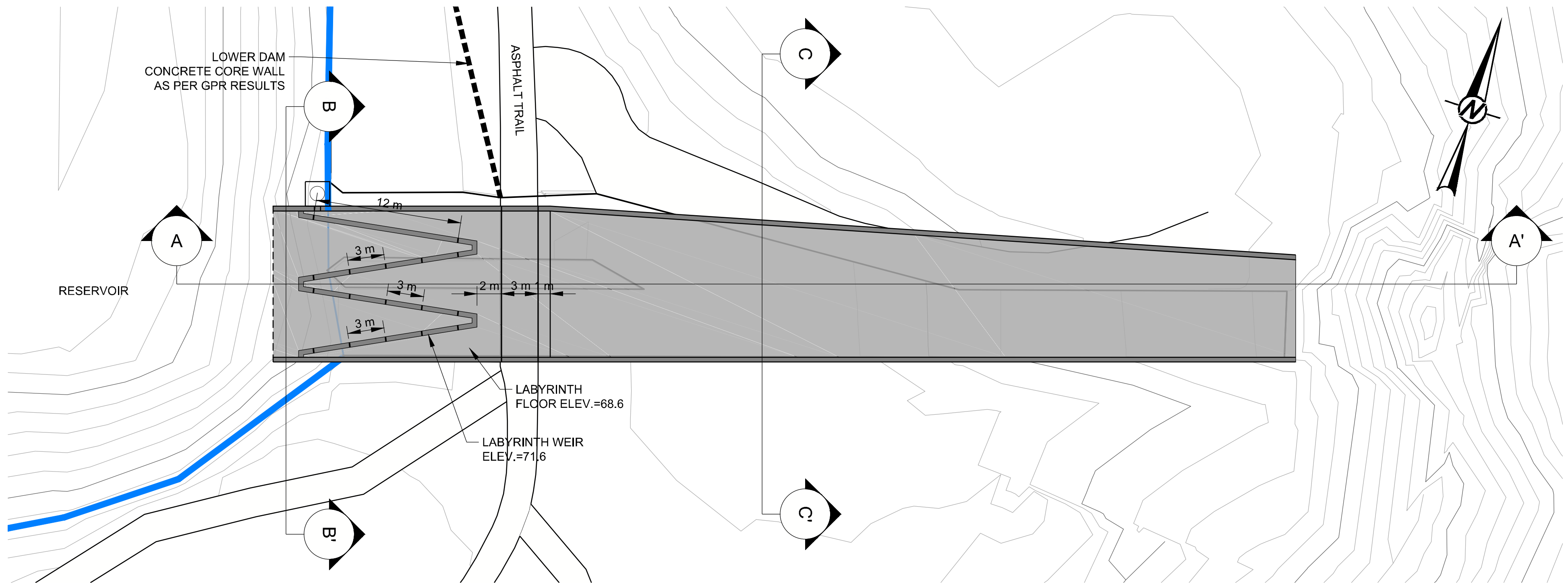
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

OPTION 4 - DAM HARDENING

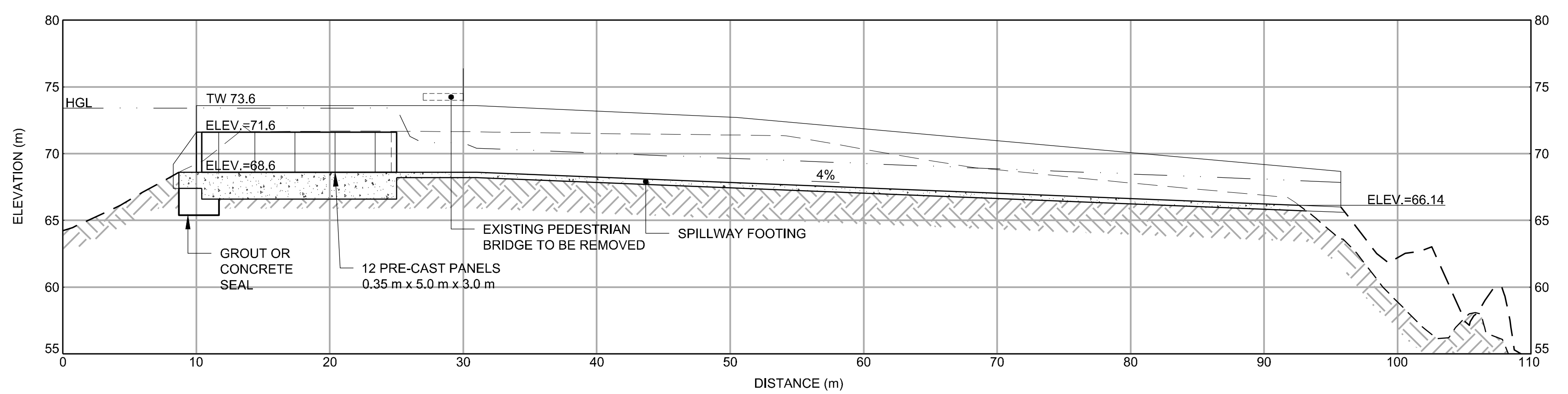
PROJECT No.	13-1447-0516/2200	FILE No.	1314470516_2200-04
DESIGN	J.G.	2014-08-01	SCALE: AS SHOWN
CADD	M.R.	2014-08-07	FIGURE
CHECK	J.G.	2014-08-29	8
REVIEW	B.D.	2014-08-29	

Golder Associates



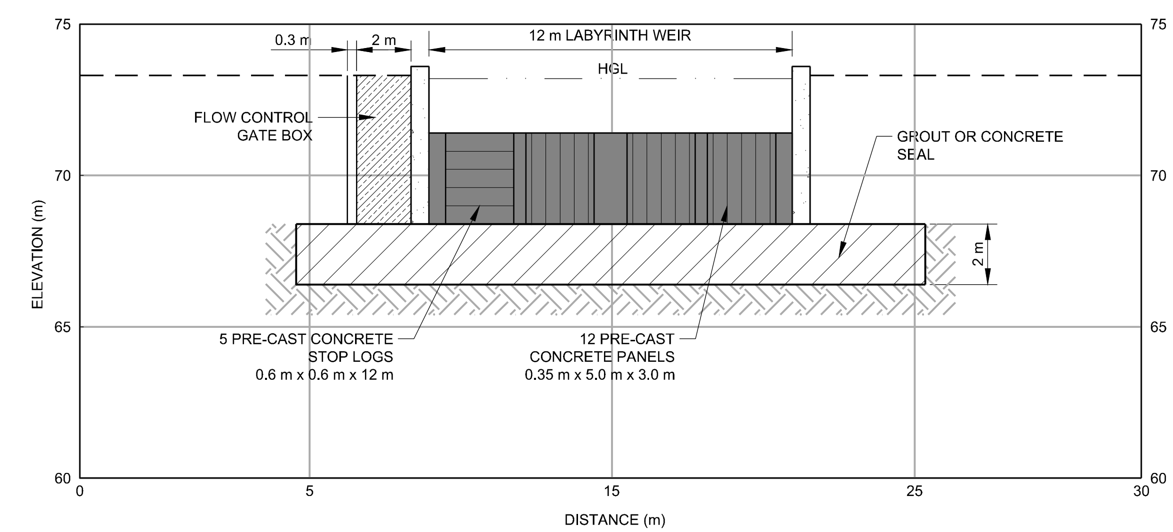
PLAN

SCALE 0 10 20 METRES



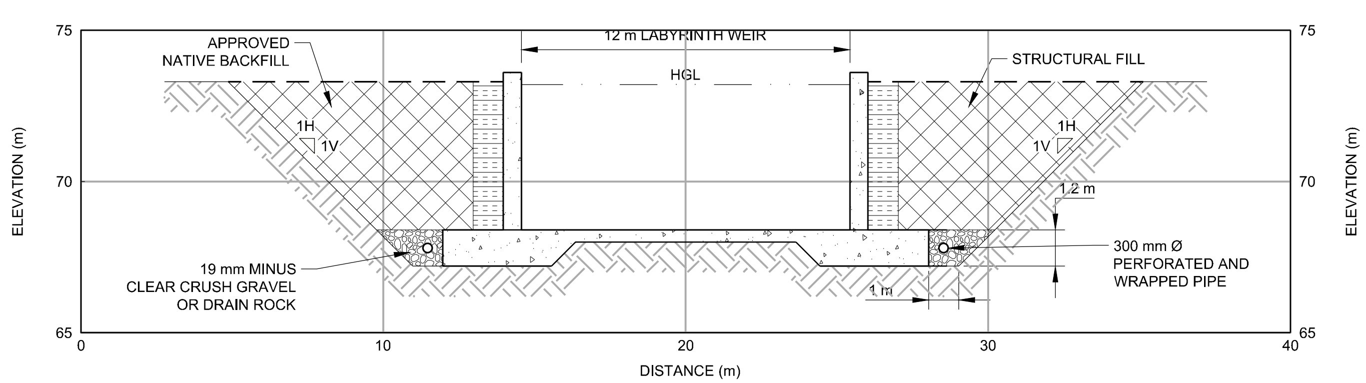
A LABYRINTH WEIR CROSS-SECTION

SCALE 0 10 20 METRES



B LABYRINTH WEIR CROSS-SECTION

SCALE 0 5 10 METRES



C LABYRINTH WEIR CROSS-SECTION

SCALE 0 5 10 METRES

REFERENCE

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

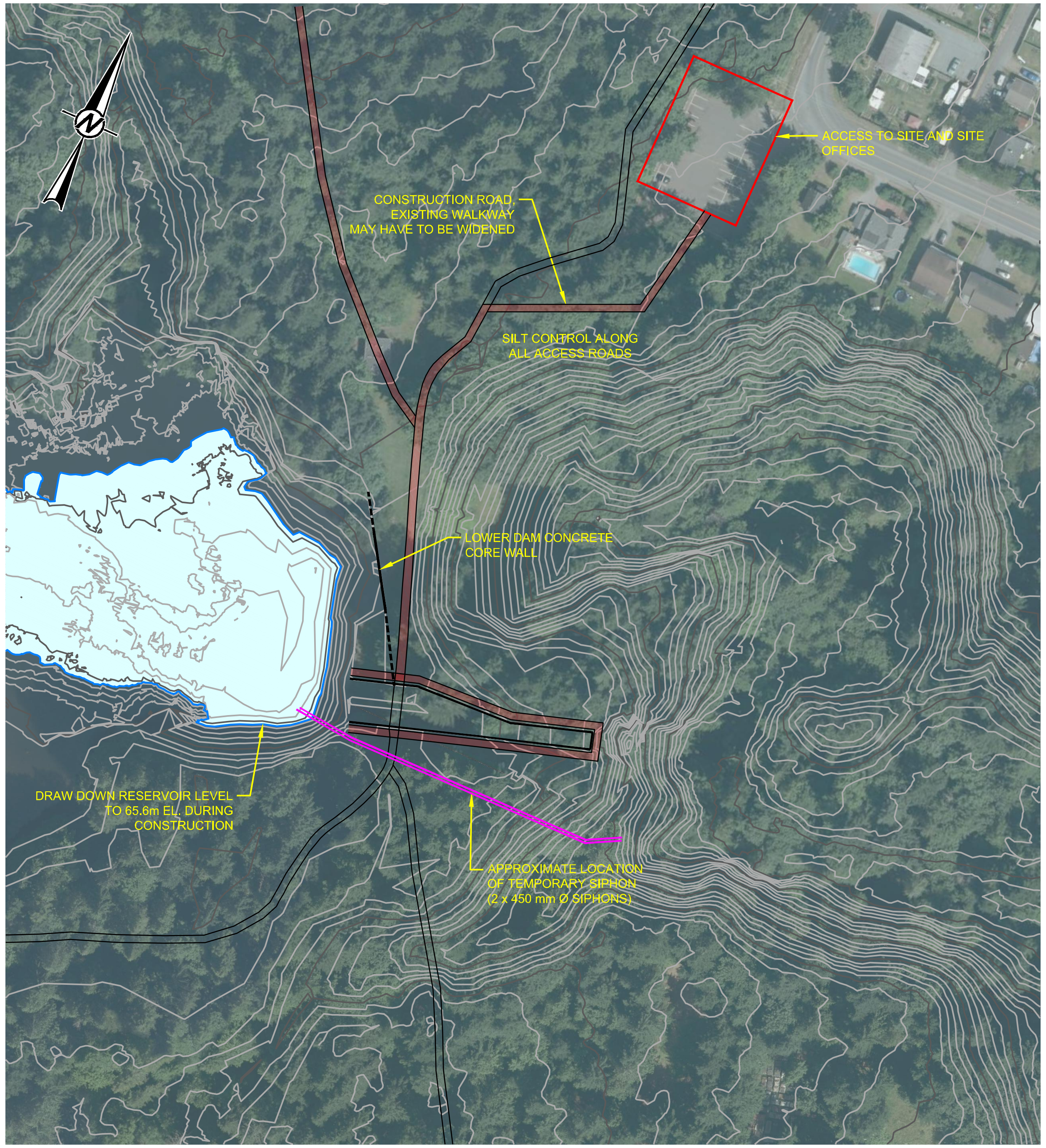
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

SHORT LIST OPTION - LABYRINTH WEIR

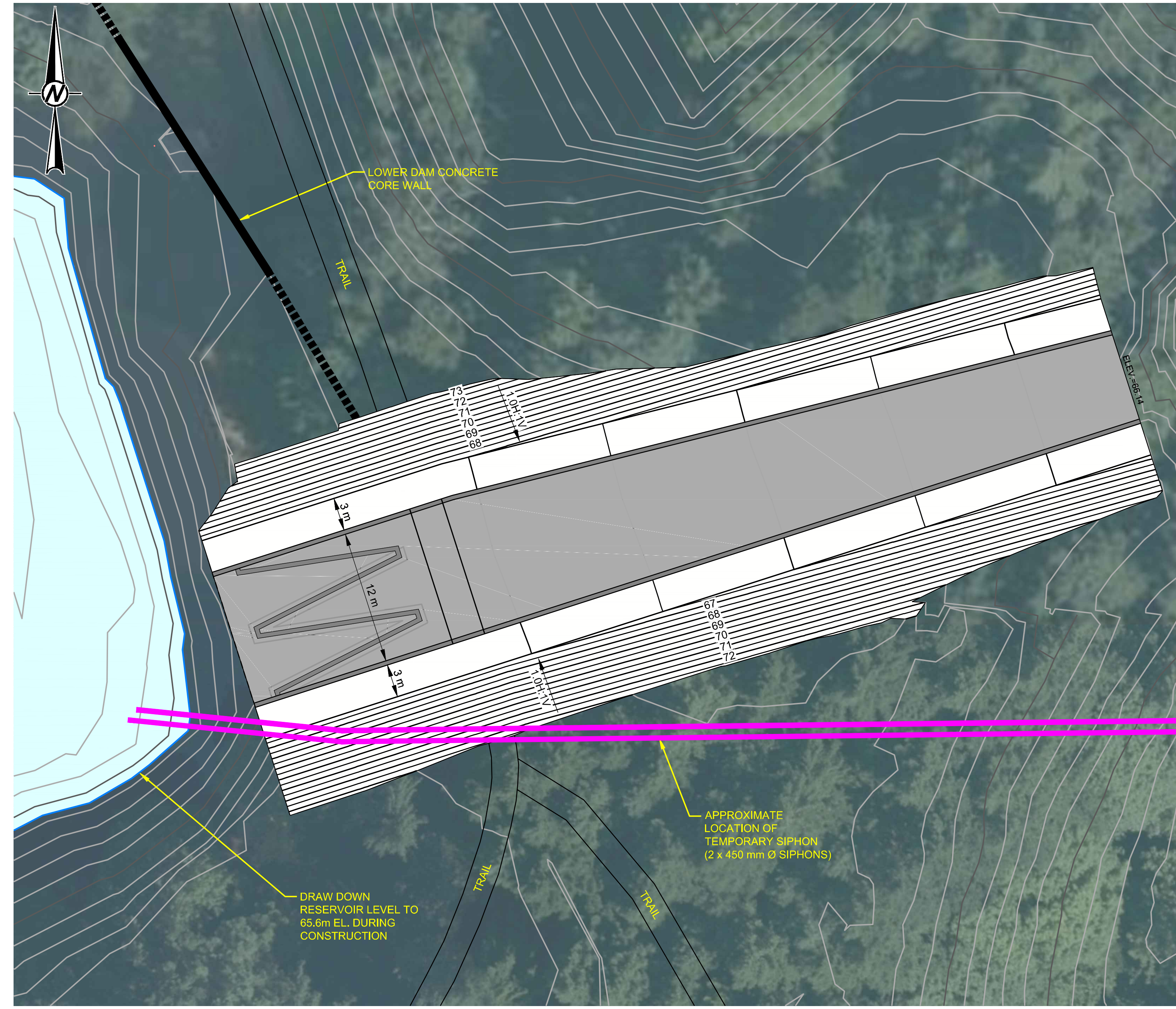
Golder Associates

PROJECT No.	13-1447-0516/2200		FILE No.	1314470516_2200-05
DESIGN	J.G.	2014-08-01	SCALE	AS SHOWN
CADD	M.R.	2014-08-07	FIGURE	
CHECK	J.G.	2014-08-29		9
REVIEW	B.D.	2014-08-29		



WATER MANAGEMENT CONCEPT AND SITE ACCESS

0 50 100
SCALE METRES



EXCAVATION PLAN AND LABYRINTH WEIR

0 10 20
SCALE METRES

NOTE

1. THE DESIGN REFLECTS THE ASSUMPTIONS USED IN DEVELOPING THE COST ESTIMATE - ALTERNATIVE APPROACHES ARE AVAILABLE.

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.
REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW

PROJECT

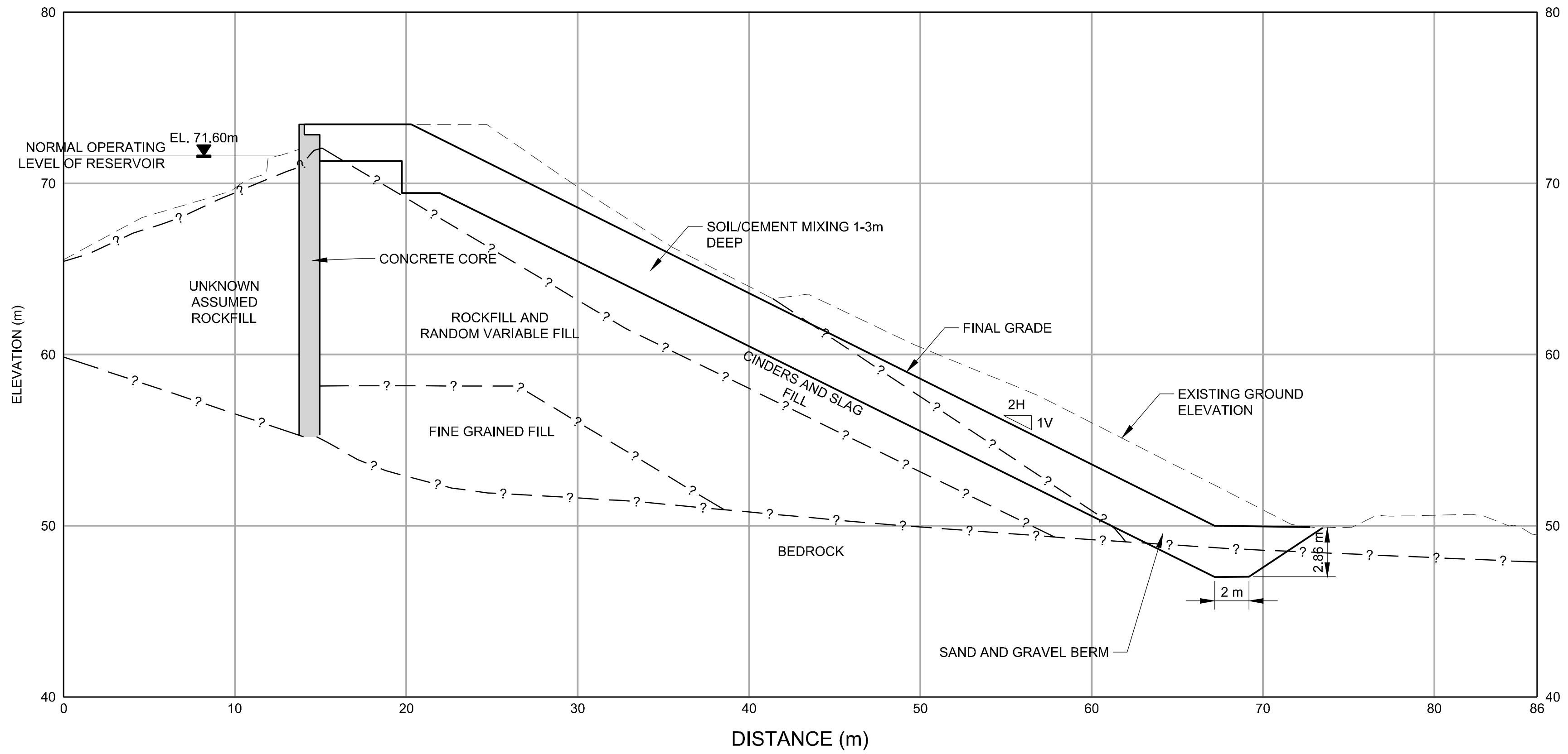
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

SHORT LIST OPTION - LABYRINTH WEIR CONSTRUCTION REQUIREMENTS

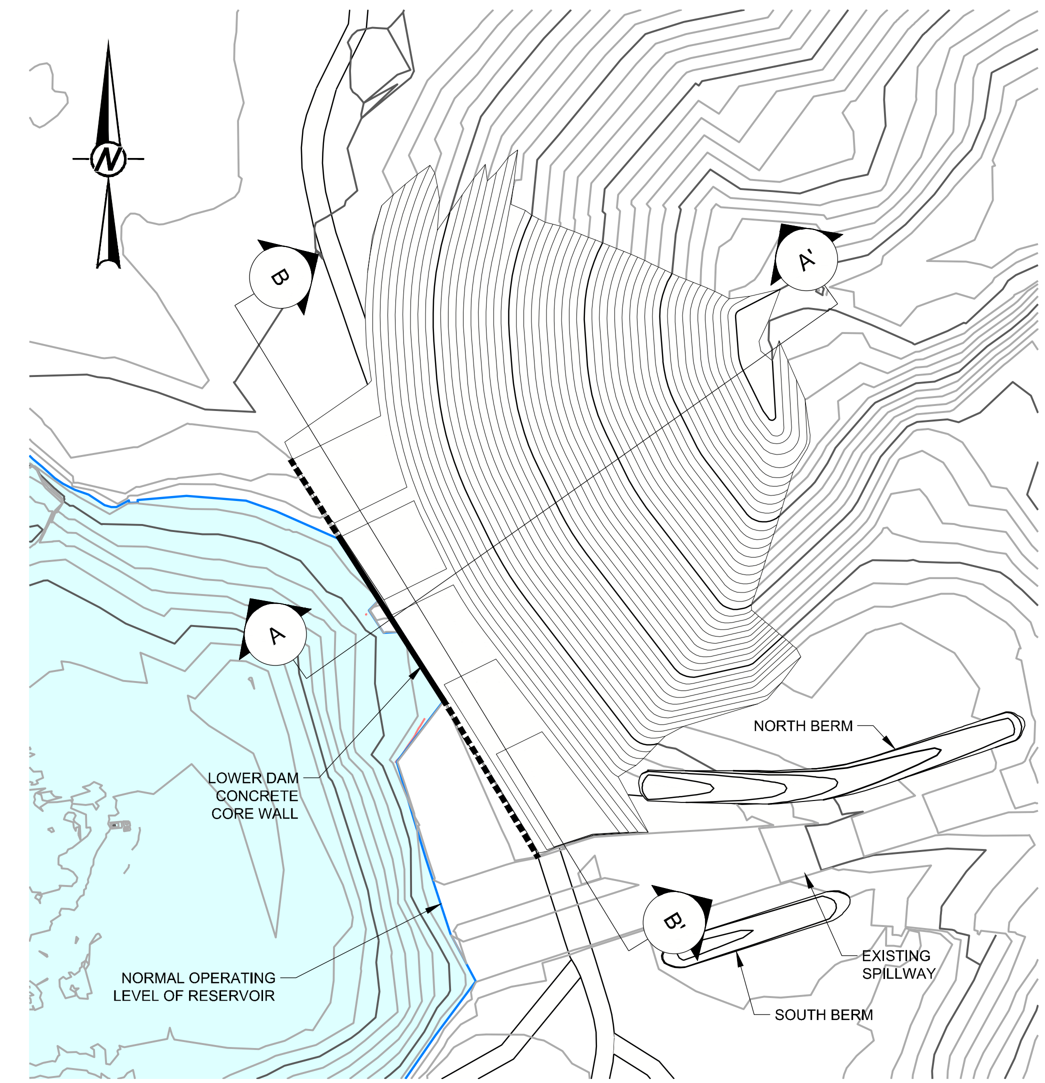
Golder Associates

PROJECT No.	13-1447-0516/2200		FILE No.	1314470516_2200-06
DESIGN	J.G.	2014-08-01	SCALE	AS SHOWN
CADD	M.R.	2014-08-07	FIGURE	10
CHECK	J.G.	2014-08-29		
REVIEW	B.D.	2014-08-29		



A CROSS-SECTION ALONG DAM

0 10 20
SCALE METRES



FINAL STRUCTURE PLAN

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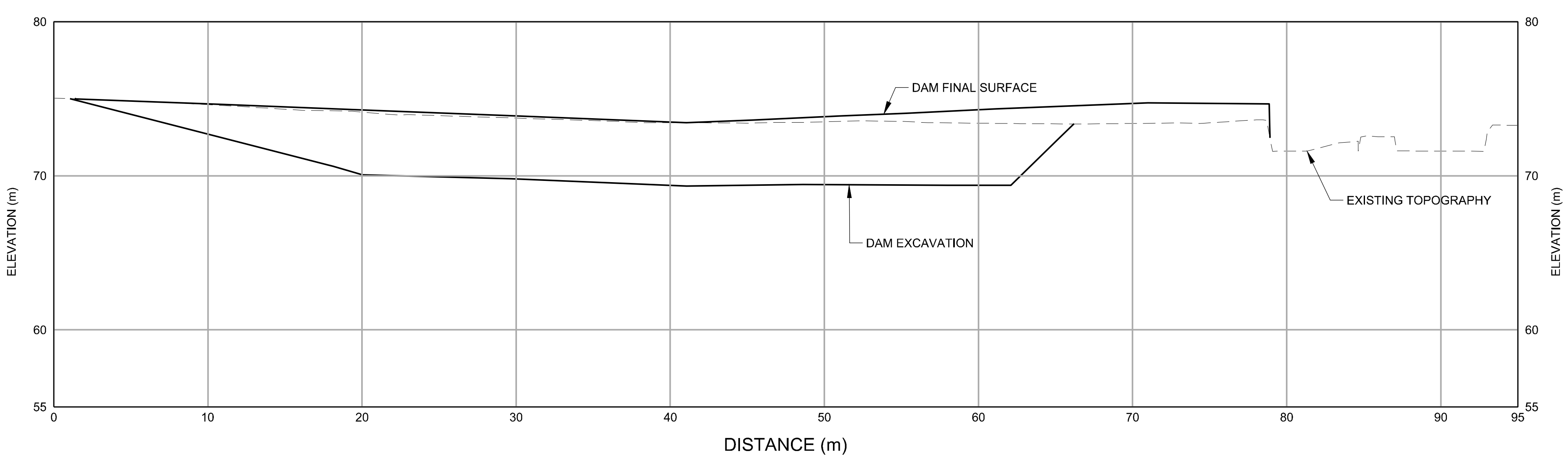
SCALE METRES



B CROSS-SECTION ACROSS DAM CREST

0 10 20
SCALE METRES

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO, CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING, CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD., PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

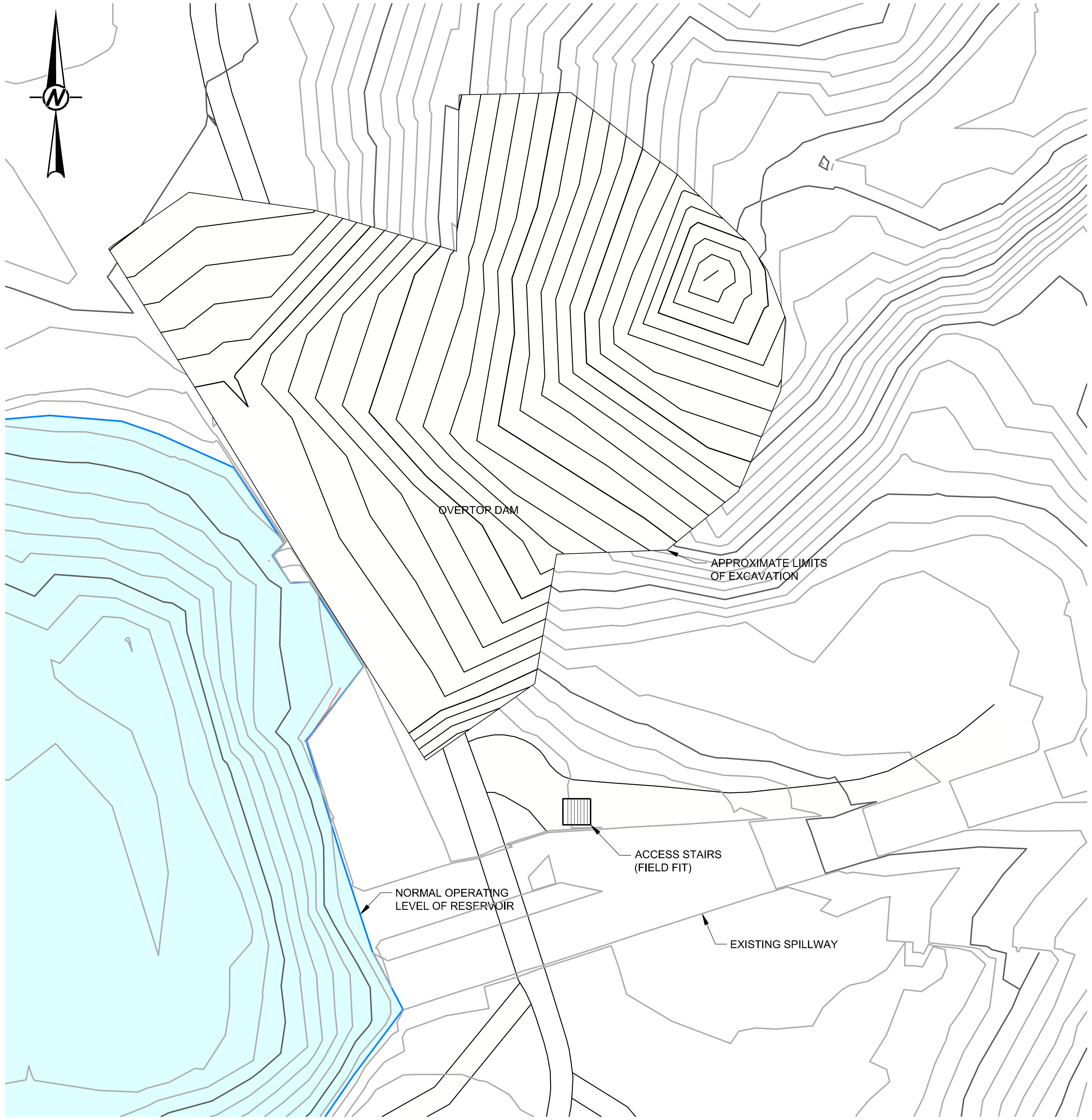
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

SHORT LIST OPTION - DAM HARDENING

Golder Associates

PROJECT No.	13-1447-0516/2200		FILE No.	1314470516_2200-08
DESIGN	J.G.	2014-08-01	SCALE	AS SHOWN
CADD	M.R.	2014-08-07	FIGURE	
CHECK	J.G.	2014-08-29		11
REVIEW	B.D.	2014-08-29		



EXCAVATION PLAN

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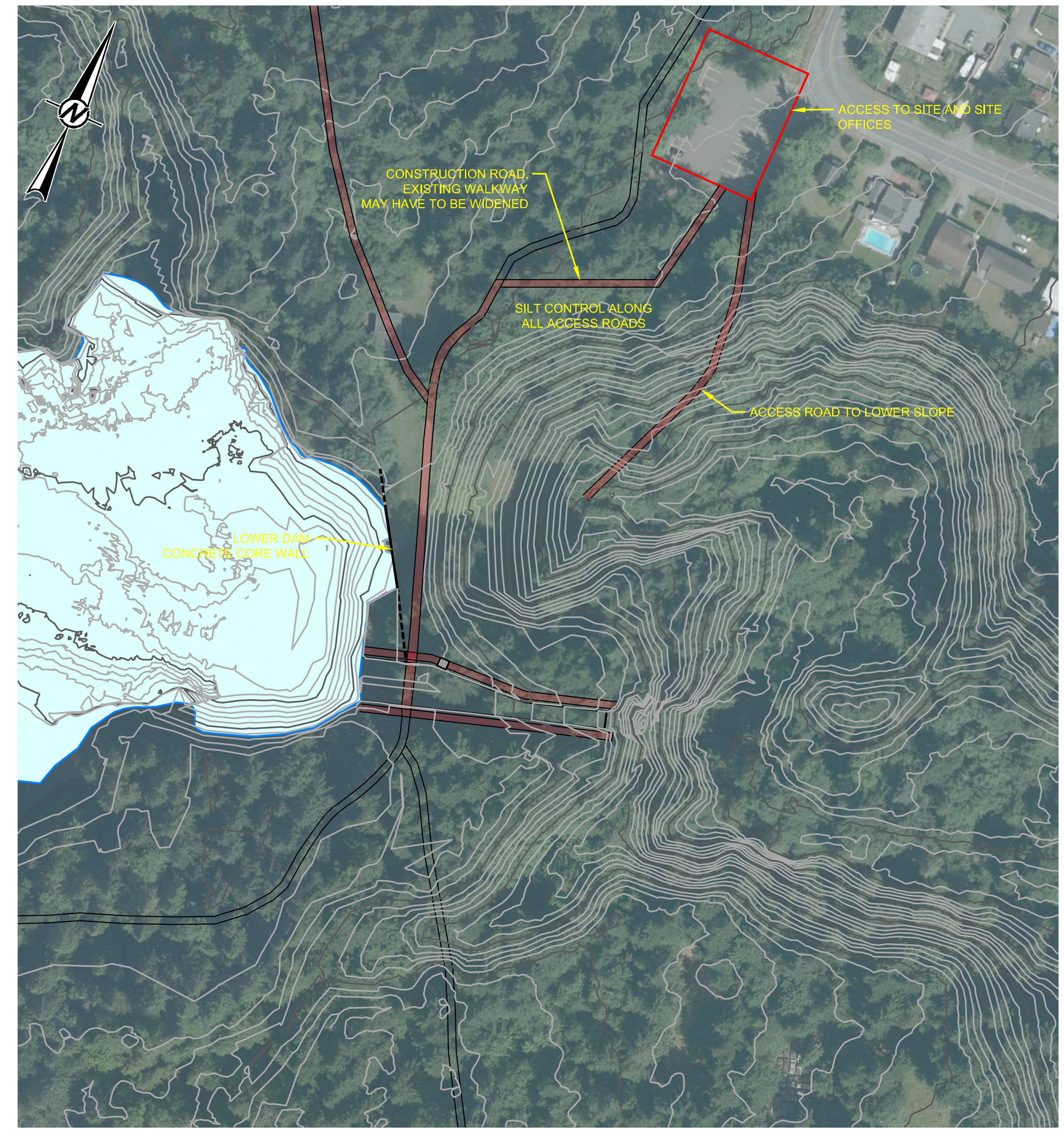
SCALE METRES



CONSTRUCTION ACCESS PLAN

0 50 100
SCALE METRES

REFERENCES

1. BATHYMETRIC AND TOPOGRAPHIC FROM CITY OF NANAIMO,
   CAD FILE: ACAD-C003-0 (BOUND).dwg, DATED: DECEMBER 20, 2013.
2. TOPOGRAPHIC DATA FROM HEROLD ENGINEERING,
   CAD FILE: collier park lower dam 2003.dwg, DATED: OCTOBER 20, 2003.
3. WILLIS CUNLIFFE TAIT & COMPANY LTD.,
   PDF FILE: Appendix C - 1980 Repairs As-builts.pdf, DATED: JULY 1978.
4. SEISMIC HAZARD ASSESSMENT MIDDLE AND LOWER CHASE DAMS. (EBA 2010)
5. AERIAL PHOTO FROM CITY OF NANAIMO WEBSITE, IMAGE FILES: 552D.tif and 652B.tif.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-08-29	ISSUED WITH DESIGN REPORT	J.G.	M.R.	J.G.	B.D.

PROJECT

CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, B.C.

TITLE

SHORT LIST OPTION - DAM HARDENING CONSTRUCTION REQUIREMENTS

Golder Associates

PROJECT No.	13-1447-0516/2200		FILE No.	1314470516_2200-07
DESIGN	J.G.	2014-08-01	SCALE	AS SHOWN
CADD	M.R.	2014-08-07	FIGURE	
CHECK	J.G.	2014-08-29		12
REVIEW	B.D.	2014-08-29		

APPENDIX A

Geo-Environmental Assessment

1.1 Geo-Environmental Conditions

1.1.1 Purpose and Approach

The purpose of the geo-environmental assessment was to obtain environmental information with respect to the chemical quality of various media (*i.e.,* soil, water, sediment, soil vapour) at the Lower Dam, in order to assess, on a preliminary basis, the potential issues with respect to remediation of the dam structure.

The Lower Colliery Dam was reported to have been constructed after 1904, to support the development and operation of local coal mines. The Lower Colliery Dam, a rock fill dam with a 1.2 metre (m) thick, vertical, concrete core wall, is approximately 24 m high, and has a crest length and width of 77 m and 10 m, respectively. Fill, consisting of mine and process waste, was placed on the downstream face of the dam sometime after the dam's construction. This fill was found (through previous investigations) to include zones of slag, cinder and ash material. Coal slag has been reported, in the literature, to potentially contain concentrations of both metal and hydrocarbon components.

As part of the geotechnical and geophysical investigation of the dam conducted in February 2014, sampling and analysis of representative samples of the slag fill material (obtained during the geotechnical drilling program) was undertaken for the assessment of potential contamination issues. Subsequently, a second phase of geo-environmental investigation was conducted, in late March 2014, to obtain additional environmental information with respect to the chemical quality of various media (*i.e.,* soil, water, sediment, soil vapour) in order to further assess potential issues with respect to contamination, and its influence on the remediation of the dam structure.

1.1.2 Inferred Applicable Standards

1.1.2.1 Soil Standards

While a dam would typically be considered industrial land use, the location of the dam (*i.e.,* within a public park) would suggest that the most conservative applicable standards would likely be the British Columbia Ministry of Environment's (BC MoE's) Contaminated Sites Regulation (CSR) Park Land Use (PL) soil standards.

Residential developments are located in the vicinity of the park, but outside the area of the dam. Commercial and industrial operations are located to the northwest of the park, but again, at some distance from the dam. No agricultural lands have been identified in the immediate vicinity of the dam, to date. Therefore, the Agricultural Land Use (AL), Residential Land Use (RL), Commercial Land Use (CL) and Industrial Land Use (IL) soil standards were not considered relevant for the purposes of this initial assessment.

With respect to potentially applicable, site-specific factors under the CSR, the following site-specific factors were considered relevant, given the initial evaluation of conditions at and near the dam:

- Intake of Contaminated Soil;
- Toxicity to Soil Invertebrates and Plants;
- Groundwater Flow to Surface Water Used by Aquatic Life (freshwater); and
- Groundwater Used for Drinking Water.

In addition, standards contained in the provincial Hazardous Waste Regulation (HWR) are also considered relevant in the assessment of conditions at this Site.

1.1.2.2 Water Standards

It is understood that the reservoir water was once used as a drinking water source, but is no longer used in that capacity. However, the reservoir does contain aquatic species (fish) and supports foraging animals and birds, as well as being an area of recreation for humans. Downstream of the dam, the surface water is inferred to support aquatic life but, to our knowledge, is not used for drinking water purposes.

With this information, the Aquatic Life (freshwater) water quality standard was inferred to be principally applicable.While there is no known use of surface water, or groundwater, for drinking water purposes, the Drinking Water standards were also referenced, for comparison purposes.

As the water samples collected were from surface water environments (and not groundwater from wells), it was also inferred that the British Columbia (Approved) Water Quality Guidelines (BCWQG) might also be relevant in the assessment of surface water quality. Consequently, these guidelines were also referenced, for comparison and evaluation purposes.

1.1.2.3 Sediment Standards

The CSR Sediment Standards for freshwater environments (Schedule 9) were referenced in the assessment of sediment quality. Sediment is soil that is predominantly covered by water. The sediment quality standards are divided into two types: sensitive and typical. Sensitive sediment quality standards are applicable where there have been identified conditions, at or in the vicinity of the area of interest, that would classify the site as a sensitive environment. Typical sediment quality standards apply to areas that are not classified as sensitive.

While a specific biological assessment of the Site has not been carried out, to our knowledge, a general review of the Chase River Dam system was conducted by Golder in 2011. In that report, it was stated that a search of the British Columbia Conservation Data Centre (CDC) Species and Ecosystem database indicated that there were no sensitive ecosystems recorded within two kilometers of the project area (with the project area being the Upper Chase River Dam; which is located within 2 kilometers of the Lower Colliery Dam).

While it is considered unlikely that there would be sensitive sediment environmental conditions at or near the Lower Colliery Dam, both the sensitive and typical sediment standards were referenced, for comparison purposes.

1.1.2.4 Soil Vapour Standards

The CSR Vapour Standards (Schedule 11) were referenced in the assessment of soil vapour quality. The standards associated with Agricultural, Park Land and Residential Land Use (AL, PL and RL) were considered relevant to this assessment. In addition, as there are no structures at or in the immediate vicinity of the known slag fill location, the standards associated with outdoor exposure were considered primarily relevant for this initial assessment, and in the selection of appropriate vapour attenuation factors.

1.1.3 Summary of Findings

The results of chemical analyses conducted on the samples collected from the Site were detailed in Certificate of Analysis reports prepared by ALS Environmental (ALS) and Maxxam Analytics (Maxxam). ALS and Maxxam are professional, CALA[1]-certified analytical laboratories that were selected by Golder to conduct the required analyses. Both laboratories have branches located in Burnaby, British Columbia.

The Certificates of Analysis associated with this project are contained in the investigation report (Golder 2014a). The results of analyses have also been tabulated and compared with the inferred relevant environmental quality standards under the CSR. The tabulated results are presented in the tables also contained in the investigation report (Golder 2014a), as are copies of the field monitoring forms filled out at the time of the sampling work.

Sampling was conducted with reference to standard environmental sampling and decontamination procedures, and those procedures applicable to specific sampling work (*i.e.,* soil vapour) recommended by the provincial regulatory authority.

1.1.3.1 Initial Analyses (February 2014)

The initial chemical analyses were conducted on selected soil samples recovered from the dam, as part of a geotechnical investigation. The samples were collected from three boreholes drilled along the dam crest, and through the surficial fill materials. Selected samples were analysed for metals, extractable petroleum hydrocarbon (EPH), polycyclic aromatic hydrocarbon (PAH) and leachate concentrations. Leachate testing included Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP) testing.

The results of the initial sampling and analysis work conducted on representative samples of the slag fill material indicated concentrations of selected metals (specifically arsenic and barium) and certain hydrocarbons (Light and Heavy Extractable Petroleum Hydrocarbons (LEPH/HEPH)) and certain polycyclic aromatic hydrocarbons (PAH; specifically benzo(a)anthracene and naphthalene) were present in this fill material that exceeded the inferred applicable land use standards (*i.e.,* the Contaminated Sites Regulation (CSR) Park Land Use (PL) soil standards). However, the slag fill material was not likely to be classified as a Hazardous Waste, based on hydrocarbon content and/or TCLP leachability testing; and while certain metals and hydrocarbons were found to be potentially leachable from the slag material by simulated precipitation, the concentrations in the leachate would likely be less than those of the CSR Aquatic Life (freshwater) standards.

1.1.3.2 Supplementary Investigation (March 2014)

The supplementary geo-environmental investigation was undertaken to obtain additional environmental information with respect to the chemical quality of various media (*i.e.,* soil, water, sediment, soil vapour) in order to further assess potential issues with respect to contamination and its potential influence on the remediation of the dam structure. The supplementary investigation included: a) further (limited) historical review to assess dam construction and limits of potential slag fill placement; b) surficial soil sampling, including eleven (11) hand-excavated, shallow test pits, to further assess shallow soil conditions, the limits of fill placement, and the potential for human and other receptor contact with slag fill material; c) surface water sampling at four locations; one in the upstream reservoir, one at a sump on the downstream face of the dam, and two in the downstream watercourses, to further assess water quality in the area of the dam and downstream of the dam and slag fill area; d) sediment sampling at four locations in the downstream watercourses to further assess sediment quality in the downstream area of the dam; and e) soil vapour sampling at two locations on the dam crest, to further assess soil vapour quality associated with the slag fill material in the main, publicly-accessible area of the dam (due to detectable concentrations of naphthalene found in the slag fill).

The results of the supplementary sampling and analytical program were as follows:

- **Soil:** The slag fill was generally described as being black in colour, and containing cinder, slag and ash components. No odours, staining or other debris was noted to be associated with this material, based on observations made at the time of the February 2014 geotechnical drilling and sampling program. In the 11 shallow test pits excavated and sampled as part of the supplementary investigation, no materials resembling slag fill material were encountered in the shallow soil (*i.e.,* less than 0.5 metres in depth).

The results of chemical analyses conducted on selected shallow soil samples indicated that two of eleven soil samples collected and analysed from the shallow test pits contained exceedances of the CSR PL soil standards. The sample collected from SS14-05, located at the downstream base of the dam contained a chromium concentration (72.4 milligrams per kilogram (mg/kg)) exceeding the CSR PL and CSR IL soil standards of 60 mg/kg. This same sample contained a nickel concentration (110 mg/kg) exceeding the CSR PL standard for nickel of 100 mg/kg. The sample collected from SS14-11, located on the south side of the dam (upper section), contained an arsenic concentration of 18.4 mg/kg, exceeding the CSR PL soil standard of 15 mg/kg (*note that this standard is for protection of drinking water).

In addition, eight of the eleven soil samples analysed as part of the supplementary investigation reported sodium concentrations in excess of 200 mg/kg, which is the CSR PL soil standard. However, sodium concentrations reported were based on an aggressive ICP-MS[2] analytical method, which is known to produce much higher sodium concentrations than the BC MoE-recommended Saturated Paste Method. Two samples that exhibited the highest sodium concentrations were re-analysed using the Saturated Paste Method. Both results yielded sodium concentrations well below the CSR PL soil standard.

Detectable hydrocarbon concentrations were limited to selected PAH constituent concentrations in five of the shallow soil samples, and extractable petroleum hydrocarbon concentrations at one shallow soil sample location. No exceedances of the inferred applicable standards for hydrocarbons were reported, for the samples analysed.

- **Water:** As no groundwater monitoring wells were identified in the area of the dam, no groundwater sampling was conducted as part of the supplementary investigation. Only samples of surface water, from the reservoir and from the downstream areas of the dam, were collected and analyzed. Field and laboratory parameter measurements of the water sample locations revealed the following:

- Water temperatures ranging from 5.5 to 8.1 degrees Celsius;
- Electrical conductivities ranging from 51 to 153.2 microSiemens per centimeter;
- pH ranging from 6.59 to 7.52 pH units;
- Redox potentials ranging from -22.7 to 122.7 millivolts;
- Dissolved oxygen concentrations ranging from 7.68 to 14.52 milligrams per litre; and
- Hardness concentrations ranging from 17.7 to 60.2 milligrams per litre (as $CaCO_3$).

Detectable concentrations of certain metals constituents, in both total and dissolved phases, were reported in the water samples collected from the Site. None of the reported concentrations exceeded the CSR AW (freshwater), CSR DW or BCWQG (freshwater) standards and/or guidelines. Detectable concentrations of extractable petroleum hydrocarbons were reported in one water sample collected from the sump on the downstream face of the dam. The concentrations reported were only slightly above the analytical detection limit, and were below the inferred applicable CSR water standards. No detectable concentrations of PAH constituents were reported in the water samples.

- **Sediment:** Shallow sediment samples were collected from the watercourses located at the downstream side of the dam. Two of the four sediment samples collected and analysed from the Site contained exceedances of the CSR sediment standards, for sensitive sites. Sed14-02, collected downstream of the dam, contained an arsenic concentration of 11.6 mg/kg, that exceeded the CSR sensitive site standard of 11 mg/kg. This sample also contained benzo (a) anthracene (0.3 mg/kg) and pyrene (0.71 mg/kg) exceeding their respective CSR sensitive site standards of 0.24 mg/kg and 0.54 mg/kg, respectively. Sed14-03, also collected downstream of the dam, contained a chromium concentration of 66.5 mg/kg, that exceeded the CSR sensitive site standard of 56 mg/kg.
- **Soil Vapour:** Two shallow soil vapour samples were collected from the area of the dam crest, and were submitted for selected chemical analyses. Detectable concentrations of certain volatile organic constituents were reported in soil vapour. However, all reported concentrations were below their respective, applicable CSR AL, PL and RL vapour standards, upon application of the permitted attenuation factors.

1.1.4 Implications for Design and Construction

Initial subsurface investigation of the Lower Dam has identified the presence of fill (coal slag fill) containing chemical concentrations exceeding the applicable land use standards. Sediment downstream of the dam (but inferred to be associated with the dam fill material) may also contain chemical concentrations exceeding the provincial standards. The full extent of this coal slag fill has not yet been determined.

As the full extent of historical slag fill is currently unknown, there is considered a potential that dam remediation work may encounter such material. Therefore, as part of the remedial planning effort, consideration and allowance for the handling, characterization and disposition of soil would be prudent. In addition, the removal and handling of contaminated soil (*i.e.,* work falling under the definition of "remediation" under the Contaminated Sites Regulation) would require regulatory notification.

Depending on the location and type of construction contemplated, the following general issues (amongst others) may need to be addressed:

- The potential for encountering contaminated soil;
- The need to dispose of or deal with contaminated soil;
- The potential to expose contaminated soil to receptors;
- The potential for erosion of contaminated soil and migration to downstream locations;
- Regulatory notification requirements and documentation;
- Leach-ability and erode-ability of stabilized and/or treated soil;
- Risks associated with contamination remaining following construction; and
- Regulatory and public (stakeholder) acceptance.

1.1.5 Summary and Further Work Needed

The results of investigations and analyses conducted, to date, by Golder at the Lower Dam site, and the interpretation of conditions and recommendations for further work, are summarized in the following sub-sections.

1.1.5.1 Initial Investigation Program

- The Lower Colliery Dam contains cinder, ash and slag fill on the downstream face.
- The slag fill is estimated to be up to 7 metres, or more, in thickness on the downstream face.
- The slag fill contains metals concentrations (specifically barium and arsenic) that exceed both the CSR PL and CSR IL soil standards.
- The slag fill contains hydrocarbon concentrations (extractable petroleum hydrocarbon (LEPH and/or HEPH) and selected polycyclic aromatic hydrocarbon (PAH) constituents) that exceed the CSR PL soil standards.
- Test results obtained, to date, do not indicate that the slag fill would be classified as a Hazardous Waste, under the HWR.
- Synthetic Precipitation Leaching Procedure (SPLP) testing suggests that the leachate generated through contact between the slag fill and precipitation would likely not result in water concentrations exceeding either the CSR AW (freshwater) standards or the BCWQ guidelines for freshwater.

1.1.5.2 Supplementary Investigation Program

- Exceedances of the CSR PL soil standards were only identified in two of the eleven shallow soil samples collected and analysed as part of the supplementary sampling program. With the exception of one sample (containing arsenic), the constituent concentration exceedances were observed to be dis-similar to that exhibited by the slag fill material. In addition, the shallow soils appeared to lack visual evidence of slag fill. This suggests that the shallow soils at the dam site may consist of different material, or have been modified (though erosion, leaching, soil redistribution, etc.).
- Water samples collected from the Site were not found to contain chemical concentrations (total, dissolved metals and hydrocarbons) that exceeded the inferred applicable CSR standards (AW freshwater, DW) or the BCWQ guidelines; with the exception of total iron in one downstream water sample.
- Sediment samples collected from the Site were found to contain selected constituent concentrations exceeding the CSR sensitive site standards, but not the CSR typical site standards.
- No vapour concentrations were found to exceed the inferred applicable CSR soil vapour standards, upon application of permitted attenuation factors.

1.1.5.3 General Comments and Observations

The near surface soils at the Site do not appear to consist of the same material as the underlying slag fill.

The surficial soils contain certain exceedances of the inferred applicable soil standards. However, when applying only the standards associated with the site-specific factors of “intake of contaminated soil” and “toxicity to soil invertebrates and plants” (which are applicable at all sites, and are the more relevant factors with respect to evaluation of direct contact exposure), no exceedances are identified, with the exception of nickel (that has a generic numerical standard).

Potential exceedances of the sensitive site standards for sediment were identified, but it is considered unlikely that such standards would apply at this Site.

Both surface water and soil vapour conditions do not appear to have been detrimentally-impacted by the presence of slag fill material.

1.1.5.4 Recommendations for Further Environmental Work

As exceedances of the inferred applicable CSR soil standards have been detected, future dam remediation activities involving the slag fill soils will likely require regulatory notification and, possibly, permitting. Such materials would also need to be appropriately handled during construction work.

In-situ management of contaminated soil, or other material, would typically include an assessment of risk to human health or the environment, resulting from these materials remaining in-place. Also, given the accessibility of the Site to potential receptors (human, terrestrial, avian, aquatic, etc.), potential exposure to the identified soil contaminants is considered possible, and the risk associated with such exposure should be evaluated.

It is recommended that a preliminary risk assessment be conducted, based on existing conditions, to help make sure that no sensitive receptors have been missed, that critical pathways have been evaluated, and to verify that no unacceptable risk is incurred as a result of in-situ management. If issues are identified through such an assessment, a plan for risk mitigation may then be developed.

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