July 25, 2014

REPORT ON

Colliery Dams, Nanaimo, BC Hydrology, Hydraulics, and Middle Dam Breach Analysis

Submitted to:
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REPORT

Report Number: 1314470516-008-R-Rev0

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Golder Associates

Executive Summary

This report has been prepared primarily to document Golder's assessment of the hydrologic and hydraulic conditions of the Middle and Lower Colliery Dams in their existing conditions. Additionally, the results of the Middle Dam breach analysis and the breach formation parameters for both the Middle and Lower Dams are included.

This memo includes the following hydrologic and hydraulic analyses:

- Detailed hydrologic analysis including 2- through 1000-year storms, Probable Maximum Precipitation (PMP) event, and likely design storms for both the Middle and Lower Dams.
- Hydraulic analyses including the calculation of the hydraulic capacities of the Nanaimo Parkway culvert, the Middle Colliery Dam spillway, and the Lower Colliery Dam spillway.
- Dam breach parameters were developed which were used as inputs to the quantitative risk assessment and Associated Engineering (AE) breach modeling.
- Middle Dam Breach Analysis to Lower Dam.

The analyses have been performed using the best available and most applicable data to the watersheds, as follows:

- Historic flow data for the Chase River is not available. However, 40 years' of rainfall data is available which has been recorded at two stations in close proximity, but not within, the Chase River watershed. These two gauging stations are at elevations that are lower than that of the Chase River watershed, thus requiring elevation adjustments to the rainfall data. Appropriate methodologies have been used to transform this rainfall data into runoff flows for various storm events.
- The rainfall event frequency required to rate dam spillway performance, for longer return period events, exceeds the locally available historic rainfall data which is limited to the past 40 years. Thus an extrapolation of the available rainfall data has been performed.
- The parameters used in these hydrologic analyses have allowed for some future development within the watershed and 100% saturated soil conditions have been modeled, as is normal practice for this type of analysis.

The hydraulic analyses have been performed using available data including as-built plans for the Nanaimo Parkway Culvert, field run survey of the Middle and Lower Dams and Spillways, and LiDAR aerial topography supplemented with bathymetric surveys of submerged areas beneath the normal pools of the Middle and Lower Lakes. Field measurements of both the Middle and Lower Dam Spillways were taken to verify and supplement the available survey data.

These calculations have determined that the spillway for the Middle Dam has the capacity to convey the flows associated with approximately the 50-year (2% annual exceedance probability) rainfall event. Storms larger than the 50-year overtop the dam embankment. The spillway for the Lower Dam has the capacity to convey the flows associated with approximately the 25-year (4% annual exceedance probability) rainfall event. Storms larger than the 25-year overtop the dam embankment.

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APPENDICES

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by the City of Nanaimo (CON) to be part of 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 City of Nanaimo, Snuneymuxw First Nation (SFN), the Colliery Dam Park Preservation Society (CDPPS) and the community.

This report provides a summary of the hydraulics and hydrology studies which have been undertaken by Golder. These studies have been carried out in support of risk assessment work, dam safety studies and dam remediation design. Separate reports have been prepared which outline separate work carried out by Golder for the project, which should be read in conjunction with this report for a more complete understanding of the project.

This report is structured such that the key components are contained within the Appendices – the main body of the report primarily refers the reader to the appropriate appendix.

This report should be read in conjunction with the "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 HYDROLOGY

2.1 Overview

The analysis and calculations provided in this section provide a detailed assessment of the watersheds contributing to the Middle and Lower Colliery Dams. Past hydrologic studies are available for these two dams, most notably the Middle and Lower Chase River Dams Spillway Hydrology Study by Water Management Consultants dated April 30, 2002. This and other studies have been reviewed as part Golder's efforts with this aspect of the project. Following review of these documents, a decision was made to perform an independent, more detailed assessment of the watersheds since this establishes the basis by which the dams will be evaluated and rehabilitated and since the previous studies provided limited details of certain key analyses which prevented verification or modification of the previous efforts.

The overall watershed analyzed comprises slightly more than 21 square kilometers to the west and southwest of the City of Nanaimo. The watershed is predominantly undeveloped mountainous topography covered mostly in forests, grassy areas, and a relatively minor component of urban development in the most downstream area of the overall watershed. The Chase River is a high gradient, mountain stream to which the subject watershed contributes. In the area of study, three major hydraulic structures exist on the Chase River that have been analyzed as part of this study; the Nanaimo Parkway embankment and culvert, the Middle Colliery Dam and Reservoir, and the Lower Colliery Dam and Reservoir. Watersheds to each of these three structures have been delineated with an additional fourth watershed delineated upstream at a point where the basin characteristics change. The hydraulic impacts of each of these structures have been accounted for and are described within the Hydraulics section of this report.

2.2 Hydrologic Analyses

This hydrologic analysis was performed in the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Hydrology Modeling System (HMS) software version 3.5 and uses standard Soil Conservation Service (SCS) methodology as described in the SCS National Engineering Handbook Section 4. The SCS methodology uses several parameters which include basin area, land usage, basin lag, and rainfall distribution to determine runoff rates and volumes. All storm events were analyzed using a SCS Type 1A distribution.

The calculation memoranda and figures presented in this section provide the supporting information for the hydrologic values input into HEC-HMS.

2.2.1 Colliery Dams Soil Groups

A detailed description of this analysis, and a summary of the results, is presented in Appendix A.

2.2.2 Curve Numbers

A detailed description of this analysis, and a summary of the results, is presented in Appendix B.

2.2.3 Time of Concentrations

A detailed description of this analysis, and a summary of the results, is presented in Appendix C.

2.2.4 Rainfall

A detailed description of this analysis, and a summary of the results, is presented in Appendix D.

2.2.5 Base Flow

A detailed description of this analysis, and a summary of the results, is presented in Appendix E.

3.0 HYDRAULICS

3.1 Overview

As indicated in Section 2, three structures have a major influence on the hydraulics within the watershed studied. The most upstream of these is the embankment and culvert associated where Nanaimo Parkway crosses the Chase River. The second and third structures are the Middle and Lower Colliery Dams which are the subject of this study. These structures have been studied in the past, but the previous studies provide limited details of certain key analyses which prevented verification or modification of the previous efforts. Therefore independent analysis of these critical elements have been included as part of this report.

3.2 Hydraulic Analysis

The hydraulic routing performed using HEC-HMS accounts for both the hydraulic performance and the volumetric storage provided at each structure. The hydraulic performance has been analyzed by developing rating curves for the culvert and spillways. Additionally, the flow conveyance associated with embankment overtopping of the Middle and Lower Colliery dams was modeled using non-level crests within HEC-HMS and appropriate broad crested weir coefficients. The culvert at Nanaimo Parkway is a very large structure and has the capacity to convey 100% of the PMF without engaging the underpass associated with Nanaimo Lakes Road.

3.2.1 Stage-Area-Storage Relationships

A detailed description of this analysis, and a summary of the results, is presented in Appendix F.

3.2.2 Rating Curves

A detailed description of this analysis, and a summary of the results, is presented in Appendix G.

3.2.3 Summary of Hydraulic Analysis (HEC-HMS) Results

A detailed description of this analysis, and a summary of the results, is presented in Appendix H.

4.0 DAM BREACH PARAMETERS

4.1 Overview

As input to the quantitative risk assessment for the Middle and Lower Colliery Dams (Golder 2014a), potential breach parameters have been developed. These parameters require subjective assessment and depend on the cause of the breach such as piping, seismic, or overtopping failures and also depend on the construction of the dam. The Middle and Lower Dams are similar in construction, both consisting of a concrete core wall buttressed with zones of rock fill, and non-cohesive (granular) soils. The Lower Dam also has a zone of cinders/slag and it should be noted that investigations indicate that the concrete core wall is likely more robust (thicker section) than the Middle Dam. A summary of the selected breach parameters and values is presented in a following section.

The breach parameters were used directly in the risk assessment (Golder 2014a) as well as input into the dam breach modelling which was carried out by AE. The breach parameters used in the risk assessment were expressed in terms of probabilities, which are intended to reflect the range of magnitude of the relevant parameter. These probabilistic ranges are described in later sections of this report.

Selected breach parameters were also provided to AE, along with various storm event hydrographs, in order to develop various breach outflow hydrographs for both dams and to carry out breach inundation modeling (AE 2014).

4.2 Methodology

Several resources were utilized to develop the breach parameters and a complete list of references is provided in a subsequent section. A useful database of historic dam failures was compiled and published by the U.S. Department of the Interior, Bureau of Reclamation, Dam Safety Office and titled, “Prediction of Embankment Dam Breach Parameters – A Literature Review and Needs Assessment (DSO-98-004). A summary of the applicability of the DSO-98-004 database to the Colliery Dams is presented below:

- 108 historic dam failure case studies in the DSO-98-004 database;
- Most are homogeneous earth fill construction;
- 7 note components of rock fill;
- 2 of these also note concrete/masonry cores;
- Reported breach development times range from 0.5 hrs to 8 hrs;
- 5 were overtopping failures;
- 2 were piping failures;
- Dam heights ranged from 21m to 67m (Lower Dam is approx. 23m);
- Reservoir storage areas ranged from 3,200,000 m3 to 650,000,000 m3 (Lower dam has 155,000 m3); and
- No other information available for comparison purposes (watershed, storm flows, overtopping depth, duration of overtopping, condition, etc.)

Other studies and methodologies utilize laboratory analysis to develop scour and erodibility potentials to predict the breach parameters. However, these have limited applicability to the Colliery Dams due to their hybrid construction and especially due to the non-erodible concrete core walls. Additionally, the scour/erodibility methodologies generally establish thresholds for scour/erosion resistance and most done provide information for rates of scour/erosion.

The rock fill zones of the dam embankments and their interaction/support of the core walls will likely prove the controlling material for the mechanics of breaching due to the location of those zones and the relative erosion resistance compared to the other zones of fill. One study titled, “Experimental Tests on Rockfill Dam Breaching Process” by Franca and Almeida provides additional applicable guidance:

- Model flume test to test the breaching process for rockfill dams.
- “One of the most remarkable results taken from the tests on rockfill dam model is their capability to resist the overflow and percolation flow when compared with earth dams.”
- Provides threshold unit flows in which slope movement begin to occur and when a general slide develops.
- Predicts a failure time between 0.9 and 2.4 hours for rockfill dams 25m in height (Lower Dam is apprx. 23 m).

4.3 Summary of Selected Breach Parameters

Timing of Initiation: Breach development starts at the peak of the outflow hydrograph.

Breach Development Progression: A stepped progression was utilized to mimic the anticipated failure mechanics of the concrete core walls.

Final Breach Invert: Full depth breach to the bottom of the reservoirs.

Final Breach Bottom Width: 10m (approximate width of natural valley invert)

Final Breach Side Slopes: 1h:1v

Lower Dam Breach Development Time: 120-minute breach development time has been determined to be the most likely, median value. However, a fast 10-minute and a slow 240-minute breach development times have been analyzed in order to bracket the full range of anticipated possibilities.

Middle Dam Breach Development Time: 60-minute breach development time has been determined to be the most likely, median value. However, a fast 10-minute and a slow 150-minute breach development times have been analyzed in order to bracket the full range of anticipated possibilities.

5.0 OVERTOPPING BREACH PROBABILITIES

5.1 Overview

To complete the risk analysis for the Middle and Lower Colliery Dams it was necessary to develop probability curves for the likelihood of dam breach for various overtopping events. In general terms, the probability of breach is a function of the construction and condition of the embankment and the duration and depth of overtopping flow.

A breach is considered to have occurred when the reservoir volume below the low-point of the dam embankment becomes hydraulically connected to the downstream reach. In overtopping breaches of dam embankments this typically occurs through the following process. First, flow begins overtopping the crest of the embankment dam as the inflow exceeds the spillway and storage capacity of the dam and reservoir. This flow is very minor at the start, but increases over time to the point where the vegetation on the downstream slope or toe of the dam embankment begins to be stripped away. This can happen at a random location, at a location where the power of the overtopping flow is concentrated, or at a location where something causes turbulent, non-laminar flow. Once an area of vegetation has been stripped away, exposing the material of which the dam embankment is constructed, erosion can initiate. This erosion propagates from the point or points of inception upstream toward the dam crest in a fashion typically described as head cut erosion. Over time, the duration of which depends on the power of the overtopping flow and the properties of the dam embankment, the head cut propagates upstream through the dam crest and the moment when the entire crest width has been compromised is considered to be the beginning of the breach.

There are case histories of many storm related dam overtopping occurrences. In some instances overtopping caused breaches, and in others the dams survived with varying states of damage. Note that damage does not equate to breach.

The Middle and Lower Colliery Dams are similar in construction and consist of concrete core walls that are buttressed by various zones of non-cohesive fills. This hybrid construction makes predicting exact breach probabilities a difficult task. However, this hybrid construction is likely fairly resilient to breaching from overtopping flows. As the outer shell materials on the downstream slopes are generally non-cohesive, erodible cinders/slag or sands/gravels, the erosion resistance of these zones is highly dependent on the vegetative cover. The vegetation on both the Middle and Lower Dams consists primarily of grass, but there are areas of poor coverage, of ivy, moss, etc. that make the reliance on vegetation for erosion resistance not possible.

However, the components of rock fill and the non-erodible concrete core wall are a highly erosion resistant combination. Even if the cinders/slag and sands/gravels zones were compromised, the underlying combination of rock fill and concrete core wall are capable of withstanding some overtopping flow without breaching. It is expected that the breach development, if it were to occur, would happen in a stepped fashion. This process would begin with the erosion of the buttressing downstream rock fill, removing support for the concrete core wall. At some point, the load imbalance could cause the upper section of the concrete core wall to fail therefore initiating the breach of the dam. This process could continue over the duration of overtopping flow, repeating until the full height of the dam is breached. This process is illustrated in the Figure 10 provided below.

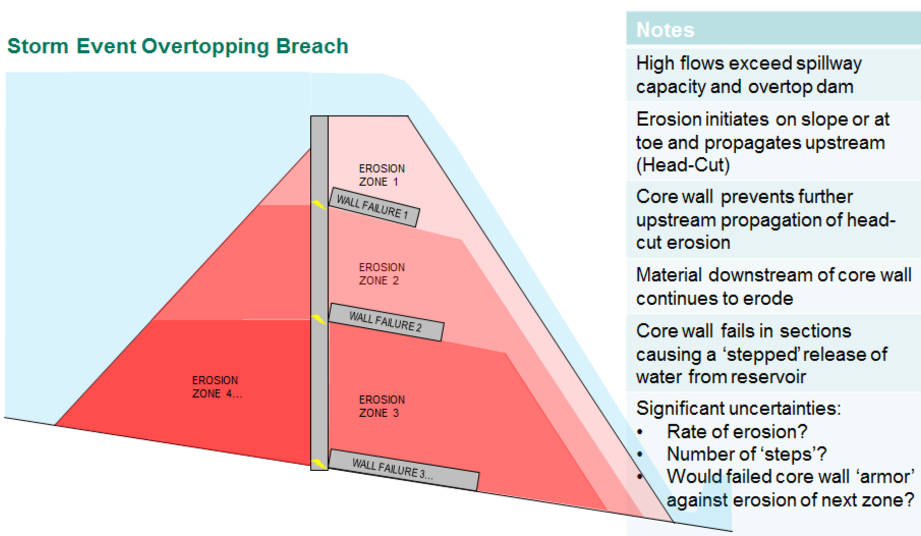

Figure 10: Overtopping Breach Stepped Progression Illustration

Figure 11 below provides curves which demonstrate the anticipated values of overtopping duration and depth for the 10, 50, and 90-percent probability of breach. As indicated previously, subjective assessment was required to develop these curves which considered information on the condition of both dams and a review of case histories.

In addition to the existing conditions at the Lower Dam, a rehabilitation concept of hardening the downstream dam embankment to resist erosion and scour associated with overtopping flows has been considered. The curves titled, "Lower Dam w Hard" in the legend description were developed for this concept and are based on a preliminary scour analysis and soil-cement-hardening assuming 2 MPA strength and a uniform 2(h):1(v) downstream slope.

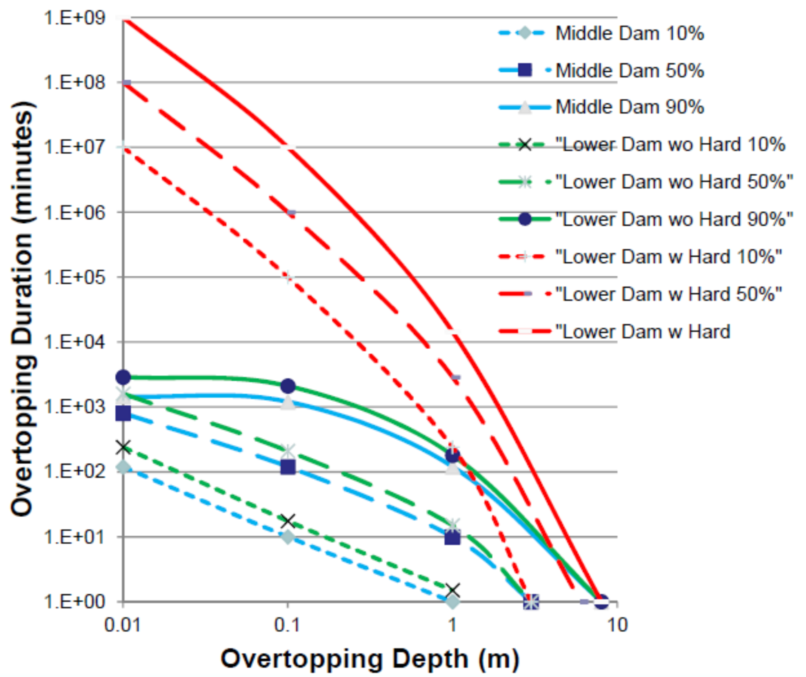

Figure 11: Probability of Breach Failure from Overtopping

6.0 OVERTOPPING RESULTS FOR RISK ANALYSIS

6.1 Overview

To complete the risk analysis for the Middle and Lower Colliery Dams it was necessary to develop overtopping information for various scenarios. The dam breach risk associated with overtopping flows increases with both duration and depth of flow. The results presented below are based on the HEC-HMS modeling described in Section 3 of this report and also incorporates various Middle Dam breach hydrographs provided by AE.

6.2 Summary of Selected Overtopping Parameters

Table 1: Middle Colliery Dam – Existing Conditions

Flow Basis	Depth of Overtopping (m)	Duration of Overtopping (min)
100-year (no breach)	0.1	59
1,000-year (no breach)	0.5	132
1,000-year + 1/3 PMP (no breach)	0.7	169
PMP (no breach)	0.9	249

Table 2: Lower Colliery Dam – Existing Conditions

Flow Basis	Depth of Overtopping (m)	Duration of Overtopping (min)
100-year w/ 60-min Middle Dam Breach	0.6	108
1,000-year w/ 60-min Middle Dam Breach	0.8	186
1,000-year + 2/3 PMP w/ 60-min Middle Dam Breach	1.0	299
PMP (no breach)	0.9	360
PMP w/ 60-min Middle Dam Breach	1.1	360

Table 3: Lower Colliery Dam – Proposed Conditions – Labyrinth Option

Flow Basis	Depth of Overtopping (m)	Duration of Overtopping (min)
60-min Middle Dam Breach	-1.1	N/A
100-year (no breach)	-0.8	N/A
100-year w/ 60-min Middle Dam Breach	-0.2	N/A
1,000-year (no breach)	-0.3	N/A
1,000-year w/ 60-min Middle Dam Breach	0.1	22
1,000-year + 2/3 PMP (no breach)	0.1	39
1,000-year + 2/3 PMP w/ 60-min Middle Dam Breach	0.4	75
PMP (no breach)	0.3	70
PMP w/ 60-min Middle Dam Breach	0.5	91

Table 4: Lower Colliery Dam – Proposed Conditions – Hardening Option

Flow Basis	Depth of Overtopping (m)	Duration of Overtopping (min)
60-min Middle Dam Breach	-0.1	N/A
100-year (no breach)	0.3	103
100-year w/ 60-min Middle Dam Breach	0.8	113
1,000-year (no breach)	0.7	184
1,000-year w/ 60-min Middle Dam Breach	1.0	186
1,000-year + 2/3 PMP (no breach)	1.0	299
1,000-year + 2/3 PMP w/ 60-min Middle Dam Breach	1.2	297
PMP (no breach)	1.1	363
PMP w/ 60-min Middle Dam Breach	1.2	361

7.0 MIDDLE DAM BREACH ANALYSIS

While the inundation modelling for this project was primarily carried out by AE, the inundation model created by AE starts downstream of the Lower Dam and it was determined that the area between the Middle and Lower Dams required inundation study. Therefore Golder performed a separate breach inundation analysis for this area using a breach hydrograph (for the Middle Dam) provided by AE. The results for this analysis are presented in Appendix I.

8.0 CLOSURE

We trust that the contents of the report meet with your current requirements. Should you have questions or need clarification of contents, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED

Josh Myers, P.E,
Senior Water Resources Engineer

Reviewed by:

ORIGINAL SIGNED	ORIGINAL SIGNED
Bruce Downing, P.Eng Principal	Gregg Hudock, P.E Associate

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9.0 REFERENCES

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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 cannot be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client cannot rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder cannot be responsible for use of portions of the report without reference to the entire report.

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.

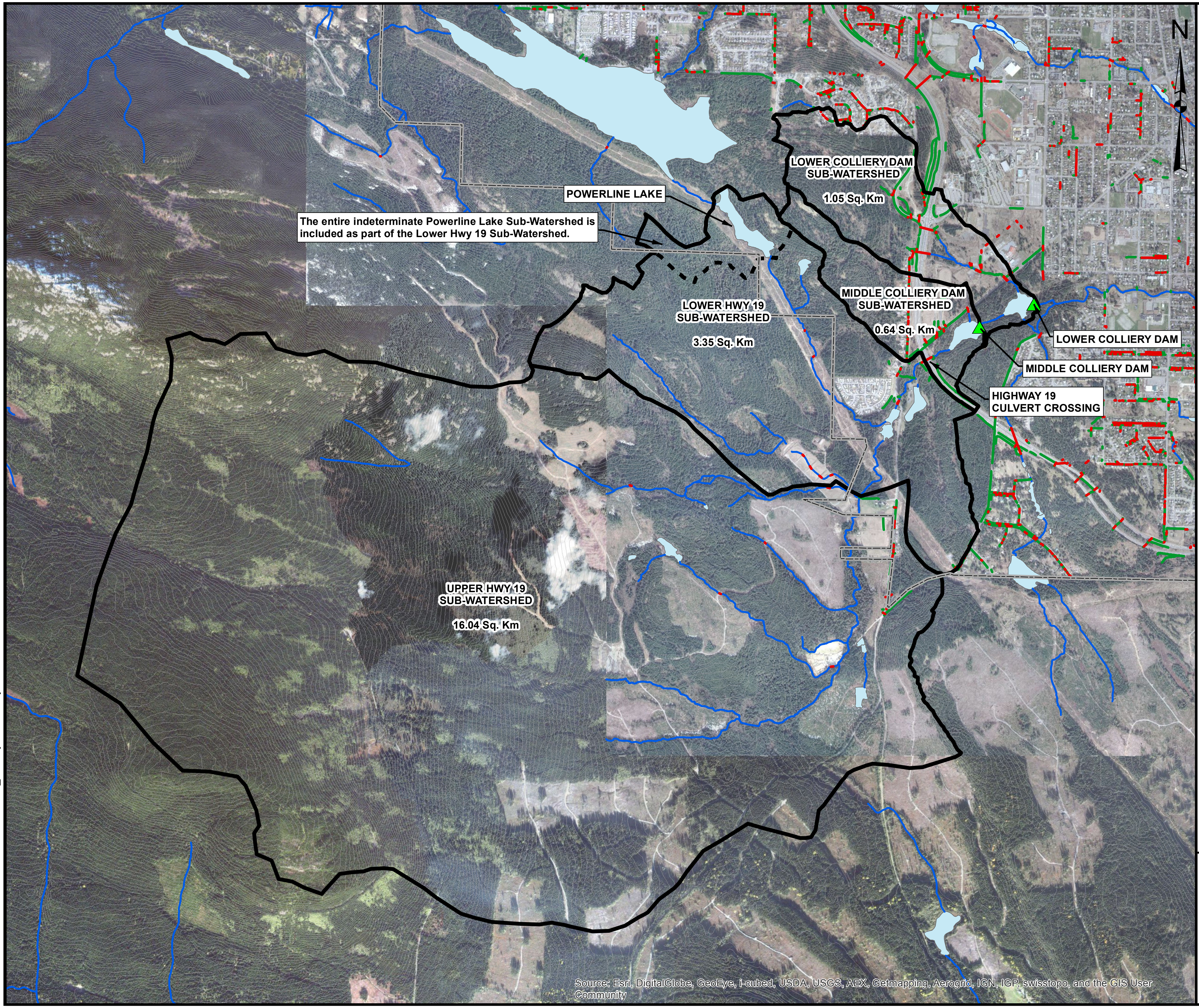
Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater 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 systems.



Document Path: Q:\GIS\Nanaimo\1314470516_Colliery Dams\Projects\FIGURE 1 Watershed.mxd

LEGEND

- DAM LOCATION
- URBAN BOUNDARY
- WATERSHEDS
- POWERLINE LAKE SUB-WATERSHED
- CULVERTS
- CHANNELS
- RIVERS
- LAKES

NOTES

Watersheds were delineated using 1-meter contours developed from LiDAR data. 1-meter contours developed from 1-arc second NED were used where LiDAR data is not available.

REFERENCES

Digital 1-Meter Contour Data (Developed from LiDAR Data) from the City of Nanaimo, 2009.

1/3-Arc Second and 1-Arc Second National Elevation Datasets (NED) from the U.S. Geological Survey (USGS), 2009.

Digital Storm Drainage Infrastructure Data from the City of Nanaimo, 2012.

250 0 250 500 Meters

REV.	DATE	DES	REVISION DESCRIPTION	GIS	CHK	RVW

PROJECT

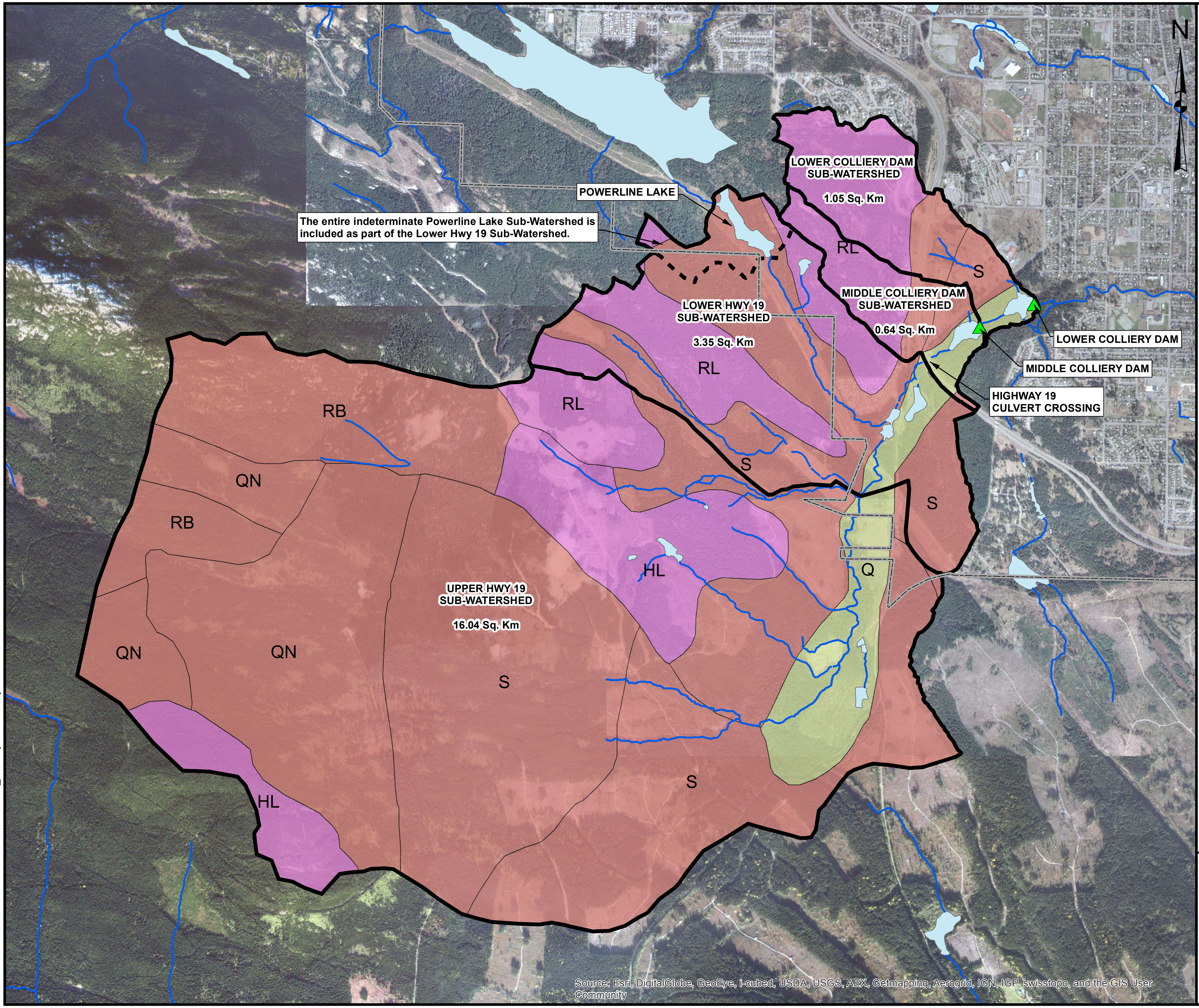
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, BC, CANADA

TITLE

COLLIERY DAMS WATERSHEDS

Golder Associates
Atlanta, GA

PROJECT No.		1314470516	FILE No.
DESIGN			SCALE: 1 cm = 250 m REV. 0
GIS	JCD	2/4/2014	
CHECK	JKM	2/4/2014	**FIGURE 1**
REVIEW	GWH	2/7/2014	



LEGEND

- DAM LOCATION
- URBAN BOUNDARY
- WATERSHEDS
- POWERLINE LAKE SUB-WATERSHED
- RIVERS
- LAKES

ASSIGNED HYDROLOGIC SOIL GROUP (HSG)

- A
- B
- C

NOTES

Watersheds were delineated using 1-meter contours developed from LiDAR data. 1-meter contours developed from 1-arc second NED were used where LiDAR data is not available.

REFERENCES

Digital 1-Meter Contour Data (Developed from LiDAR Data) from the City of Nanaimo, 2009.

1/3-Arc Second and 1-Arc Second National Elevation Datasets (NED) from the U.S. Geological Survey (USGS), 2009.

Digital Storm Drainage Infrastructure Data from the City of Nanaimo, 2012.

BC Ministry of Environment, MOE Technical Report 17, Soils of Southern Vancouver Island, Report No. 44, British Columbia Soil Survey, 1985.

NRCS, Part 630 Hydrology, National Engineering Handbook, Chapter 7 Hydrologic Soil Groups, 210-VI-NEH, 2007.

Aerial Photos from the City of Nanaimo, 2012.

Aerial Photos from the City of Nanaimo, 2009.

REV.	DATE	DES	REVISION DESCRIPTION	GIS	CHK	RVW

PROJECT

CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, BC, CANADA

TITLE

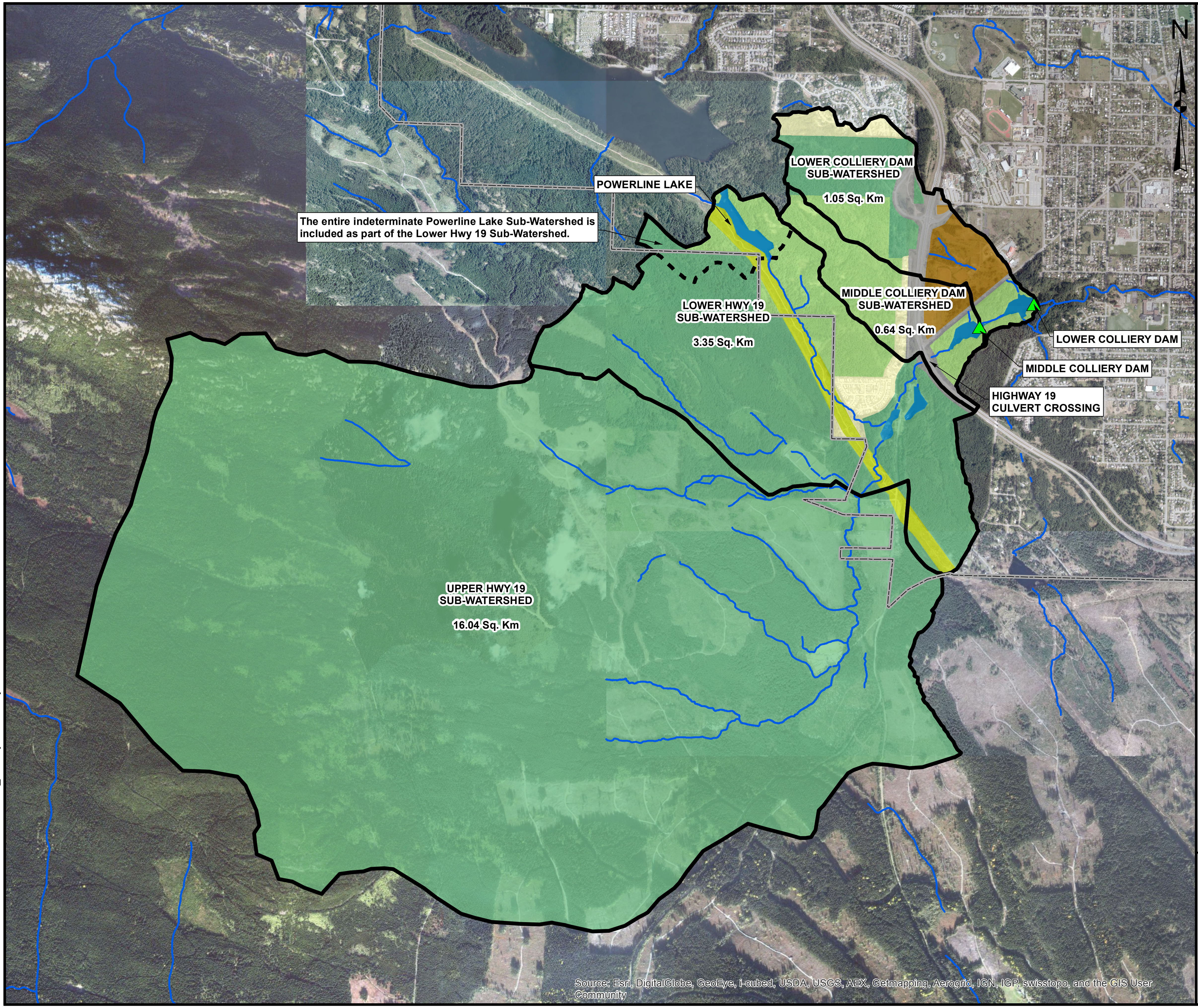
COLLIERY DAMS SOILS

Golder Associates
Atlanta, GA

PROJECT No.	1314470516		FILE No.	
DESIGN			SCALE: 1 cm = 250 m	REV. 0
GIS	JCD	2/4/2014		
CHECK	JKM	2/4/2014		
REVIEW	GWH	2/7/2014		

FIGURE 2

Document Path: Q:\GIS\Nanaimo\1314470516_Colliery Dams\Projects\Soils.mxd



LEGEND

- DAM LOCATION
- URBAN BOUNDARY
- WATERSHEDS
- POWERLINE LAKE SUB-WATERSHED
- RIVERS

LAND USE

- NEIGHBOURHOOD
- URBAN NODE
- RESOURCE
- OPEN SPACE
- PARK
- HIGHWAY RIGHT-OF-WAY
- WATER

NOTES

Watersheds were delineated using 1-meter contours developed from LiDAR data. 1-meter contours developed from 1-arc second NED were used where LiDAR data is not available.

Land use northeast of the Urban Boundary was determined using the City of Nanaimo Official Community Plan, parcel data, and aerial imagery.

Land use southwest of the Urban Boundary was determined using the Arrowsmith Benson - Cranberry Bright Official Community Plan and aerial imagery.

REFERENCES

Digital 1-Meter Contour Data (Developed from LiDAR Data) from the City of Nanaimo, 2009.

1/3-Arc Second and 1-Arc Second National Elevation Datasets (NED) from the U.S. Geological Survey (USGS), 2009.

Digital Storm Drainage Infrastructure Data from the City of Nanaimo, 2012.

Digital Cadastre Data from the City of Nanaimo, 2012.

City of Nanaimo Official Community Plan, 2008.

Arrowsmith Benson - Cranberry Bright Official Community Plan, 1999.

Aerial Photos from the City of Nanaimo, 2012.

Aerial Photos from the City of Nanaimo, 2009.

250 0 250 500 Meters

REV.	DATE	DES	REVISION DESCRIPTION	GIS	CHK	RVW

PROJECT

CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, BC, CANADA

TITLE

COLLIERY DAMS
FUTURE LAND USE

Golder Associates
Atlanta, GA

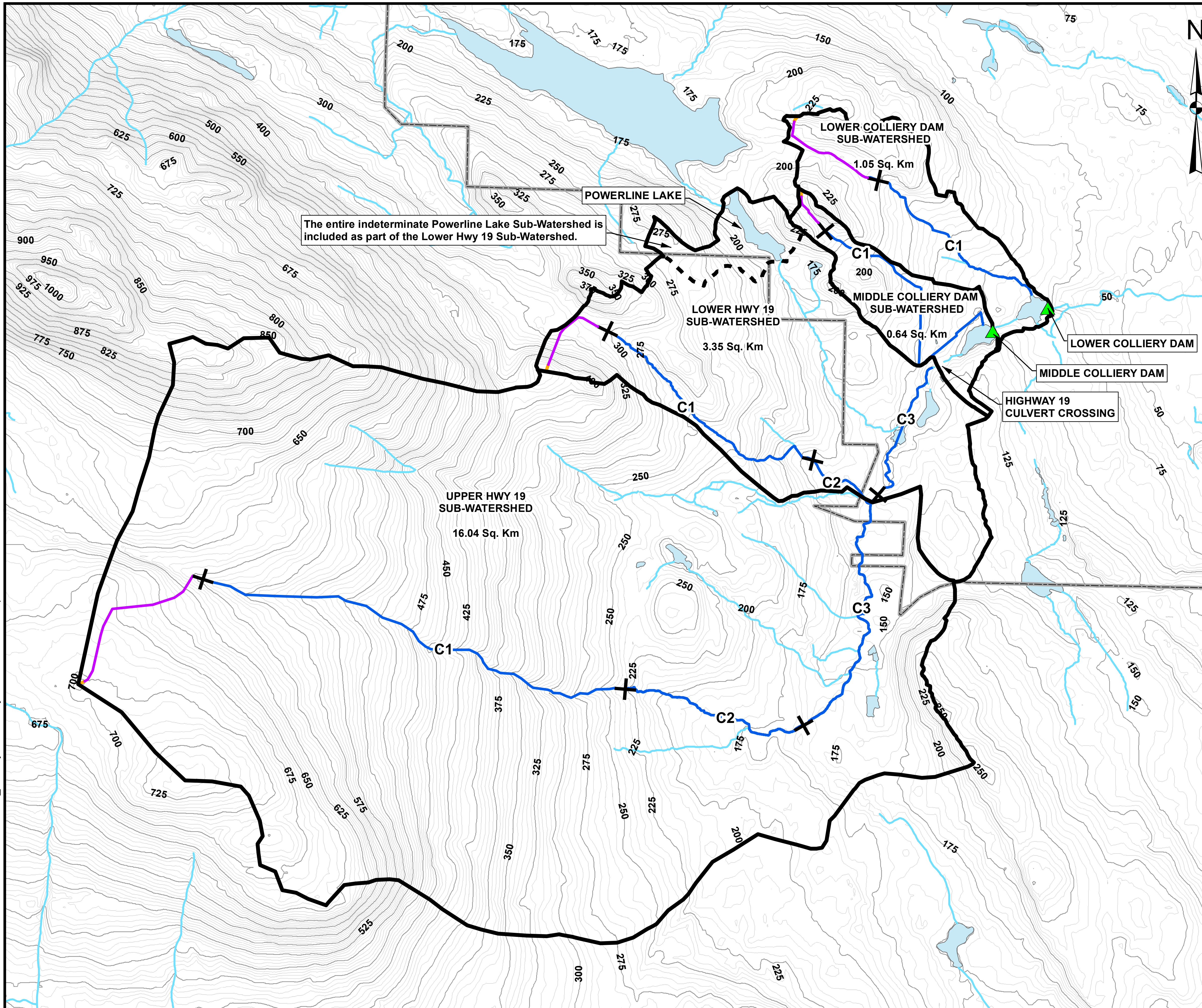
PROJECT No.	1314470516	
DESIGN	XXX	
GIS	JCD	2/4/2014
CHECK	JKM	2/4/2014
REVIEW	GWH	6/20/2014

FILE No.

SCALE: 1 cm = 250 m | REV. 0

FIGURE 3

Document Path: Q:\GIS\Nanaimo\1314470516_Colliery Dams\Projects\Landuse.mxd



LEGEND

- DAM LOCATION
- WATERSHEDS
- POWERLINE LAKE SUB-WATERSHED
- URBAN BOUNDARY
- RIVERS
- LAKES

FLOW TYPE

- CHANNEL
- SHALLOW CONCENTRATED
- OVERLAND/SHEET

NOTES

Watersheds were delineated using 1-meter contours developed from LiDAR data. 1-meter contours developed from 1-arc second NED were used where LiDAR data is not available.

REFERENCES

Digital 1-Meter Contour Data (Developed from LiDAR Data) from the City of Nanaimo, 2009.

1/3-Arc Second and 1-Arc Second National Elevation Datasets (NED) from the U.S. Geological Survey (USGS), 2009.

Digital Storm Drainage Infrastructure Data from the City of Nanaimo, 2012.

250 0 250 500 Meters

REV.	DATE	DES	REVISION DESCRIPTION	GIS	CHK	RVW

PROJECT

CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, BC, CANADA

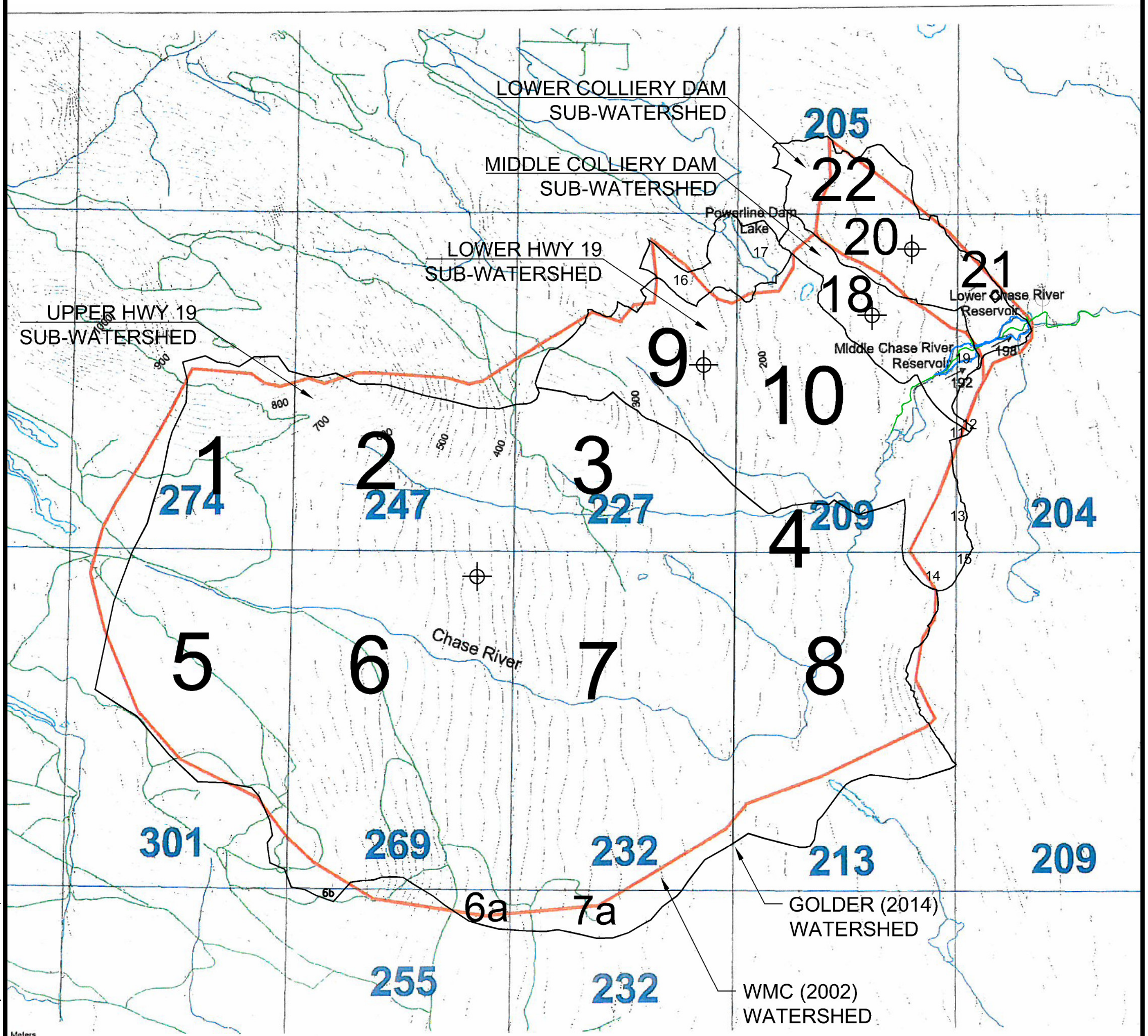
TITLE

COLLIERY DAMS
FLOW PATHS

PROJECT No.		1314470516	FILE No.
DESIGN			SCALE: 1 cm = 250 m REV. 0
GIS	JCD	2/4/2014	
CHECK	JKM	2/4/2014	**FIGURE 4**
REVIEW	GWH	2/7/2014	

Golder Associates
Atlanta, GA

Document Path: Q:\GIS\Nanaimo\1314470516_Colliery Dams\Projects\FIGURE 4 Flowpaths.mxd



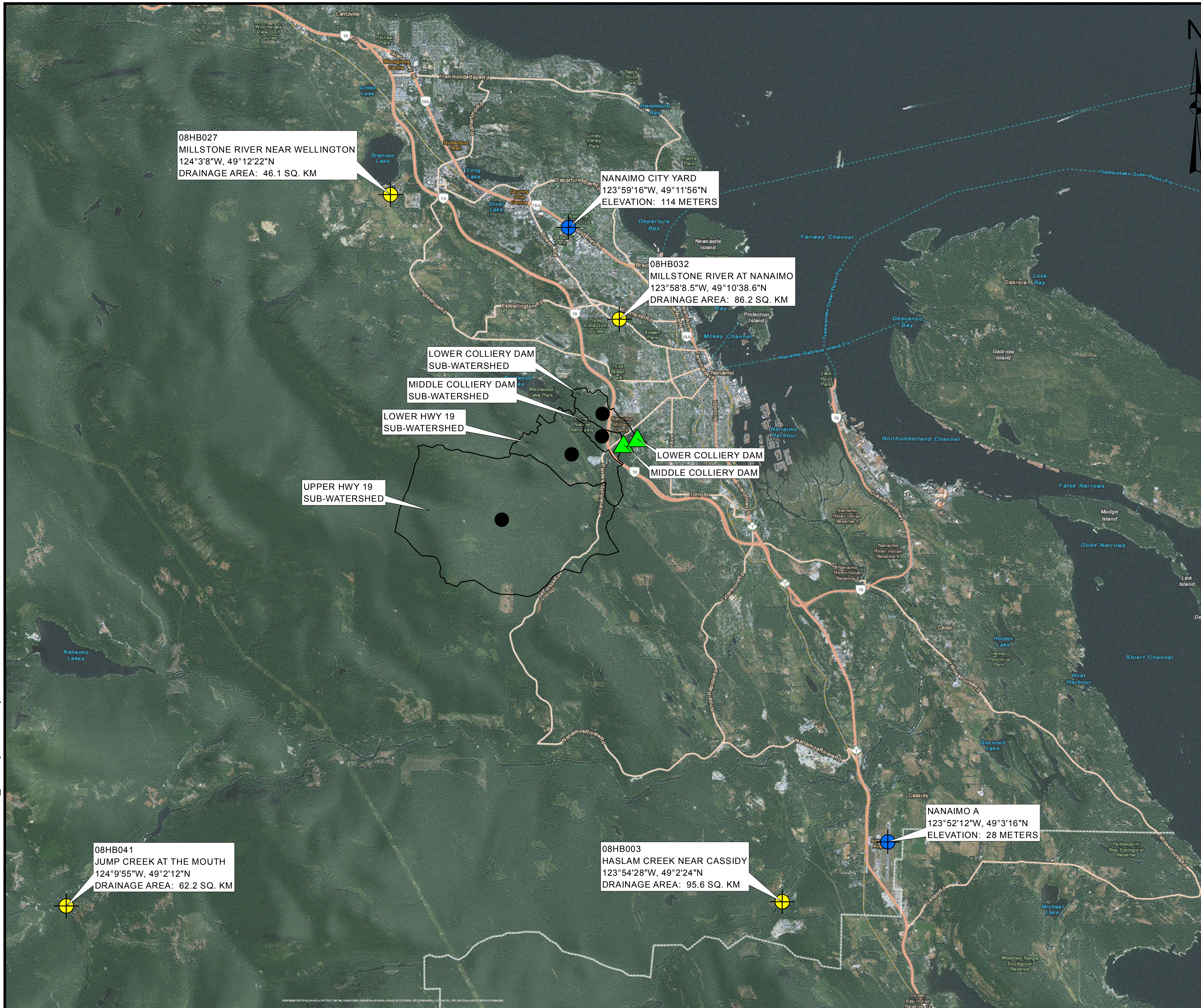
LEGEND

5 SECTION ID

301 PMP ESTIMATE (MM) FROM WMC

REFERENCE:
PMP GRID FROM CDN WATER MANAGEMENT CONSULTANTS INC (WMC) REGIONAL PMP STUDY (2002)

PROJECT	MIDDLE AND LOWER COLLIERY DAMS CITY OF NANAIMO, BC			
TITLE	**PROBABLE MAXIMUM PRECIPITATION RAINFALL ESTIMATE MAP**			
Golder Associates	PROJECT No.	1314470516	FILE No.	PMP Estimates-v04
	DESIGN	-	-	SCALE NTS
	CADD	RJC	02/14	
	CHECK	JKM	02/14	**FIGURE 5**
	REVIEW	GWH	02/14	



LEGEND

- SUB-WATERSHED CENTROID
- HYDROMETRIC STATION FOR BASE FLOW
- HYDROMETRIC STATION FOR RAINFALL
- DAM LOCATION

NOTES

Watersheds were delineated using 1-meter contours developed from LiDAR data. 1-meter contours developed from 1-arc second NED were used where LiDAR data is not available.

REFERENCES

Historical Data & Station Information, Available Online from the Water Survey of Canada (WSC).

Esri Map Service, World Boundaries and Places, Dec 2013.

Esri Map Service, World Imagery, Nov 2013.

Esri Map Service, World Transportation, Aug 2013.

REV.	DATE	DES	REVISION DESCRIPTION	GIS	CHK	RVW

PROJECT

CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, BC, CANADA

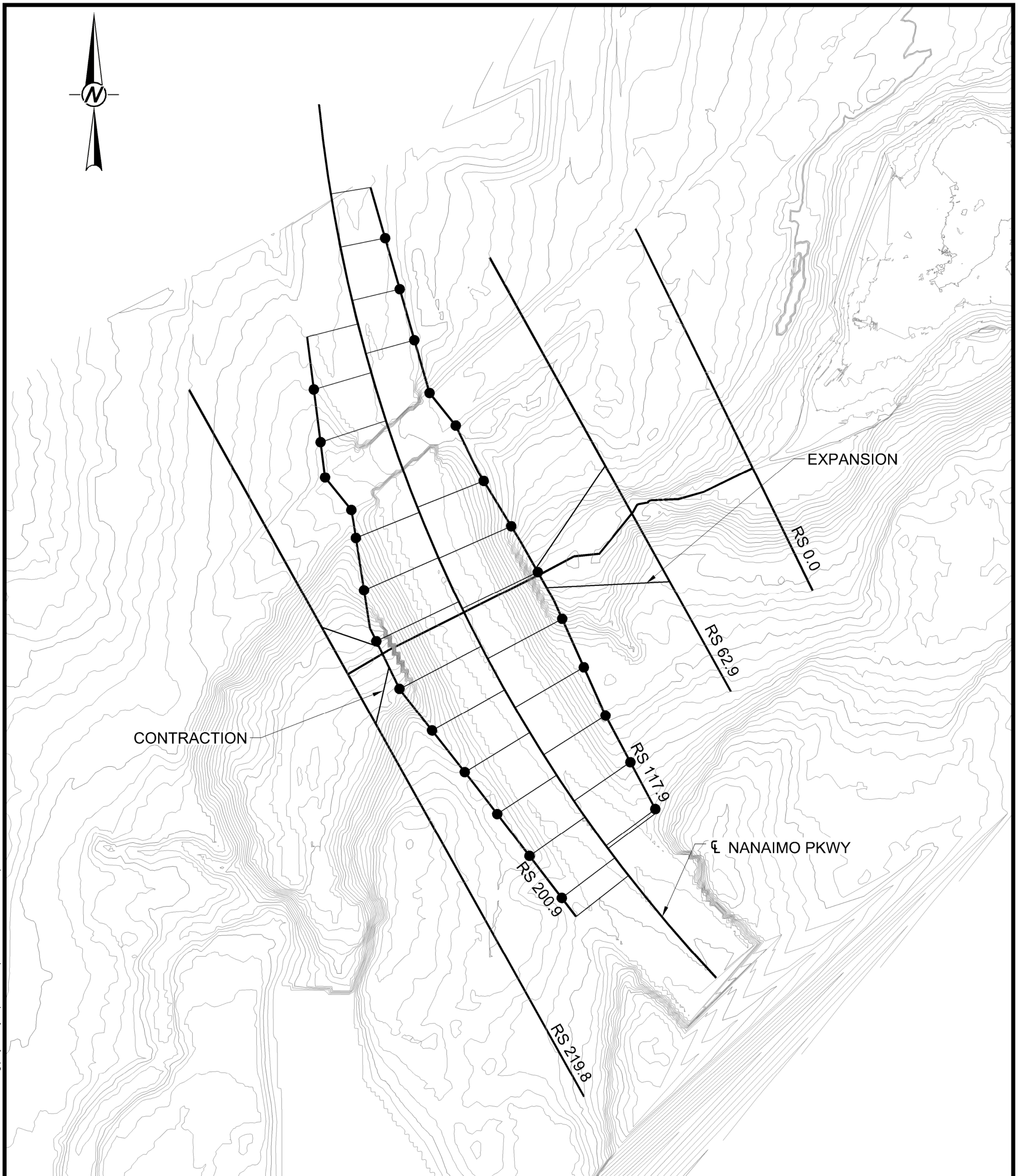
TITLE

COLLIERY DAMS
HYDROMETRIC STATIONS

Golder Associates
Atlanta, GA

PROJECT No.		1314470516	FILE No.
DESIGN			SCALE: NTS REV. 0
GIS	JCD	2/5/2014	**FIGURE 6**
CHECK	JKM	6/18/2014	
REVIEW	GWH	6/20/2014	

Document Path: Q:\GIS\Nanaimo\1314470516_Colliery Dams\Projects\FIGURE 6 Stations.mxd



PROJECT

MIDDLE AND LOWER COLLIERY DAMS
CITY OF NANAIMO, BC

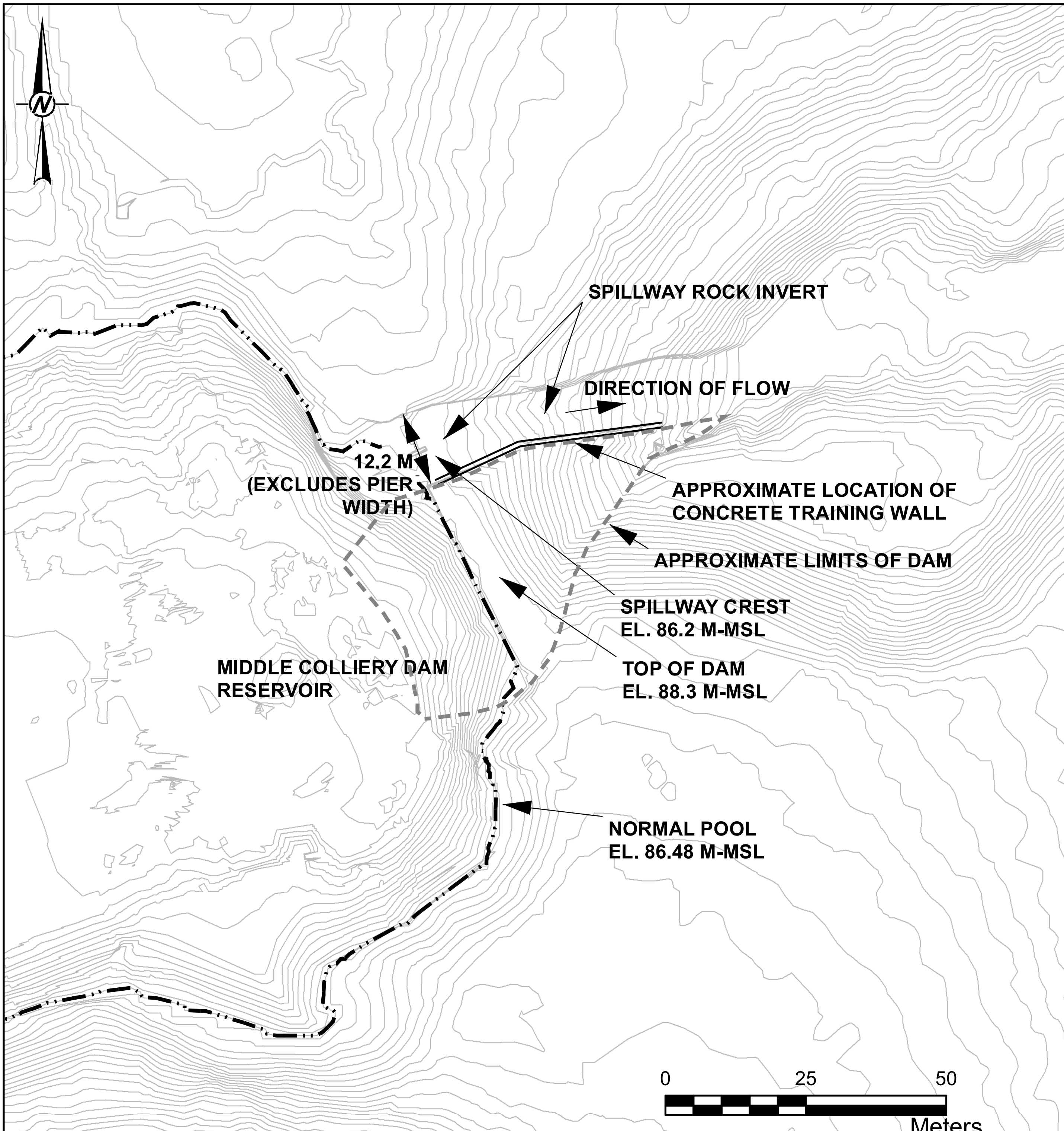
TITLE

NANAIMO PKWY
RATING CURVE
HEC-RAS MODEL EXHIBIT

Golder Associates

PROJECT No.		1314470516	FILE No.	1314470516-HEC-RAS
DESIGN	-	-	SCALE	AS SHOWN
CADD	RJC	02/14		
CHECK	JKM	02/14	**FIGURE 7**	
REVIEW	GWH	02/14		

X:\Clients\Nanaimo\1314470516_Colliery Dams\600_Calculations\HEC-RAS\1314470516-HEC-RAS.dwg | Layout: Layout | Modified: ccpowell 06/19/2014 3:23 PM | Plotted: JCDavis 07/09/2014



LEGEND

APPROXIMATE EXTENTS OF NORMAL POOL

CONTOURS

NOTES

REPRESENTATIVE CROSS SECTIONS WERE DEVELOPED USING 1-METER CONTOURS DEVELOPED FROM LIDAR DATA.

REFERENCE

1-METER CONTOUR DATA FROM PLAN DRAWINGS PREPARED BY KLOHN CRIPPEN BERGER, PROVIDED BY THE CLIENT.

CLIENT
CITY OF NANAIMO
NANAIMO, BC, CANADA

PROJECT
COLLIERY DAMS

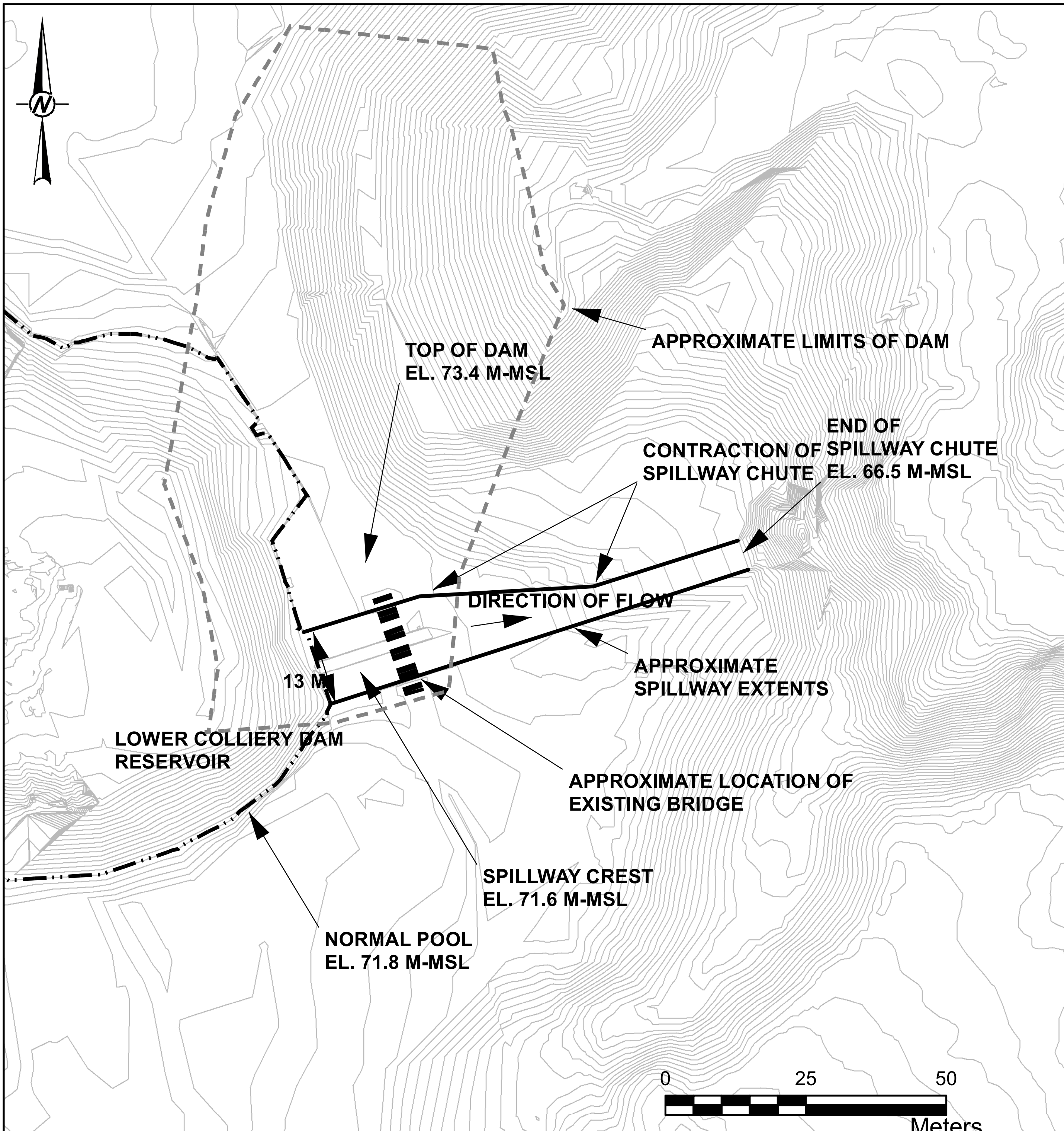
TITLE
MIDDLE COLLIERY DAM
SPILLWAY GEOMETRY FOR RATING CURVE

CONSULTANT

Golder Associates

YYYY-MM-DD	2014-06-20
PREPARED	JCD
DESIGN	N/A
REVIEW	JKM
APPROVED	GWH

PROJECT	CONSULTANT	Rev.	
1314470516	GOLDER ASSOCIATES INC		**FIGURE 8**



LEGEND

APPROXIMATE EXTENTS OF NORMAL POOL

CONTOURS

NOTES

REPRESENTATIVE CROSS SECTIONS WERE DEVELOPED USING 1-METER CONTOURS DEVELOPED FROM LIDAR DATA.

REFERENCE

1-METER CONTOUR DATA FROM PLAN DRAWINGS PREPARED BY KLOHN CRIPPEN BERGER, PROVIDED BY THE CLIENT.

CLIENT
CITY OF NANAIMO
NANAIMO, BC, CANADA

PROJECT
COLLIERY DAMS

TITLE
LOWER COLLIERY DAM
SPILLWAY GEOMETRY FOR HEC-RAS RATING CURVE

CONSULTANT

Golder Associates

YYYY-MM-DD	2014-06-20
PREPARED	JCD
DESIGN	N/A
REVIEW	JKM
APPROVED	GWH

PROJECT 1314470516 — CONSULTANT GOLDER ASSOCIATES INC — Rev.

FIGURE 9

Path: Q:\GIS\Nanaimo\1314470516_Colliery Dams\Projects\FIGURE 9 Lower Dam.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM:

25mm

Document Path: Q:\GIS\Nanaimo\1314470516_Colliery Dams\Projects\FIGURE 12 Middle Breach Inundation Map.mxd

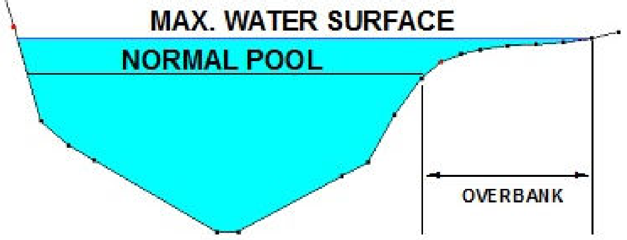
LEGEND

- APPROXIMATE EXTENTS OF NORMAL POOL
- CONTOURS
- CHASE RIVER
- CROSS SECTION
- BREACH ZONE
- ROAD

8+64 CROSS SECTION STATION

0.2 m/s AVERAGE VELOCITY
+1.1 m MAXIMUM WATER SURFACE RISE

0.0 m/s AVERAGE OVERBANK FLOOD VELOCITY
0.71 m AVERAGE OVERBANK FLOOD DEPTH



NOTES

Breach inundation zone was determined using 1-meter contours developed from LiDAR data.

REFERENCES

1-Meter Contour Data From Plan Drawings Prepared by Klohn Crippen Berger, Provided by the Client.

Digital Transportation Data from the City of Nanaimo, Accessed January 15, 2014.

Esri Map Service, World Imagery, Nov 2013.

The methods used to develop the inundation zone and floodwave arrival time are approximate and should only be used as a guidance. Actual areas inundated will depend on failure and pre-failure hydrologic conditions, and may differ significantly from the information shown on these maps.

The inundation zone was established using a breach hydrograph of the Middle Colliery Dam, provided by Associated Engineers (AE).

0 25 50 75 Meters

REV.	DATE	DES	REVISION DESCRIPTION	GIS	CHK	RVW

PROJECT
CITY OF NANAIMO
COLLIERY DAMS
NANAIMO, BC, CANADA

TITLE
**MIDDLE COLLIERY DAM
BREACH INUNDATION MAP**

Golder Associates
Atlanta, GA

PROJECT No.		1314470516	FILE No.
DESIGN			SCALE: 1 cm = 15 m REV. 0
GIS	JCD	6/19/2014	
CHECK	JKM	6/19/2014	**FIGURE 12**
REVIEW	GWH	6/20/2014	

APPENDIX A

Colliery Dams Soil Groups

Golder Associates

CALCULATIONS

Date:	01/31/2014	**Made By:**	MTC
Project No.:	1314470516	**Checked By:**	JKM
Subject	Hydrologic Soil Groups (HSG)	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

HYDROLOGIC SOIL GROUPS (HSG)

Method

The purpose of this analysis is to determin the Hydrologic Soil Group for soils within the watershed using available soils data for runoff estimation using the NRCS Curve Number method. NRCS NEH-630 defines HSG by corresponding quantitative saturated permeability, and the depth to an impermeable layer or water table. The soil survey, however, specifies qualitative descriptors for permeability and drainage only. No quantitative definitions are provided. Therefore, the qualitative descriptors were assigned to each NEH-630 permeability category based on the distribution and number of qualitative descriptors used. Some overlap of the quantitative groups in NEH-630 Tables 7-1 and 7-2 exist between the assigned Moderate and Slow permeability descriptors, introducing some uncertainty between the ultimate HSG chosen.

References

[1] BC Ministry of Environment (1985), *MOE Technical Report 17, Soils of Southern Vancouver Island, Report No. 44, British Columbia Soil Survey.*

[2] NRCS (2007), *Part 630 Hydrology, National Engineering Handbook, Chp 7 Hydrologic Soil Groups* , 210-VI-NEH.

HSG Criteria

Permeability[A] Designations used in the Source [1]:	**Drainage[B] Designations used in the Source [1]:**
Very Rapid	Rapidly
Rapid, or very permeable	Well
Moderate	Moderately
Slow	Poorly
Very Slow	Very Poorly

See qualitative permeability designators listed under Tables 7-1 and 7-2 from Source [2] for distribution of the applicable permeability categories.

Table 7-1 used for soils with shallow impervious layers, high water table, or poorly to very poorly drained soils indicating a potential high water table.

Table 7-2 used for soils with no impervious layer, low water table, or rapidly to moderately drained soils indicating expected low water tables.

Definitions: A. Permeability: The ease with which gases and liquids penetrate or pass through a bulk mass of soil or a layer of soil.

B. Drainage: The rapidity and extent of the removal of water from the soil by runoff and flow through the soil to underground spaces.

Golder Associates

CALCULATIONS

Date:	01/31/2014	**Made By:**	MTC
Project No.:	1314470516	**Checked By:**	JKM
Subject	Hydrologic Soil Groups (HSG)	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Tables from Source [2]

Table 7–1 Criteria for assignment of hydrologic soil groups when a water impermeable layer exists at a depth between 50 and 100 centimeters [20 and 40 inches]

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>40.0 μm/s (>5.67 in/h)	≤40.0 to >10.0 μm/s (≤5.67 to >1.42 in/h)	≤10.0 to >1.0 μm/s (≤1.42 to >0.14 in/h)	≤1.0 μm/s (≤0.14 in/h)
	and	and	and	and/or
Depth to water impermeable layer	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	<50 cm [<20 in]
	and	and	and	and/or
Depth to high water table	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	<60 cm [<24 in]
Permeability:	**Very Rapid**	**Rapid**	**Moderate**	**Slow**

Table 7–2 Criteria for assignment of hydrologic soil groups when any water impermeable layer exists at a depth greater than 100 centimeters [40 inches]

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>10 μm/s (>1.42 in/h)	≤10.0 to >4.0 μm/s (≤1.42 to >57 in/h)	≤4.0 to >0.40 μm/s (≤0.57 to >0.06 in/h)	≤0.40 μm/s (≤0.06 in/h)
	and	and	and	and/or
Depth to water impermeable layer	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]
	and	and	and	and/or
Depth to high water table	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]
Permeability:	**Rapid**	**Moderate**	**Slow**	**Very Slow**

Golder Associates

CALCULATIONS

Date:	01/31/2014	**Made By:**	MTC
Project No.:	1314470516	**Checked By:**	JKM
Subject	Hydrologic Soil Groups (HSG)	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

HSG Assignment

Symbol	Name	Description (Source [1])
HL	Hiller	Gravelly to very gravelly loamy sand Bedrock at 10 to 50 centimeters
Q	Quailicum	Gravelly to very gravelly loamy sand Loose sand at considerable depth, no water table within 3 meters
QN	Quinsam	Gravelly loamy sand to gravelly sandy loam Strongly cemented at 70 to 120 cm, with lateral water movement Unweathered very compact at 120 to 150 cm
RB	Robertson	Gravelly loam to cobbly, very gravelly sandy loam Bedrock at 50 to 100 cm
RL	Roswall	Gravelly to very gravelly sandy loam Bedrock at 50 to 100 cm
S	Shawnigan	Gravelly to very gravelly sandy loam Strongly cemented at 70 to 110 cm, with lateral water movement unweathered very compact at 110 to 130 cm

Symbol	Permeability[1]	Drainage[1]	Table	HSG Assigned[2]	Notes
HL	No Information	Rapid	7-1	B	Assume rapid permeability based on drainage, and very gravel sand texture
Q	Rapid	Rapid	7-2	A	HSG A is justified for Loose sand texture.
QN	Moderate	Well	7-1	C	
RB	No Information	Well	7-1	C	Assume moderate permeability based on drainage, and loam texture.
RL	No Information	Rapid	7-1	B	Assume rapid permeability based on drainage, and sandy loam texture.
S	Moderate	Well	7-1	C	

Where multiple soil types are specified, weighted curve numbers should be chosen based on the percentage of each type of soil present.

Notes:
1. Source [1]
2. Assigned by analyzing data in Source [1] with Source [2]

APPENDIX B

Curve Numbers

Golder Associates

CALCULATIONS

Date:	February 3, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Curve Number Calculation	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

CURVE NUMBERS

WATERSHED		AREA (sq. km)	ARC-II CN	ARC-III CN
1	Upper Hwy 19	16.04	69	84
2	Lower Hwy 19	3.33	67	83
3	Middle Colliery	0.64	63	80
4	Lower Colliery	1.04	68	84
Composite		21.06	68	84

Converted to ARC-III using Table 10-1, in NEH-630 (2004).

Watershed Details

Watershed 1

LAND USE	HSG	FUTURE CN	AREA (sq. km)	CN x A (sq. km)
Highway Right-of-Way	A	57	0.00	0
	B	72	0.00	0
	C	81	0.00	0
Neighbourhood	B	70	0.00	0
	C	80	0.00	0
Open Space	A	39	0.01	0
	C	74	0.02	1
Parks	A	25	0.00	0
	B	55	0.00	0
	C	70	0.00	0
Resource	A	33	0.84	28
	B	60	2.31	139
	C	73	12.87	940
Urban	C	94	0.00	0
Water		100	0.00	0
TOTAL			16.04	1107

Watershed 2

LAND USE	HSG	FUTURE CN	AREA (sq. km)	CN x A (sq. km)
Highway Right-of-Way	A	57	0.00	0
	B	72	0.00	0
	C	81	0.01	0
Neighbourhood	B	70	0.03	2
	C	80	0.08	6
Open Space	A	39	0.02	1
	C	74	0.23	17
Parks	A	25	0.00	0
	B	55	0.28	15
	C	70	0.20	14
Resource	A	33	0.14	5
	B	60	0.82	49
	C	73	1.45	106
Urban	C	94	0.00	0
Water		100	0.07	7
TOTAL			3.33	223

Assumptions and References

- Highway Right-of-Way is 30% impervious and 70% open space with good cover.
- Neighbourhood is a residential district with average lot size of 1/2 acre (25% impervious).
- Open Space cover is good.
- Parks are wooded with good cover.
- Resource areas are 70% woods with good cover, 25% open space with fair cover, and 5% bare earth to account for future resource development and management.
- Urban areas are commercial/business districts.
- Existing cover was determined from aerial photos from the City of Nanaimo (2009 & 2012).
- Future land use within the Middle and Lower Chase River Dam watersheds was determined from future land use maps: Map One of the City of Nanaimo's Official Community Plan (2008) and Map Two of the Arrowsmith Benson - Cranberry Bright Official Community Plan (1999).

Golder Associates

CALCULATIONS

Date:	February 3, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Curve Number Calculation	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Watershed 3

Highway Right-of-Way	A	57	0.02	1
	B	72	0.00	0
	C	81	0.08	6
Neighbourhood	B	70	0.02	2
	C	80	0.01	1
Open Space	A	39	0.00	0
	C	74	0.00	0
Parks	A	25	0.07	2
	B	55	0.32	18
	C	70	0.01	1
Resource	A	33	0.00	0
	B	60	0.00	0
	C	73	0.00	0
Urban	C	94	0.08	8
Water		100	0.02	2
TOTAL			0.64	40

Watershed 4

Highway Right-of-Way	A	57	0.00	0
	B	72	0.05	3
	C	81	0.08	6
Neighbourhood	B	70	0.10	7
	C	80	0.00	0
Open Space	A	39	0.00	0
	C	74	0.00	0
Parks	A	25	0.06	2
	B	55	0.15	8
	C	70	0.01	1
Resource	A	33	0.00	0
	B	60	0.37	22
	C	73	0.00	0
Urban	C	94	0.20	19
Water		100	0.02	2
TOTAL			1.04	71

• Curve numbers are chosen from Tables 2.2a and 2.2c in NRCS TR-55.
• Future cover for Park areas and Resource Protection areas will remain the same as the existing cover.
• Areas outside of the City of Nanaimo will remain Resource areas.

APPENDIX C

Time of Concentrations

Golder Associates

CALCULATIONS

Date:	1/31/2014	**Made by:**	ADD
Project No.:	1314470516	**Checked by:**	JKM
Subject:	Time of Concentration	**Reviewed by:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

TIME OF CONCENTRATION

Golder calculated the time of concentration for the watershed using the SCS travel time method and formulas from the TR-55 Urban Hydrology Manual. The following tables summarize the results for sheet flow, shallow concentrated flow, and channel flow in each sub-watershed. Inputs include the surface condition (roughness coefficient), the longest flow length, upstream and downstream elevations along with an assumed bottom width, normal depth, and side slope for channel flow. The longest flow paths were delineated and measured within Esri's ArcMap 10.1 software program using 1-meter contours developed from LiDAR data (public dataset available from the City of Nanaimo). 1-meter contours developed from 1-arc second NED (public dataset available from the USGS) were used where LiDAR data is not available. Flow paths were divided into sheet flow, shallow concentrated flow, and channel flow segments using the following equations. Maximum overland flow length is assumed to be 150 feet (46 meters), and shallow concentrated flow is considered to occur after 150 feet of overland flow up until the point where natural channel flow or constructed channel flow begins. All channels are assumed to be trapezoidal with 3H:1V sideslopes.

Formulae:

Average Flow Path Slope

$$S = \frac{E_1 - E_2}{L}$$

where:

S = Average land slope, ft/ft
E1 = Upstream elevation, ft
E2 = Downstream elevation, ft
L = Flow length, ft

Travel Time for Sheet Flow

$$Tt = \frac{0.007\ (nL)^{0.8}}{(P_2)^{0.5}\ S^{0.4}}$$

Tt = Travel time, hr
***n* =** Manning's roughness coefficient
L = Flow length, ft
P2 = 2-year, 24-hour rainfall, in.
S = Slope, ft/ft

Golder Associates

CALCULATIONS

Date: 1/31/2014 **Made by:** ADD

Project No.: 1314470516 **Checked by:** JKM

Subject: Time of Concentration **Reviewed by:** GWH

Project Short Title: Nanaimo/Colliery Dams/Nanaimo, BC

Travel Time for Unpaved Shallow Concentrated Flow and Channel Flow

$$T_t = \frac{L}{3600\,V}$$

Tt = Travel time, hr
L **=** Flow length, m
V = Average Velocity, m/s

Average Velocity for Unpaved Concentrated Shallow Flow

$$V = 4.918\,(S)^{0.5}$$

V = Average Velocity, m/s
V = Slope, m/m

Average Velocity for Channel Flow (Manning's Equation)

$$V = \frac{1.0}{n}\,R^{2/3}\,S^{1/2}$$

V = Average velocity, m/s
n = Manning's roughness coefficient
R = Hydraulic radius = A/P, m
P = Wetted perimeter, m
S = Slope of hydraulic surface, m/m

<u>Time of Concentration:</u>

Sheet/Overland Flow Travel Time

Sub-Watershed	SHEET/OVERLAND FLOW								
	2-year 24-hour (mm)	2-year 24-hour (in)	Surface Condition	Roughness Coef. (imperial)	Flow Path Length (m)	Upstream Elevation (m)	Downstream Elevation (m)	Slope (m/m)	Travel Time (hour)
Upper Hwy 19	70.3	2.77	Woods: Light underbrush	0.40	46	703	700	0.065	0.333
Lower Hwy 19	60.8	2.39		0.40	46	397	394	0.065	0.358
Middle Colliery	58.9	2.32		0.40	46	221	210	0.239	0.217
Lower Colliery	58.3	2.30		0.40	46	207	200	0.152	0.261

Notes:
Maximum overland flow length is assumed to be 150 feet (46 meters).

Golder Associates

CALCULATIONS

Date: 1/31/2014 **Made by:** ADD

Project No.: 1314470516 **Checked by:** JKM

Subject: Time of Concentration **Reviewed by:** GWH

Project Short Title: Nanaimo/Colliery Dams/Nanaimo, BC

Shallow Concentrated Flow Travel Time

Sub-Watershed	SHALLOW CONCENTRATED FLOW						
	Surface Condition	Flow Path Length (m)	Upstream Elevation (m)	Downstream Elevation (m)	Slope (m/m)	Velocity (m/s)	Travel Time (hour)
Upper Hwy 19	Unpaved	1129	700	600	0.089	1.46	0.214
Lower Hwy 19		523	394	303	0.174	2.05	0.071
Middle Colliery		214	210	200	0.047	1.06	0.056
Lower Colliery		674	200	170	0.045	1.04	0.180

Notes:
Shallow concentrated flow is considered to occur after 150 feet (46 meters) of overland flow up until the point where natural channel flow or constructed channel flow exists.

Channel Flow Travel Time and Total Time of Concentration

Sub-Watershed (Channel)	CHANNEL FLOW											
	Mannings n	Assumed Bottom Width (m)	Assumed Avg. Depth (m)	Assumed Channel Sideslope	Assumed Hydraulic Radius (m)	Flow Path Length (ft)	U/S Elevation (m)	D/S Elevation (m)	Slope (m/m)	Velocity (m/s)	Travel Time (hour)	Flow Q (m^3/s)
Upper Hwy 19 (C1)	0.1630	0.3	1.00	3	0.5	3027	600	225	0.124	1.36	0.620	4.48
Upper Hwy 19 (C2)	0.1142	0.5	1.25	3	0.6	1361	225	152	0.054	1.49	0.253	7.94
Upper Hwy 19 (C3)	0.0663	1	1.75	3	0.9	2012	152	122	0.015	1.73	0.324	18.88
Lower Hwy 19 (C1)	0.1577	0.3	0.50	3	0.3	1832	303	145	0.086	0.76	0.671	0.68
Lower Hwy 19 (C2)	0.1205	0.5	0.70	2	0.4	611	122	92	0.049	0.94	0.180	1.25
Lower Hwy 19 (C3)	0.0819	1.5	1.75	3	0.9	1136	122	92	0.026	1.90	0.166	22.50
Middle Colliery (C1)	0.1379	0.5	0.40	3	0.2	1982	200	87	0.057	0.64	0.861	0.43
Lower Colliery (C1)	0.1403	1	0.50	3	0.3	1469	170	71	0.067	0.83	0.492	1.04

Notes:
All channels are assumed to be trapezoidal
Manning's n values calculated using Jarrett's Equation: $n = 0.39S^{0.38}R^{-0.16}$
Assumed average depths were determined by iterating between travel time and channel flow using the U.S. Army Corps of Engineers' HEC-HMS software.

Total Time of Concentration and Lag Time

Sub-Watershed	CUMULATIVE FLOW		
	Time of Conc. (hour)	Time of Conc. (min)	Lag Time (min)
Upper Hwy 19	1.74	105	63
Lower Hwy 19	1.45	87	52
Middle Colliery	1.13	68	41
Lower Colliery	0.93	56	34

APPENDIX D
Rainfall

Golder Associates — CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

RAINFALL

Rainfall over the Colliery Dams watershed was modeled with a SCS Type IA distribution. Rainfall depths for the 24-hour Probable Maximum Precipitation (PMP) and other 24-hour duration storm events were determined using methodology described herein.

Probable Maximum Precipitation

Rainfall over the Colliery Dams watershed was modeled with a SCS Type IA distribution. Rainfall depths for the 24-hour PMP were based on the regional PMP study performed by CDN Water Management Consultants Inc (WMC) for BC Hydro (2002). This study is based on methodolgy described in HMR-57 and estimates the 24-hour PMP for 1.25 minute longitude and latitude grid cells throughout southwestern British Columbia (WMC, 2002). The PMP grid was used in conjunction with Autodesk's AutoCAD Civil 3D 2014, as depicted in the attached figure, to assign composite rainfall depths for the 24-hour PMP for each sub-watershed. The following table summarizes how each sub-watershed was divided into smaller sections and corresponding PMP values in order to calculate a composite PMP for each sub-watershed.

Composite PMP for Colliery Dams Sub-Watersheds

Sub-Watershed	Section ID	Area (sq. m)	24-hr, PMP (mm)	
Upper Hwy 19	1	1,104,435	274	
	2	1,664,794	247	
	3	1,380,172	227	
	4	366,637	209	
	5	1,849,313	301	
	6	3,504,223	269	
	6a	106,843	255	
	6b	16,242	255	
	7	3,442,050	232	
	7a	305,157	232	
	8	2,302,213	213	
	Total	16,042,079	**249.0**	*Composite PMP*
Lower Hwy 19 (Includes Powerline Lake)	9	1,021,425	227	
	10	1,890,611	209	
	11	4,907	204	
	13	29,270	204	
	14	74,886	213	
	15	8,422	209	
	16	181,055	227	
	17	135,720	209	
	Total	3,346,296	**215.5**	*Composite PMP*
Middle Colliery	12	5,095	204	
	18	586,529	209	
	19	48,921	204	
	Total	640,544	**208.6**	*Composite PMP*
Lower Colliery	20	445,523	209	
	21	202,808	204	
	22	403,722	205	
	Total	1,052,053	**206.5**	*Composite PMP*

CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Rainfall During Other Storm Events

Rainfall depths for 24-hour duration storm events ranging from 2-year to 50,000-year frequencies were determined by developing an Intensity-Duration-Frequency curve for each sub-watershed through a comparative analysis described in this section.

1. Verify that rainfall data generated from Climate BC software is consistent with rainfall data for nearby hydrometric stations (archived data from Environment Canada) so that Climate BC can be utilized for the entirety of this analysis.

2. Determine and compare ratios between known PMP values and Climate BC total rainfall values; if similarities exist, the same methodology will be applied in the following step.

3. Determine ratios of total rainfall between the centroids of the sub-watersheds and the nearby hydrometric stations.

4. Apply ratios to adjust the station specific IDF curves and generate an alternate IDF curve for each sub-

1. Compare Rainfall Data from Climate BC and Environment Canada

IDF curves and average total monthly rainfall data are available as online archived data from Environment Canada for two nearby hydrometric stations - Nanaimo City Yard and Nanaimo A. The average total monthly rainfall from Environment Canada was compared to average monthly rainfall downloaded from the Centre for Forest Conservation Genetics' (CFCG) Climate BC, software designed to generate high-resolution climate data in British Columbia and western North America, at the location of the two hydrometric stations. The table below compares the average total monthly rainfalls from Environment Canada and Climate BC. The rainfall data extracted from the Climate BC software is consistent with the rainfall data from Environment Canada; therefore, Climate BC was utilized for the remainder of this analysis.

Average Monthly Rainfall (mm) at Hydrometric Stations

	Nanaimo City Yard Elevation: 114 m		Nanaimo A Elevation: 28 m	
Month	**Environment Canada (1971-2000)**	**Climate BC (1971-2010)**	**Environment Canada (1971-2000)**	**Climate BC (1971-2000)**
January	163.4	152	141.7	160
February	121.4	122	122.5	127
March	109.6	113	106.3	115
April	68.9	70	62.9	64
May	55.5	62	49.9	51
June	50.8	52	44.9	46
July	26.8	27	25.9	24
August	29.7	28	31.6	30
September	34.8	42	38.5	39
October	98.5	93	97.0	96
November	184.4	190	190.5	187
December	154.8	159	166.4	187
Annual	**1,098.6**	**1,110**	**1,078.1**	**1,126**

Golder Associates

CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

2. Determine and Compare Ratios Between Known PMPs and Total Rainfall

After the rainfall data downloaded from Climate BC was verified, the remaining monthly and seasonal rainfall data was extracted from the location of the centroid of each of the four sub-watersheds, the Nanaimo City Yard station, and the Nanaimo A station. Ratios of rainfall at each sub-watershed to rainfall at each hydrometric station were calculated later in this analysis. Before establishing relationships between rainfall at each of the sub-watersheds and the hydrometric stations, a check of this methodology was performed.

Rainfall data was downloaded from Climate BC at locations within the Colliery Dams watershed with known PMP values (associated with the sub-watershed sections previously described). Ratios of the PMP values were used to check the ratios of average rainfall between each location. Rainfall data was downloaded and PMP values were determined at the location of the centroid of each sub-watershed and at a location immediately downstream of the Lower Colliery Dam (Lower Dam). Ratios of seasonal and annual total rainfall between the centroids and Lower Dam were calculated and compared to ratios of PMP values between the centroids and Lower Dam. The following tables provides a summary of the test results. The rainfall ratios are similar to the PMP ratios; therefore, ratios of total rainfall between sub-watersheds and hydrometric stations in the Nanaimo area will be used to determine rainfall depths for specific storm events.

Comparison of Total Rainfall and PMP Ratios

Location		Spring	Summer	Autumn	Winter	Annual
Lower Dam Elevation: 67 m	Total Rainfall* (mm)	237	104	315	430	1086
	PMP (mm)	204				
Upper Hwy 19 Centroid Elevation: 402 m	Total Rainfall* (mm)	283	118	395	525	1321
	PMP (mm)	249				
	Rainfall Ratio to Lower Dam	1.19	1.13	1.25	1.22	1.22
	Average Rainfall Ratio	**1.20**				
	PMP Ratio to Lower Dam	**1.22**				

*Monthly Total Rainfall was determined from Climate BC software for locations at the center of each watershed and downstream of the Lower Dam. Seasonal Total Rainfall values for Spring, Summer, Autumn, and Winter were determined from cumulative rainfall for December through February, March through May, June through August, and September through November, respectively.

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CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Comparison of Total Rainfall and PMP Ratios Continued

Location		Spring	Summer	Autumn	Winter	Annual
Lower Hwy 19 Centroid Elevation: 250 m	Total Rainfall* (mm)	253	108	345	454	1160
	PMP (mm)	215.5				
	Rainfall Ratio to Lower Dam	1.07	1.04	1.10	1.06	1.07
	Average Rainfall Ratio	**1.07**				
	PMP Ratio to Lower Dam	**1.06**				
Middle Colliery Centroid Elevation: 167 m	Total Rainfall* (mm)	245	106	329	440	1121
	PMP (mm)	208.6				
	Rainfall Ratio to Lower Dam	1.03	1.02	1.04	1.02	1.03
	Average Rainfall Ratio	**1.03**				
	PMP Ratio to Lower Dam	**1.02**				

*Monthly Total Rainfall was determined from Climate BC software for locations at the center of each watershed and downstream of the Lower Dam. Seasonal Total Rainfall values for Spring, Summer, Autumn, and Winter were determined from cumulative rainfall for December through February, March through May, June through August, and September through November, respectively.

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CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Comparison of Total Rainfall and PMP Ratios Continued

Location		Spring	Summer	Autumn	Winter	Annual
Lower Colliery Centroid Elevation: 131 m	Total Rainfall* (mm)	242	105	323	435	1106
	PMP (mm)	206.5				
	Rainfall Ratio to Lower Dam	1.02	1.01	1.03	1.01	1.02
	Average Rainfall Ratio	**1.02**				
	PMP Ratio to Lower Dam	**1.01**				

*Monthly Total Rainfall was determined from Climate BC software for locations at the center of each watershed and downstream of the Lower Dam. Seasonal Total Rainfall values for Spring, Summer, Autumn, and Winter were determined from cumulative rainfall for December through February, March through May, June through August, and September through November, respectively.

3. Determine Ratios of Total Rainfall

Ratios of seasonal and annual total rainfall between the centroids of the sub-watersheds and the hydrometric stations were calculated and summarized in the following tables. The rainfall ratios will be used to determine rainfall depths for specific storm events. Determine ratios of total rainfall between the centroids of the sub-watersheds and the nearby hydrometric stations.

Average Seasonal and Annual Total Rainfall at Hydrometric Stations

Location		Spring	Summer	Autumn	Winter	Annual
Nanaimo City Yard Station Elevation: 114 m	Total Rainfall* (mm)	245	107	325	433	1110
Nanaimo A Station Elevation: 28 m	Total Rainfall* (mm)	230	100	321	474	1126

*Monthly Total Rainfall was determined from Climate BC software for locations of hydrometric stations. Seasonal Total Rainfall values for Spring, Summer, Autumn, and Winter were determined from cumulative rainfall for December through February, March through May, June through August, and September through November, respectively.

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CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Ratios of Average Season and Annual Total Rainfall

Location		Spring	Summer	Autumn	Winter	Annual
Upper Hwy 19 Centroid Elevation: 402 m	Total Rainfall* (mm)	283	118	395	525	1321
	Rainfall Ratio to Nanaimo City Yard	1.16	1.10	1.22	1.21	1.19
	Average Rainfall Ratio to Nanaimo City Yard	**1.18**				
	Rainfall Ratio to Nanaimo A	1.23	1.18	1.23	1.11	1.17
	Average Rainfall Ratio to Nanaimo A	**1.18**				
Lower Hwy 19 Centroid Elevation: 250 m	Total Rainfall* (mm)	253	108	345	454	1160
	Rainfall Ratio to Nanaimo City Yard	1.03	1.01	1.06	1.05	1.05
	Average Rainfall Ratio to Nanaimo City Yard	**1.04**				
	Rainfall Ratio to Nanaimo A	1.10	1.08	1.07	0.96	1.03
	Average Rainfall Ratio to Nanaimo A	**1.05**				

*Monthly Total Rainfall was determined from Climate BC software for locations at the center of each watershed. Seasonal Total Rainfall values for Spring, Summer, Autumn, and Winter were determined from cumulative rainfall for December through February, March through May, June through August, and September through November, respectively.

CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Ratios of Average Season and Annual Total Rainfall Continued

Location		Spring	Summer	Autumn	Winter	Annual
Middle Colliery Centroid Elevation: 167 m	Total Rainfall* (mm)	245	106	329	440	1121
	Rainfall Ratio to Nanaimo City Yard	1.00	0.99	1.01	1.02	1.01
	Average Rainfall Ratio to Nanaimo City Yard	**1.01**				
	Rainfall Ratio to Nanaimo A	1.07	1.06	1.02	0.93	1.00
	Average Rainfall Ratio to Nanaimo A	**1.01**				
Lower Colliery Centroid Elevation: 131 m	Total Rainfall* (mm)	242	105	323	435	1106
	Rainfall Ratio to Nanaimo City Yard	0.99	0.98	0.99	1.00	1.00
	Average Rainfall Ratio to Nanaimo City Yard	**0.99**				
	Rainfall Ratio to Nanaimo A	1.05	1.05	1.01	0.92	0.98
	Average Rainfall Ratio to Nanaimo A	**1.00**				

*Monthly Total Rainfall was determined from Climate BC software for locations at the center of each watershed. Seasonal Total Rainfall values for Spring, Summer, Autumn, and Winter were determined from cumulative rainfall for December through February, March through May, June through August, and September through November, respectively.

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CALCULATIONS

Date:	February 7, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rainfall	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

4. Apply Ratios of Total Rainfall to Known IDF Curves

The ratios for the winter season, the most critical season for strong storms, were applied to the rainfall depths of the Nanaimo City Yard station IDF curve in order to generate an IDF curve for each of the Colliery Dams sub-watersheds. The Nanaimo City Yard station IDF curve was chosen because the station is at a higher elevation that is more similar to the elevations within the Colliery Dams watershed. The following table summarizes calculated rainfall depths for each sub-watershed at specific storm events.

Rainfall Depths for Colliery Dams Sub-Watersheds

Return Period*,** (years)	24-hour Rainfall Depth (mm)								
	Nanaimo City Yard	Upper Hwy 19		Lower Hwy 19		Middle Colliery		Lower Colliery	
		Ratio	1.21	Ratio	1.05	Ratio	1.02	Ratio	1.00
2	58.0	70.3		60.8		58.9		58.3	
5	73.2	88.8		76.8		74.4		73.5	
10	83.3	101.0		87.3		84.6		83.7	
25	96.1	116.5		100.8		97.7		96.5	
50	105.6	128.0		110.7		107.3		106.1	
100	115.0	139.4		120.6		116.9		115.5	
200	125.7	152.3		131.7		127.7		126.2	
500	138.9	168.4		145.6		141.1		139.5	
1,000	148.9	180.5		156.1		151.3		149.6	
2,000	158.9	192.6		166.6		161.4		159.6	
5,000	172.1	208.7		180.4		174.9		172.9	
10,000	182.1	220.8		190.9		185.0		182.9	
50,000***	205.3	249.0		215.3		208.6		206.3	

*200-year storm events and higher are based on logarithmic extrapolation

**Return periods are extended to the PMP values presented in the previous section.

***50,000-year rainfall depths are very close to PMP rainfall depths.

APPENDIX E

Base Flow

Golder Associates

CALCULATIONS

Date:	February 5, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Base Flow	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

BASE FLOW

Four hydrometric stations with stream flow data from 1954 to 2012 (years on record varies for each station) were located near Nanaimo using online archived data available from the Water Survey of Canada (WSC). The average monthly mean base flow (cms) during the wet season (October - March) was determined for each of the four datasets and assigned a unit value (cms/sq. km). These unit values were averaged and used to establish an average monthly base flow for each sub-watershed. The following tables summarize the base flow results.

Average Monthly Mean Base Flow for Nanaimo Area Hydrometric Stations

Location	Station ID	Years on Record	Drainage Area (sq. km)	Average Monthly Mean (cms)	Average Monthly Mean (cms/sq. km)
HASLAM CREEK NEAR CASSIDY	08HB003	1954-1998	95.6	6.10	0.0638
MILLSTONE RIVER NEAR WELLINGTON	08HB027	1961-1974	46.1	2.45	0.0531
MILLSTONE RIVER AT NANAIMO	08HB032	1961-2012	86.2	4.09	0.0475
JUMP CREEK AT THE MOUTH	08HB041	1970-2011	62.2	6.81	0.1095
				Average Monthly Base Flow (cms/sq. km):	0.0685

Average Monthly Mean Base Flow applied to Colliery Dams Sub-Watersheds

Sub-Watershed		Drainage Area (sq. km)	Calculated Average Monthly Base Flow (cms)	Used Average Monthly Base Flow (cms)
Upper Hwy 19	1	16.04	1.0986	1.1
Lower Hwy 19	2	3.33	0.2281	0.3
Middle Colliery	3	0.64	0.0438	0.1
Lower Colliery	4	1.04	0.0712	0.1

APPENDIX F

Stage-Area-Storage Relationships

CALCULATIONS

Date:	February 5, 2014	**Made By:**	JCD/ADD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Stage-Area-Storage Relationships	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Stage-Area-Storage Relationships

Golder estimated the stage-area-storage relationships for the Middle and Lower Colliery reservoirs, as well as upstream of the culvert running under Highway 19. These surface areas were calculated using Autodesk's AutoCAD Civil 3D 2013 software, and storage volumes were calculated using the average-area-end method. Surface areas of the Lower and Middle Colliery reservoirs were derived from 0.5-meter and 1-meter contours, respectively, developed as part of an underwater sonar profiling survery performed by AquaCoustic Remote Technologies Inc in 2003. Surface areas measured beyond the Lower and Middle Colliery reservoirs and upstream of the Highway 19 culvert were derived from 1-meter contours (appear to have been created and derived from LiDAR data) as presented in plan drawings prepared by Klohn Crippen Berger. Results are given in the following tables and figures. The storage volumes corresponding to specific elevations of interest were determined by fitting a second-order polynomial trendline to the stage-storage data points of the Middle and Lower Colliery reservoirs (as presented in the following figures).

Stage-Area-Storage for the Middle Colliery Reservoir

Elevation (m-msl)	Area (sq m)	Volume (cu m)	
77.0	44	0	
77.5	277	80	
78.0	876	368	
78.5	2,238	1,147	
79.0	4,494	2,830	
79.5	4,494	5,077	
80.0	9,823	8,656	
80.5	11,745	14,048	
81.0	13,442	20,345	
81.5	14,477	27,325	
82.0	15,582	34,840	
82.5	16,519	42,865	
83.0	17,179	51,290	
84.0	18,550	69,154	
85.0	19,846	88,353	
86.0	21,043	108,797	
86.2		**114,547**	*Spillway Crest*
86.48		**121,064**	*
87.0	24,072	131,355	
88.0	26,493	156,637	
88.3		**168,151**	*Top of Dam*
89.0	28,945	184,356	
90.0	31,308	214,483	
91.0	34,757	247,515	

*Water surface elevation during the 2003 underwater sonar profiling survey

Golder Associates

CALCULATIONS

Date:	February 5, 2014	**Made By:**	JCD/ADD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Stage-Area-Storage Relationships	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Stage-Area-Storage for the Lower Colliery Reservoir

Elevation (m-msl)	Area (sq m)	Volume (cu m)	
61	1	0	
62	142	71	
63	1,493	889	
64	3,775	3,523	
65	6,727	8,774	
66	9,671	16,973	
67	12,623	28,120	
68	14,753	41,807	
69	17,088	57,728	
70	18,532	75,538	
71	19,572	94,590	
71.60		**108,850**	*Spillway Crest*
71.80		**113,639**	*
72	23,769	116,261	
73	28,996	142,644	
73.40		**154,681**	*Top of Dam*
74	33,383	173,834	

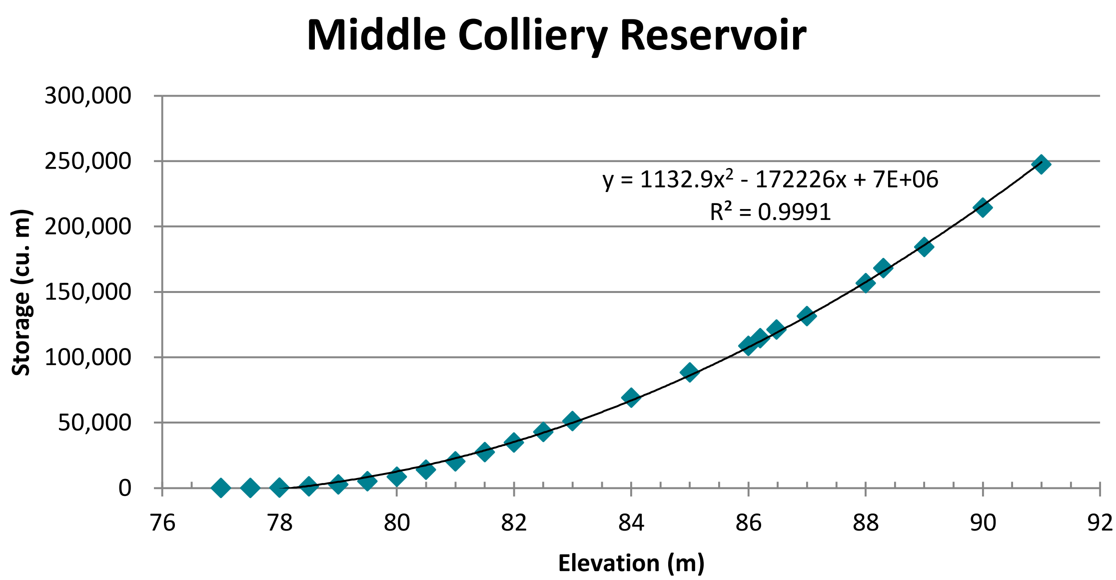
*Water surface elevation during the 2003 underwater sonar profiling survey

Stage-Area-Storage for Upstream of Culvert Passing Under Highway 19

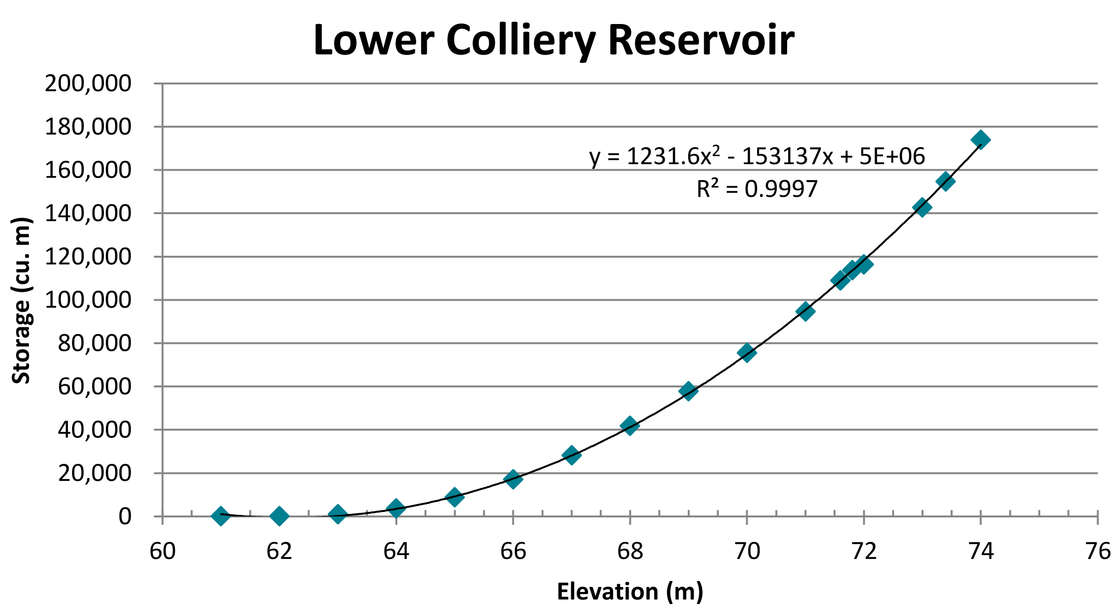
Elevation (m-msl)	Area (sq m)	Volume (cu m)	
92	78	0	
93	1,244	661	
94	3,103	2,834	
95	4,534	6,653	
96	5,747	11,793	
97	6,670	18,001	
98	7,434	25,053	
99	8,097	32,818	
100	8,725	41,230	
101	9,378	50,281	
102	10,039	59,990	
103	10,777	70,399	
104	11,454	81,514	
105	12,168	93,326	
106	13,032	105,926	
107	14,137	119,510	
108	30,356	**141,757**	*Spillway Crest (Nanaimo Lakes Road underpass)*
109	34,722	174,296	
110	39,414	211,364	
111	45,902	254,022	

CALCULATIONS

Date:	February 5, 2014	**Made By:**	JCD/ADD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Stage-Area-Storage Relationships	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		



Elevation-Storage Relationship for the Middle Colliery Reservoir



Elevation-Storage Relationship for the Lower Colliery Reservoir

APPENDIX G

Rating Curves

Golder Associates **CALCULATIONS**

Date:	06/16/2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rating Curves for Existing Conditions	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

RATING CURVES

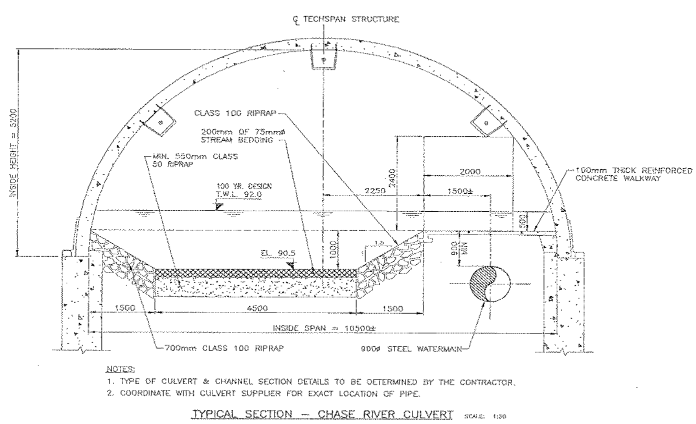
Nanaimo Parkway Methodology

As part of the hydrology and hydraulic analysis of the Middle and Lower Colliery Dams, located on the Chase River in Nanaimo, BC, a hydraulic analysis of the existing Nanaimo Parkway (Highway 19) is necessary due to its significance to the watershed hydraulics. Ministry of Transportation and Highways Plans labeled 'As-Built' and dated August 1997 for the Chase River Crossing and Utility Construction by Willis Cunliffe Tait Consulting Engineers were utilized for the specific information needed to complete the hydraulic analysis of the culvert. The information contained in these plans was compared to and supplemented by data made available by the Client which includes 1-meter contours (appear to have been created and derived from LiDAR data) as presented in plan drawings prepared by Klohn Crippen Berger.

The U.S. Army Corps of Engineers Hydrologic Engineer Center (HEC) River Analysis System (RAS) Version 4.1.0 was used to develop a rating curve for the culvert system. The existing underpass associated with Nanaimo Lakes Road was also included in the HEC-RAS model, however the range of flows modeled did not result in sufficient depths to engage this area. The culvert and road crossing were modeled as a bridge in order to account for the complex geometry of the culvert bottom and arched top. Flows from 10 to 400 m^3/sec in 10 m^3/sec increments were analyzed and the resulting headwater depths recorded to create the rating curve.

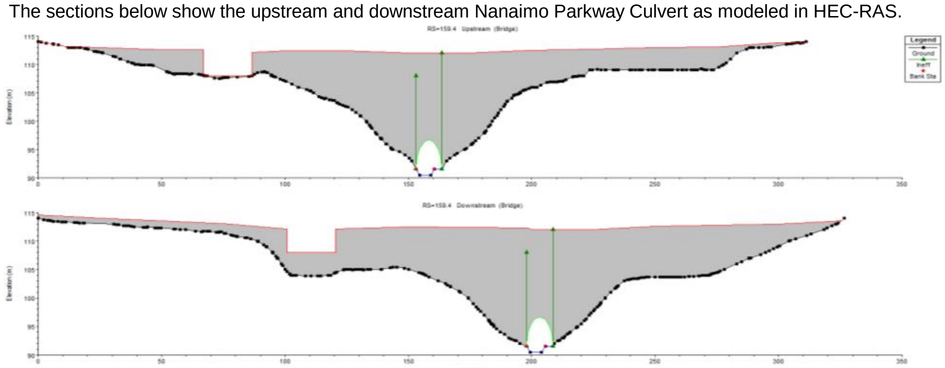
Nanaimo Parkway Culvert Typical Section

The typical section of the Nanaimo Parkway Culvert presented below is from drawing no. R6-V5301-H76 of the Ministry of Transportation and Highways Plans labeled 'As-Built' and dated August 1997 for the Chase River Crossing and Utility Construction by Willis Cunliffe Tait Consulting Engineers.



Nanaimo Parkway Culvert HEC-RAS Section

The sections below show the upstream and downstream Nanaimo Parkway Culvert as modeled in HEC-RAS.



Golder Associates

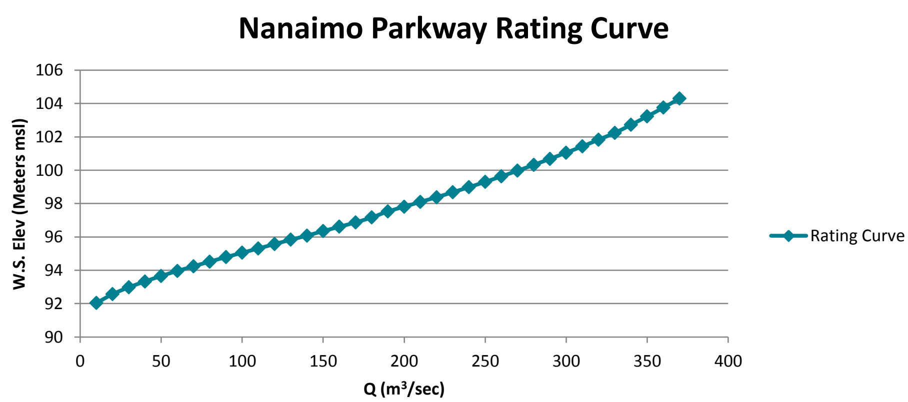
CALCULATIONS

Date:	06/16/2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rating Curves for Existing Conditions	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Nanaimo Parkway Rating Curve

U.S. Culvert Invert: 90.5 meters (msl)

Q (m^3/sec)	W.S. Elev. Meters (msl)	Head (meters above U.S. Culvert Invert)	Q (m^3/sec)	W.S. Elev. Meters (msl)	Head (meters above U.S. Culvert Invert)
10	92.04	1.54	210	98.10	7.60
20	92.57	2.07	220	98.38	7.88
30	92.98	2.48	230	98.68	8.18
40	93.33	2.83	240	98.98	8.48
50	93.66	3.16	250	99.30	8.80
60	93.96	3.46	260	99.63	9.13
70	94.24	3.74	270	99.97	9.47
80	94.52	4.02	280	100.32	9.82
90	94.79	4.29	290	100.68	10.18
100	95.05	4.55	300	101.05	10.55
110	95.31	4.81	310	101.43	10.93
120	95.57	5.07	320	101.83	11.33
130	95.83	5.33	330	102.24	11.74
140	96.08	5.58	340	102.72	12.22
150	96.35	5.85	350	103.23	12.73
160	96.61	6.11	360	103.75	13.25
170	96.87	6.37	370	104.30	13.80
180	97.17	6.67	380	104.77	14.27
190	97.53	7.03	390	105.26	14.76
200	97.81	7.31	400	105.75	15.25



Golder Associates

CALCULATIONS

Date:	06/16/2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rating Curves for Existing Conditions	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Middle Dam Methodology

The following Rating Curve for the Middle Dam was calculated using the standard weir equation as the spillway's control section is defined and relatively uniform. Note, this rating curve only accounts for the spillway flows. The flow going over the dam in overtopping events has been modeled as a level 'Dam Top' in HEC-HMS using elevation, length, and coefficient parameters.

HEC-RAS Version 4.1.0 was used to validate the Middle Dam rating curve and evaluate the chute downstream of the control section. The 1-meter contours presented in plan drawings prepared by Klohn Crippen Berger and provided by the Client were referenced to create representative cross sections of the spillway. The HEC-RAS modeling results compare closely to the calculated rating curve using the weir equation, but also indicate that portions of the concrete training wall height are overtopped by flows in the chute that exceed 45 m^3/sec.

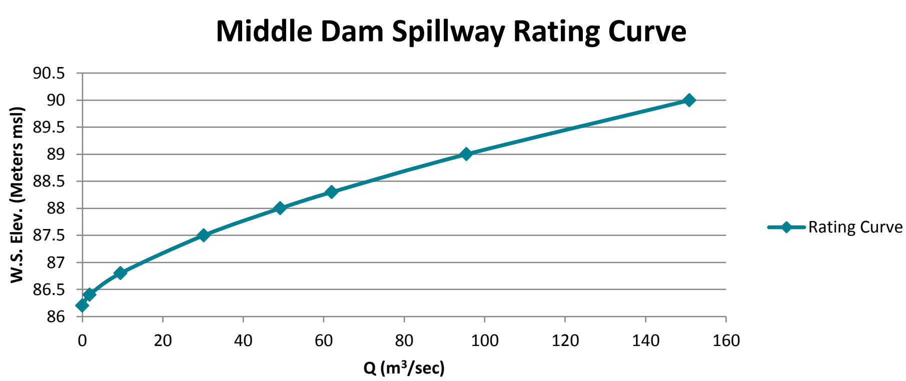
Additionally, the rating curve developed correlates very closely with the rating curve developed in the 2002 "City of Nanaimo Middle and Lower Chase River Dams Spillway Hydrology Study" by Water Management Consultants (WMC).

Middle Dam Spillway Rating Curve

c: 1.67
l: 12.2 meters
Elevation: 86.2 meters (msl)

W.S. Elev. Meters (msl)	Q* (m^3/sec)	Head (meters above crest)	Notes
86.2	0.0	0	Crest Elevation
86.4	1.8	0.2	
86.8	9.5	0.6	
87.5	30.2	1.3	
88.0	49.2	1.8	
88.3	62.0	2.1	Top of dam elevation
89.0	95.5	2.8	
90.0	150.9	3.8	

*Does not include dam overtopping.



Golder Associates

CALCULATIONS

Date:	06/16/2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rating Curves for Existing Conditions	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Lower Dam Methodology

HEC-RAS Version 4.1.0 was used to develop a rating curve for the existing Lower Dam spillway. The 1-meter contours presented in plan drawings prepared by Klohn Crippen Berger and provided by the Client were referenced to create representative cross sections of the spillway. Additionally, field measurements of the pedestrian bridge were taken and is modeled as such. Note, this rating curve only accounts for flows through the spillway. The flow overtopping the dam has been modeled as a non-level 'Dam Top' in HEC-HMS using coefficient and cross section parameters. This cross section is represented by 8 points along the dam and accounts for the Lower Dam's irregular dam top. Flows from 5 to 105 m^3/sec in 5 m^3/sec increments were analyzed and the resulting headwater depths recorded to create the rating curve.

The HEC-RAS model results were compared to the rating curve developed in 2002 by WMC and provided in Table 3.1: Middle Chase River Dam Spillway Capacity in the "City of Nanaimo Middle and Lower Chase River Dams Spillway Hydrology Study" by Water Management Consultants (WMC). The modeling results show some variation to the WMC Lower Dam rating curve. For example, Golder found that 55 m^3/sec will pass through the existing spillway without overtopping the dam at 73.4 meters (msl); WMC reported the Lower Dam spillway capacity to be 35 m^3/sec. However the WMC study then references previous studies that indicate a spillway capacity of 55 m^3/sec. Similiar to the WMC study, the Golder HEC-RAS model also shows that certain flows are causing a hydraulic jump in and upstream of the converging section of the spillway.

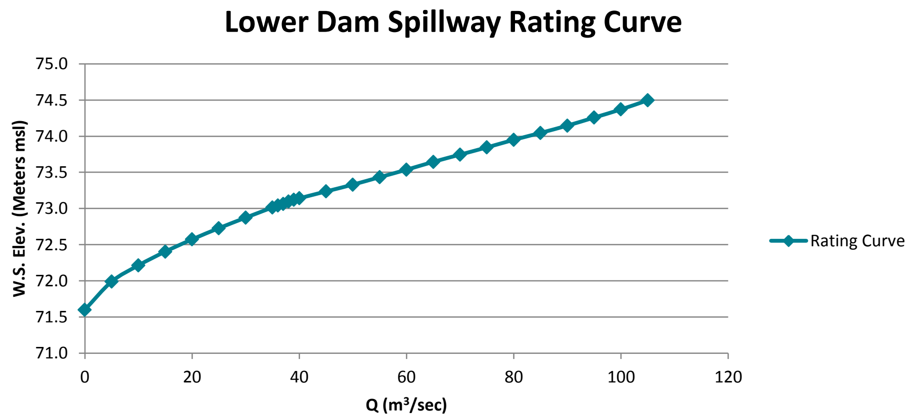
Lower Dam Spillway Rating Curve

W.S. Elev. Meters (msl)	Q* (m^3/sec)	Head (meters above crest)	Notes
71.60	0.0	0	Crest Elevation
71.99	5.0	0.4	
72.21	10.0	0.6	
72.40	15.0	0.8	
72.57	20.0	1.0	
72.73	25.0	1.1	
72.87	30.0	1.3	
73.02	35.0	1.4	
73.04	36.0	1.4	
73.06	37.0	1.5	
73.10	38.0	1.5	
73.12	39.0	1.5	
73.14	40.0	1.5	
73.24	45.0	1.6	
73.33	50.0	1.7	
73.43	55.0	1.8	Top of dam elevation: 73.4 m-msl
73.54	60.0	1.9	
73.65	65.0	2.0	
73.75	70.0	2.1	
73.85	75.0	2.2	
73.95	80.0	2.3	
74.05	85.0	2.4	
74.15	90.0	2.5	
74.26	95.0	2.7	
74.37	100.0	2.8	
74.50	105.0	2.9	

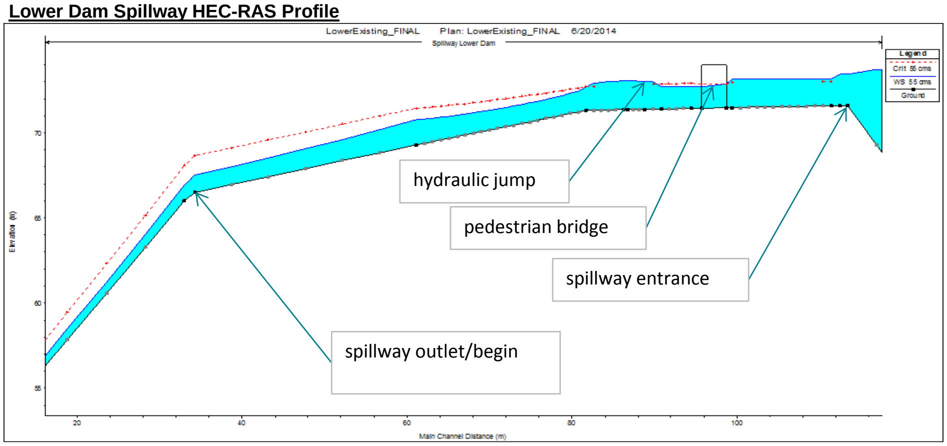
*Does not include dam overtopping.

CALCULATIONS

Date:	06/16/2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Rating Curves for Existing Conditions	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

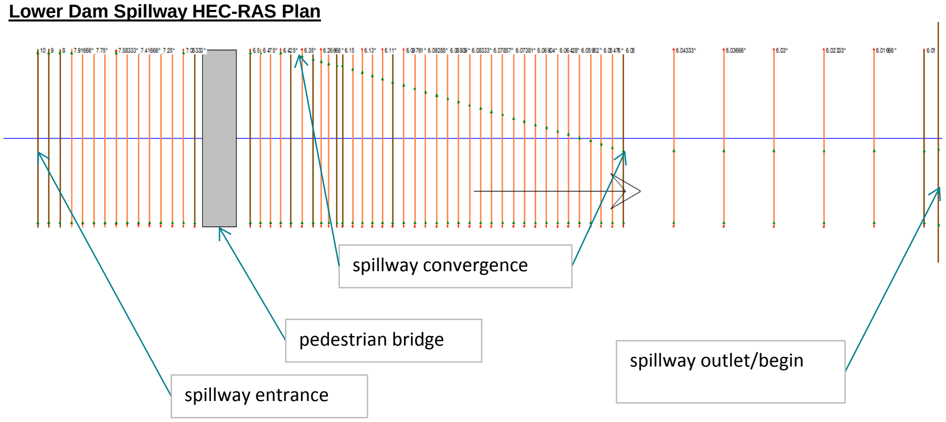


Lower Dam Spillway HEC-RAS Profile



Note: Black nodes on 'ground' line indicate user defined cross sections. Grey nodes indicate cross sections interpolated by HEC-RAS.

Lower Dam Spillway HEC-RAS Plan



Note: Dark red lines indicate user defined cross sections. Orange lines indicate cross sections interpolated by HEC-RAS.

APPENDIX H

Summary of Hydraulic Analysis (HEC-HMS) Results

Golder Associates

CALCULATIONS

Date:	June 18, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Summary of Results	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

HEC-HMS Results

A rainfall-runoff analysis was performed in the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) Version 3.5 to predict the performance of the reservoirs and spillways at the Middle and Lower Dams. The design storms were selected based on Table 6-1 of the Canadian Dam Assosiation's (CDA) Dam Safety Guidelines (2007). The design storm of the Middle Dam, a 'high' consequence dam, is 1/3 between the 24-hour, 1000-year storm event and the 24-hour, Probable Maximum Precipitation (PMP) storm event (1000yr+1/3). The design storm of the Lower Dam, a 'very high' consequence dam, is 2/3 between the 24-hour, 1000-year storm event and the 24-hour, Probable Maximum Precipitation (PMP) storm event (1000yr+2/3). All storm events were analyzed using a SCS Type 1A distribution. A discharge coefficient of 1.5 was used for the level and non-level 'Dam Tops.' Model results are summarized below.

Summary of Design Storms

	Middle Dam (1000yr+1/3)		Lower Dam (1000yr+2/3)	
Existing Top of Dam Elevation	88.3	m-msl	73.4	m-msl
Existing Spillway Crest Elevation	86.2	m-msl	71.6	m-msl
Initial Reservoir Water Surface Elevation	86.48	m-msl	71.8	m-msl
Peak Inflow	121.8	m^3/sec	144.4	m^3/sec
Peak Reservoir Water Surface Elevation	89.0	m-msl	74.4	m-msl
Peak Outflow (Total)	121.5	m^3/sec	144.0	m^3/sec
Peak Outflow (Spillway)	93.5	m^3/sec	102.3	m^3/sec
Peak Outflow (Overtopping)	28.0	m^3/sec	41.7	m^3/sec
Freeboard	-0.7	m	-1.0	m

Middle Dam Results

Storm Event*	Peak Inflow (m^3/sec)	Peak WSE (m-msl)	Peak Outflow (m^3/sec) *Total*	*Spillway*	*Overtopping*	Freeboard (m)
2-year, 24-hour	23.4	87.2	22.7	22.7	0	1.1
5-year, 24-hour	35.7	87.6	34.9	34.9	0	0.7
10-year, 24-hour	44.3	87.8	43.4	43.4	0	0.5
25-year, 24-hour	55.5	88.1	54.4	54.4	0	0.2
50-year, 24-hour	64.1	88.3	62.8	62.7	0.1	0
100-year, 24-hour	72.6	88.4	72	69.1	3.0	-0.1
1000-year, 24-hour	104.0	88.8	103.6	85.5	18.1	-0.5

*Refer to the previous section 'Hydrology' for rainfall depths during each storm event.

Lower Dam Results

Storm Event*	Peak Inflow (m^3/sec)	Peak WSE (m-msl)	Peak Outflow (m^3/sec) *Total*	*Spillway*	*Overtopping*	Freeboard (m)
2-year, 24-hour	23.4	72.7	22.8	22.8	0	0.7
5-year, 24-hour	36.1	73.0	35.1	35.1	0	0.4
10-year, 24-hour	44.9	73.2	44.0	44.0	0	0.2
25-year, 24-hour	56.2	73.4	55.3	55.2	0.1	0
50-year, 24-hour	64.9	73.6	64.0	62.4	1.6	-0.2
100-year, 24-hour	74.5	73.7	73.5	69.3	4.2	-0.3
1000-year, 24-hour	107.2	74.1	106.6	88.3	18.3	-0.7

*Refer to the previous section 'Hydrology' for rainfall depths during each storm event.

APPENDIX I

Middle Dam Breach Analysis

CALCULATIONS

Date:	June 17, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Middle Dam Breach	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Middle Dam Breach Analysis

A breach analysis of the Middle Dam was performed in the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) River Analysis System (RAS) Version 4.1.0 for a breach failure of the dam, as defined in the previous section 'Breach Parameters.' A breach inundation map of the Lower Dam reservoir was created in Esri® ArcMap™ Version 10.1 using 1-meter contours which appear to have been created and derived from LiDAR data, as presented in plan drawings prepared by Klohn Crippen Berger and provided by the Client. Site specific surveys were not completed at the dam sites by Golder.

Methodology

Golder conducted the dam breach analysis using the USACE HEC-RAS computer model. A digital elevation model (DEM) was generated in ArcGIS Version 10.1 using the provided 1-meter contour data; the DEM was used to generate floodplain cross sections within the Lower Dam reservoir and downstream of the Lower Dam. The crest elevation and the top of dam elevation of the Lower Dam were provided in the "City of Nanaimo Middle and Lower Chase River Dams Spillway Hydrology Study" by Water Management Consultants, April 30, 2002 and verified against the provided contour data.

Hydraulic modeling was performed using a mixed flow regime for the unsteady-state flow analysis. The dam breach was simulated by using the breach hydrograph for the previously defined breach of the Middle Dam, provided by Associated Engineers (AE) in a separate report. The model extends downstream to the Lower Dam and analyzes the flood-wave within the Lower Dam reservoir. Key modeling assumptions include the following:

- The existing Lower Dam spillway is assumed to be fully functional. Evaluating breach parameters and rehabilitation options is an ongoing process and is still being refined. For purposes of analyzing a breach of the Middle Dam, the Lower Dam spillway was assumed to be upgraded to a labyrinth spillway with a crest elevation at 71.6 meters (msl).

- A constant inflow of 2 m^3/sec was included throughout the simulation duration for model stability.

- Manning's n values were 0.04 within the reservoir and 0.06 at the reservoir banks.

- The lake level at the Lower Dam reservoir was modeled at normal pool (71.8 m-msl which is +0.2 meters higher than the lower dam crest to accommodate base flow depth).

- The conservation of mass target was +/- 1%.

CALCULATIONS

Date:	June 17, 2014	**Made By:**	JCD
Project No.:	1314470516	**Checked By:**	JKM
Subject	Middle Dam Breach	**Reviewed By:**	GWH
Project Short Title:	Nanaimo/Colliery Dams/Nanaimo, BC		

Updated Lower Dam Spillway Rating Curve - 12 Meter Labyrinth Weir

W.S. Elev. Meters (msl)	Q* (m^3/sec)	Head (meters above crest)	Notes
71.60	0.0	0.0	Crest Elevation
71.75	6.4	0.2	
71.90	18.7	0.3	
72.20	50.3	0.6	
72.50	84.5	0.9	
72.80	118.1	1.2	
73.10	150.2	1.5	
73.40	180.8	1.8	Top of Dam Elevation
73.70	210.1	2.1	
74.00	238.7	2.4	
74.30	266.9	2.7	
74.60	295.1	3.0	
76.10	445.7	4.5	
77.60	624.1	6.0	
80.60	1073.0	9.0	

*Only accounts for spillway flows. Does not account for flows over the dam.

Results

The results of the dam breach modeling were exported from HEC-RAS into Esri® ArcMap™ Version 10.1. An inundation map was created in ArcMap™ using world imagery, provided by Esri Map Service, as the base layer. The inundation map is presented in Figure 12 and shows the locations of cross-sections modeled in HEC-RAS; average velocities in the channel and at the banks; maximum change in water surface elevation in the channel; and average water depth on the banks. The maximum rise in water surface elevation is 2.3 meters and occurs directly downstream of the Middle Dam. The maximum velocity is 9.2 m/sec and also occurs directly downstream of the Middle Dam within the main channel. The conceptual 12 meter wide labyrinth spillway at the lower dam is capable of passing the fast breach of the middle dam without overtopping the lower dam embankment.

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