# PEMBERTON VALLEY
# FLOOD MITIGATION PLANNING

## FINAL REPORT

Prepared for:

**Pemberton Valley Dyking District**
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Pemberton, BC  V0N 1B0

Prepared by:
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5 June 2020

NHC Ref. No. 3004610

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# CREDITS AND ACKNOWLEDGEMENTS

Northwest Hydraulic Consultants Ltd. (NHC) would like to thank the Pemberton Valley Dyking District (PVDD) for initiating this study, making available background information and providing advice and support through-out the project. PVDD's main representative was Mr. Steve Flynn, Operations and Maintenance Manager. Mr. Kevin Clark, PVDD's new Operations and Maintenance Manager joined near project completion. We also gratefully acknowledge input received from the Squamish Lillooet Regional District, Lil'wat First Nation, and Village of Pemberton.

The following NHC personnel participated in the project:

- Field Investigations (Daniel Arnold, Rachel Managh)
- Geomorphic Assessments and Flood Mitigation (Wil Hilsen)
- Flood Risk Assessment (Julie Van de Valk, Heather Murdock)
- Hydraulic Modelling (Vanessa Bennett)
- Mapping and GIS (Ben Humphreys, Sarah North)
- Project Review (Neil Peters)
- Project Management and Technical Lead (Monica Mannerström)

Thurber Engineering Ltd. was retained as a subconsultant to provide an overview geotechnical assessment of dikes in the Valley.

# EXECUTIVE SUMMARY

Recently updated floodplain maps for Lillooet River at Pemberton showed that the valley is subject to considerable flood hazards and that the level of protection offered by present diking is lower than previously believed. The main reasons are: 1) sedimentation caused by the 2010 Capricorn Creek (Mount Meager) landslide leading to increased aggradation in the Lillooet River channel; and, 2) a shift in the hydrologic regime resulting in higher flood flow estimates. It is expected that some dike overtopping is likely to occur already at the 50-year flood and the present diking will not protect against the 200-year design flood. Other identified shortcomings include non-standard dike geometries, high seepage flows and inadequate protection against erosion. Low-lying areas, such as the lower end of Arn Canal, were found to have less drainage capacity than required. In view of the increased flood hazards, Pemberton Valley Dyking District (PVDD), the Village of Pemberton (VOP), the Lil'wat First Nation (LFN) and Squamish-Lillooet Regional District (SLRD) have recognized an urgent need for comprehensive flood mitigation planning and have formed the Pemberton Valley Emergency Management Committee (PVEMC).

Northwest Hydraulic Consultants Ltd. (NHC) was retained to develop flood mitigation options, implementing both structural and non-structural flood mitigation measures. Structural measures included building or upgrading dikes, installing flood control structures and, for this report, also included providing sediment management. Non-structural measures encompassed flood adaptation and avoidance, such as floodproofing new development by placing buildings on fill or raised foundations and, planning new development away from the most flood prone areas.

An asset inventory was prepared to identify essential areas. The number of houses in the floodplain were estimated using Statistics Canada census data and the information was summarized on a population density map. Asset maps, showing community buildings, roads and other infrastructure were also prepared. The present degree of dike protection of key assets was then assessed. An overview level geotechnical assessment was provided by Thurber Engineering Ltd. to determine to what extent the dikes in the valley can be upgraded and to explore seepage and related issues.

The increased Pemberton Valley flood hazards in combination with identified assets, emphasized the importance of both near-term actions and long-term strategic planning to avoid loss of life; minimize the number of people displaced and structures or infrastructure damaged; and reduce economic, cultural, social, recreational and agricultural losses; as well as damage to the environment.

To address main deficiencies, PVEMC requested that a series of near-term actions be identified and support provided with funding applications to the UBCM Community Emergency Preparedness Fund for Structural Mitigation Grants. Funding for the following structural measures was applied for:

- Raising a section of the Miller-Lillooet Dike C. A breach of this dike would result in rapid, severe flooding.
- Improving portions of the Poleyard Dike. A breach in the dike could lead to an avulsion of the river and flooding across the Birkenhead fan with severe erosion and damage to built-up areas.
- Removing sediment from gravel bars in the Lillooet River depositional zone. It is recognized that the removals are unlikely to lower the design flood profile in a significant way, rather they will

provide storage for additional incoming material and to some degree, prevent further increases to the flood profile.
- Improving the Arn Canal outlet. By improving the canal conveyance and outlet capacity, the frequency of flooding and impacts to adjacent housing can be reduced, particularly near the outlet of the canal.

Long-term structural flood mitigation options were also assessed, focusing on three diking projects to the 200-year standard:

- Raising and upgrading the various components of the “Miller-Lillooet-Pemberton Dike”.
- Constructing a set-back dike to protect the main Pemberton Village area.
- Constructing a set-back dike to protect Mount Currie and the industrial park, immediately to the west, partly by raising a section of Highway 99.

The cost of these projects would be very high and computed return-on-investment (ROI) ratios relatively low, suggesting the projects may be difficult to fund. The Mount Currie set-back dike has the highest ROI and could potentially be cost-shared with Ministry of Transportation and Infrastructure.

As a future project, it was recommended that the influx of gravel be managed upstream of the Forest Services Road by establishing a sediment trap area. By laterally switching the channel from one side to the other, the area would allow material to be removed in the dry with limited environmental impact.

Considering the challenges with dike construction, non-structural flood mitigation measures are critical for safeguarding the area. Planning and regulating new development as well as developing emergency preparedness measures, including flood forecasting and warning systems, are strongly recommended. The core of the Pemberton Valley flood mitigation plan includes: 1) Dike Upgrades and Construction; 2) Gravel Removals; 3) Infrastructure Improvements; 4) Land Use Planning and Emergency Preparation; and, 5) Additional Hydraulic Modelling.

Detailed recommendations are listed in the report with some key elements summarized here. PVDD will need to continue to inspect and maintain dikes, with the intent of achieving a uniform standard of protection for main areas in the short term and exploring more major improvements in the long-term. As the material from the Capricorn slide moves through the river system, channel monitoring and large, regular gravel removals are required. Additional hydraulic modelling of tributary channels to assess the capacity of tributary dikes should be completed. Arn Canal is an important drainage feature in need of improvements, particularly at its outlet. Development should be avoided in the high hazard areas identified on the flood maps. Emergency planning and preparedness, already well underway by the PVEMC, is strongly supported.

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# 1 INTRODUCTION

## 1.1 Project Background

Updated floodplain mapping prepared for Lillooet River (NHC 2018) showed that the valley is subject to considerable flood hazards and that the level of protection offered by present diking is lower than previously believed. The main reasons for this are: 1) sedimentation caused by the 2010 Capricorn (Mount Meager) landslide leading to increased aggradation in the Lillooet River channel; and, 2) a shift in the hydrologic regime resulting in higher flood flow estimates.

The flood magnitudes when dikes begin to overtop can be estimated by comparing flood profiles simulated during the floodplain mapping project with surveyed dike crest elevations. Some overtopping is likely at the 50-year flood and the present diking will not protect against the 200-year flood. Other identified short-comings in various locations include non-standard dike geometries, high seepage flows and inadequate protection against erosion. Areas, such as the lower end of Arn Canal, have been found to have less drainage capacity than required. In view of the increasing flood hazards, Pemberton Valley Dyking District (PVDD), the Village of Pemberton (VOP), the Lil'wat First Nation (LFN) and Squamish Lillooet Regional District (SLRD) have recognized an urgent need for comprehensive flood mitigation planning.

Substantial dike upgrades are likely to be very costly and the optimal degree of protection in terms of diking will need to be carefully evaluated. Other flood mitigation measures must also be considered, both in the near- and long-term. As sand and gravel materials from the Meager Slide move through the river system, it is critical that the current sediment management program in the diked reaches be intensified, and that additional sediment removals be undertaken upstream of the mapped reach. This sediment removal work is being pursued as a series of separate projects and is not described in detail in the present project.

To develop an overall flood mitigation plan, PVDD retained Northwest Hydraulic Consultants Ltd. (NHC) to identify current deficiencies in flood protection and to recommend future mitigation measures. To combine resources and advance flood mitigation work, the Pemberton Valley Emergency Management Committee (PVEMC) was formed. The committee is made up of the PVDD, VOP, LFN, and the SLRD.

## 1.2 Objectives

The main objective of the project is to develop potential flood mitigation options for the Pemberton Valley (area covered by the 2018 floodplain mapping). Pemberton Valley flood mitigation measures broadly fall into three categories:

- Sediment management
- Structural protection (building or upgrading dikes and installing flood control structures)
- Adaptation/ avoidance (floodproofing new development by placing new buildings on fill or raised foundations, and planning new development away from the most flood prone areas).

The approximately 40 km of existing regulated dikes in the valley, comprised of 12 separate dikes, provide varying degrees of flood protection for much of the populated floodplain area. However, the dikes are substandard for current design flow and sediment conditions. Dike upgrades can be prohibitively expensive, particularly if ground improvement, such as densification, is required to meet earthquake standards. Except for the dikes protecting the most developed and populated floodplain areas, projects to upgrade many of the dikes within the valley to provincial standards would likely have unfavourable cost-benefit ratios.

The project aim is to reduce overall flood losses by combining flood protection and adaptation. Specific goals identified by PVDD were:

- Protect priority areas with the largest concentration of residential development and high value property (i.e. the Village of Pemberton and the Lil'wat First Nation community of Mount Currie).
- Explore the construction of set-back and ring dikes positioned near high value areas.
- Upgrade the most vulnerable reaches of diking to achieve a uniform standard for a particular dike (without transfer of risk).
- Evaluate the benefits of installing a pump station (temporary or permanent) at the Arn Canal outlet at the Pemberton Creek and improve overall drainage capacity.
- Develop other potential flood protection improvements with high Return-On-Investment (ROI) ratios.
- Prioritize projects based on flood protection benefits, including both increased public safety and future avoided flood losses.

Specified deliverables are:

- Identified flood protection improvement options for the Pemberton Valley.
- Prioritized options based on high return-on-investment (ROI) ratios.

As part of the project, PVDD requested that NHC assist with a grant application for structural mitigation measures under the UBCM Community Emergency Preparedness Fund. A draft report supporting the application was issued by NHC on 25 October 2019 and a final report issued 10 December 2019 (NHC 2019).

On 10 December 2019, NHC gave a presentation to the PVEMC in Pemberton, describing initial results and outlining challenges with developing flood mitigation for the Valley.

## 1.3 Report Outline

In addition to introductory Section 1; Section 2 outlines the development of an asset and infrastructure inventory to identify items vulnerable to flooding. In Section 3 potential mitigation options are explored, followed by recommendations in Section 4. Section 5 contains a brief closure and Section 6 a list of references.

# 2 ASSET AND INFRASTRUCTURE INVENTORY

## 2.1 Valley Development

### 2.1.1 Population

The first step in the asset inventory assessment focussed on identifying high population areas in the Pemberton Valley. The number of houses in different parts of the floodplain were estimated using Statistics Canada census data. Future development was not considered as this information was incomplete. **Map 1** provides an overview of the population density in the valley. A blue colour represents a low population intensity with yellow shading corresponding to the highest intensity. (The assessment is qualitative and does not correspond to a particular people/area value.)

North of Miller Creek, the population density is relatively low, significantly increasing in Pemberton Village and Mount Currie. Higher density areas also exist between these two centres and downstream of Mount Currie. Areas outside the Lillooet River floodplain, such as the Xit'Olacw Village, were not mapped. The 2016 Census indicates the Village of Pemberton has a population of 2,574 with 1,028 private dwellings; Mount Currie has a population of 1,285 with 433 private dwellings; and, the SLRD Area C a population of 1,663 with 964 private dwellings. Of the total population, about 60% live in the floodplain and half of all the buildings are located within the floodplain.

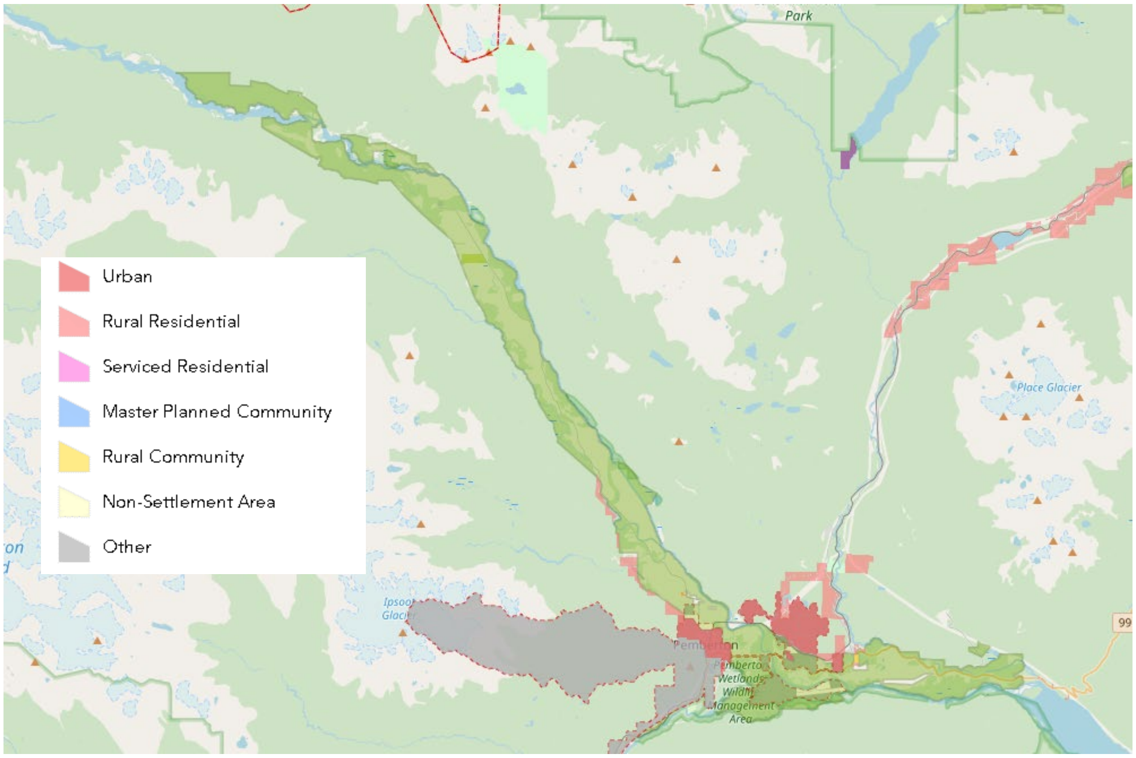
### 2.1.2 Asset inventory

Community asset data provided by the Village of Pemberton and Lil'Wat Nation (for Mount Currie IR) shows a high concentration of key infrastructure, community centres, schools, emergency facilities, and utilities that are potentially exposed to flooding or could be inaccessible or inoperable during a flood event. The information is summarized in **Maps 2** and **3**. Most of these assets are vulnerable and would require flood protection or adaptation. Also shown are linear infrastructure such as roads, which are most subject to flooding, and hydro and telecommunication lines.

Asset information sources and summaries are provided in **Appendix A**.

### 2.1.3 Land Use

The primary land use in the Pemberton Valley is agricultural. **Figure 1** shows the distribution between agricultural land (dark green polygons) and other land uses, which are primarily either urban settlement areas or rural residential. Commercial activities occur mainly within the Village of Pemberton and Mount Currie. An industrial park is located in the floodplain east of Mount Currie, between the Lillooet and Birkenhead Rivers.



Land use data from SLRD Public Map

**Figure 1. Pemberton Valley Land Use**

## 2.2 Dike Assessment

The degree of protection provided by existing dikes to key areas was assessed by: 1) reviewing previous reports; 2) carrying out field assessments; 3) completing an evaluation of dike quality using similar tools as developed for MFLNRO for Lower Mainland dikes (NHC 2015); 4) comparison of dike crest elevations with the 200-year flood profile; and, 5) a geotechnical field/drilling program.

As part of the floodplain mapping project, Highmark Land Surveying and Engineering Ltd. surveyed dike locations and crest elevations. Many of the dikes have been upgraded and improved over time and available design and/or construction reports were provided by PVDD.

### 2.2.1 Dike Condition Assessment

In September 2019, NHC staff (Wil Hilsen, Daniel Arnold and Rachel Managh) carried out a field assessment. Steve Flynn of PVDD gave an initial tour of the diking. The field staff noted deficiencies, such as bank erosion, seepage and settlement issues, substandard dike geometries and poorly functioning flood-boxes. **Map 4** categorizes the overall dike condition, which is the average rating of several factors including crest elevation vs. design crest level (freeboard), dike geometry, geotechnical stability, erosion protection, vegetation and animal control, and encroachments (e.g. buildings on or near the dike). The detailed methodology is provided in **Appendix B**.

Brief descriptions and photos of observed "Locations of Concern" are included in **Appendix B.** The dikes were inspected and assessed at numerous locations (see **Map 4**) however continuous assessments were not completed and additional unmapped areas of concern may exist.

Generally, the dikes do not meet present-day standards and fall in the 'fair-to-poor' and 'poor-to-unacceptable' categories. The dikes have traditionally been constructed of local alluvial materials and the Dyking District has operated under financial constraints. The following specific observations were made:

- The Miller-Lillooet Dike, particularly downstream of the railroad bridge (right bank) is in 'poor-to-unacceptable' condition. In this location, the river makes a sharp bend and is prone to erosion. The land-side slope of the dike is over-steepened. Seepage issues have been observed in the past. Preventing the dike from failing in this location is of highest priority.
- Ayers Dike, providing important protection for Village and First Nation lands, is rated 'poor-to-unacceptable', the main concern being inadequate erosion protection. A few years ago the dike was raised, the land-side slope reduced and a seepage control toe-drain included in the design. However, erosion protection upgrades were not performed and are still required. The dike would likely overtop prior to the Miller-Lillooet Dike.
- Other dikes rated 'poor to unacceptable' include the Poleyard, Pemberton Meadows Berm, Hungerford, Ryan, Airport Road and Nesuch Dikes. The main issue with the Poleyard Dike is its substandard erosion protection and dike geometry.
- Other dikes, such as the Forestry Road, Strobl, Miller-Boneyard and Pemberton Creek Dikes are generally rated as 'fair-to-poor', although there are a number of erosion concerns.

### 2.2.2 Dike Freeboard Assessment

Using the Lillooet River simulated 200-year flood profile (NHC, 2018) and surveyed dike crest elevations, the available freeboard, corresponding to the elevation between the dike crest and the simulated flood level, was estimated. The flood profile simulation assumed that the Miller-Lillooet, Adventure Ranch, Airport Road Dike A and Pemberton Creek dikes were raised to contain the flow in the main channels; all other dikes were allowed to overtop.

The dikes in the valley were not designed to the current 200-year flood standard. With increasing sediment loading and higher flood flow estimates, the diking standard is now lower than previously believed.

A colour coded map showing presently estimated freeboard allowances is provided in **Map 5**:

- A minimum freeboard of 0.6 m is typically required for dikes meeting standards and is here shown as green. As seen from the map, only a few short reaches are shown as green.
- A 'fair' rating (yellow) indicates a freeboard between 0.6 and 0.3 m. Only a few short reaches are shown as yellow.

- When a freeboard of only 0.3 to 0 m is available (orange or ‘poor’), the dike may start to overtop at the design flood from standing waves and/or debris accumulations. Only a few short reaches are shown as orange.
- Most dikes are shown as red, indicating the lack of freeboard allowance, suggesting direct overtopping at the design flood. Once a dike is overtopped it is likely to breach from the overflow, causing erosion of the dike crest and landside of the dike.

The floodplain mapping project was based on the 200-year Lillooet River flood in combination with tributary flows likely to occur at that time. The 200-year tributary flows were not specifically modelled except for the Birkenhead. Available freeboard can therefore not be assessed for the other tributary dikes and are not colour-coded on the map (e.g. Pemberton Creek, Miller Creek, and Ryan River).

As part of this project, additional Birkenhead River cross-sections were surveyed and the floodplain mapping project model extended by about 250 m. Assuming a Birkenhead River 200-year preliminary flood flow of 650 $m^3/s$, in combination with a 200-year Lillooet River flood, the Poleyard Dike freeboard was assessed. **Map 5** shows that under these conditions, the dike would be overtopped or have minimal freeboard at a number of locations.

Because most of the diked reaches are subject to bed aggradation, sediment removal is critical to maintaining dike freeboard. Previous geomorphic assessments concluded that removing sediment upstream of the Forest Services Road (FSR) in the Upper Lillooet Valley would be advantageous. In addition, removals from gravel bars over most of the modelled Lillooet River reach would be beneficial in terms of increasing storage for future depositions.

### 2.2.3 Geotechnical Assessment

PVDD requested that an overview level geotechnical assessment be included in the project to determine to what extent the dikes in the valley can be upgraded and to explore seepage and other related issues. NHC retained Thurber Engineering Ltd. (TEL) for this work and TEL’s summary report is included in **Appendix C**.

The TEL field investigations consisted of drilling ten test holes (one in Poleyard Dike, four in Miller-Lillooet Dike, one in Pemberton Creek Dike, two in Miller-Boneyard Dike, and two in Ryan River Dike). The results of the investigation and laboratory testing are summarized in **Appendix C**. Topics discussed include potential for seepage, settlement and seismic performance. TEL concluded that the dike underlying material include granular soils that may be susceptible to liquefaction during very large seismic events. Field assessments of soil density and other properties to support a seismic assessment have not been completed.

Following preparation of Appendix C, TEL provided additional information on general seismic hazards for the Pemberton Valley Dyking District’s dikes. An assessment based on Natural Resource Canada’s fifth generation on-line seismic hazard calculator was made to compare ground accelerations in Pemberton vs. Victoria, Richmond, Abbotsford and Calgary; with Calgary known to have a low seismic hazard. Expressed as peak ground accelerations (PGAs), the seismic hazard for Pemberton was seen to be intermediate as shown in Figure 2. The Pemberton PGAs are more than in Calgary but significantly less than the other locations in Southwestern BC.

In TEL's experience, liquefaction and large deformations may initiate in loose to very loose granular soils, the soils most susceptible to liquefaction, when site-specific PGAs are in the range of 0.12g to 0.22g. The graph below provides approximate return periods when liquefaction may occur for the locations considered. The minimum seismic return period (i.e. liquefaction threshold) for the Pemberton area is about 1,000 years compared to 100 years for Victoria.

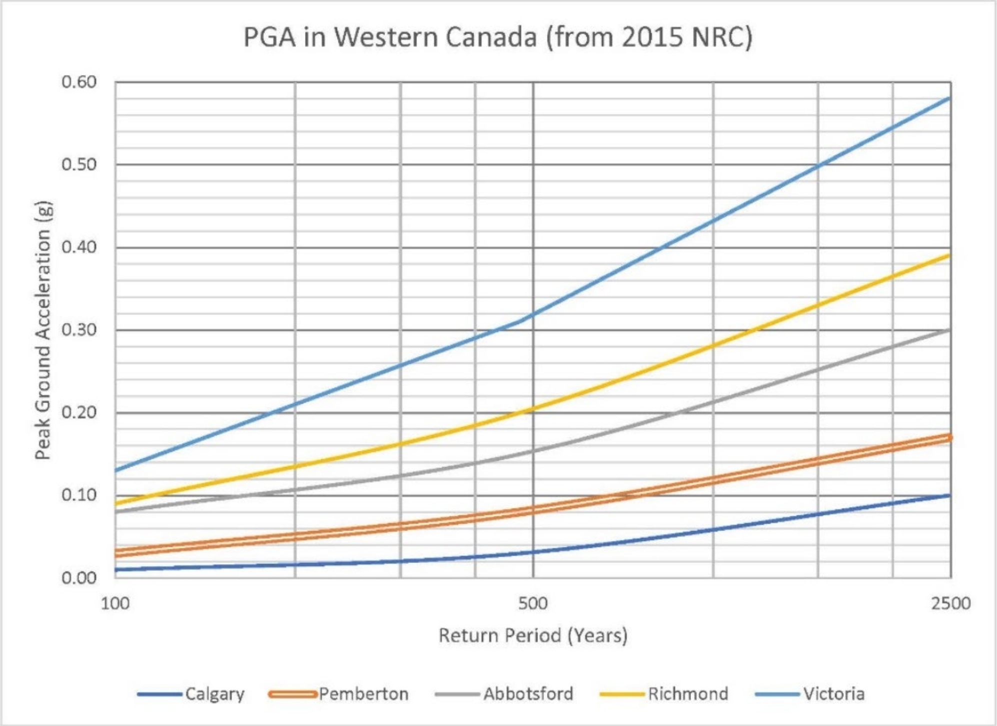


**Figure 2: Comparison of peak ground accelerations**

## 2.3 Arn Canal

The Arn Canal (**Figure 3**) is a man-made drainage channel that collects runoff from agricultural and developed areas inside the Pemberton Creek and Lillooet River dikes (KWL 2009). The canal is important for conveying internal drainage flows during high precipitation events and discharging these flows through the floodbox culverts at the Pemberton Creek dike into the lower end of Pemberton Creek, in a location backwatered by the Lillooet River during higher flows.

According to observations by PVDD, at Lillooet River flows of about 500 m$^3$/s, the flap-gates at the Arn Canal outlet close to prevent Lillooeet River backflow, in turn causing drainage flows to pond and flood adjacent areas, including nearby development. PVDD has identified a need to increase the floodbox capacity and explore pumping options for when Lillooet River water levels are too high to allow gravity flow.

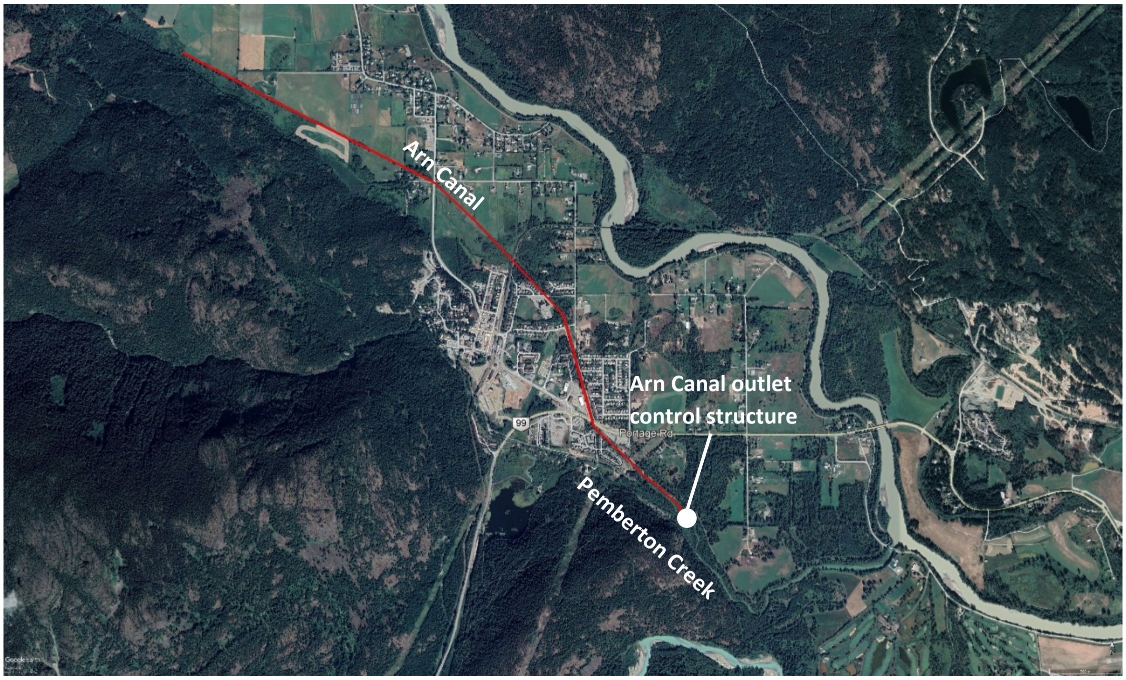


**Figure 3. Arn Canal Approximate Alignment**

# 3 FLOOD MITIGATION OPTIONS DEVELOPMENT

Canada has adopted the United Nations' Sendai Framework for Disaster Risk Reduction, a voluntary agreement recognizing that the responsibility for reducing disaster risk lies with different levels of government and emergency management partners. The initiative by PVDD, VOP, LFN, and SLRD to form the PVEMC conforms with the approach. Key elements of the framework are the four emergency management pillars: mitigation, preparedness, response and recovery. The focus of this project is flood mitigation planning.

The increased Pemberton Valley flood hazards in combination with identified assets, emphasize the importance of both near-term actions and long-term strategic planning. Protection and adaptation measures must consider overall risk and at least initially, focus on densely populated areas with highest asset values. Key objectives are to:

- Avoid loss of life
- Minimize the number of people displaced and damage to structures and infrastructure
- Minimize economic, cultural, social, recreational and agricultural losses
- Limit environmental damage

Maintenance of existing dikes is a key component of flood mitigation in the Valley. With limited funding, PVDD has carried out extensive upgrades of dikes where most needed. It is recommended that dike monitoring be continued and improvements introduced as necessary, to ensure that a uniform standard is maintained. Operation/ Maintenance Manuals for the dikes need to be prepared or updated to better facilitate dike inspections and maintenance protocols.

With high velocity flows, many dikes are exposed to erosion. Erosion needs to be monitored and riprap placed as required. From an environmental perspective, it is much preferred that rock be placed during the fisheries window under controlled conditions rather than end-dumped from trucks as an emergency measure during floods.

Monitoring the influx of gravel and removing material where practical without negative environmental impact is a high priority item and should be carried out annually.

The PVDD has been successful in obtaining funding support for various projects over the past ten years. The work has included:

- Material removals from the Lillooet and Birkenhead Rivers and Pemberton and Miller Creeks
- Upgrades for the Poleyard Dike, Pemberton Creek Dike, Ayers Dike
- Erosion protection for Pemberton Creek and Ayers Dike

It is recommended that similar works be continued in the future.

This section of the report reviews near-term and long-term structural flood mitigation, as well as non-structural options.

## 3.1 Near-Term Structural Flood Mitigation

The floodplain mapping project (NHC 2018) showed where dike crest elevations are too low and the current work has highlighted more specific dike deficiencies. To address the main short-comings, PVEMC requested that a series of near-term actions be identified and support provided with funding applications. NHC (2019) prepared a technical summary for PVEMC's funding application to the UBCM Community Emergency Preparedness Fund for a Structural Mitigation Grant. Structural measures applied for included:

- Raising a section of the Miller-Lillooet Dike C
- Improving portions of the Poleyard Dike
- Removing sediment from gravel bars in the Lillooet River depositional zone
- Improving the Arn Canal outlet

According to an announcement on 24 February 2020, the Lil'wat Nation was awarded $750,000 for upgrades to Poleyard Dike, and the Squamish Lillooet Regional District $750,000 for sediment removal and landslide monitoring equipment on Mount Currie (not discussed in this report). To date, the outcome of other funding applications has not been finalized.

### 3.1.1 Raise a Section of Miller-Lillooet Dike C

The Miller-Lillooet Dike C is located on the right bank of Lillooet River (viewed downstream) between the railway bridge (River Chainage Km 16.7) and the Highway 99 crossing (Km 13.3). A significant concern is that the upstream 1.4+ km length as shown in **Figure 4** is susceptible to overtopping during floods with a return period of about 50 years (1,540 $m^3/s$) or less.

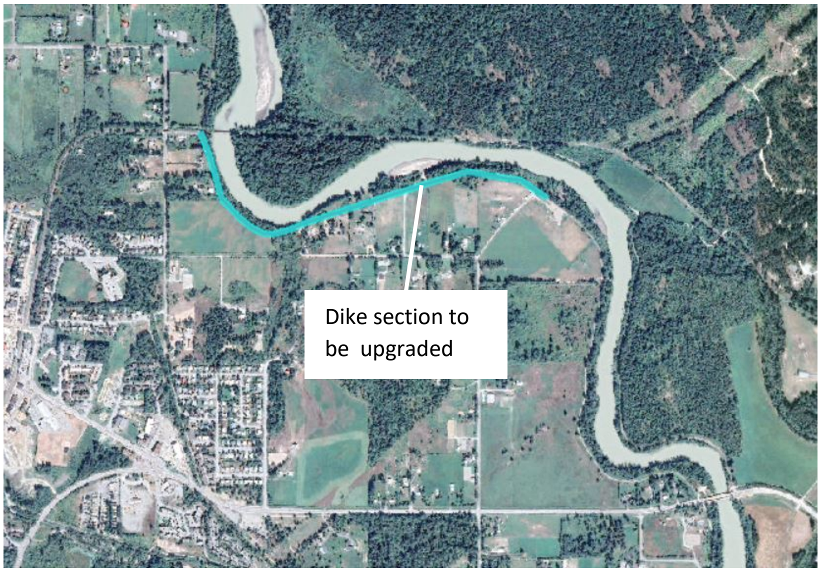


**Figure 4. Location of Proposed Miller – Lillooet Dike C Upgrade**.

**Figure 5** shows the dike crest height and water level along the channel centreline during selected peak Lillooet River flood events. Water levels in the figure were computed assuming the Miller-Lillooet, Adventure Ranch, Airport Road Dike A and Pemberton Creek dikes were raised to prevent overtopping; all other dikes in the valley were allowed to overtop.

The proposed project is to raise the dike height by approximately 0.5 m to the simulated 100-year water level, widen the dike crest to a minimum 4.5 m and flatten the land-side slope to a standard 2.5H: 1V. While of very limited scope, these dike improvements are intended to reduce the likelihood that overtopping and breaching would occur at this particularly critical location, where a dike breach would rapidly, and with minimal warning time, flood the Village of Pemberton, potentially resulting in loss of life. The inundation sequence is illustrated in **Figure 6**. If a breach were to occur at a location in the approximately 6 km section of the Miller-Lillooet Dike upstream of the railroad or in the sections further downstream (which are also susceptible to overtopping), flood waters would progress more slowly through the floodplain, allowing for more evacuation time for the densely populated floodplain areas.

As described in **Appendix D** the recommended upgrade forms a strategic improvement to delay rapid flooding of a particularly vulnerable area and increase public safety. The Miller-Lillooet Dike C is considered ‘high-consequence’ and  upgrades typically require a seismic assessment. To date, the seismic stability of the underlying ground has not been tested. However, preventing an initial breach in this location is urgent and forms part of PVEMC’s emergency work.

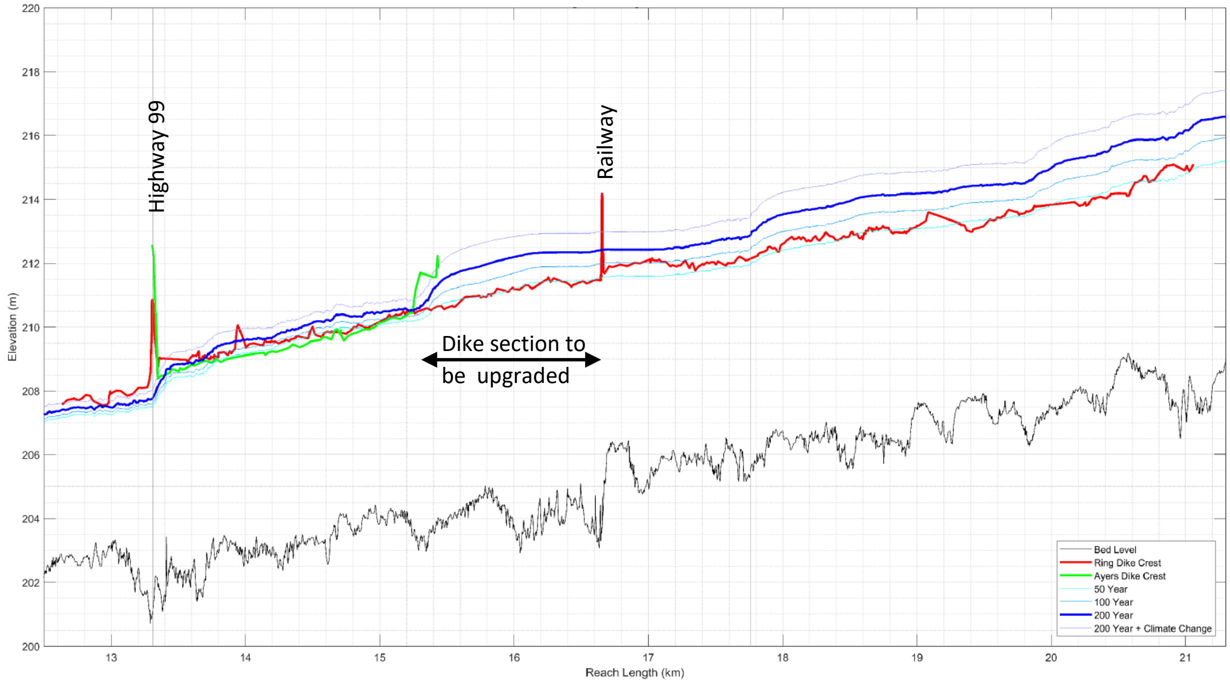


**Figure 5. Lillooet River water surface profile for several scenarios (Km 12.5 to Km 21.5).**

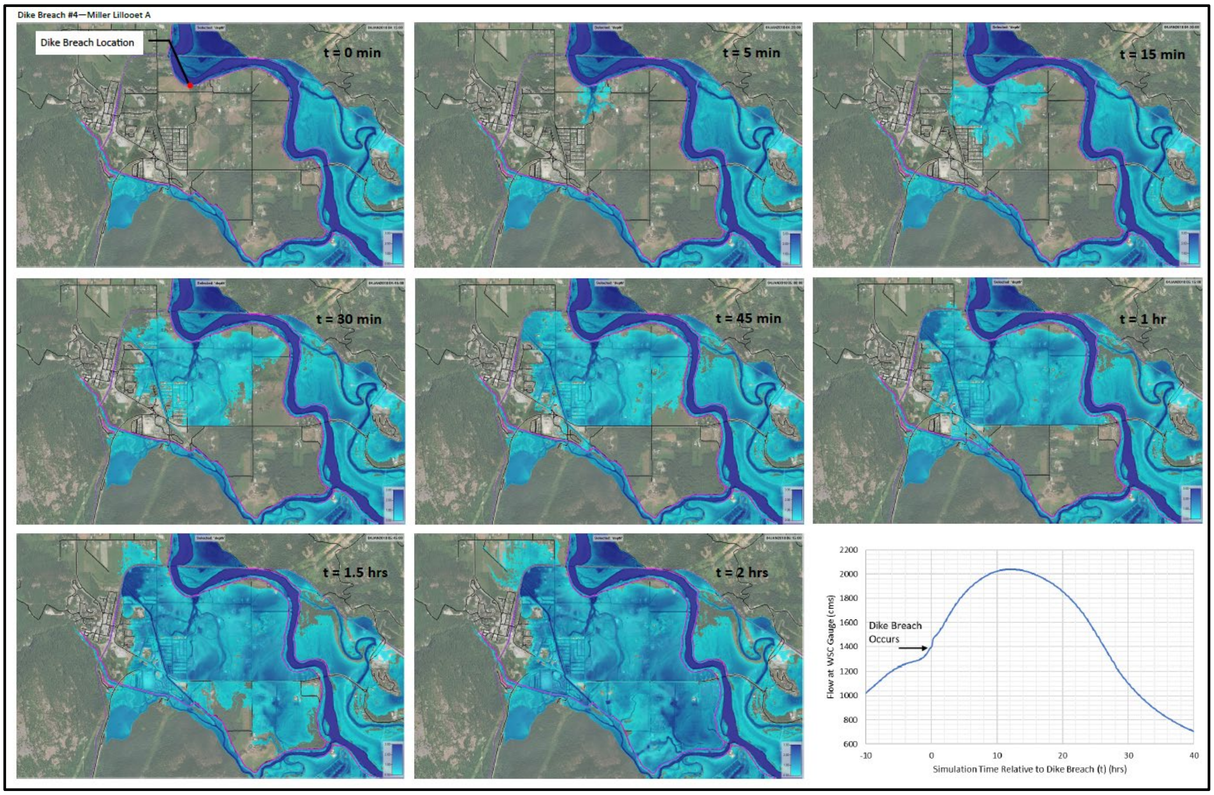


**Figure 6. Miller – Lillooet Dike C breach scenario.**

### 3.1.2 Poleyard Dike Upgrade

The Poleyard Dike (**Map 5**) is located on the right bank (viewed downstream) of the Birkenhead River and protects the Lil'wat Nation community of Mount Currie, on the Birkenhead River fan (**Figure 7**). Recent simulation of the Birkenhead River 200-year flood indicated that the Poleyard Dike would overtop in some locations, likely resulting in a breach of the dike. A breach in the dike could lead to an avulsion of the river and flooding across the fan with severe erosion and damage to built-up areas. The floodplain mapping study showed that the area is also exposed to relatively shallow water flooding from Lillooet River. Upgrades to the Poleyard Dike would not prevent Lillooet River flooding. Similarly, the dike would not alleviate internal drainage problems in the inter-river area.

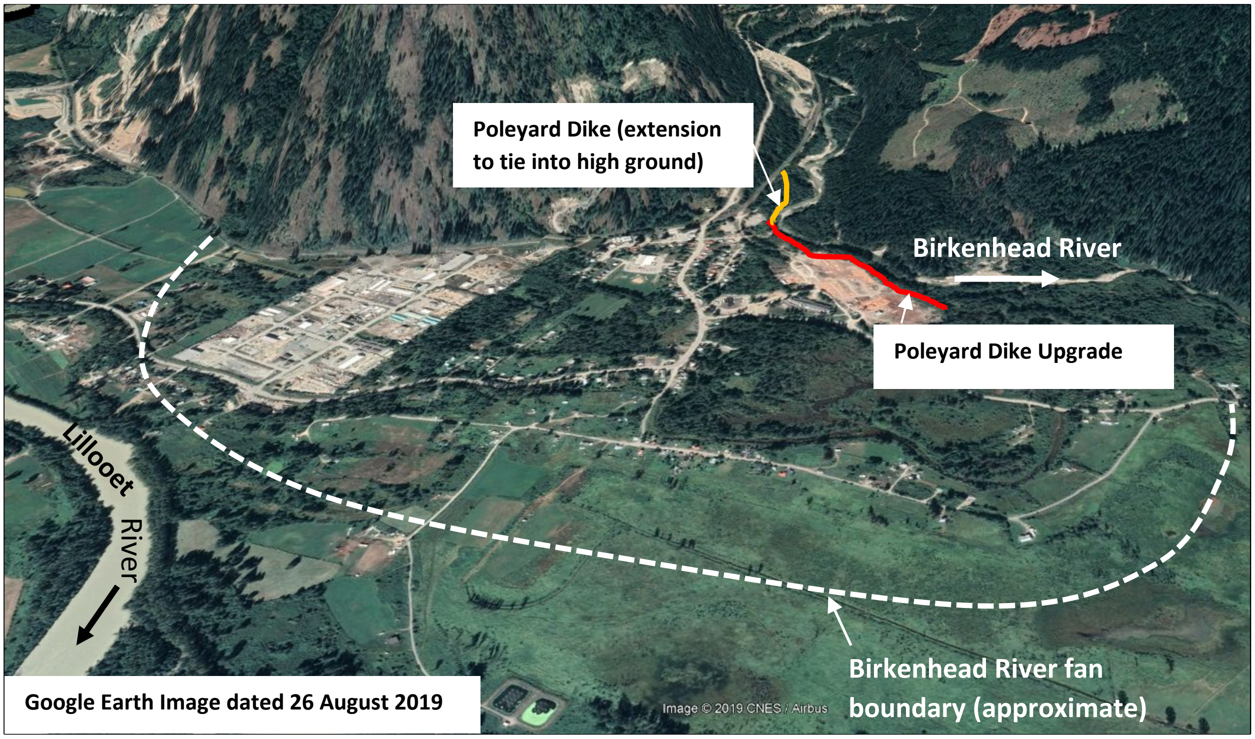


**Figure 7. Oblique Google Earth image of Birkenhead River fan (with vertical exaggeration).**

The Poleyard Dike is approximately 0.7 km long. It does not tie into high ground at the upstream end and is open at the downstream end. The main purpose of the dike is to keep Birkenhead River confined to a narrow corridor along the north side of the fan.

Some of the key limitations and deficiencies with the dike are:

- The existing ground upstream of the dike can overtop and the dike must be extended upstream by about 140 m to tie into higher ground  at the railway embankment.
- The flood profile plotted in **Figure 8** shows that the dike generally has insufficient freeboard and would likely overtop over an approximately 100 m long section.
- The dike has inadequate erosion protection and the current dike geometry does not meet provincial standards.
- The dike upgrade will not provide protection against Lillooet River flood events. However, these do not impact the developed areas higher on the fan.

Recommended improvements are as follows:

- Raise and extend the dike upstream to withstand the 200-year Birkenhead River flood, presently being refined under a separate NHC project. Improve the dike cross-section to more closely adhere to provincial standards. Add erosion protection in critical areas. (The Birkenhead provides valuable fish habitat and any upgrade must avoid negative impacts.)

- NHC (2014) developed a comprehensive gravel removal program for the Birkenhead River downstream of the reach protected by the Poleyard Dike. The excavated channel improved the capacity of the river, lowering upstream water levels and also creating prime salmon spawning habitat. The project summary report highlighted monitoring of future sediment deposition and the need for regular removals. The channel has now largely filled in and additional removals are required in the near future to prevent upstream water levels from increasing. (Gravel removals were not part of the present funding application.)
- To facilitate flood-forecasting, a real-time stream gauge on the Birkenhead River is strongly recommended. Continuous flow records will also allow for updating flood flow estimates. We understand funding through other programs has been designated for this important work.

Hydrologic analyses (NHC 2018) indicated that there has been a trend of increasing flows over time since the 1970's at the Lillooet River at Pemberton Water Survey of Canada (WSC) gauge (08MG005). A similar trend may have occurred on the Birkenhead River but cannot be confirmed due to the lack of flow records. NHC (2018) carried out water level sensitivity analyses using projected peak flows for end-of-century. The proposed dike raising will tentatively accommodate some climate change impacts. Also, downstream sediment removals will help offset climate change effects by reducing channel capacity losses over time. In the future, if a ring dike is built to protect Mount Currie, the Poleyard Dike will serve as the Birkenhead leg of the ring dike.

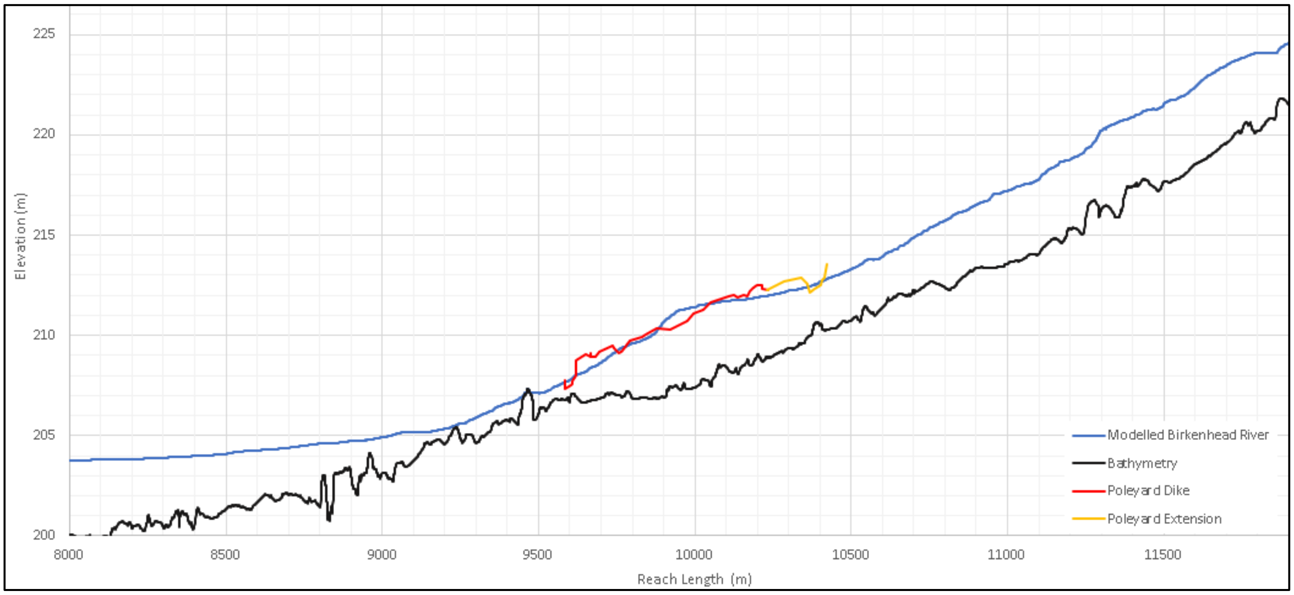


**Figure 8. Birkenhead River simulated 200-year flood profile and existing dike/ground profile.**

### 3.1.3 Sediment Management in the Lillooet River Depositional Zone

A high priority action is material removal from gravel bars in Lillooet River (NHC 2019b). It is recognized that the removals are unlikely to lower the design flood profile in a significant way, rather they will provide storage for additional incoming material and to some degree, prevent further increases to the flood profile. Tentatively, a volume of 60,000 m$^3$ was earmarked for removal from the locations shown in Figure 9. Since removals take place in the dry, impacts on fish habitat are minimal. Habitat improvements in the form of Large Woody Debris (LWD) are incorporated in back-channels but since the channels fill quite rapidly, the effectiveness of these measures is likely relatively low.

Sediment supply from the 2010 Meager Creek landslide will remain high for several decades. The slug of coarse sediment moving down the river has increased channel instability in the Upper Lillooet River, and the sand and fine gravel component has already reached the depositional zone downstream of the Ryan River Confluence. The effects of sedimentation on flood levels were assessed as part of the Lillooet River Floodplain Mapping (NHC 2018). The model demonstrated that a 0.5 m increase in bed levels over a 1 km long section of channel upstream of Highway 99 Bridge resulted in a 0.3 m increase in flood levels. Based on the present rate of infilling, the reach upstream of the bridge could infill by up to 0.5 m by 2025. Without a substantial sediment management program in place aggradation of the channel bed will reduce the effectiveness of the dikes.

The river reach between the Ryan River and Green River confluences is considered to be the highest priority area for profile maintenance. **Figure 9** presents the location of proposed Lillooet River sediment removals in the depositional zone, now completed for 2020[1].

**Figure 9. Bar locations proposed for Lillooet River sediment removals.**

As a separate future project, it is recommended that the influx of gravel be managed upstream of the Forest Services Road (**Figure 10**) by establishing a sediment trap area. By laterally switching the channel

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[1] Although considered non-structural in some contexts, for this report sediment removals are classified as a structural flood mitigation measure.

from one side to the other, the area would allow material to be removed in the dry with limited environmental impact.

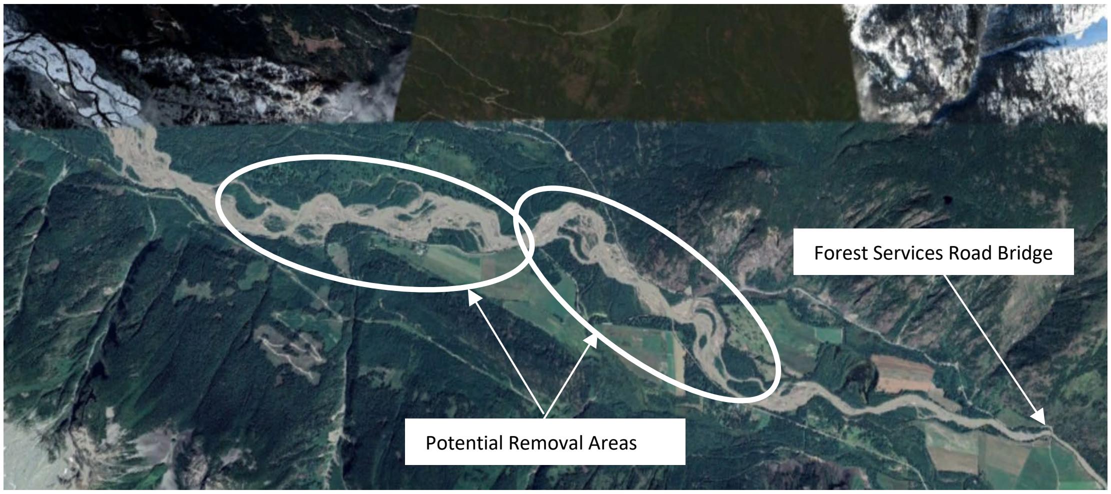


**Figure 10. Potential sediment trap area**

### 3.1.4 Arn Canal Outlet

Flooding along the Arn Canal falls in a different category than flooding from potential dike overtopping and breaching by the Lillooet River and its tributaries. While more frequent, the flooding from Arn Canal results in lesser flood depths and extents than flooding from a major river event. By improving the canal conveyance and outlet capacity, the frequency of flooding and impacts to adjacent housing can be reduced, particularly near the outlet of the canal. In recent years, flooding appears to have become more common, potentially as a result of increasing precipitation intensity due to climate change. The current flap-gated culverts at the canal outlet no longer perform adequately.

The Arn Canal is a man-made drainage channel that collects runoff from agricultural and developed areas within the Pemberton Creek and Lillooet River dikes. It discharges through a gravity floodbox (3 large culverts) in the Pemberton Creek dike  into the lower end of Pemberton Creek, in a location backwatered by the Lillooet River during moderate and higher flows. The outlet is controlled by a series of gates, intended to be closed to prevent Lillooet River/Pemberton Creek back flooding into the canal. According to observations by PVDD, waters upstream of the outlet often flood adjacent areas and as flows continue to back up, nearby development is affected.

PVDD has identified a need to increase the drainage capacity at the outlet control structure in order to drain the internal land areas more efficiently. There is also a need to upgrade the outlet control system to reduce potential for gate failures and to improve the functionality of the outlet controls. Pumping options are required for when Lillooet River water levels are too high, preventing gravity flow and a pump intake design will need to be developed. PVDD requested a proposal from NHC (2019c) to design improvements to the Arn Canal.

### 3.1.5 Prioritizing Near-Term Mitigation

Of the four near-term mitigation options, the projects to upgrade a section of Miller-Lillooet Dike C and the Poleyard Dike are considered to be the highest priority as these are required to reduce the risk of catastrophic flooding behind the dikes.

Gravel removals from the identified gravel bars will be required annually to ensure that the capacity of the channel is maintained as more material from the Meager slide moves into the dike reach. Gravel management upstream of FSR Bridge is recommended and will be pursued as a separate project.

Although less critical than the other recommended mitigation measures, POV and PVDD are encouraged to proceed with upgrading the Arn Canal as funding becomes available.

## 3.2 Long-Term Structural Flood Mitigation

The Lillooet River has a history of flooding, followed by reactive measures to reduce impacts during future floods. In the 1940's and 50's the river was straightened in several locations by cutting off meander loops in order to maximize the land area that could be used for farming. However, these changes also steepened the channel slope and increased flow velocities. Material from the excavations was piled on the river banks to act as berms. As more development took place, the berms were raised to better protect against flooding. The berms, although now approaching dike standards, still provide inadequate protection. The floodplain mapping project (NHC 2018) showed that the updated 200-year design flood would overwhelm the diking and result in multiple breaches, inundating most of the valley. Considering the relatively sparse population throughout most of the Pemberton Valley, raising all dikes to withstand the 200-year flood would be cost-prohibitive and have comparatively poor cost-benefit ratios. A flood protection program, relying strictly on continuous dike upgrades, is unlikely practical.

Main areas requiring flood protection in the form of diking are the densely built-up areas of Pemberton Village and Mount Currie. Protection of these two areas is discussed below. Upgrading other dikes is likely to have low returns on investment and is not considered here.

In retrospect, straightening the river channel and building dikes immediately adjacent to the river and its tributaries was a short-sighted solution. Had the dikes been set back from the channels, the system would now be less confined and the wider channel flood corridor would have greater capacity to convey flood flows and transport and store bedload sediment. An ideal mitigation measure would be to setback the dikes and establish this wider floodway. However, considering present land values, this option is unlikely acceptable and alternatives need to be explored.

Even well constructed dikes have limitations. If a dike is designed to withstand the 200-year flood, it may well fail during a longer return period event such as the 300-year flood. A dike may protect one location but can potentially raise flood levels in adjacent areas. Diking regulations aim to mitigate these transfer of risk effects, in some instances leading to the upgrade of other existing dikes or the construction of new dikes. As improved dikes are provided, development in certain protected areas may increase, potentially leading to associated increases in flood risk due to the expanded assets.

Dike construction costs vary considerably. For Pemberton Valley dike upgrades to the 200-year flood level including a freeboard allowance, a very rough preliminary cost of $2M/km was approximated assuming seismic improvements are not required. New dike construction, including seismic ground improvements may exceed $10M/km, the ground improvements constituting 60% of the cost. The actual costs will depend on fill and riprap material sourcing, land costs for establishing dike right of ways (ROWs), relocation of buildings presently in the ROW, necessary raising of roads crossing dikes or installation of flood gates, etc. There will be large variations in the costs depending on which dike is considered for upgrade and more detailed costs must be estimated on a case-by-case basis.

### 3.2.1 Miller-Lillooet-Pemberton Dike Upgrade

The various components of the “Miller-Lillooet-Pemberton Dike” (Miller-Lillooet Dikes A, B, C, Adventure Ranch, Airport Road A and Pemberton Creek) that protect Pemberton Village, form a continuous “dike ring”. Part of this dike ring (Miller-Lillooet Dikes A, B, and C) is a ‘*high-consequence*’ dike, meaning failure of the dike is associated with high risk. Upgrading a ‘*high-consequence*’ dike to the 200-year standard requires that the dike meets seismic guidelines. Before approval under the Dike Maintenance Act can be obtained to upgrade the dike, the dikes and underlying dike foundation material must be tested and analyzed to see if ground compaction, dike re-alignment, or other dike modification measures are necessary to meet seismic requirements (Seismic Design Guidelines for Dikes, 2nd Edition, Golder Associates, 2014). If ground improvement is deemed necessary, the cost of improving the dike is likely going to be too high for the project to proceed. (Based on personal communication with Thurber geotechnical engineers, ground improvements for the dike would be in the order $6 M/km).

The first step is to determine if the raised dike and it’s foundations meet the displacement criteria in the Seismic Guidelines. This can be assessed using a cone penetration test and methodology as outlined in the Guidelines. (Typical assessment costs are in the order of $20,000/ 500 m length of dike.) It is recommended that at least a few test sites be selected and the status of the underlying ground determined. Considering that the earthquake hazard in Pemberton Valley is roughly half of the hazard in the Fraser Valley (Natural Resources Canada National Building Code of Canada Seismic Hazard Values http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/calc-en.php), the Miller-Lillooet Dike may meet requirements without ground improvement, significantly reducing dike upgrade costs.

With a total length of about 13 km (Google Image in **Figure 11**), only about 8.5 km needs a significant raise as the dike section along Pemberton Creek has at least some freeboard above the design flood profile. It is estimated that the total cost of upgrading the dike could range from $22M up to over $60M, depending on the seismic requirements. Assuming a minimum crest width of 4 m, a potential height increase of 2 m and land-side slope of 2.5H : 1V, the dike footprint would be some 10 to 12 m wider than presently and require a right-of-way allowance to cover the increased footprint, plus allow for maintenance equipment to travel along the toe of the dike. Buildings should be setback at least 7.5 m from the land-side toe of the dike. To achieve this, development along the dike would likely need to be removed in some locations, adding to the cost of the dike. The raised dike, about 5 m high, would have considerable visual impact on the surrounding areas. There would likely be some transfer of risk to the left bank (viewed downstream) that would need to be addressed.

**Figure 11: Miller-Lillooet-Pemberton Dike Upgrade Approximate Alignment**

Assuming a cost of $22M, a Return-on-Investment (ROI) ratio of 2:1 was estimated (see **Appendix E**), where:

$$ROI = \frac{Cost\ of\ potential\ damages\ during\ the\ asset\ life\ cycle}{Mitigation\ Project\ Costs}$$

$$\begin{aligned} &Cost\ of\ damages\ during\ the\ asset\ life\ cycle \\ &\qquad = Estimated\ yearly\ damages\ x\ Remaining\ life\ span\ of\ asset \end{aligned}$$

$$Estimated\ yearly\ damages = \frac{Total\ estimated\ cost\ of\ damages}{Frequency\ of\ hazard}$$

### 3.2.2 Pemberton Village Set-back Dike

Optionally, a set-back dike could be built on the approximate alignment shown in **Figure 12**. The alignment would have minimal transfer of risk as it would not significantly reduce flow conveyance. However, the dike would block several local roads, requiring either the sealing of road openings during a flood or raising the roads to dike crest elevations. The set-back dike would have a total length of about 4.2 km (2.8 km new dike and 1.4 km Pemberton Creek dike upgrade), with an approximate cost in the order of $19M, assuming no ground compaction.

Assuming a cost of $19M, a Return-on-Investment (ROI) ratio of 1.9:1 was estimated (**Appendix E**).

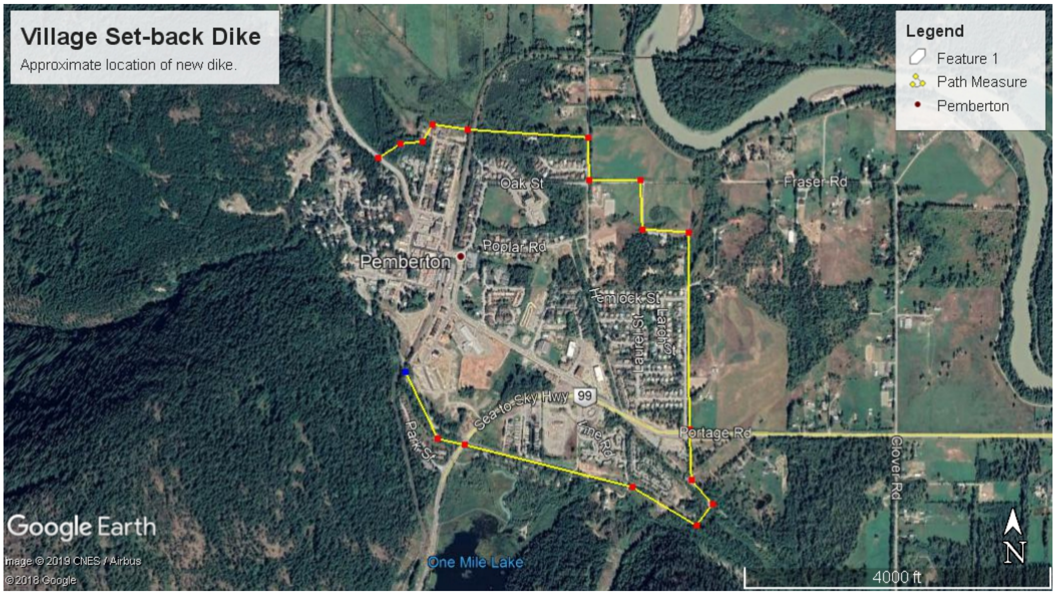


**Figure 12: Pemberton Village Set-back Dike Approximate Alignment**

### 3.2.3 Mount Currie Set-back Dike

Upgrading the Lillooet River left bank dikes (Ayers Dike, Nesuch A, Map 4) to protect floodplain areas north of the Lillooet River, including Mount Currie, to a 200-year flood standard is likely to be impractical because of high costs and transfer of risk. Significant upgrades would raise flood levels and adversely affect right bank dike freeboard and increase flooding in other developed areas. However, protecting the main Mount Currie and the Village of Pemberton industrial park area with a set-back dike as shown in **Figure 13**, would be more economically viable. Because the dike would be set-back from the river by a considerable distance, there would not be any transfer of risk.

**Figure 13: Mt. Currie Community Set-back Approximate Alignment**

The option involves raising a 1.8 km length of Highway 99 and, for costing purposes, it was assumed that the work would be undertaken collaboratively with Ministry of Transportation and Infrastructure (MOTI) at a time when repaving of the highway is required. The highway would be tied to high ground just west of the industrial area and to the downstream end of the Poleyard Dike. The total length of the dike would be in the order of 3 km. The road elevation is relatively high and the expected raising of the road would vary from 0.5 m to 1 m. Allowances need to be made for re-construction of all of the driveways/intersections etc to match grades, raising a road to be a dike is generally a complex project.

Assuming a cost of $7M, a Return-on-Investment (ROI) ratio of 3.8:1 was estimated (see **Appendix E**). Depending on the willingness of MOTI to cost-share, the ROI may be higher.

### 3.2.4 Other Options Considered

#### *North Arm Floodway*

The potential benefits of providing a secondary flood channel parallel to the Lillooet River was investigated by reactivating the North Arm floodway in the hydraulic model as shown in **Figure 14**. In order to reduce the 200-year flood to a 50-year flood, approximating a condition where minimal improvements to the dikes would be required, the floodway would need to carry a flow of approximately 580 $m^3/s$. In order to convey this flow, the channel would need to be at least 50 m wide and several metres deep. Ensuring sufficient flow capacity is not practical and the option was not further explored. Several cross-roads would be affected requiring bridges.

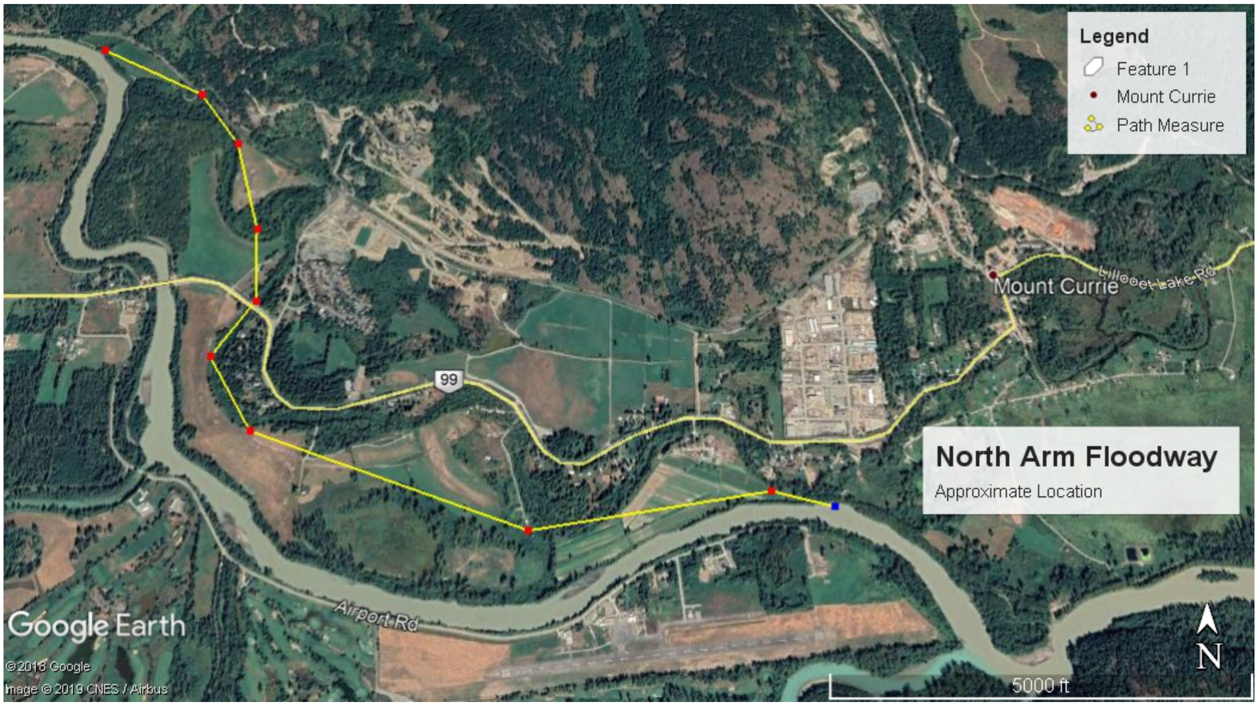


**Figure 14. North Arm Floodway**

### *Meander-loop Storage*

Using the abandoned meander loops for storage was briefly explored. The review showed that the meander loops would quickly fill and not provide any significant flood reduction benefit.

### *Upper Basin Storage*

Storage in the upper basin was also discussed. Considering the shape of the hydrograph, a reservoir 1 km long, 1 km wide and 13 m deep would be required to reduce the 200-year flood to a 50-year flood. Such a reservoir would fill with sediment over time and have significant environmental impacts. Suitable locations were not readily found and the option is not recommended.

## 3.2.5 Prioritizing Long-Term Mitigation

Considering the possible cost implications of the provincial seismic guidelines, it is recommended that some testing of the soils underlying dikes and assessment of the dike alignments be completed in strategic locations to determine if ground improvement, or other dike modifications would generally be required. If yes, future dike upgrades may become cost-prohibitive and plans for any major dike improvements unfeasible. Even if no seismic design modifications are required, costs are high and unlikely within reach of the local communities.

Although the estimated, highly approximate ROI ratios exceed 1.0, the identified dike projects are unlikely to get funding under programs such as the federal Disaster Mitigation Adaptation Fund (DMAF). Estimated ROI's for projects receiving funding to date have been considerably higher. Also, this program requires local authorities to fund more than half of the projects. Considering the relatively small tax base of the Pemberton area, raising sufficient funding for major projects would be challenging.

Of the three diking projects explored, the Mount Currie set-back dike appears to be most promising. It was assumed that the project would be undertaken collaboratively with MOTI and it is recommended that PVEMC contact MOTI to discuss the feasibility of this work. It may be possible to use material removed from the river for diking, particularly if mixed with a controlled finer material to ensure adequate compaction and seepage prevention. This may reduce estimated diking costs.

Upgrading the entire right bank Miller-Lillooet-Pemberton dike to protect against the 200-year flood would result in transfer of risk to the left bank of the river. The work would not proceed without also upgrading Ayers Dike and possible protection of other land areas. From a transfer of risk perspective, a village set-back dike would be more viable. However, the set-back dike would not provide any protection to areas outside the dike. Some development may need to be relocated to make space for a new set-back dike footprint and ROWs. Dike maintenance requirements would increase as the Miller-Lillooet-Pemberton dike up-keep would be continued.

Considering the design flood flow estimates, the ongoing channel aggradation and the current height and condition of the dikes, protecting Pemberton Village with dikes upgraded to provincial standards is far from straight-forward. In the near-term an interim approach should be adopted to ensure that the dikes do not fail in critical areas where public safety is a major concern.  If an area behind a dike is equally at high risk, raising the low spots in the dike to achieve a uniform standard is recommended.

The simulated 200-year water surface profile suggests large energy losses at River Chainage 13.4 Km (bend upstream of HWY 99 Bridge) and at 15.4 Km (bend with large gravel bar near the downstream end of the near-term Miller-Lillooet dike upgrading project described in Section 3.1.1). No major loss is noted at the RR bridge (**Figure 5**). These sudden drops in the water surface profile indicate constriction points in the channel. If the flow conveyance at a constriction point could be increased by setting back the present dike, it may be possible to locally reduce flood levels. Previous modelling tested the impacts of lowering the channel bed in this reach. The results showed minimal benefit. It should be noted that the plotted water surface profile is for the centre of the channel. Since the river makes a series of sharp bends in this reach, there is super-elevation of flow at the outside of the bends. The water surface partially captures the elevation variations (up to 0.5 m) between the banks. It is recommended that further testing be done in the model to explore if flood levels can be reduced by locally setting back a roughly 500 m long portion of the Miller-Lillooet Dike.

In some instances, “private dikes” on single legal parcels may be of benefit for public works facilities and key infrastructure. Such dikes are not regulated by the province. However, it would need to be confirmed that the dikes do not aggravate flooding of adjacent areas.

In the past, lowering of the Lillooet Lake by enlarging the lake outlet has been considered. Previous work by KWL (2010) showed that lowering the lake level by as much as 3 m would have no appreciable impact on Lillooet River flood levels within the PVDD service area.

Use of floodways or flow storage areas was found not to provide practical flood mitigation solutions for Lillooet River.

## 3.3 Non-Structural Flood Measures

This flood mitigation planning report is focused mainly on structural measures (i.e. dikes and sediment management). However, given diking system limitations and the many challenges to upgrade and maintain the dikes to provincial standards, non-structural measures must also be incorporated into comprehensive mitigation plans. Non-structural measures include developing detailed flood hazard information, educating the public and increasing awareness, planning and regulating new development in flood hazard areas, plus emergency planning, response and recovery. These and related measures are critical to reducing future flood losses, ensuring public safety and building community resilience.

The recent floodplain mapping study (NHC, 2018) made several recommendations regarding non-structural measures, and the PVDD, VOP, LFN and SLRD are actively implementing a number of these, including work on emergency response plans. To complement this ongoing work, the sections below provide some suggestions for consideration by these governments and their development approval and emergency planning personnel.

### 3.3.1 Planning and Regulating New Development

The recently prepared floodplain and hazard maps provide a basis for updating planning and development regulatory tools including Official Community Plans, Zoning Bylaws, Floodplain Management Bylaws (Section 524 *Local Government Act*) and Development Permit Areas. Amendments to these regulatory tools (or adoption of new tools and policies) could:

- Continue to encourage new development (i.e. Urban Growth Area in OCP) to areas of higher ground outside of the Lillooet River floodplain.
- Update floodplain management bylaws to designate the new 2018 mapping and implement the new Flood Construction Levels (FCL's).
- Adopt new setback criteria in the floodplain bylaws to allow room for future dike widening, dike maintenance and emergency inspections and "flood fighting".
- Ensure any new subdivision plans near the diking system provide adequate dike rights of way for future dike improvements.
- Consider prohibiting new subdivisions and/or require special building provisions for new construction on existing lots in high hazard areas. Local hazard criteria would need to be adopted (for example, where potential flood depths are greater than 2 m and/or the area has a "Significant Hazard Rating" for the 1:200 event as shown on the hazard maps).
- Special provisions for these high hazard areas could include the requirement to build on compacted landfills protected against erosion, or on raised concrete foundation walls with scour protection and/or the use of water-resistant building materials below the FCL. A site specific flood assessment by a Qualified Professional Engineer may also be required.
- As part of Arn Canal improvement work and investigations, determine "minimum ponding elevations" for areas potentially flooded by high water in the Arn Canal. These drainage criteria could be useful for the design of site grading for new development.

- For new development on the dike-protected alluvial fans, including Miller Creek, Pemberton Creek, and Birkenhead River, consider completion of hazard assessment studies to develop standard building requirements (as an alternative to requiring site specific engineering assessments).

### 3.3.2 Emergency Preparedness Measures – Flood Forecasting and Warning

The PVEMC partners are currently developing a comprehensive emergency management plan. While there are many components to such a plan, the following discussion provides suggestions for improving flood forecasting and warning.

Accurate and reliable river gauges are critical for effective flood forecasting and emergency response. Two specific recommendations from the floodplain mapping study (NHC 2018) are restated here:

> *"8) WSC (Water Survey of Canada) should continue to obtain flow measurements at Station 08MG005 and update the rating tables for the gauge as needed. WSC is encouraged to install or re-activate gauges on the tributaries, currently not in operation. It is particularly important that a gauge be re-installed on the Birkenhead River. In order of priority, the Green, Ryan and Miller watersheds should also be gauged.*
>
> *9) The gauge at the FSR Bridge needs to be monitored and maintained as it provides important warning time for a river blockage caused by a major landslide. The gauge levels may help responders assess when the upper valley roads become impassable. (It is recognized that the gauge has limited value for peak flow measurements because larger floods overflow the banks and bypass the bridge opening.)"*

In addition to continuous recording gauges, the installation and monitoring of manual staff gauges at critical locations along the dikes can greatly assist dike patrol personnel in determining the rate of rise in flood waters and measuring available freeboard on the dikes. Training of a few local authority staff (in addition to PVDD personnel) to become local flood observers/assessors and ensuring that these staff have a detailed knowledge of the diking system (including the type of information presented in Appendix B) could be vital to an effective flood response.

Establishing appropriate criteria to initiate flood warnings and evacuations for communities protected by dikes is extremely challenging. Also, for rivers such as the Lillooet, Ryan, Green and Birkenhead that respond very quickly to rainfall events, it may take only a few hours for the rivers to rise from normal highwater levels to severe flood conditions. Whereas the application of overly conservative criteria could lead to false alarms and needless disruption; insufficient warnings could impact public safety. Reliable information on river levels and closely monitoring the condition of the dikes during events is critical.

A few factors to be considered in developing a warning protocol could include:

- Use of clear terminology and a standard sequence of advisories, warnings and orders.
- The actual and forecast rate of rise of river levels during a flood event (from both local gauge observations and information from the River Forecast Centre - RFC).

- The condition of the dikes and flood levels at which the dikes become potentially "unsafe". Without any specific dike stability or seepage issues noted by dike patrols, this "trigger level" would typically be reached when the flood level rises, or is forecast to rise within the freeboard allowance (say 0.3 to 0.6 m) of the dike crest.
- Possible dike breach locations and the time available for evacuation before evacuation routes become impassable.
- The length of time from when an order to evacuate is given to the time when people (especially the most vulnerable groups) can be safely evacuated to refuge areas.

# 4 RECOMMENDATIONS

The following recommendations form the core of the Pemberton Valley flood mitigation plan:

1. Dike Upgrades and Construction

    a. Continued inspection and maintenance of existing dikes is a key flood mitigation measure in the Valley. Adequate resources must be made available to ensure that this important work is carried out.

    b. Appendix B of this report summarized some dike deficiencies identified in the field. It is recommended that these be assessed further and addressed as required.

    c. Whereas some dikes presently have Operation and Maintenance Manuals, some are outdated, incomplete or missing. It is recommended that a complete set of up-to-date manuals be prepared, providing guidelines for inspection, channel gravel removal requirements, right-of-way allowances and incorporating other pertinent information.

    d. Two near-term dike improvements have been identified and funding for these applied for. As sufficient funding becomes available, the identified most critical portions of Miller-Lillooet Dike C and the Poleyard Dike should be upgraded. Right-of-way arrangements need to be established for the Lillooet Dike C as soon as possible.

    e. Based on the completed dike quality and freeboard assessments, and following a risk-based approach, identify high priority dike improvement areas. As required, raise dike crest levels, improve cross-sectional geometries and apply erosion protection to reduce flood risks in critical areas and achieve a more uniform standard for areas at equal risk.

    f. A number of federal and provincial funding programs for flood mitigation work have been established. It is recommended that suitable funding opportunities be explored and identified, and funding applied for as needed.

    g. A portion of the Miller-Lillooet-Pemberton dike is classified as high consequence. Upgrading the dike to 200-year standards will require that the high-consequence portion of the dike meets seismic standards. It is recommended that geotechnical testing (cone penetration tests) be carried out to determine if ground compaction or other improvements are necessary in order to meet standards.

h. Raising a portion of Highway 99 at Mount Currie and connecting the raised road portion to high ground west of the industrial area and to the Poleyard Dike at the east end is a potential solution for protecting Mount Currie. It is recommended that PVEMC contact MOTI to jointly explore this solution.

i. A number of challenges are associated with building a set-back dike to protect the Village of Pemberton. However, it is recommended that the option be discussed with the broader community to assess potential interest.

## 2. Gravel Removals

a. As material from the Meager Creek slide moves through the Pemberton Valley, it is recommended that a regular sediment removal program be established for the bars in the Lillooet River mid-reach, particularly between the Ryan and Green River confluences.

b. To improve gravel management, it is recommended that a sediment trap reach be established upstream of the FSR Bridge. The river is wide and braided in this reach and by providing a double channel configuration, it is expected the active channel can be switched from side-to-side, allowing material to be periodically removed in the dry from the inactive side channel.

c. The PVDD has established gravel removal locations on the tributary creeks. It is recommended that PVDD continue with removals as required.

d. It is recommended that the channel bed within the floodplain mapping reach be monitored and resurveyed every 5-10 years and compared to the previous survey. If large variations, say exceeding 0.5 m, are noted the model should be rerun and the design profile/ mapping updated.

## 3. Infrastructure Improvements

a. As funding becomes available, the Arn Canal outlet should be upgraded to reduce flooding at the downstream end of the Canal.

b. A proposal for modelling the Arn Canal and improving channel conveyance was prepared for PVDD. This work should be undertaken as funding becomes available.

c. Previous work on Pemberton Creek has shown that the Highway 99 Bridge at the Creek has insufficient capacity, raising creek flood levels upstream of the bridge. As Highway 99 is an important evacuation route for the area, MOTI should be encouraged to replace the bridge with a higher capacity structure to avoid wash out of the highway.

## 4. Land Use Planning and Emergency Preparation

a. It is recommended that the recently prepared floodplain and hazard maps be used as a basis for updating Official Community Plans, Zoning Bylaws, Floodplain Management Bylaws and Development Permit Areas. This is to encourage new development on higher ground outside the floodplain, implement new FCLs, adopt set-back criteria to allow room for dike widening and flood response, set dike right-of-way allowances, reduce development in high hazard areas, enforce building on fill/ raised foundations or using water-resistant building materials. For tributary fan areas, carrying out hazard assessment studies and developing standard building requirements is recommended.

b. Accurate and reliable river gauges are critical. As previously recommended, WSC should continue to obtain flow measurements at Station 08MG005 and update the rating tables for the gauge as needed. WSC is encouraged to install or re-activate gauges on the tributaries, currently not in operation. It is particularly important that a gauge be re-installed on the Birkenhead River. In order of priority, the Green, Ryan and Miller watersheds should also be gauged.

c. The gauge at the FSR Bridge needs to be monitored and maintained as it provides important warning time for a river blockage caused by a major landslide. The gauge levels may help responders assess when the upper valley roads become impassable.

d. In addition to continuous recording gauges, the installation and monitoring of additional manual staff gauges is recommended to assist dike patrol personnel in determining the rate of rise in flood waters and measuring available freeboard on the dikes. Training of a few local authority staff (in addition to PVDD personnel) to become local flood observers/assessors is encouraged.

e. Tracking river levels and closely monitoring dike conditions during floods is of critical importance. It is recommended that clear terminology and a standard sequence of advisories, warnings and orders be used. The actual and RFC forecasted rate of rise of river levels during a flood event should be tracked and compared to dike levels at which the dikes become potentially “unsafe”. Without any specific dike stability or seepage issues noted by dike patrols, this “trigger level” would typically be reached when the flood level rises, or is forecast to rise within the freeboard allowance (say 0.3 to 0.6 m) of the dike crest.

f. A detailed evacuation plan should be developed, taking into account possible dike breach locations and the time available for evacuation before evacuation routes become impassable. The length of time from when an evacuation order is given to the time when people (especially the most vulnerable groups) can be safely evacuated to refuge areas must be considered. Community preparedness information and training regarding the emergency management plan must be developed and distributed.

5. Additional Hydraulic Modelling
    a. Additional assessment of conveyance improvements in the reach between the Lillooet River Highway 99 and railroad bridges is recommended to explore potential dike set-back scenarios to improve conveyance.

    b. 200-year tributary profiles should be modelled to assess tributary dike levels upstream of Lillooet backwater influence. (The Birkenhead River flood profile is currently being modelled under a separate project.)

    c. Update the model bathymetry, model runs and floodplain mapping every 5-10 years. For model recalibration, collect high watermark information at floods with return periods exceeding about 20 years.

# 5 CLOSURE

We appreciate the opportunity to work on this interesting project and trust this report meets your current requirements. Please let us know if you have any questions or require further clarification.

# 6 REFERENCES

KWL 2009. Arn Canal Drainage Improvement Project, Field Investigations and Hydraulic Analysis of Arn Canal. Report prepared for PVDD.

KWL 2010. Lillooet Lake Lowering Analyses. Summary of Hydraulic Modelling. Report prepared for PVDD.

NHC 2014. Birkenhead River Flood Hazard Reduction, 2014 Sediment and Debris Management. Design Brief.

NHC 2015. Lower Mainland Dike Assessment – Final Report. GS15MN-054. Prepared for Ministry of Forests, Lands and Natural Resource Operations. With input from Thurber Engineering Ltd. July 2015.

NHC 2018. Lillooet River Floodplain Mapping – Final Report. Prepared for Pemberton Valley Dyking District. 31 August 2018.

NHC 2019b. Lillooet River Flood Mitigation Program – Preliminary Sediment Management Plan: Final Report. Revision 3. Prepared for Pemberton Valley Dyking District. 25 March 2019.

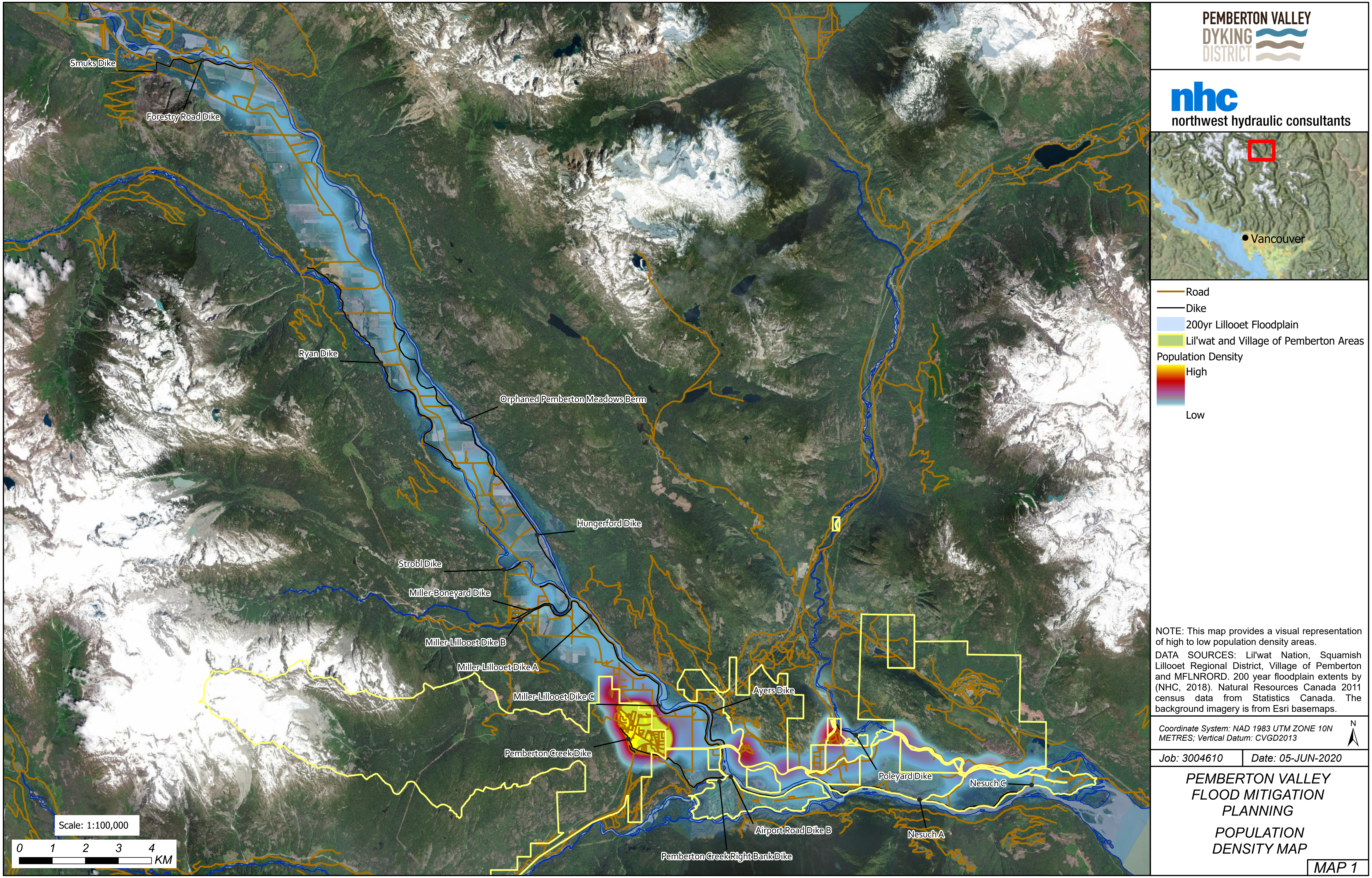
NHC 2019a. Pemberton Valley Flood Mitigation Planning, UBCM Community Emergency Preparedness Fund, Structural Flood Mitigation 2019 Grant Funding Application.

NHC 2019c. Arn Canal Hydraulic Modelling, Proposal for Engineering Services.

# Maps

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



NOTE: This map provides a visual representation of high to low population density areas.

DATA SOURCES: Lil'wat Nation, Squamish Lillooet Regional District, Village of Pemberton and MFLNRORD. 200 year floodplain extents by (NHC, 2018). Natural Resources Canada 2011 census data from Statistics Canada. The background imagery is from Esri basemaps.

*Coordinate System: NAD 1983 UTM ZONE 10N METRES; Vertical Datum: CVGD2013*

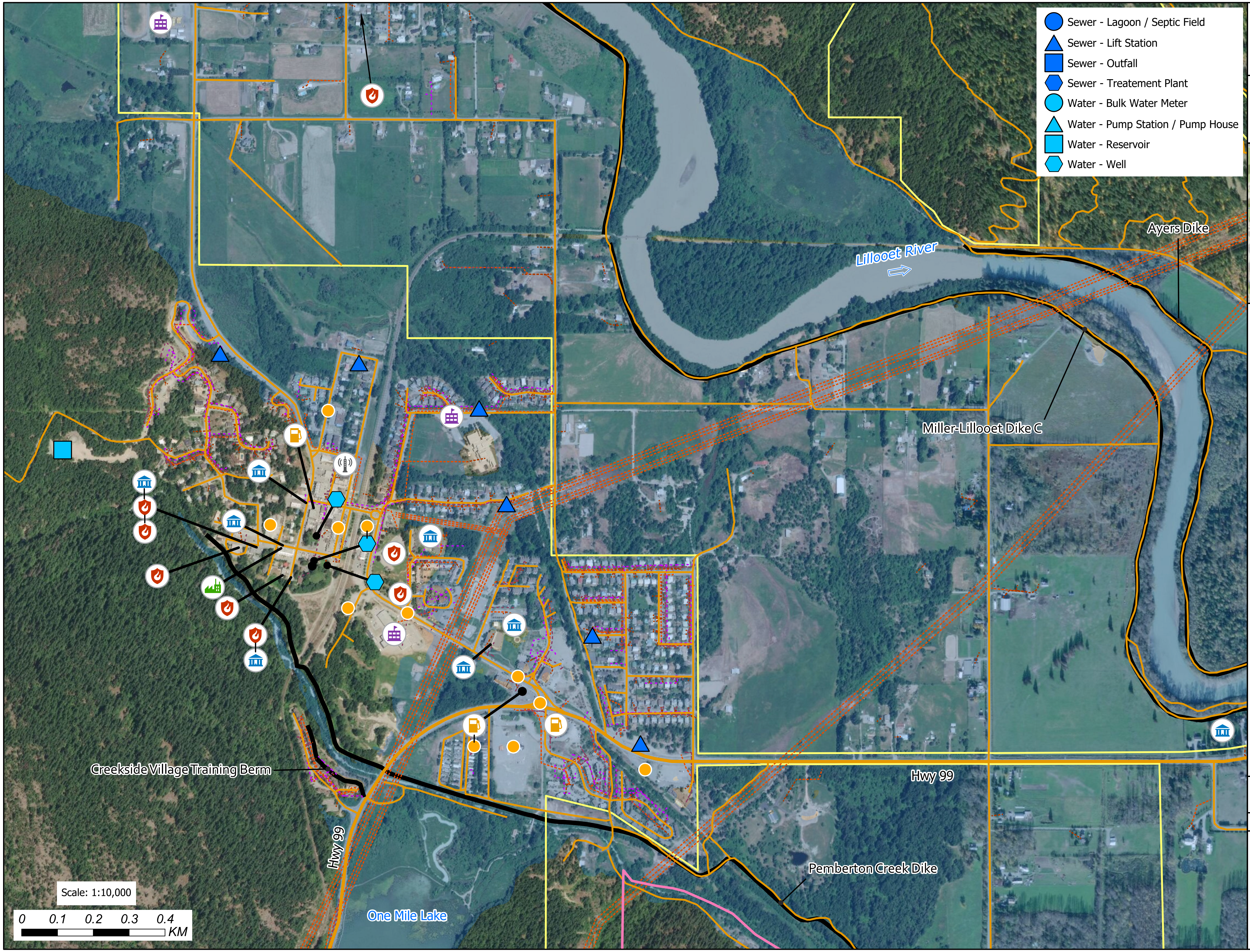
*Job: 3004610*

*Date: 05-JUN-2020*

# *PEMBERTON VALLEY FLOOD MITIGATION PLANNING*

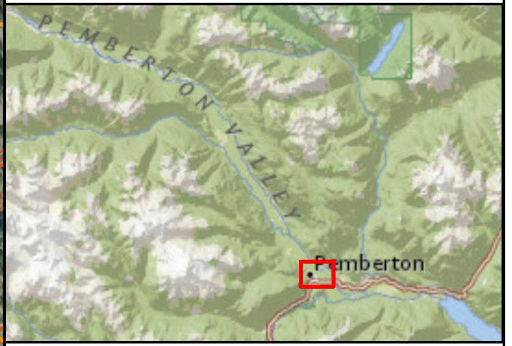
## *POPULATION DENSITY MAP*

*MAP 1*



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- ● Contaminated Sites
- Cell Tower
- Emergency Facility
- Community Facility
- Health Facility
- School
- Gas Station
- Energy and Utility Facility
- Dike
- Roads
- Highway 99
- Telecomunication Line
- Hydro Line
- Area of Cultural Significance
- 200yr Lillooet Floodplain
- Village of Pemberton Area

DATA SOURCES: Asset data from Lil'wat Nation, Squamish Lillooet Regional District, Village of Pemberton and MFLNRO. Other assets may be located within the region but not included in the data provided for this study. The background imagery is from Esri basemaps.

*Coordinate System: NAD 1983 UTM ZONE 10N METRES; Vertical Datum: CVGD2013*

N

*Job: 3004610* *Date: 05-JUN-2020*

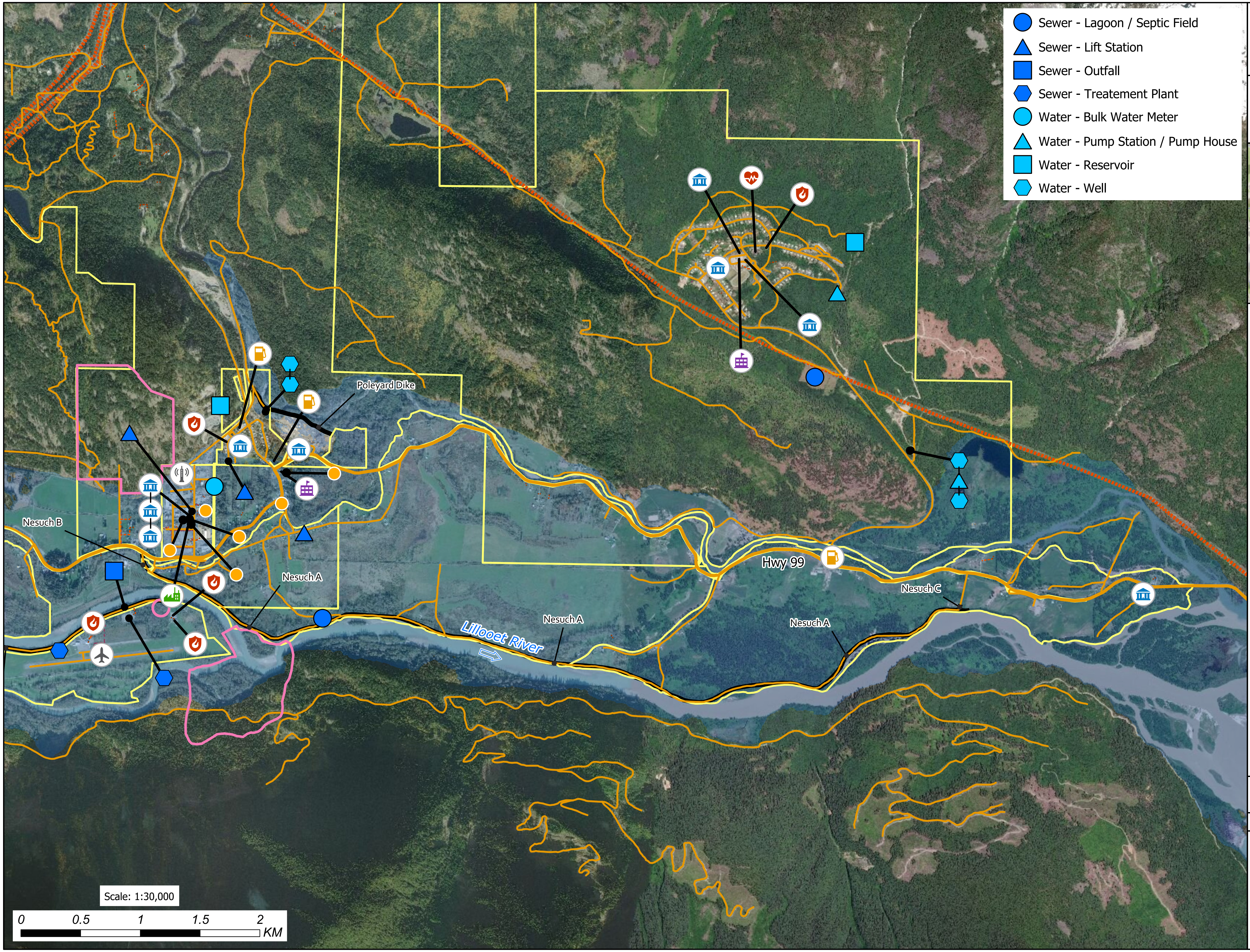
*PEMBERTON VALLEY FLOOD MITIGATION PLANNING*

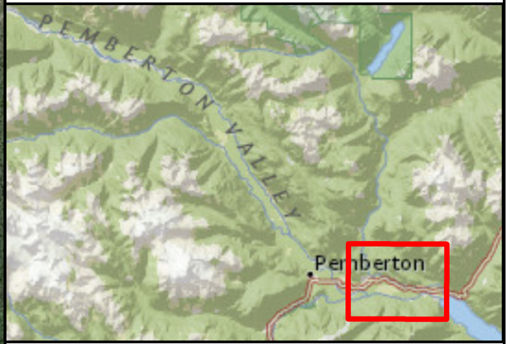
*ASSET MAP*

*MAP 2*

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants





- ● Contaminated Sites
- Cell Tower
- Emergency Facility
- Community Facility
- Health Facility
- School
- Gas Station
- Energy and Utility Facility
- Dike
- Roads
- Highway 99
- Telecomunication Line
- Hydro Line
- Area of Cultural Significance
- 200yr Lillooet Floodplain
- Village of Pemberton Area

DATA SOURCES: Asset data from Lil'wat Nation, Squamish Lillooet Regional District, Village of Pemberton and MFLNRO. Other assets may be located within the region but not included in the data provided for this study. The background imagery is from Esri basemaps.

*Coordinate System: NAD 1983 UTM ZONE 10N METRES; Vertical Datum: CVGD2013*

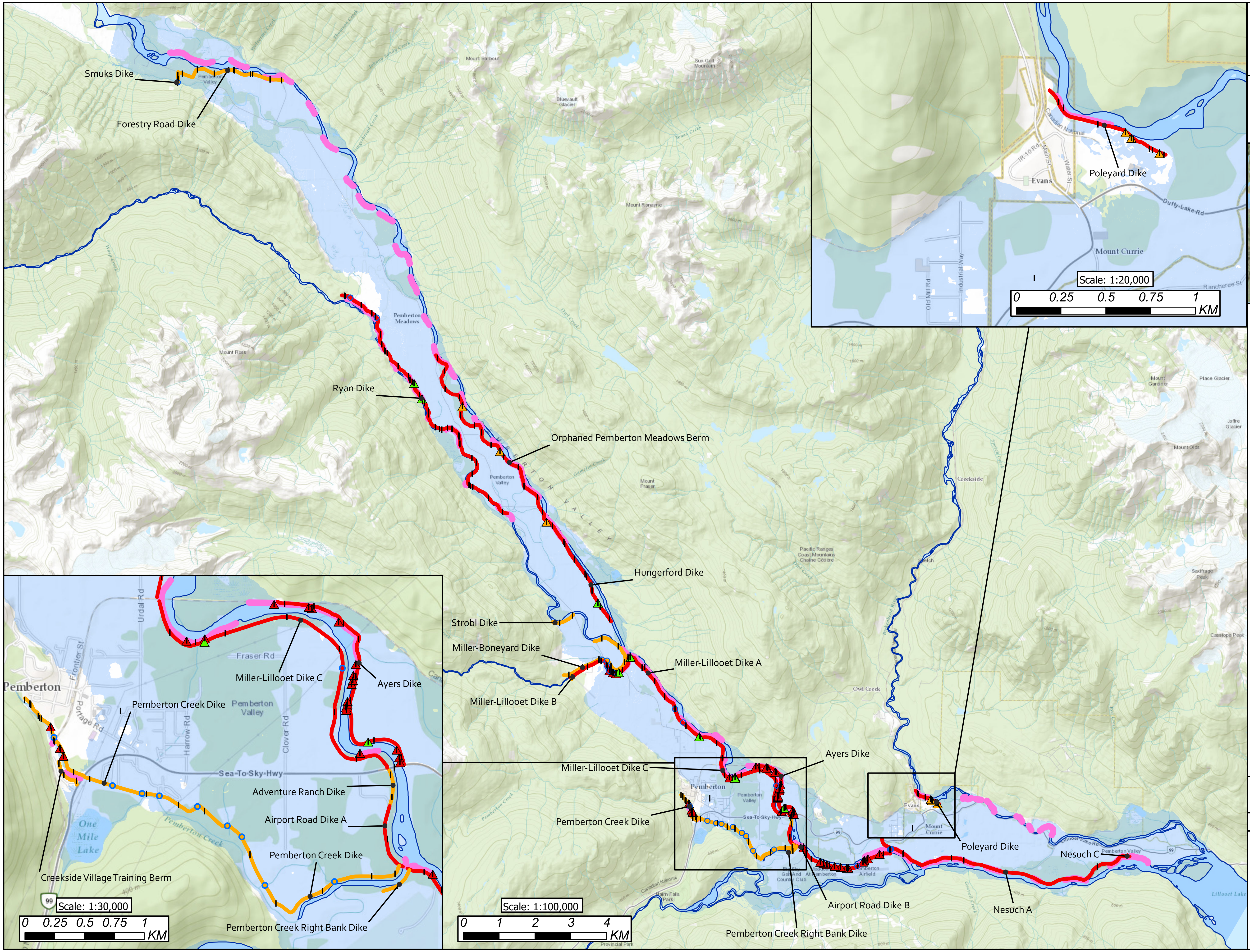
N

| *Job: 3004610* | *Date: 05-JUN-2020* |
|---|---|

# *PEMBERTON VALLEY FLOOD MITIGATION PLANNING*

## *ASSET MAP*

*MAP 3*



PEMBERTON VALLEY
DYKING
DISTRICT

nhc
northwest hydraulic consultants

○ Flood Box
▬ Riprap Extent
▨ 200yr Lillooet Floodplain
| NHC Dike Assessment Point

Location of Concern (NHC 2019)
- ▲ Dike Erosion
- ▲ Dike Seepage or Settlement Issues
- ▲ Substandard Dike Geometry

Overall Dike Condition Ranking
- ▬ Poor to Unacceptable
- ▬ Fair to Poor
- ▬ Good to Fair

NOTES: Dikes only assessed at locations shown. Additional areas of concern may exist. For dike assessment procedure, see NHC report (2019).

DATA SOURCES: The background imagery is from Esri basemaps.

Coordinate System: NAD 1983 CSRS UTM ZONE 10N Units: METRES; Vertical Datum: CVGD2013

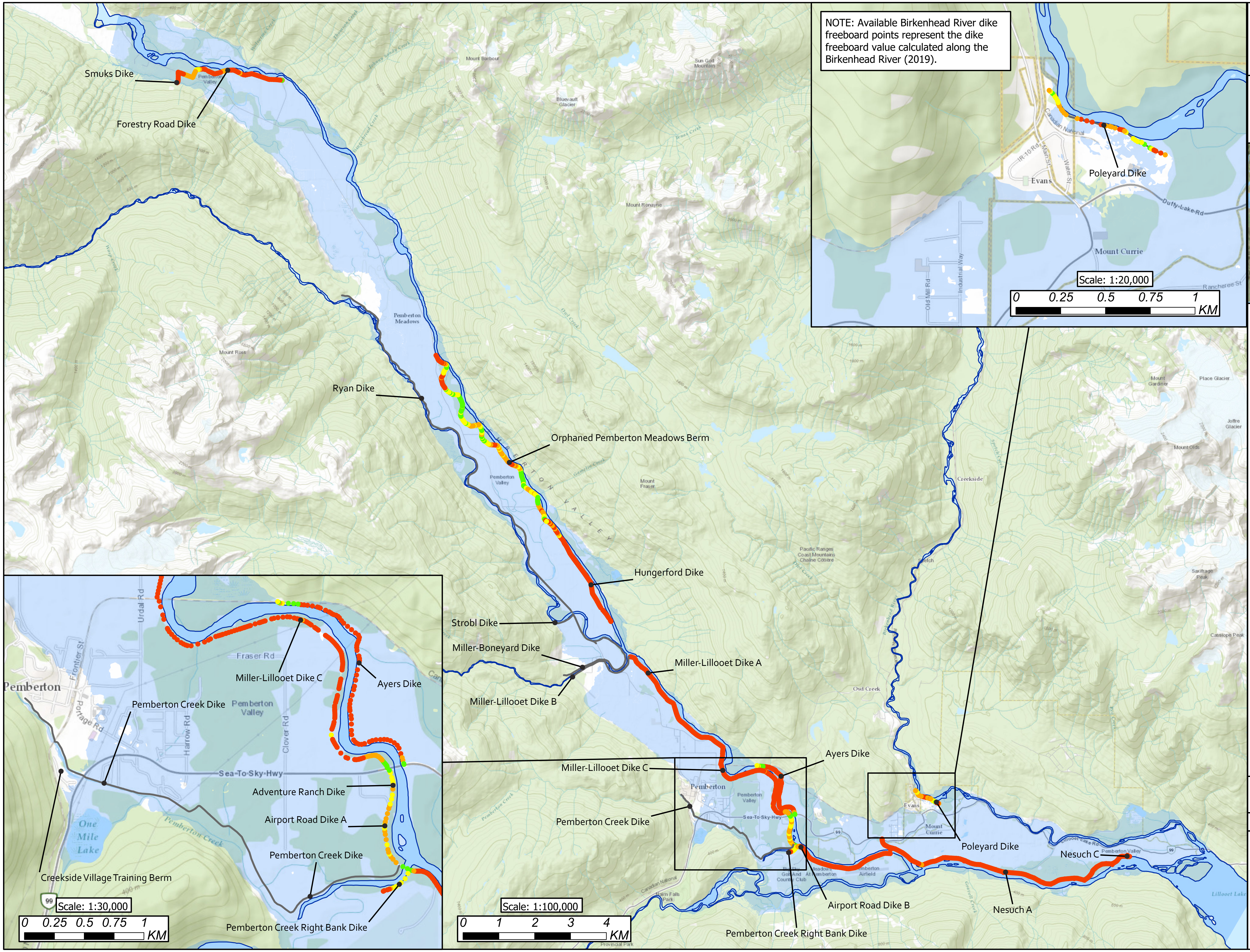
N

| Job: 3004610 | Date: 05-JUN-2020 |
|---|---|

# PEMBERTON VALLEY FLOOD MITIGATION PLANNING

## DIKE CONDITION ASSESSMENT MAP

MAP 4



NOTE: Available Birkenhead River dike freeboard points represent the dike freeboard value calculated along the Birkenhead River (2019).

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants

Tributary Dikes
200yr Lillooet Floodplain
Available Dike Freeboard (200yr) [1, 2]
● >0.6m *Good*
● 0.3-0.6m *Fair*
● 0-0.3m *Poor*
● <0m *Unacceptable*

NOTES: [1] Available Lillooet River dike freeboard points represent the dike freeboard value calculated along the Lillooet River. Dike freeboard based on surveyed dike crest elevations and 200 year Lillooet River flood without freeboard (NHC, 2018), unless stated otherwise.
[2] Independent flood events have not been modelled for contributing tributaries, except for Birkenhead River (2019).

DATA SOURCES: The background imagery is from Esri basemaps.

*Coordinate System: NAD 1983 UTM ZONE 10N METRES; Vertical Datum: CVGD2013*

N

*Job: 3004610* | *Date: 05-JUN-2020*

*PEMBERTON VALLEY FLOOD MITIGATION PLANNING*

*LILLOOET AND BIRKENHEAD RIVER DESIGN FLOOD EVENT DIKE FREEBOARD MAP*

MAP 5

# APPENDIX A: DATA INVENTORY

# TABLE OF CONTENTS

# LIST OF TABLES

# 1 DATA DISPLAYED ON MAPS

This section identifies the sources of the layers displayed on the maps, any alterations made to the data, and summarizes data limitations.

## 1.1 Asset Inventory Map

**Table 1.1 Layers on asset inventory map**

| Layer | Source | Notes | Alterations | Limitations |
|---|---|---|---|---|
| Contaminated Sites | VoP and Lil'wat Nation, downloaded Aug. 15 and Aug. 31 respectively. | Only location provided, no details about type or severity of contamination. | None. | May be inaccurate or incomplete – datasets were not independently verified. |
| Cell Tower | SLRD, downloaded Aug. 19, 2019. | Redundant with dataset downloaded from VoP. | Verified consistent | May be inaccurate or incomplete – not verified. |
| Emergency Facility | VoP, SLRD and Lil'wat Nation, downloaded Aug. 15, Aug. 16, and Aug. 31 respectively. | Includes emergency facilities such as fire halls, police headquarters, ambulance stations, search and rescue bases and Emergency Operations Centres. | Infrastructure was categorized. | May be inaccurate or incomplete – datasets were not independently verified. |
| Community Facility | VoP, SLRD and Lil'wat Nation, downloaded Aug. 15, Aug. 16, and Aug. 31 respectively. | Includes daycares, community centres and government buildings. | Infrastructure was categorized. | May be inaccurate or incomplete – datasets were not independently verified. |
| Health Facility | VoP, SLRD and Lil'wat Nation, downloaded Aug. 15, Aug. 16, and Aug. 31 respectively. | Includes health centres and hospitals. | Infrastructure was categorized. | May be inaccurate or incomplete – datasets were not independently verified. |
| School | VoP, SLRD and Lil'wat Nation, downloaded Aug. 15, Aug. 16, and Aug. 31 respectively. | Includes primary and secondary school facilities. | Infrastructure was categorized. | May be inaccurate or incomplete – datasets were not independently verified. |

| Layer | Source | Notes | Alterations | Limitations |
|---|---|---|---|---|
| Gas Station | VoP and Lil'wat Nation, downloaded Aug. 15 and Aug. 31 respectively. | VoP layer and stations from the Lil'wat nation contaminated sites information. | None. | May be inaccurate or incomplete – datasets were not independently verified. |
| Energy and Utility Facility | VoP and Lil'wat Nation, downloaded Aug. 15 and Aug. 31 respectively. | Infrastructure including government works yards, post stations, capacitor station, waste transfer stations and | Infrastructure was categorized. | May be inaccurate or incomplete – datasets were not independently verified. |
| Water and Sewer Infrastructure | VoP, SLRD and Lil'wat Nation, downloaded Aug. 15, Aug. 16, and Aug. 31 respectively. | Layer includes wells, water reservoirs, life stations, treatment plants, pump facilities, and sewer facilities. | Infrastructure was categorized. | May be inaccurate or incomplete – datasets were not independently verified. |
| Dike | Collected during field survey for this project. | See notes in project report. | None. | See limitations in project report. |
| Road | SLRD, downloaded Aug. 19, 2019. | Includes forest service roads which may not be maintained to a standard where they are accessible to all. | None. | Does not include proposed roads. May be inaccurate or incomplete – datasets were not independently verified. |
| Telecommunication Line | SLRD, downloaded Aug. 19, 2019. | Communications lines identified in SLRD data. | Merged lines from Shaw and Telus. | All lines symbolized the same. May be inaccurate or incomplete – datasets were not independently verified. |
| Hydro Line | SLRD, downloaded Aug. 19, 2019. | Underground and aboveground hydro transmission and distribution lines. | Merged underground, aboveground, | All lines symbolized the same. May be inaccurate or incomplete – datasets were not |
| Area of Cultural Significance | VoP and Lil'wat Nation, downloaded Aug. 15 and Sept. 4 respectively. | No data was downloaded specific to SLRD. | Merged data sources together. | May not have consistent coverage through SLRD. May be inaccurate or incomplete – datasets were not independently verified. |

| Layer | Source | Notes | Alterations | Limitations |
|---|---|---|---|---|
| 200yr Floodplain Extent | NHC Lillooet River Floodplain Mapping project, completed Aug. 31, 2018. | Flood extents including freeboard. | None. | Modelled flood extents have the same limitations as the flood model (See flood mapping report). |
| Lil'wat and Village of Pemberton Areas | VoP and Lil'wat Nation, downloaded Aug. 15 and Aug. 31 respectively. | Administrative boundary edges. | Merged layers together. | Not applicable. |

## 1.2 Population Distribution Map

The population heatmap is based on a visual representation of population. To represent population distribution, a Social Vulnerability Index dataset from Natural Resources Canada (NRCan) was used. This dataset is based on the 2011 Canadian census as adapted and analyzed by Natural Resources Canada (NRCan). NRCan's analysis has not yet been published, but was described to NHC by M. Journeay (pers com, Oct. 11, 2018) and is detailed below. The population data is based on data published at the census dissemination area (DAUID) level and has been refined to cover settled areas (SAUID). This refinement used Statistics Canada land cover information collected through the Landsat remote sensing program. This analysis was adapted to restrict DAUID polygons to settled areas through removing forests, wilderness areas, parks, agricultural land, etc. This output was refined in rural and remote areas by using NRCan Canvec data. The statistics for a given DAUID were then distributed over the settled areas using a weighted average (rather than an assumption of uniform density) based on the Night Light Development Index (NLDI). The NLDI identifies the concentration of lights seen at night and was developed by the National Oceanic and Atmospheric Administration (NOAA)'s National Centres for Environmental Information. Areas with greater concentrations of light at night were assigned a higher portion of the population. For the area just north of the Nesuch A Dike, project reviewers identified that the population distribution to the SAUID was unrealistically high. For the SAUID polygon with the unrealistically high value, the population value from the intersecting 2016 census dissemination area polygon of 5 was applied to this SAUID.

Using this population dataset, points were randomly distributed within each settled area to represent the number of people in each area. A heatmap symbology was then applied to the points, to visualize point concentration.

# 2 DOWNLOADED DATA

The following table summarizes all datasets downloaded. The table identifies their source, the date downloaded, a brief description and a data use agreement if applicable.

**Table 2.1 List of all downloaded data**

| Dataset | Source | Brief Description | Data Use Agreement |
|---|---|---|---|
| address_082019 | SLR, downloaded Aug. 16, 2019 | address and building classification | Not applicable |
| CellTowers | SLR, downloaded Aug. 16, 2019 | Location of cell towers | Not applicable |
| Lilwat Subset - Critical infrastructure v1.xlsx | SLR, downloaded Aug. 16, 2019 | description and location of buildings, also included in dataset below | Not applicable |
| Roll Detail T08_46_16 | SLR, downloaded Aug. 16, 2019 | Property assessment data table | Not applicable |
| Roll Detail T08_47_57 | SLR, downloaded Aug. 16, 2019 | Property assessment data table | Not applicable |
| WATER_INTAKES | SLR, downloaded Aug. 16, 2019 | None within study area | Not applicable |
| TranspNetwork | SLR, downloaded Aug. 16, 2019 | Transportation network for entire study area | Not applicable |
| TRANSFER_STATIONS | SLR, downloaded Aug. 16, 2019 | One within study area | Not applicable |
| TELUS_TRANSMISSION_LINE | SLR, downloaded Aug. 16, 2019 | Location of Telus lines | Not applicable |
| SHAW_TRANSMISSION_LINE | SLR, downloaded Aug. 16, 2019 | Location of Shaw lines | Not applicable |
| REC_SITES | SLR, downloaded Aug. 16, 2019 | None within study area | Not applicable |
| PLANNING_ZONING_062018 | SLR, downloaded Aug. 16, 2019 | Zoning | Not applicable |
| PLANNING_RGS | SLR, downloaded Aug. 16, 2019 | Identifies settled areas | Not applicable |
| PLANNING_OCP | SLR, downloaded Aug. 16, 2019 | OCP land use designation | Not applicable |
| Muster | SLR, downloaded Aug. 16, 2019 | None within study area | Not applicable |
| HELIPORT | SLR, downloaded Aug. 16, 2019 | None within SLRD | Not applicable |
| Facilities | SLR, downloaded Aug. 16, 2019 | Day cares, SAR stations, etc. | Not applicable |
| EvacRoutes | SLR, downloaded Aug. 16, 2019 | Outlined evacuation routes for SLRD | Not applicable |
| ENV_OGMA | SLR, downloaded Aug. 16, 2019 | Forest range practices within study area | Not applicable |
| EHS_TSUNAMIZONE | SLR, downloaded Aug. 16, 2019 | None within study area | Not applicable |
| EHS_FLOODPLAINS | SLR, downloaded Aug. 16, 2019 | Old floodplain within study area | Not applicable |
| EHS_FIREZONE | SLR, downloaded Aug. 16, 2019 | Fire zones within study area | Not applicable |
| CONSERVACY_AREAS | SLR, downloaded Aug. 16, 2019 | Conservancy areas within study area - little overlap | Not applicable |
| CATCHMENT_BASINS | SLR, downloaded Aug. 16, 2019 | Basins all outside of study area | Not applicable |
| Broadcast | SLR, downloaded Aug. 16, 2019 | Radio broadcast locations | Not applicable |
| BDY_SLRD | SLR, downloaded Aug. 16, 2019 | Boundary of SLR and VoP | Not applicable |

| Dataset | Source | Brief Description | Data Use Agreement |
|---|---|---|---|
| BCHYDRO_TRANSMISSION_UGS | SLR, downloaded Aug. 16, 2019 | Underground secondary lines | Not applicable |
| BCHYDRO_TRANSMISSION_UGP | SLR, downloaded Aug. 16, 2019 | Underground primary lines | Not applicable |
| BCHYDRO_TRANSMISSION_LINE | SLR, downloaded Aug. 16, 2019 | Transmission lines | Not applicable |
| Cultural Protection Areas | VoP, downloaded Aug. 15, 2019 | Areas of cultural significance | Not applicable |
| Helipad | VoP, downloaded Aug. 15, 2019 | One within study area | Not applicable |
| Airport | VoP, downloaded Aug. 15, 2019 | One within study area | Not applicable |
| ALR | VoP, downloaded Aug. 15, 2019 | ALR within VoP | Not applicable |
| Sewer outfall | VoP, downloaded Aug. 15, 2019 | Sewer outfall | Not applicable |
| Water reservoir | VoP, downloaded Aug. 15, 2019 | water reservoir | Not applicable |
| Treatment plant | VoP, downloaded Aug. 15, 2019 | treatment plant | Not applicable |
| VOP lift stations | VoP, downloaded Aug. 15, 2019 | VOP lift stations | Not applicable |
| Well locations | VoP, downloaded Aug. 15, 2019 | well locatoins | Not applicable |
| Water main | VoP, downloaded Aug. 15, 2019 | Water main, no attribute data | Not applicable |
| Cell towers | VoP, downloaded Aug. 15, 2019 | Redundant with SLRD layer | Not applicable |
| Gas stations | VoP, downloaded Aug. 15, 2019 | Gas stations | Not applicable |
| Contaminated sites | VoP, downloaded Aug. 15, 2019 | Contaminated sites identified | Not applicable |
| Community infrastructure | VoP, downloaded Aug. 15, 2019 | Primary school, community centre, child care, secondary school, senior housing | Not applicable |
| Emergency Centre | VoP, downloaded Aug. 15, 2019 | Some differences between SLRD layer. Includes hospital, SAR, Wildfire Base, Ambulance Bay, Fire Station, RCMP, VOP EOC | Not applicable |
| BC Assessment Data | VoP, downloaded Aug. 15, 2019 | Total value | Not applicable |
| Future potential growth areas | VoP, downloaded Aug. 15, 2019 | Areas identified for future potential growth | Not applicable |
| Urban growth areas | VoP, downloaded Aug. 15, 2019 | Areas identified for urban growth | Not applicable |
| Civic address points | VoP, downloaded Aug. 15, 2019 | Some alignment with assessment data | Not applicable |
| Municipal boundary | VoP, downloaded Aug. 15, 2019 | Municipal boundary outline for VoP | Not applicable |
| Landuse designations (OCP) | VoP, downloaded Aug. 15, 2019 | OCP land use designations | Not applicable |
| Zoning Code | VoP, downloaded Aug. 15, 2019 | Zoning designations | Not applicable |

| Dataset | Source | Brief Description | Data Use Agreement |
|---|---|---|---|
| 190828_LilwatCommunityFarm | Lil'wat Nation, downloaded Aug. 31, 2019 | 1 identified polygon | Signed agreement[1] |
| 190828_HazardousSites | Lil'wat Nation, downloaded Aug. 31, 2019 | 3 identified sites | Signed agreement[1] |
| 181031_SensitiveEcosystemInventory | Lil'wat Nation, downloaded Aug. 31, 2019 | Ecosystem descriptions | Signed agreement[1] |
| 180228_Lilwat_Reserve_Boundaries | Lil'wat Nation, downloaded Aug. 31, 2019 | Administrative boundaries of reserve | Signed agreement[1] |
| 181031_sensitivityRating | Lil'wat Nation, downloaded Aug. 31, 2019 | Unknown - high, medium and low | Signed agreement[1] |
| 2014_CLUP_Zones_USL | Lil'wat Nation, downloaded Aug. 31, 2019 | Land use zoning with some special notes such as mushroom farming | Signed agreement[1] |
| Water_Points | Lil'wat Nation, downloaded Aug. 31, 2019 | Water infrastructure identified | Signed agreement[1] |
| BCH_Poles | Lil'wat Nation, downloaded Aug. 31, 2019 | BC hydro poles | Signed agreement[1] |
| SewerFacilities_1 | Lil'wat Nation, downloaded Aug. 31, 2019 | 2 septic field areas and infrastructure components | Signed agreement[1] |
| Community_buildings | Lil'wat Nation, downloaded Aug. 31, 2019 | 8 community buildings identified | Signed agreement[1] |
| EOC | Lil'wat Nation, downloaded Aug. 31, 2019 | 4 emergency facilities | Signed agreement[1] |
| 198028_AddressData_Points | Lil'wat Nation, downloaded Aug. 31, 2019 | Building points | Signed agreement[1] |
| 190904_Cultural sites | Lil'wat Nation, downloaded Sept. 4, 2019 | Cultural sites | Signed agreement[1] |

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[1] Confidentiality and non-reproduction agreement between Lil'wat Nation Lands and Resources Department and Northwest Hydraulic Consultants, Aug. 28, 2019.

# APPENDIX B: DIKE CONDITION ASSESSMENT

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# LIST OF TABLES

# LIST OF MAPS

# 1 DIKE CONDITION ASSESSMENT

This Appendix provides details on the methodology and results of NHC's dike condition assessment. Included are: 1) the dike freeboard assessment ranking matrix; 2) the dike quality assessment matrix used to classify the dike condition; 3) a list of locations of concern and related specific issues. Details about the geotechnical assessment can be found in Appendix C.

**It should be noted that the assessments are based on the specific sites visited. Other deficiencies may exist than those described in this report.**

## 1.1 Dike Freeboard Assessment

The dike freeboard assessment was based on the elevation of the 200 year flood level at the centreline of the river and the surveyed elevation of the dike crest, at the nearest projected point from the river centreline. The freeboard was classified following the classifications identified in Table 2. Points used in the Dike Freeboard Assessment are shown in Map 5.

**Table 1 Matrix Used for Dike Freeboard Assessment**

| Rating | Good (=4) | Fair (=3) | Poor (=2) | Unacceptable (=1) |
|---|---|---|---|---|
| **1. Crest Elevation vs DCL** | Dike ties into high ground or otherwise prevents backwater flooding. Crest levels exceed DCL's (freeboard requirements are fully met with 0.6 m of freeboard).<br>Long-term bed aggradation or debris depositions are unlikely to impact the design profile significantly or, there is a regular channel maintenance program in effect.<br>Lateral channel changes are unlikely to raise the design profile. | Dike ties into high ground or otherwise prevents backwater flooding. A minimum freeboard of 0.3 m is available over most of the dike length. Some lower spots exist that can be plugged during floods.<br>Long-term bed aggradation or debris depositions may to some extent impact the design profile but the channel is fairly well maintained or rates are low. Lateral channel changes may to some extent change the design profile. | Dike ties into high ground or otherwise prevents backwater flooding. Crest levels exceed design flood levels but there is no freeboard. Some lower spots exist that can be plugged during floods.<br>Long-term bed aggradation or debris depositions have taken place affecting the design profile but, the channel has occasionally been maintained in the past. There is lateral instability and the design profile has changed over time. | Dike does not tie into high ground or there is risk of backwater flooding. Crest levels fall below design flood levels with less than 0 m of freeboard.<br>Bed aggradation or debris depositions are compromising the capacity of the dike and channel maintenance is inadequate.<br>There is significant lateral instability affecting the design profile and the profile is not regularly updated. |

## 1.2 Dike Quality Assessment Matrix

Dike quality was assessed through a standardized ranking framework which considered: dike geometry; erosion protection; vegetation and animal control; and appurtenant structures. The classifications used for each of the items assessed are shown in Table 2. While considered in other dike assessment projects, administrative arrangements were not explicitly considered in this project. Similarly, ‘geotechnical stability – seismic’ was not included in the calculation of overall score as it was not ranked on a four point scale. However, ‘geotechnical stability – general’ was included.

An average of all of the factors considered was used to determine the overall score for each dike. The results of the overall dike condition assessment are displayed on Map 4. (A breakdown of each category for each dike are shown in the attribute table of the ‘Dike’ layer included in the data for this project.)

**Table 2 Matrix Used for Dike Quality Assessment**

| Rating Item | Good (=4) | Fair (=3) | Poor (=2) | Unacceptable (=1) |
|---|---|---|---|---|
| **1. Crest Elevation vs DCL (Freeboard)** | See Table 1 above. | See Table 1 above. | See Table 1 above. | See Table 1 above. |
| **2. Geometry**<br>**- Crest width**<br>**- Landside slope**<br>**- Waterside slope** | Crest width meets applicable standards and side slopes meet or exceed relevant specifications. (Crest width ≥ 4 m, landside slope ≥ 3H:1V, waterside slope ≥ 2.5H:1V). | Crest width and side slopes generally meet applicable standards. Deficiencies unlikely to compromise the dike stability. | Crest widths are less than fair and/or side slopes are over-steepened in some locations, causing concern. | Crest widths and/or side slopes are consistently inadequate. |
| **3a. Geotechnical Stability - General** | | | | |
| - Dike stability under flood conditions | Dike is stable during present design flood conditions and can likely be raised (<1 m) for future design levels without affecting stability. | Minor stability problems expected during design flood event but these will unlikely diminish the dike performance. Raising the dike for future design flood conditions may be problematic. | Some stability problems may occur during the design flood but damage is likely to be repairable. Raising the dike for future flood conditions is not possible without extensive reconstruction. | Dike is likely to fail due to geotechnical problems at flood levels less than the design event and prior to overtopping. Raising the dike is not feasible (poor foundation and fill materials). |
| - Seepage (piping and landside heave) | Seepage and landside heave have not been observed in the past and are not expected for present design flood conditions. | Minor seepage problems may occur. | Piping / landheave has been observed in the past. | Significant piping / landheave has been observed in the past and are potential causes for breaching. |
| - Long term settlement | Long-term settlement is minimal. | Settlement may require minor raising of dike to maintain design levels. | The dike has settled and settlement is likely to continue. | Extensive settlement has been observed. |

| Rating Item | Good (=4) | Fair (=3) | Poor (=2) | Unacceptable (=1) |
|---|---|---|---|---|
| **3b. Geotechnical Stability – Seismic** [1.] | Dike meets seismic standards. Not included. | Dike almost meets seismic standards. Not included. | Dike is seismically unstable. Not included. | The dike is seismically unstable. Not included. |
| **5 Erosion Protection**<br>**- Location of dike**<br>**- Exposure to erosion**<br>**- Quality of protection** | No protection is required because dike is well set back from river or ocean and flow velocities are low/ wave action limited. Or, dike has adequate erosion protection. | There is erosive action but it does not jeopardize the stability of the dike. Riprap appears to be properly designed but has some weaknesses. Erosion protection needs monitoring. | Riprap is undersized or not properly tied-in. Slumping or other damage has been reported and repairs should be undertaken. Protection may withstand design flood. | Erosion protection is inadequate. Dike may potentially fail due to erosive action of the dike or immediate foundation material. |
| **6. Vegetation/Animal Control**<br>**- Vegetation type/ sod cover**<br>**- Animal burrows, other animal activities impacting dike sideslopes and/or crest** | No woody vegetation or brush obscuring dike slopes. Vegetation is predominantly grasses that are regularly mowed. No reported animal burrows, other animal damage or activities impacting dike sideslopes / crest. | Minimal woody vegetation. Dike slopes generally well maintained. Some animal burrows and/or other activity impacting dike sideslopes / crest reported but damage has been repaired. | Small woody vegetation. Dike slopes covered with brush and difficult to inspect. Some animal burrows, other animal damage or activities impacting dike sideslopes / crest. | Large woody vegetation that would cause problems in windfall. Slopes covered with thick brush. Significant animal activity with unrepaired burrows or other severe damage to dike sideslopes or crest. |
| **6. Encroachments**<br>**- Buildings**<br>**- Road**<br>**- RW crossings/ land use** | No buildings or fences encroach on the dike ROW / access and there are no road / RW crossings affecting the dike. The dike is not used as a road/railroad and there are no conflicting land-uses. | Some buildings marginally encroach on dike ROW. Roads / RWs cross the dike, causing a slight lowering in the dike crest. A main road is located on the dike. No fences or conflicting land-uses. | Buildings encroach on ROW. Fences obstruct inspection personnel or emergency response. Road / RW crossings result in minor gaps that can be blocked during design flood. No conflicting land-use. | Buildings significantly encroach on dike. Road / RW crossings result in major gaps that are difficult to fill in order to prevent flooding. Top of dike is used for housing, parking etc. |

1. Geotechnical Stability – Seismic was not included in the average score.

## 1.3 Locations of Concern

An overview map is provided which shows the locations of field observations and each location of concern in Map B.1. Each location of concern is assigned an identifier which corresponds to information and photos in Table 3.

**Table 3 Locations of Concern Summary Table**

| Location of Concern |
|---|
| **LOC1 –** Dike Seepage or Settlement Issue<br>**Location:** 50.4249°N, -122.9160°W<br>**Description:** Located a hole in the ground which is 2 metres in diameter and 0.5 metres deep. The hole is located 4 metres from toe of the dike. Unsure of cause of hole, it may be related to subsurface flow from the river, causing boil/ sinkhole.<br>**Photos:**<br><br> |

| Location of Concern |
|---|
| **LOC2 –** Substandard Dike Geometry<br>**Location:** 50.4211°N, -122.9131°W<br>**Description:** Hole in the ground which is 0.8 metres in diameter and 0.3 metres deep. The hole's origin is unclear, it is located at the toe of the land-facing side of the dike and could be related to subsurface flow from river, causing boil/ sinkhole.<br>**Photo:**<br> |

**Location of Concern**

**LOC3 –** Substandard Dike Geometry

**Location:** 50.4191°N, -122.8972°W

**Description:** The berm is lowered by approximately 1 m for access road to the river. The depression is 6 metres in length and has slopes of 3H : 1V.

**Photo:**

## Location of Concern

**LOC4 –** Substandard Dike Geometry

**Location:** 50.4078°N, -122.8825°W

**Description:** There is a 0.5 metre dip in the dike with slopes of 2H: 1V into and out of the dip.

**Photo:**

**Location of Concern**

**LOC5 –** Substandard Dike Geometry
**Location:** 50.3901°N, -122.8642°W
**Description:** The length of the orphan dike from this location to the Hungerford Dike is poor and may fail at high water.
**Photo:**

| Location of Concern |
|---|
| **LOC6 –** Dike Seepage or Settlement Issue<br>**Location:** 50.3698°N, -122.8441°W<br>**Description:** Signs of cattle, animal disturbance and deterioration of dike.<br>**Photo:**<br> |

**Location of Concern**

**LOC7 –** Dike Erosion Issue

**Location:** start at 50.35279°N, -122.8397°W; end at 50.35228°N, -122.8383°W; length 110m

**Description:** Area of oversteep riverbank, almost vertical and/or undercut in some locations.

**Photo:**

| Location of Concern |
|---|
| **LOC8 –** Dike Erosion Issue<br>**Location:** 50.3520°N, -122.8371°W<br>**Description:** NHC had conversation with local farmer named Chad who identified the site as having turbid subsurface flow but who withdrew comment in second conversation.<br>**Photo:** No photo |
| **LOC9 –** Dike Seepage or Settlement Issue<br>**Location:** 50.3523°N, -122.8360°W<br>**Description:** Steve Flynn commented on July 29, 2019 that this was the location of boil formation during past flood events.<br>**Photo:** No photo |
| **LOC10 –** Dike Seepage or Settlement Issue<br>**Location:** 50.3561°N, -122.8314°W<br>**Description:** Steve Flynn commented on July 29, 2019 that this was the location of boil formation during past flood events.<br>**Photo:** No photo |

**Location of Concern**

**LOC11 –** Dike Seepage or Settlement Issue

**Location:** 50.3361°N, -122.8045°W

**Description:** There is a sinkhole on top of the dike on the side adjacent to the water. The hole is 0.4 m in diameter and 0.45 m deep. Anecdotal information from the adjacent landowner suggests the dike condition at this location has not noticeably changed for more than ten years (Steve Flynn pers. comm 10 Jan 2020).

**Photo:**

**Location of Concern**

**LOC12 –** Dike Erosion Issue

**Location:** start at 50.3258°N, -122.7927°W; end at 50.32598°N, -122.7905°W; length 100m

**Description:** Visible riprap launching and instability on the waterside of dike.

**Photo:**

**LOC13 –** Dike Seepage or Settlement Issue

**Location:** 50.3257°N, -122.7905°W

**Description:** Steve Flynn commented on July 29, 2019 that this was the location of boil formation during past flood events.

**Photo:** No photo

| Location of Concern |
|---|
| **LOC14 –** Dike Erosion Issue<br>**Location:** start at 50.3286°N, -122.7823°W; end at 50.32402°N, -122.7728°W; length 1160m<br>**Description:** Section of poor armouring with poorly graded rocks and inconsistent coverage.<br>**Photo:**<br><br> |

**Location of Concern**

**LOC15 –** Dike Erosion Issue

**Location:** 50.3272°N, -122.7748°W

**Description:** Isolated, 5 metre long scallop.

**Photo:**

**Location of Concern**

**LOC16 –** Dike Erosion Issue
**Location:** start at 50.3232°N, -122.7731°W; end at 50.32057°N, -122.7739°W; total length 300m
**Description:** Along this stretch of dike, there are a series of scallops and areas where additional armouring is required.
**Photo:**

| Location of Concern |
|---|
| **LOC17 –** Dike Seepage or Settlement Issue<br>**Location:** 50.31818°N, -122.7713°W<br>**Description:** The area has a large number of unexplained ground disturbances along the land-facing side of the dike, extending to the inside bend. Cause of disturbances is unknown.<br>**Photo:**<br> |

**Location of Concern**

**LOC18 –** Dike Erosion Issue

**Location:** start at 50.31756°N, -122.768°W; end at 50.3166°N, -122.7676°W; length 110m

**Description:** There is a section of over-steepened armour with some undercutting.

**Photo:**

**Location of Concern**

**LOC19 –** Dike Erosion Issue
**Location:** 50.3173°N, -122.7723°W
**Description:** Section of missing or inadequate armour.
**Photo:**

## Location of Concern

**LOC20 –** Dike Erosion Issue

**Location:** 50.3194°N, -122.8087°W

**Description:** Downstream of this point the extent of riprap coverage appears inadequate. The existing riprap is heavily overgrown and difficult to inspect.

**Photo:**

## Location of Concern

**LOC21 –** Dike Erosion Issue

**Location:** start at 50.3178°N, -122.8076°W; end at 50.3172°N, -122.8072°W; length 60m

**Description:** The berm was likely raised during a flood event and fill was placed on top of riprap. Since placement, the fill has started to migrate through voids in the riprap. The riprap along the side of the raised berm appears inadequate.

**Photo:**

**Location of Concern**

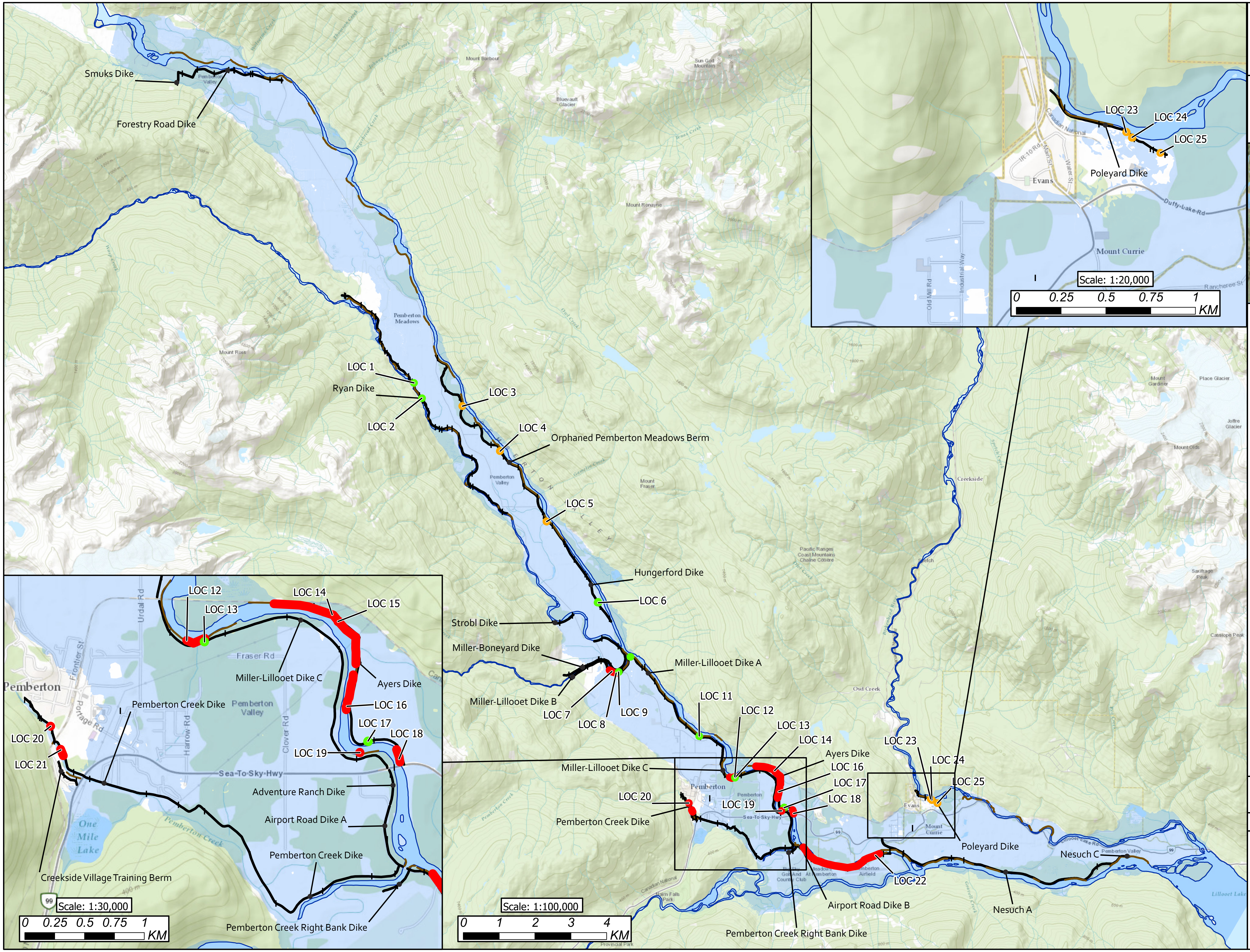
**LOC22 –** Dike Erosion Issue

**Location:** start at 50.3082°N, -122.7638°W; end at 50.3065°N, -122.734°W; length 2410m

**Description:** This is a section of missing, poor quality, failed, poorly graded and/or unstable armour.

**Photo:**

| Location of Concern |
|---|
| **LOC23 –** Substandard Dike Geometry<br>**Location:** 50.3202°N, -122.7138°W<br>**Description:** The dike downstream of location does not meet geometry criteria, especially not the required width.<br>**Photo:** No photos. |
| **LOC24 –** Substandard Dike Geometry<br>**Location:** 50.3199°N, -122.7134°W<br>**Description:** The dike top width is 2.5 m.<br>**Photo:** No photos. |
| **LOC25 –** Substandard Dike Geometry<br>**Location:** 50.3191°N, -122.7112°W<br>**Description:** The dike top width is 2 m.<br>**Photo:** No photos. |



PEMBERTON VALLEY DYKING DISTRICT

nhc
northwest hydraulic consultants

| | |
|---|---|
| I | NHC Dike Assessment Point |
| — | Riprap Extent |
| — | Dike Alignment |
| ▨ | 200yr Floodplain Extent |

Location of Concern

| | |
|---|---|
| 🟥 | Dike Erosion Issue |
| 🟧 | Substandard Dike Geometry |
| 🟩 | Dike Seepage or Settlement Issue |

NOTES: Dikes only assessed at locations shown. Additional areas of concern may exist. For dike assessment procedure and details on locations of concern, see NHC (2019).

DATA SOURCES: The background imagery is from Esri basemaps.

*Coordinate System: NAD 1983 UTM ZONE 10N METRES; Vertical Datum: CVGD2013*

N

*Job: 3004610* *Date: 05-JUN-2020*

## *PEMBERTON VALLEY FLOOD MITIGATION PLANNING*

## *LOCATIONS OF CONCERN OVERVIEW MAP*

*MAP B.1*

# APPENDIX C: GEOTECHNICAL ASSESSMENT

THURBER ENGINEERING LTD.

October 31, 2019 File: 27300

Northwest Hydraulic Consultants
405 - 495 Dunsmuir Street
Nanaimo, BC
V9R 6B9

Attention: Wil Hilsen, P.Geo.

# PEMBERTON DIKE ASSESSMENT
# GEOTECHNICAL REPORT

Dear Wil:

As requested, Thurber Engineering Ltd. (Thurber) has conducted a geotechnical investigation for the above project. This report presents the results of the investigation and our geotechnical engineering input for the project.

It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

## 1. BACKGROUND

The Pemberton Valley Dyking District (PVDD) has retained Northwest Hydraulic Consultants (NHC) to carry out an assessment of the flood protection dikes in the Pemberton Valley. Our scope of work was to conduct a geotechnical investigation and provide geotechnical input for conceptual planning of future dike upgrades. We assume that future upgrades will comprise raising the dikes by up to 1 m.

## 2. GEOTECHNICAL INVESTIGATION

### 2.1 Program of work

The field investigation consisted of drilling ten test holes (TH19-01 to TH19-10) at locations selected by the PVDD and NHC on the Pemberton Valley dikes listed in the table below. The test holes were drilled to depths of nominally 6 m using a truck-mounted solid stem auger drill operated by Southland Drilling Co. Ltd. on October 16 and 17, 2019. The approximate locations of the test holes are shown on Drawings No. 27300-1 to No. 27300-5 (attached).

| Dike | Test Holes |
|---|---|
| Poleyard | TH19-01 |
| Miller – Lillooet | TH19-02, TH19-03, TH19-05, TH19-06 |
| Pemberton Creek | TH19-04 |
| Miller – Boneyard | TH19-07, TH19-08 |
| Ryan River | TH19-09, TH19-10 |

The soil conditions encountered in the test holes were logged in the field by an experienced geotechnical engineer and representative disturbed samples were collected for routine moisture content testing and visual classification in our laboratory. Fines content analyses (% passing 75 µm sieve) and Atterberg limit testing were carried out on select representative samples.

All test holes were located on dikes or within the dike right-of-way and were fully grouted in general accordance with B.C. groundwater protection regulations and MFLNRO requirements.

## 2.2 Results of the Investigation

The results of the investigation and laboratory testing are summarized on the attached test hole logs. The logs provide a complete, detailed description of the conditions encountered and should be used in preference to the generalized descriptions given below.

TH19-01 was drilled on the Poleyard Dike east of the Lil'wat Nation water well. The soil profile encountered in TH19-01 comprised about 1.5 m of dike fill consisting of sand with some gravel overlying gravelly sand to the maximum depth investigated.

THs 19-02, 19-03, 19-05, and 19-06 were drilled on the Miller – Lillooet Dike between Highway 99 to the south and Miller Creek Bridge to the north. The soil profile encountered in THs 19-02 and 19-03 generally comprised 1.5 m to 1.8 m of dike fill consisting of sand with some silt overlying sand with zones of sandy silt to silty sand extending to the maximum depth investigated.

The soil profile encountered in TH19-05 comprised about 1.5 m of dike fill consisting of gravelly sand with some silt overlying silty gravel and sand to the maximum depth investigated.

The soil profile encountered in TH19-06 comprised about 1 m of dike fill consisting of silty sand with some gravel overlying silt to the maximum depth investigated, with a zone of sand with some silt between depths of about 3.6 m and 4.6 m.

TH19-04 was drilled on the Pemberton Creek Dike south of the intersection of Underhill Road and Vine Road. The soil profile encountered in TH19-04 comprised about 1.5 m of dike fill consisting of gravelly sand overlying gravel and sand extending to a depth of about 4.5 m. Below the gravel and sand, there was organic silt extending to the maximum depth investigated. The organic silt had low plasticity (PI<10) based Atterberg limit testing on a sample taken at a depth of about 5.8 m.

THs 19-07 and 19-08 were drilled on the Miller – Boneyard Dike between Cedar Grove Road and the mouth of Ryan River. The soil profile encountered in THs 19-07 and 19-08 generally comprised 1 m to 1.5 m of dike fill consisting of gravelly sand overlying gravel and sand extending to a depth of about 3 m. Below the gravel and sand was a sand layer. In TH19-08 the sand layer extended to the maximum depth investigated. In TH19-07, silt was encountered below the sand layer starting at a depth of about 5.3 m and extending to the maximum depth investigated. The silt was low to non-plastic (PI<5) based on the Atterberg limit testing on a sample taken at a depth of about 5.8 m in TH19-07.

THs 19-09 and 19-10 were drilled on the Ryan River Dike in the vicinity of the intersection of Green Road and Pemberton Meadows Road. The soil profile encountered in THs 19-09 and 19-10 generally comprised 2 m to 2.3 m of dike fill consisting of silty sand overlying sandy silt to silt and sand to the maximum depth investigated.

These subsurface conditions encountered during the investigation are generally consistent with the surficial geology described in the Geological Survey of Canada's report "Surficial geology and landslide inventory of the upper Sea to Sky corridor, British Columbia" available in Open File 5324. The surficial geology map in this report indicates that the Pemberton Valley dikes are mostly on floodplain sediments comprising sand and silt. Some of the dikes are on alluvial fan sediments comprising sand and gravel.

Groundwater levels are anticipated to generally follow water levels in the waterways adjacent to the dikes and can be expected to vary with rainfall, drainage and infiltration.

## 3. GEOTECHNICAL INPUT

The geotechnical input provided below is high-level input that is intended to provide guidance for assessing feasibility and guiding planning of future dike upgrades and must not be interpreted to be design recommendations. Our input is based on the results of our investigation and apply only to the dikes investigated and for dike raises of up to 1 m.

We understand that design and construction of any dike upgrades must conform to requirements of the Ministry of Forests, Lands and Natural Resources (MFLNRO) to obtain approval under the Dike Management Act. Accordingly, dike design should follow the guidance provided in MFLNRO's document titled "General Guidelines – Comprehensive Geotechnical Investigation and Design Report" (February 2010) and "Dike Design and Construction Guide – Best Management Practices for British Columbia" (July 2003). These documents require that the geotechnical design address dike fill material, seepage, stability, settlement and seismic performance.

MFLNRO's standard dike section typically includes 3H:1V waterside and landside slopes and a 4 m wide crest. Waterside slopes of 2H:1V can be acceptable with rip-rap protection. The landslide slopes can be steepened to 2H:1V if adequate seepage control measures are provided.

We understand that the design and specification of any rip rap and other erosion control measures for the dike crest and slopes will be completed by NHC. We also understand that the PVDD would prefer to avoid the need for seepage control measures (i.e. a filter zone) in dike upgrades, if feasible.

We understand that the PVDD would prefer to construct dike upgrades from material similar to what was used to complete the upgrades to the Ayers Dike in 2014. This material comprised crushed till-like material (silt and cobbles).

### 3.1 Earth Dike Design

Design of the upgrades to the earth dikes should consider the composition and configuration of the existing dike and subgrade. We foresee that dike upgrades will typically be possible by maintaining the existing dike with completion of typical site preparation (i.e. stripping of vegetation, removal of deleterious material and compaction of subgrade). Removal and replacement of dike material can usually be avoided; however, there may be an increased chance of poor dike performance (i.e. stability and settlement problems and large seepage volumes).

Selection of suitable dike fill at the appropriate moisture content is critical to successful compaction during construction and for the long-term performance of the dike. Preferably, earth dikes should be constructed using low permeability, fine-grained, cohesive soil or till-like, silty soil. The MFLNRO recommends using soil with 15% to 30% fines (particles sized smaller than 75 µm sieve). High fines fill with a fines content at the high end of the 15% to 30% range is preferable. However, while soil with higher fines content should reduce seepage, it may require potentially difficult moisture conditioning in order to bring it to its optimum moisture content for compaction. High fines fill is typically placed within 2% of its optimum moisture content so placement and compaction during wet weather may not be possible. In general, we expect that the material similar to what was used in the 2014 Ayers Dike upgrades will be acceptable.

Dike design should consider compatibility between old fill, new fill, and the subgrade. If the effective opening size of the gravel present within the existing dikes or dike foundations is not small enough to retain high fines fill, particle migration and loss of fines may occur.

### 3.2 Stability

Dike stability depends on factors including the soil strength, dike slopes and setback, the site topography and bathymetry, and the flood height. Based on the subsurface conditions encountered, we expect that dikes constructed with the MFLNRO's standard dike section will be acceptably stable under the design flood conditions (i.e. 1 in 200 year return period flood).

In areas where stability is a concern, modifications to the standard dike section may be required, such as flattening the slopes, constructing a toe berm on the landside of the dike or providing improved seepage control measures. Relocation of the dikes or sections of the dikes to create a setback may also be used to increase dike stability.

## 3.3 Seepage

Design of dike upgrades must also consider seepage, which presents a risk of piping through the dike or the dike foundation. Piping is one of the leading causes of failure of earth dams and dikes that have unfiltered seepage exits. Seepage forces can also cause soil heave on the landside of a dike when a surficial impervious layer caps an underlying permeable layer containing excessive hydraulic pressures. Landside heave is not expected to be a design concern for the Pemberton Valley dikes based on the soil profiles encountered during the investigation.

Piping occurs when excessive seepage forces cause the migration of soil particles through the soil matrix resulting in internal erosion and eventually retrogressive failure. The hydraulic gradient represents the seepage force through the dike or the dike foundation, and higher hydraulic gradients are more likely to cause piping. The average hydraulic gradient can be calculated as the height of the flood divided by the seepage path length. The height of the flood should be measured from the water level on the waterside of the dike to the break in the toe of either the existing or future landside slope, whichever results in a greater flood height. The seepage path length can be taken as the distance from the water level at the land side of the dike to the break in the toe of the landside slope. The maximum safe average hydraulic gradients for the various dike foundation materials encountered during our investigation are listed in the table below.

| Dike | Representative Foundation Material | Maximum Safe Average Hydraulic Gradient (-) |
|---|---|---|
| Poleyard | Sand and Gravel | 0.22 |
| Miller – Lillooet | Silty Sand | 0.12 |
| Pemberton Creek | Sand and Gravel | 0.22 |
| Miller – Boneyard | Sand and Gravel | 0.22 |
| Ryan River | Sand and Silt | 0.11 |

If it is impractical to provide a seepage path length to control average hydraulic gradient to safe levels, seepage control measures may be required. The measures may also reduce the risk presented by dike irregularities with locally increased susceptibility to piping. Seepage control measures could include construction of cutoff trenches, waterside impervious layers, landside seepage berms, pervious toe filters and pressure relief wells. We foresee that the most practical seepage control measure for these dikes would be installation of toe filters.

## 3.4 Settlement

The soft silt layer encountered below the dike in TH19-06 and the organic silt encountered below 4.5 m depth in TH19-04 are potentially compressible. Some settlement may occur if the dikes in these areas are raised. For conceptual design, consideration should be given to overbuilding these dikes by nominal amount (e.g. by 10% of the increase in dike height) and increasing the frequency on monitoring and maintenance in these areas.

### 3.5 Seismic Performance

The relevant geotechnical seismic hazard for dikes is the occurrence of large seismic displacements that could cause damage and reduce the level of flood protection. Large deformations could result in formation of preferential flow paths through the dike that could lead to piping, decreased dike stability and loss of flood protection due to lowering of the dike crest elevation.

Thurber's experience with seismic design and assessment of dikes has been that the degree of seismic deformations largely depends on whether or not liquefaction of the foundation soils occurs. If liquefaction does not occur, deformations tend to be small (i.e. less than 1 m) and if it does occur, deformations can be much larger (i.e. greater than 1 m). There does not tend to be a gradual increase in displacement with increasing seismic hazard (i.e. stronger earthquakes), but rather a large increase when the earthquake exceeds a threshold level that initiates liquefaction. Accordingly, liquefaction is the most significant contributor to the seismic vulnerability for most dikes.

Dikes constructed on liquefiable soil near riverbanks or slopes could experience large seismic deformations. Setback dikes, short dikes and dikes on non-liquefiable subgrades (i.e. clay-like soils and sufficiently dense .granular soils) can be expected to have smaller seismic deformations under a given seismic hazard.

The test hole logs indicate that there are granular soils that may be susceptible to liquefaction present under the Pemberton Valley dikes. Based on our experience with past dike seismic assessments. we anticipate the earthquake return period initiating liquefaction could be in the range of 500 to 1000 years.

## 4. CLOSURE

We trust that this letter provides sufficient information for your needs at this time. Should you require clarification of any item or additional information, please do not hesitate to contact us.

Yours truly,

Thurber Engineering Ltd.
Steven Coulter, P.Eng.
Review Engineer

PROFESSIONAL
PROVINCE OF
S. P. N. COULTER
# 35819
BRITISH COLUMBIA
ENGINEER

A
Project Engineer

Attachments

Statement of Limitations and Conditions (1 page)
Dwg. 27300-1 - Key Plan (1 Page)
Dwg. 27300-2 to 27300-5 - Test Hole Location Plans (4 Pages)
Thurber Test Hole Logs (10 Pages)

THURBER

# STATEMENT OF LIMITATIONS AND CONDITIONS

## 1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

## 2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. THURBER IS NOT RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

## 3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

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## 5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

## 6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

## 7. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

Plotted: October 29, 2019

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LEGEND:

● TEST HOLE

NOTES:

1. BASE AIR PHOTO TAKEN FROM ESRI IMAGERY SERVICE (DIGITAL GLOBE, 2014).
2. TEST HOLE LOCATIONS ARE APPROXIMATE (BASED ON HAND-HELD GPS).

CLIENT

NORTHWEST HYDRAULIC CONSULTANTS

**KEY PLAN**

PEMBERTON DIKE ASSESSMENT

PEMBERTON, B.C.

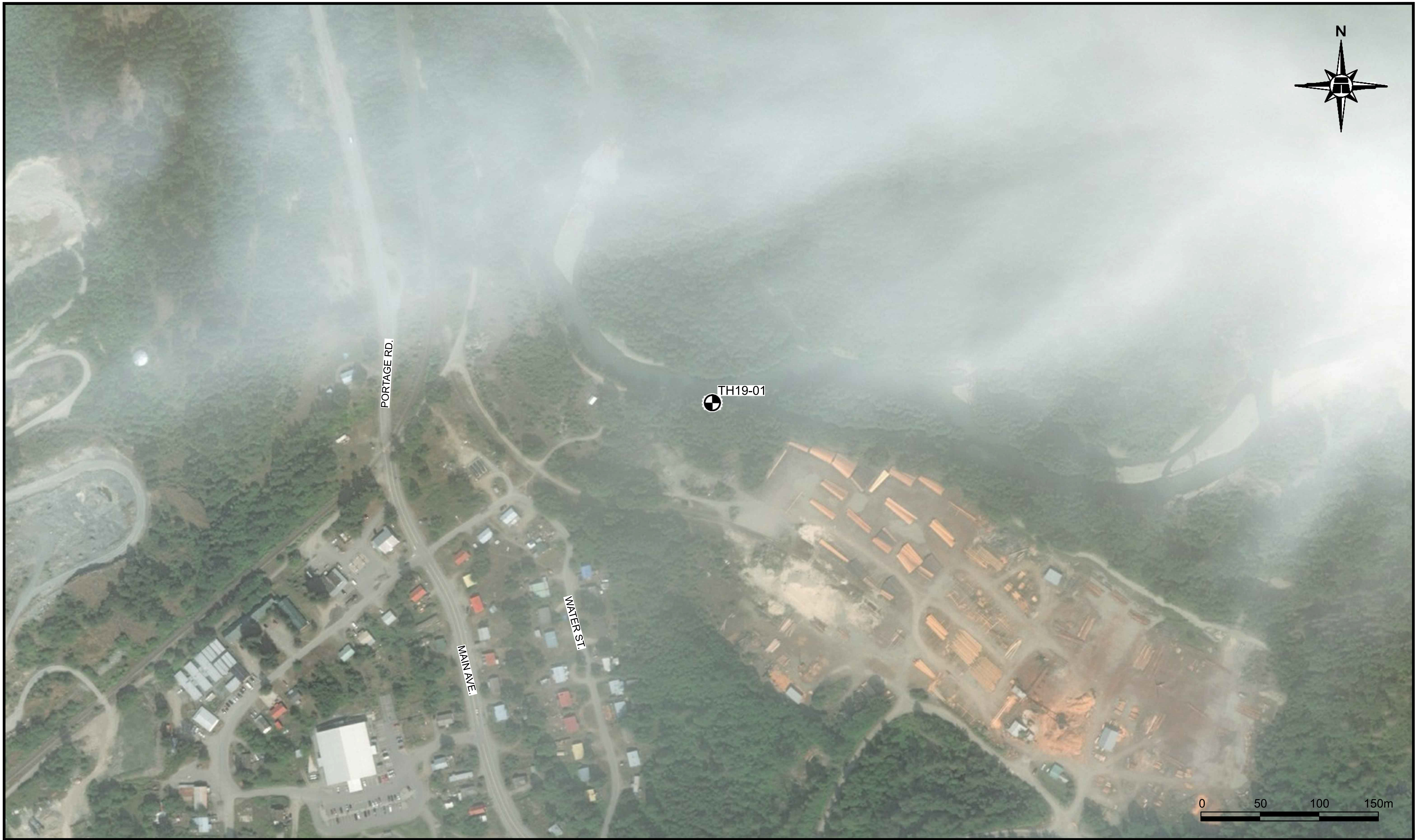
| DESIGNED | DRAWN | APPROVED |
|---|---|---|
| ATMS | MOM | SNC |

| DATE | SCALE |
|---|---|
| 29/10/19 | 1:75,000 |

| PROJECT No. | DWG. No. | REV. |
|---|---|---|
| 27300 | 1 | 0 |

CANCEL PRINTS BEARING EARLIER NUMBER

Plotted: October 29, 2019



LEGEND:

● TEST HOLE

NOTES:
1. BASE AIR PHOTO TAKEN FROM ESRI IMAGERY SERVICE (DIGITAL GLOBE, 2014).
2. TEST HOLE LOCATIONS ARE APPROXIMATE (BASED ON HAND-HELD GPS).
3. SEE KEY PLAN (DWG.27300-1) FOR LOCATION WITH RESPECT TO PROJECT AREA.

AB

CLIENT

NORTHWEST HYDRAULIC CONSULTANTS

**TEST HOLE LOCATION PLAN**
**(1 OF 4)**

PEMBERTON DIKE ASSESSMENT
PEMBERTON, B.C.

| DESIGNED | DRAWN | APPROVED |
|---|---|---|
| ATMS | MOM | SNC |

| DATE | SCALE |
|---|---|
| 29/10/19 | 1:3000 |

| PROJECT No. | DWG. No. | REV. |
|---|---|---|
| 27300 | 2 | 0 |

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CANCEL PRINTS BEARING EARLIER NUMBER

Plotted: October 29, 2019

LEGEND:

● TEST HOLE

NOTES:

1. BASE AIR PHOTO TAKEN FROM ESRI IMAGERY SERVICE (DIGITAL GLOBE, 2014).
2. TEST HOLE LOCATIONS ARE APPROXIMATE (BASED ON HAND-HELD GPS).
3. SEE KEY PLAN (DWG.27300-1) FOR LOCATION WITH RESPECT TO PROJECT AREA.

CLIENT
NORTHWEST HYDRAULIC CONSULTANTS

**TEST HOLE LOCATION PLAN**
**(2 OF 4)**

PEMBERTON DIKE ASSESSMENT
PEMBERTON, B.C.

| DESIGNED | DRAWN | APPROVED |
|---|---|---|
| ATMS | MOM | SNC |

| DATE | SCALE |
|---|---|
| 29/10/19 | 1:7500 |

| PROJECT No. | DWG. No. | REV. |
|---|---|---|
| 27300 | 3 | 0 |

CANCEL PRINTS BEARING EARLIER NUMBER

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Plotted: October 29, 2019

LEGEND:

● TEST HOLE

NOTES:

1. BASE AIR PHOTO TAKEN FROM ESRI IMAGERY SERVICE (DIGITAL GLOBE, 2014).
2. TEST HOLE LOCATIONS ARE APPROXIMATE (BASED ON HAND-HELD GPS).
3. SEE KEY PLAN (DWG.27300-1) FOR LOCATION WITH RESPECT TO PROJECT AREA.

CLIENT

NORTHWEST HYDRAULIC CONSULTANTS

## TEST HOLE LOCATION PLAN
## (3 OF 4)

PEMBERTON DIKE ASSESSMENT
PEMBERTON, B.C.

| DESIGNED | DRAWN | APPROVED |
|---|---|---|
| ATMS | MOM | SNC |

| DATE | SCALE |
|---|---|
| 29/10/19 | 1:3000 |

| PROJECT No. | DWG. No. | REV. |
|---|---|---|
| 27300 | 4 | 0 |

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CANCEL PRINTS BEARING EARLIER NUMBER

LEGEND:

● TEST HOLE

NOTES:

1. BASE AIR PHOTO TAKEN FROM ESRI IMAGERY SERVICE (DIGITAL GLOBE, 2014).
2. TEST HOLE LOCATIONS ARE APPROXIMATE (BASED ON HAND-HELD GPS).
3. SEE KEY PLAN (DWG.27300-1) FOR LOCATION WITH RESPECT TO PROJECT AREA.

AB

CLIENT
NORTHWEST HYDRAULIC CONSULTANTS

### TEST HOLE LOCATION PLAN
### (4 OF 4)

PEMBERTON DIKE ASSESSMENT
PEMBERTON, B.C.

| DESIGNED | DRAWN | APPROVED |
|---|---|---|
| ATMS | MOM | SNC |

| DATE | SCALE |
|---|---|
| 29/10/19 | 1:10,000 |

| PROJECT No. | DWG. No. | REV. |
|---|---|---|
| 27300 | 5 | 0 |

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CANCEL PRINTS BEARING EARLIER NUMBER

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.** 19-01

**LOCATION:** See DWG.27300-2
N 5574344, E 520144 (Est.)

**CLIENT:** Northwest Hydraulic Consultants
**PROJECT:** Pemberton Dike Assessment

**TOP OF HOLE ELEV:**
**METHOD:** Solid Stem Auger
**DRILLING CO.:** Southland Drilling Co. Ltd.
**INSPECTOR:** AAR

**DATE:** October 16, 2019
**FILE NO.:** 27300
**REVIEWED BY:** SNC

PENETRATION (blows/300 mm)

WATER CONTENT (%)
○ Disturbed
● Undisturbed
Plastic Limit — Liquid Limit

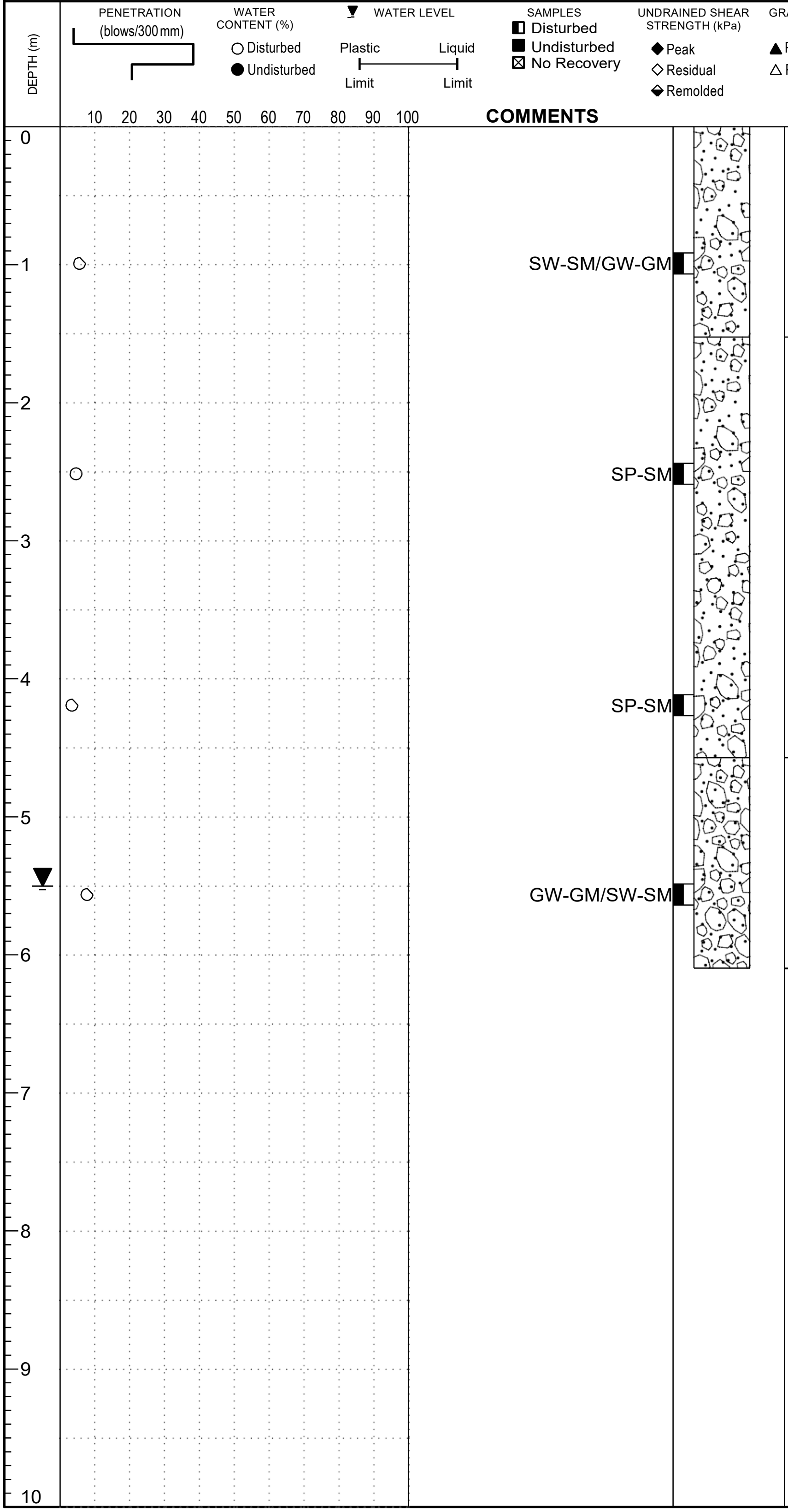
▼ WATER LEVEL

SAMPLES
◧ Disturbed
■ Undisturbed
☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa)
◆ Peak
◇ Residual
◈ Remolded

GRAIN SIZE (%)
▲ Passing #200 sieve
△ Passing #4 sieve

SOIL HEADSPACE READING (ppm)
✖ GASTECH reading
✕ PID reading



SOILS DESCRIPTION

Brown, moist SAND with some gravel and a trace of silt (DIKE FILL)

Grey-brown, moist, gravelly SAND with a trace of silt.

- dry below 3.1 m depth

Grey-brown, moist GRAVEL and SAND with traces of silt and organics.

End of hole at required depth.
Water observed at 5.5 m depth upon completion of drilling.

LOG OF TEST HOLE (COORD EST) 27300.GPJ THURBER_MOM.GDT 30/10/19- THURBER MOM.GLB

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.** **19-02**

**LOCATION:** See DWG.27300-3
N 5573864, E 516404 (Est.)

**TOP OF HOLE ELEV:**

**METHOD:** Solid Stem Auger

**DRILLING CO.:** Southland Drilling Co. Ltd.

**INSPECTOR:** AAR

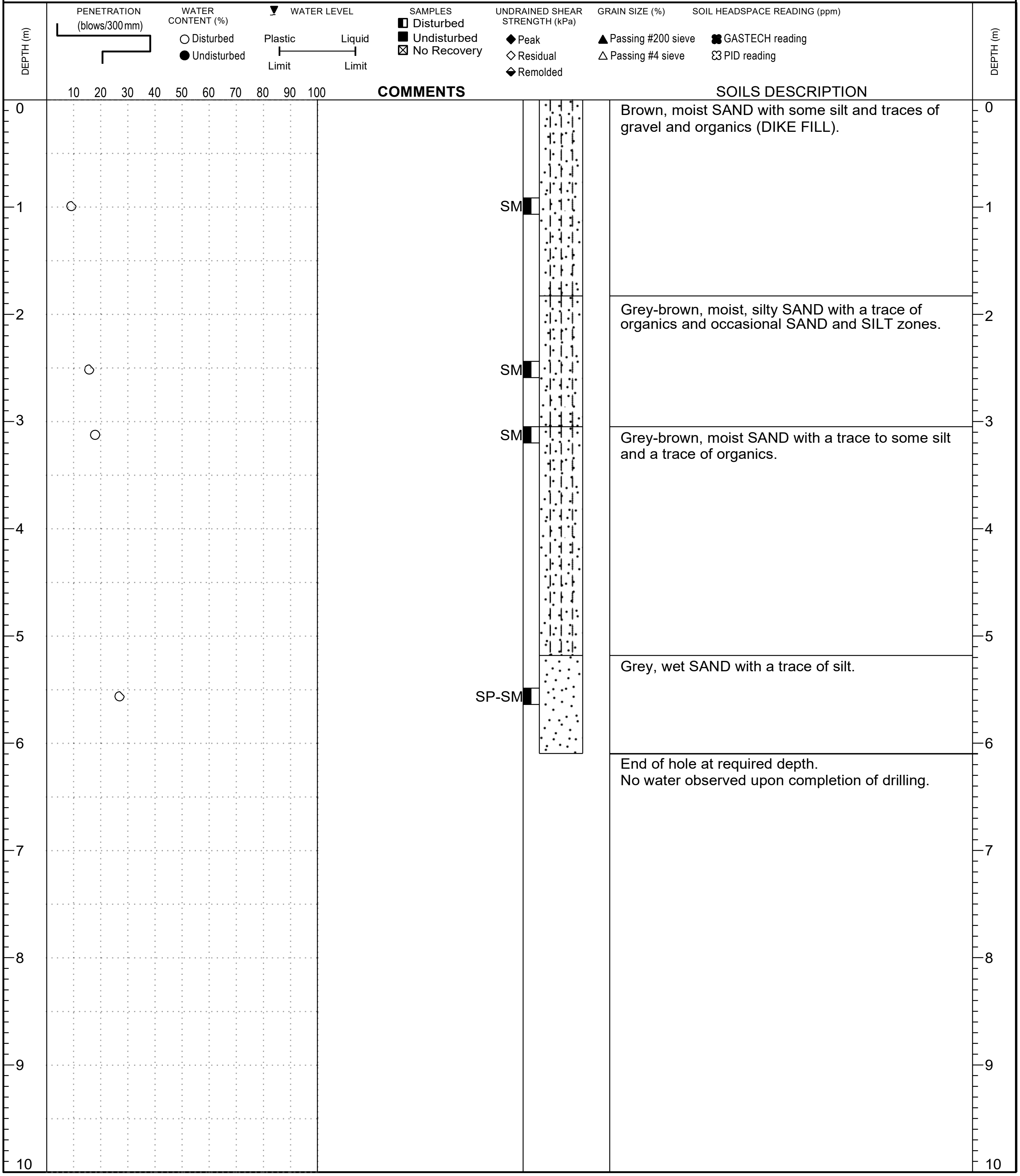
**CLIENT:** Northwest Hydraulic Consultants

**PROJECT:** Pemberton Dike Assessment

**DATE:** October 16, 2019

**FILE NO.:** 27300

**REVIEWED BY:** SNC



Brown, moist SAND with some silt and traces of gravel and organics (DIKE FILL).

Grey-brown, moist, silty SAND with a trace of organics and occasional SAND and SILT zones.

Grey-brown, moist SAND with a trace to some silt and a trace of organics.

Grey, wet SAND with a trace of silt.

End of hole at required depth.
No water observed upon completion of drilling.

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.**
**19-03**

**LOCATION:** See DWG.27300-3
N 5574867, E 514909 (Est.)

**CLIENT:** Northwest Hydraulic Consultants

**PROJECT:** Pemberton Dike Assessment

**TOP OF HOLE ELEV:**

**METHOD:** Solid Stem Auger

**DRILLING CO.:** Southland Drilling Co. Ltd.

**INSPECTOR:** AAR

**DATE:** October 16, 2019

**FILE NO.:** 27300

**REVIEWED BY:** SNC

PENETRATION (blows/300 mm)

WATER CONTENT (%)
○ Disturbed
● Undisturbed

Plastic Limit ├──┤ Liquid Limit

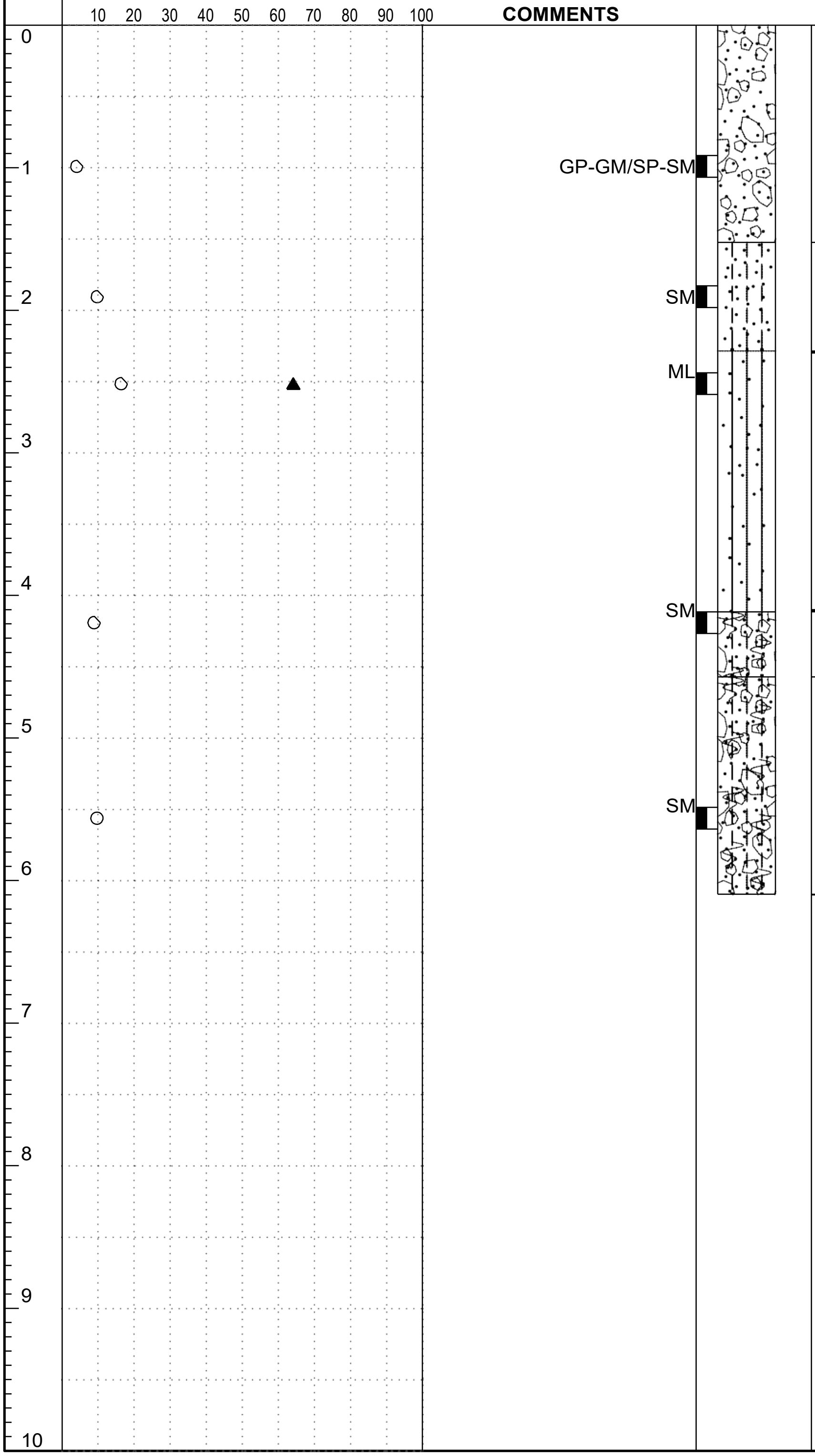
▼ WATER LEVEL

SAMPLES
◧ Disturbed
■ Undisturbed
☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa)
◆ Peak
◇ Residual
◈ Remolded

GRAIN SIZE (%)
▲ Passing #200 sieve
△ Passing #4 sieve

SOIL HEADSPACE READING (ppm)
✱ GASTECH reading
✳ PID reading



**SOILS DESCRIPTION**

Brown-grey, moist, gravelly SAND with a trace of silt (DIKE FILL).

Brown, moist, silty SAND with a trace of gravel.

Soft, brown, moist, sandy SILT.

Grey-brown, moist, silty SAND with some gravel and organics.

Grey-brown, moist, gravelly SAND with some silt and organics.

End of hole at required depth.
No water observed upon completion of drilling.

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOHOLE NO.**
**19-04**

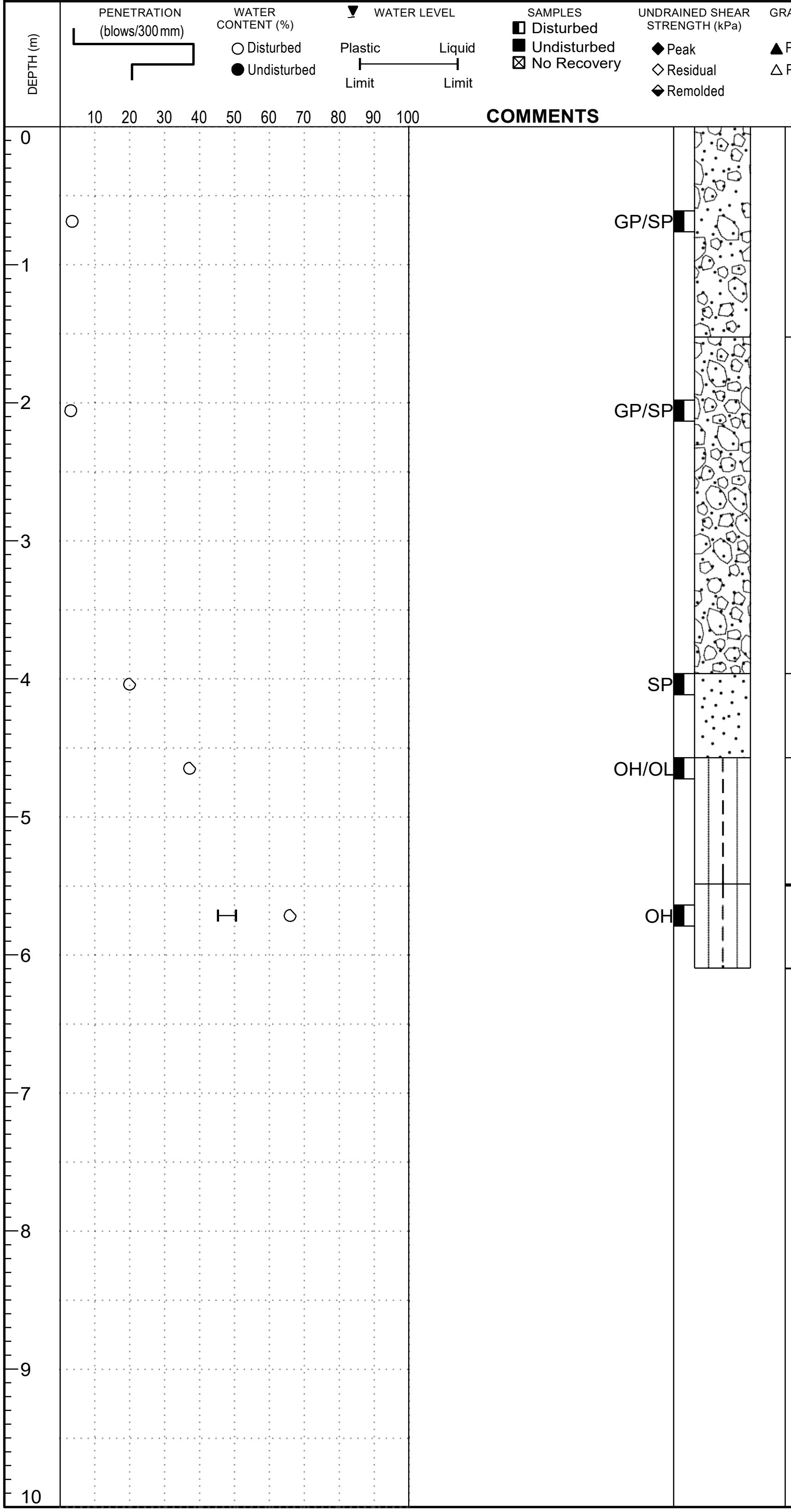
**LOCATION:** See DWG.27300-3
N 5573581, E 514507 (Est.)

**TOP OF HOLE ELEV:**
**METHOD:** Solid Stem Auger
**DRILLING CO.:** Southland Drilling Co. Ltd.
**INSPECTOR:** AAR

**CLIENT:** Northwest Hydraulic Consultants
**PROJECT:** Pemberton Dike Assessment

**DATE:** October 16, 2019
**FILE NO.:** 27300
**REVIEWED BY:** SNC

PENETRATION (blows/300 mm)
WATER CONTENT (%): ○ Disturbed ● Undisturbed; Plastic Limit ⊢—⊣ Liquid Limit
WATER LEVEL
SAMPLES: ◧ Disturbed ■ Undisturbed ☒ No Recovery
UNDRAINED SHEAR STRENGTH (kPa): ◆ Peak ◇ Residual ⬙ Remolded
GRAIN SIZE (%): ▲ Passing #200 sieve △ Passing #4 sieve
SOIL HEADSPACE READING (ppm): ✖ GASTECH reading ✕ PID reading



| COMMENTS | SOILS DESCRIPTION |
|---|---|
| GP/SP | Brown, moist, gravelly SAND and a trace of silt (DIKE FILL). |
| GP/SP | Brown-grey, moist GRAVEL and SAND with a trace of silt. |
| SP | Grey, wet SAND with traces of silt and gravel and occasional pumice fragments. |
| OH/OL | Firm, brown-grey, moist to wet ORGANICS and SILT with some sand and a trace of clay. |
| OH | Firm, dark brown-grey, moist to wet ORGANICS and SILT with traces of clay and sand. |
|  | End of hole at required depth.<br>No water observed upon completion of drilling. |

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.** **19-05**

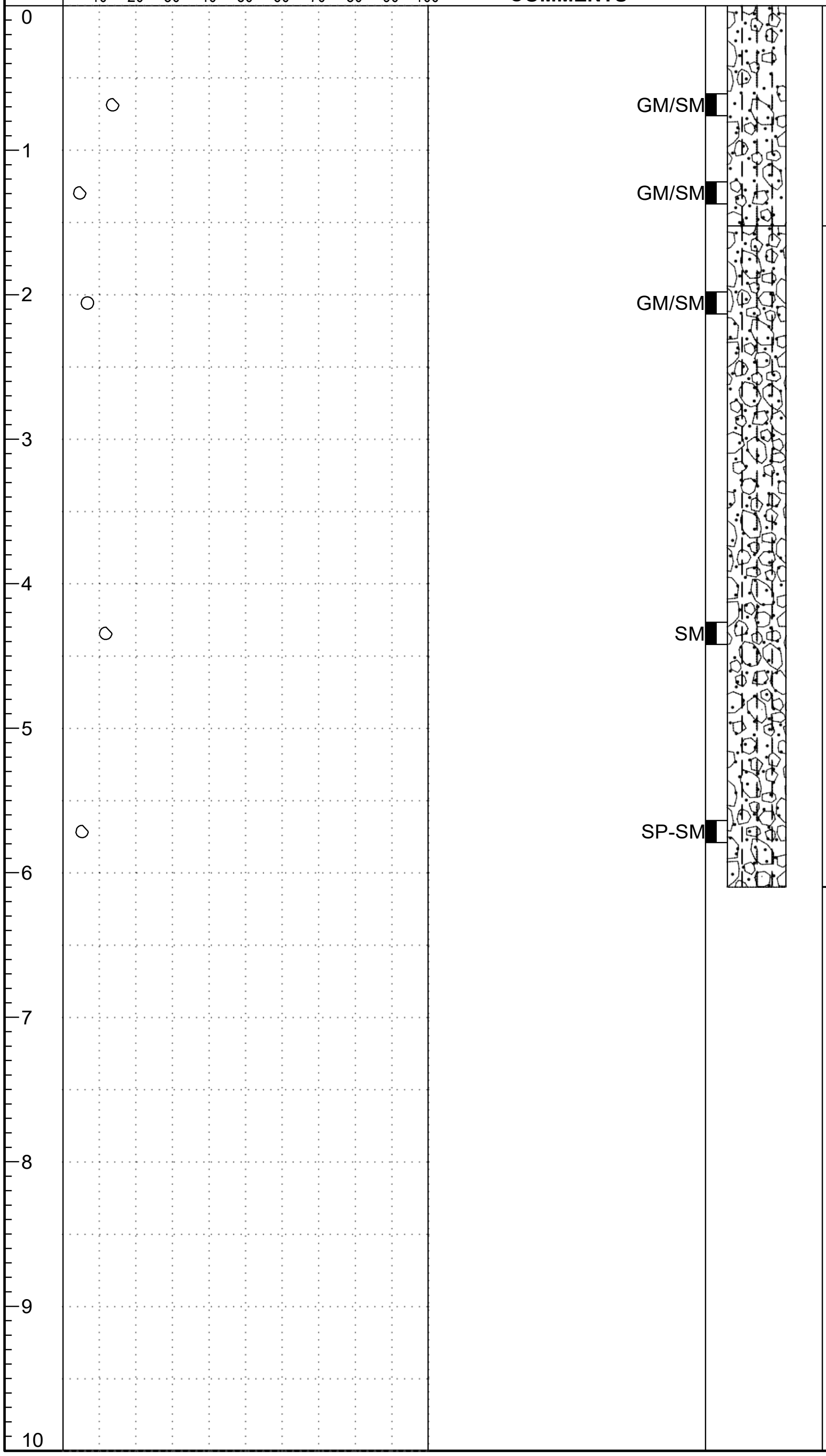
**LOCATION:** See DWG.27300-4
N 5578234, E 512013 (Est.)

**CLIENT:** Northwest Hydraulic Consultants
**PROJECT:** Pemberton Dike Assessment

**TOP OF HOLE ELEV:**
**METHOD:** Solid Stem Auger
**DRILLING CO.:** Southland Drilling Co. Ltd.
**INSPECTOR:** AAR

**DATE:** October 16, 2019
**FILE NO.:** 27300
**REVIEWED BY:** SNC

| DEPTH (m) | PENETRATION (blows/300 mm) | WATER CONTENT (%) | WATER LEVEL | SAMPLES | UNDRAINED SHEAR STRENGTH (kPa) | GRAIN SIZE (%) | SOIL HEADSPACE READING (ppm) | DEPTH (m) |
|---|---|---|---|---|---|---|---|---|
| | | ○ Disturbed<br>● Undisturbed<br>Plastic Limit ├──┤ Liquid Limit | ▼ | ◧ Disturbed<br>■ Undisturbed<br>☒ No Recovery | ◆ Peak<br>◇ Residual<br>⬖ Remolded | ▲ Passing #200 sieve<br>△ Passing #4 sieve | ✖ GASTECH reading<br>✕ PID reading | |



**SOILS DESCRIPTION**

Grey, moist, gravelly SAND with some silt (DIKE FILL).

Grey, moist, silty GRAVEL and SAND.

End of hole at required depth.
No water observed upon completion of drilling.

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.** **19-06**

**LOCATION:** See DWG.27300-4
N 5577812, E 511684 (Est.)

**TOP OF HOLE ELEV:**

**METHOD:** Solid Stem Auger

**DRILLING CO.:** Southland Drilling Co. Ltd.

**INSPECTOR:** AAR

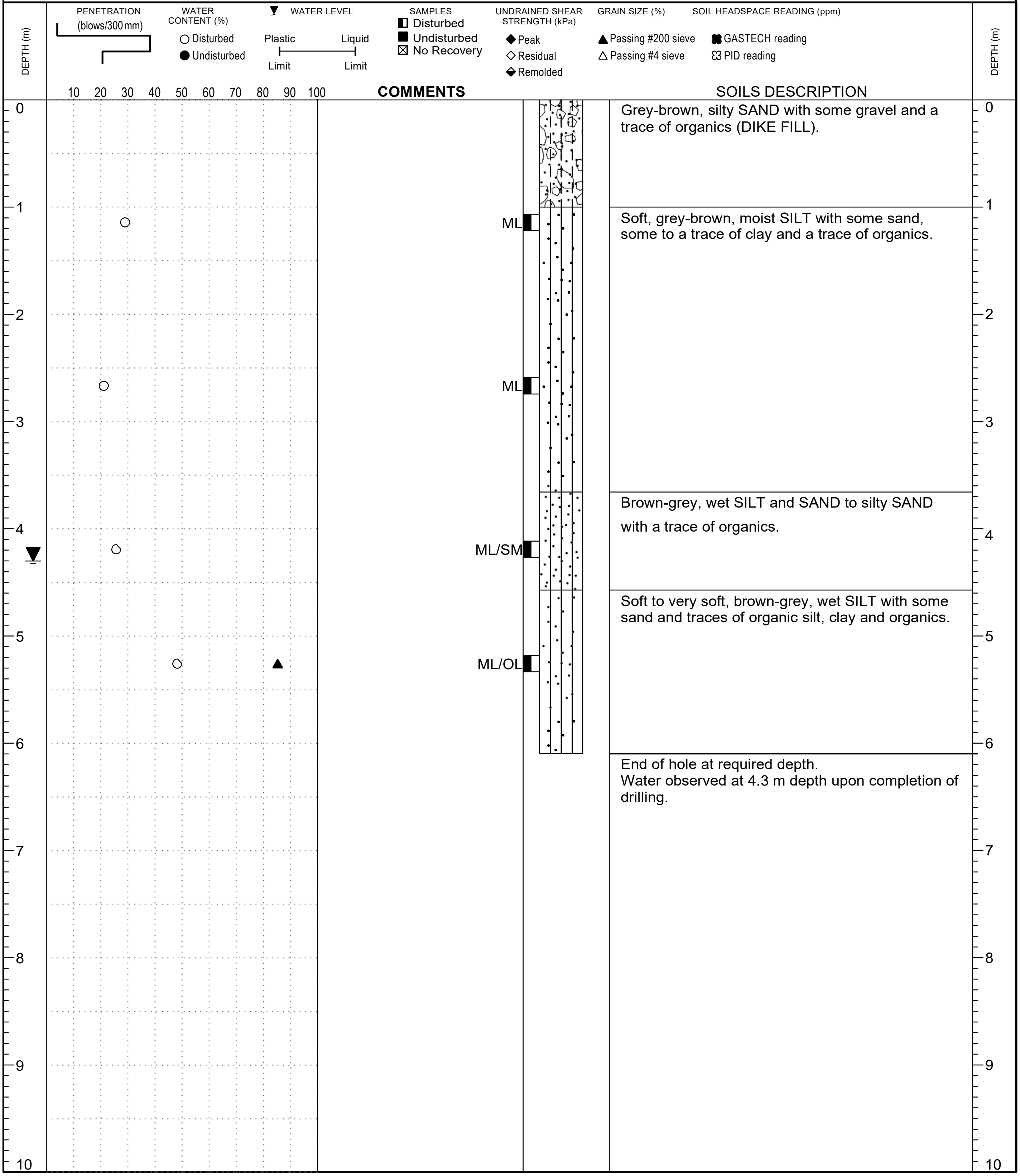
**CLIENT:** Northwest Hydraulic Consultants

**PROJECT:** Pemberton Dike Assessment

**DATE:** October 17, 2019

**FILE NO.:** 27300

**REVIEWED BY:** SNC



Grey-brown, silty SAND with some gravel and a trace of organics (DIKE FILL).

Soft, grey-brown, moist SILT with some sand, some to a trace of clay and a trace of organics.

Brown-grey, wet SILT and SAND to silty SAND with a trace of organics.

Soft to very soft, brown-grey, wet SILT with some sand and traces of organic silt, clay and organics.

End of hole at required depth.
Water observed at 4.3 m depth upon completion of drilling.

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.**
**19-07**

**LOCATION:** See DWG.27300-4
N 5578123, E 511036 (Est.)

**TOP OF HOLE ELEV:**

**METHOD:** Solid Stem Auger

**DRILLING CO.:** Southland Drilling Co. Ltd.

**INSPECTOR:** AAR

THURBER

**CLIENT:** Northwest Hydraulic Consultants

**PROJECT:** Pemberton Dike Assessment

**DATE:** October 17, 2019

**FILE NO.:** 27300

**REVIEWED BY:** SNC

PENETRATION (blows/300 mm)

WATER CONTENT (%)
○ Disturbed
● Undisturbed
Plastic Limit ├──┤ Liquid Limit

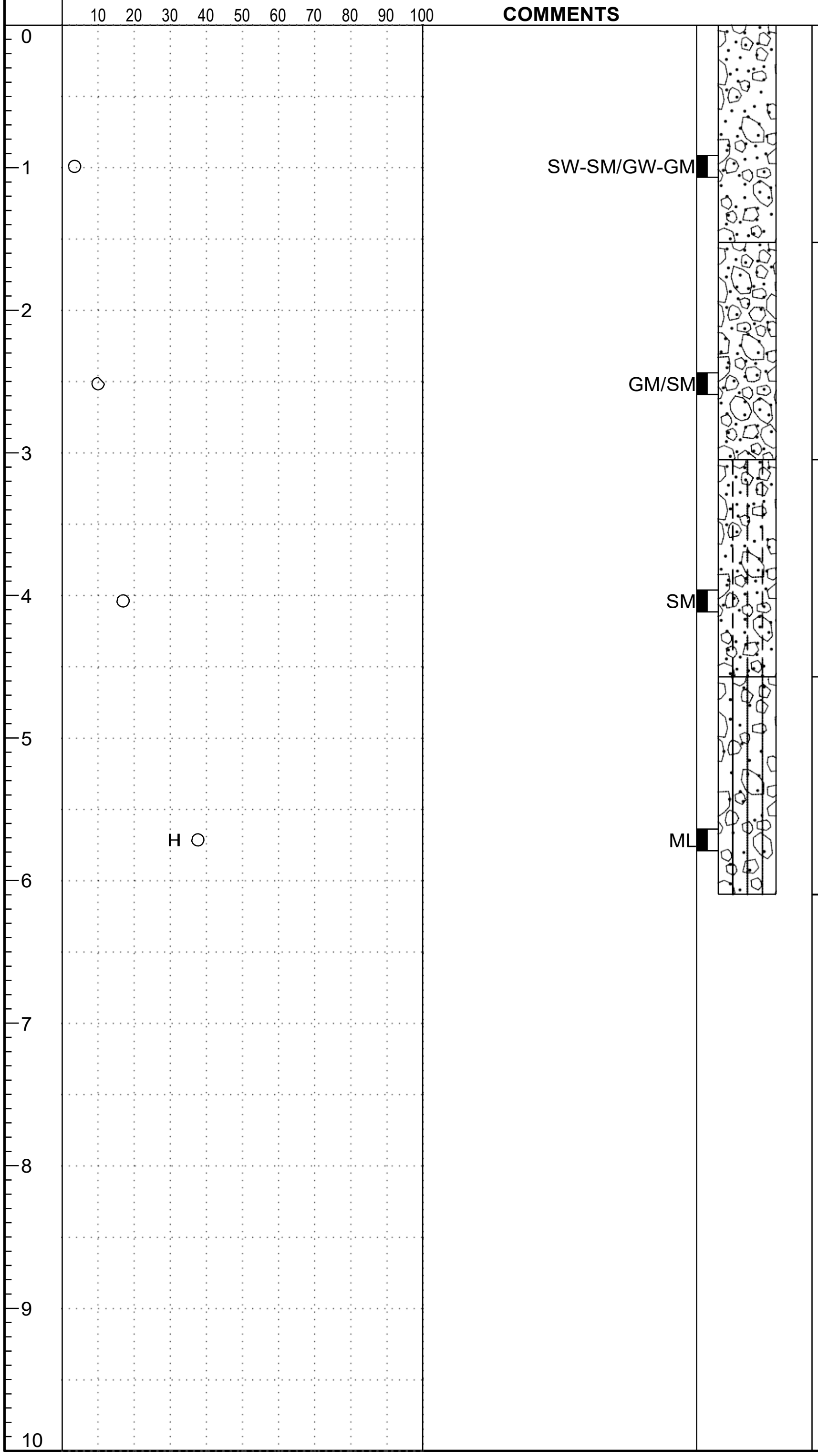
▼ WATER LEVEL

SAMPLES
◧ Disturbed
■ Undisturbed
☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa)
◆ Peak
◇ Residual
⬙ Remolded

GRAIN SIZE (%)
▲ Passing #200 sieve
△ Passing #4 sieve

SOIL HEADSPACE READING (ppm)
✖ GASTECH reading
✕ PID reading



SOILS DESCRIPTION

Grey, moist, gravelly SAND with a trace of silt (DIKE FILL).

Grey-brown, moist to wet GRAVEL and SAND with a trace of silt.

Brown-grey, wet, gravelly SAND with some silt and a trace of organics.

Very soft, grey, wet SILT with some sand and gravel.

End of hole at required depth.
No water observed upon completion of drilling.

Sheet 1 of 1

# LOG OF TEST HOLE

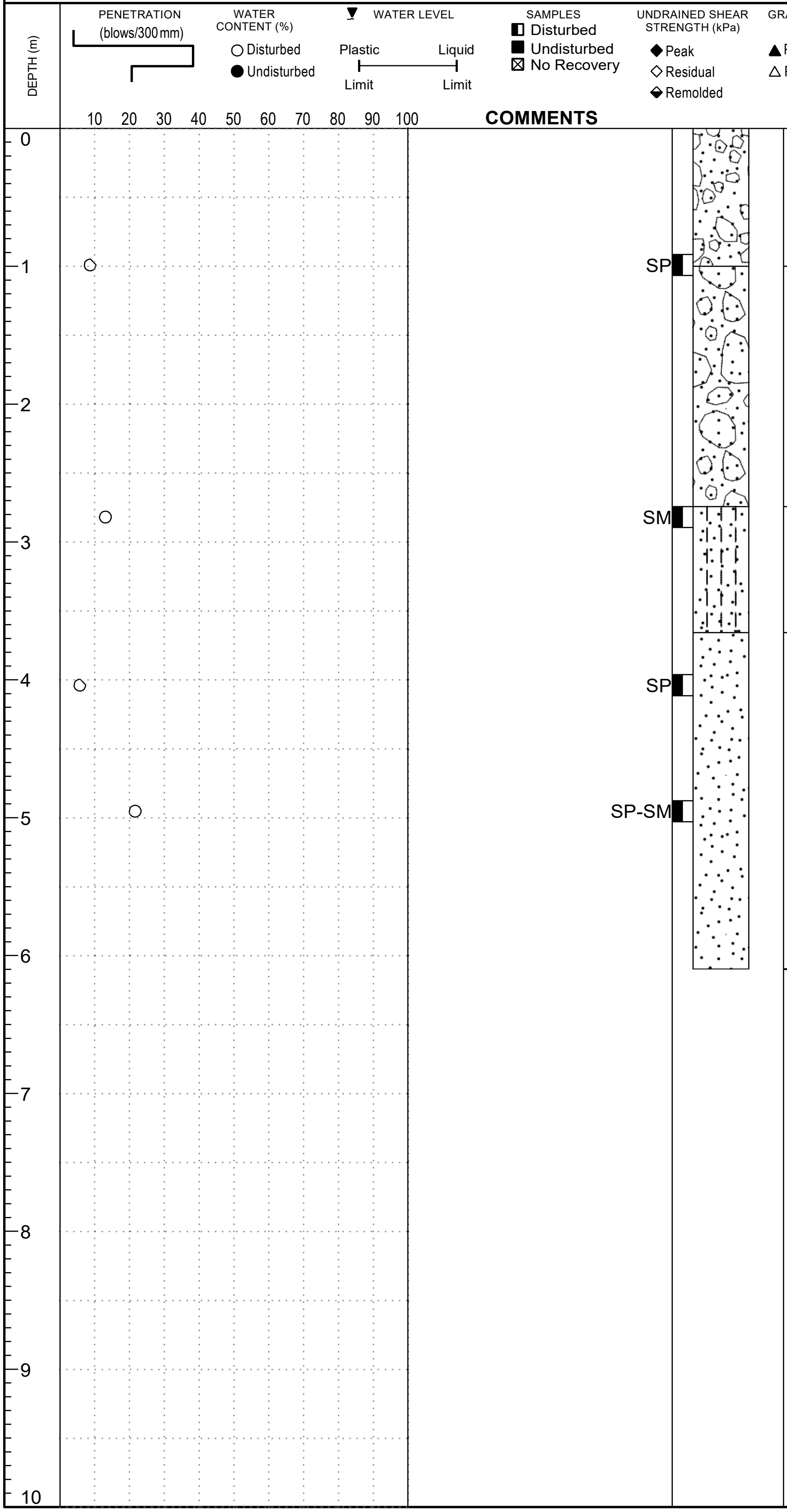
**TEST HOLE NO.**
**19-08**

**LOCATION:** See DWG.27300-4
N 5578362, E 511777 (Est.)

**TOP OF HOLE ELEV:**
**METHOD:** Solid Stem Auger
**DRILLING CO.:** Southland Drilling Co. Ltd.
**INSPECTOR:** AAR

**CLIENT:** Northwest Hydraulic Consultants
**PROJECT:** Pemberton Dike Assessment

**DATE:** October 17, 2019
**FILE NO.:** 27300
**REVIEWED BY:** SNC



SOILS DESCRIPTION

Grey, moist, gravelly SAND with a trace of silt (DIKE FILL).

Brown-grey, moist SAND and COBBLES with a trace of silt.

Brown, moist SAND with some silt, a trace of gravel and occasional zones of silty SAND.

Grey-brown, moist SAND with a trace of silt.

- wet below 5.5 m depth

End of hole at required depth.
No water observed upon completion of drilling.

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.**
**19-09**

**LOCATION:** See DWG.27300-5
N 5583803, E 507542 (Est.)

**CLIENT:** Northwest Hydraulic Consultants
**PROJECT:** Pemberton Dike Assessment

**TOP OF HOLE ELEV:**
**METHOD:** Solid Stem Auger
**DRILLING CO.:** Southland Drilling Co. Ltd.
**INSPECTOR:** AAR

**DATE:** October 17, 2019
**FILE NO.:** 27300
**REVIEWED BY:** SNC

DEPTH (m)

PENETRATION (blows/300 mm)

WATER CONTENT (%)
○ Disturbed
● Undisturbed
Plastic Limit ├──┤ Liquid Limit

▼ WATER LEVEL

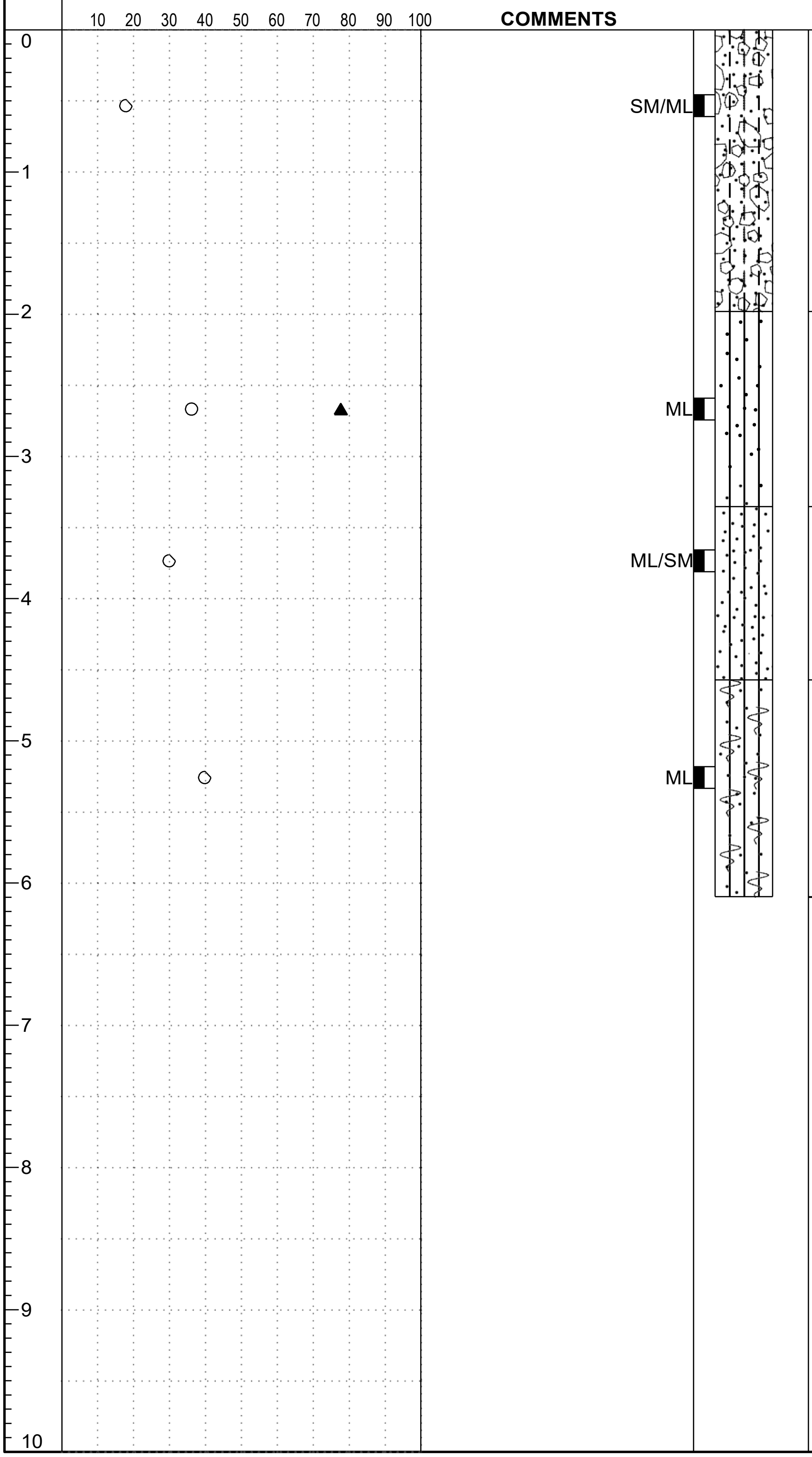
SAMPLES
◧ Disturbed
■ Undisturbed
☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa)
◆ Peak
◇ Residual
⬖ Remolded

GRAIN SIZE (%)
▲ Passing #200 sieve
△ Passing #4 sieve

SOIL HEADSPACE READING (ppm)
✱ GASTECH reading
✲ PID reading

COMMENTS



SOILS DESCRIPTION

Brown, moist, silty SAND with some gravel and a trace of organics (DIKE FILL).

Soft, grey-brown, wet, sandy SILT with zones of silty SAND and a trace of organics.

Brown-grey, wet SILT and SAND with a trace of organics.

Soft, brown-grey, sandy SILT with some organics.

End of hole at required depth.
No water observed upon completion of drilling.

DEPTH (m)

Sheet 1 of 1

# LOG OF TEST HOLE

**TEST HOLE NO.**
**19-10**

**LOCATION:** See DWG.27300-5
N 5585519, E 506117 (Est.)

**CLIENT:** Northwest Hydraulic Consultants

**PROJECT:** Pemberton Dike Assessment

**TOP OF HOLE ELEV:**

**METHOD:** Solid Stem Auger

**DRILLING CO.:** Southland Drilling Co. Ltd.

**INSPECTOR:** AAR

**DATE:** October 17, 2019

**FILE NO.:** 27300

**REVIEWED BY:** SNC

PENETRATION (blows/300 mm)

WATER CONTENT (%)
○ Disturbed
● Undisturbed

WATER LEVEL
Plastic Limit — Liquid Limit

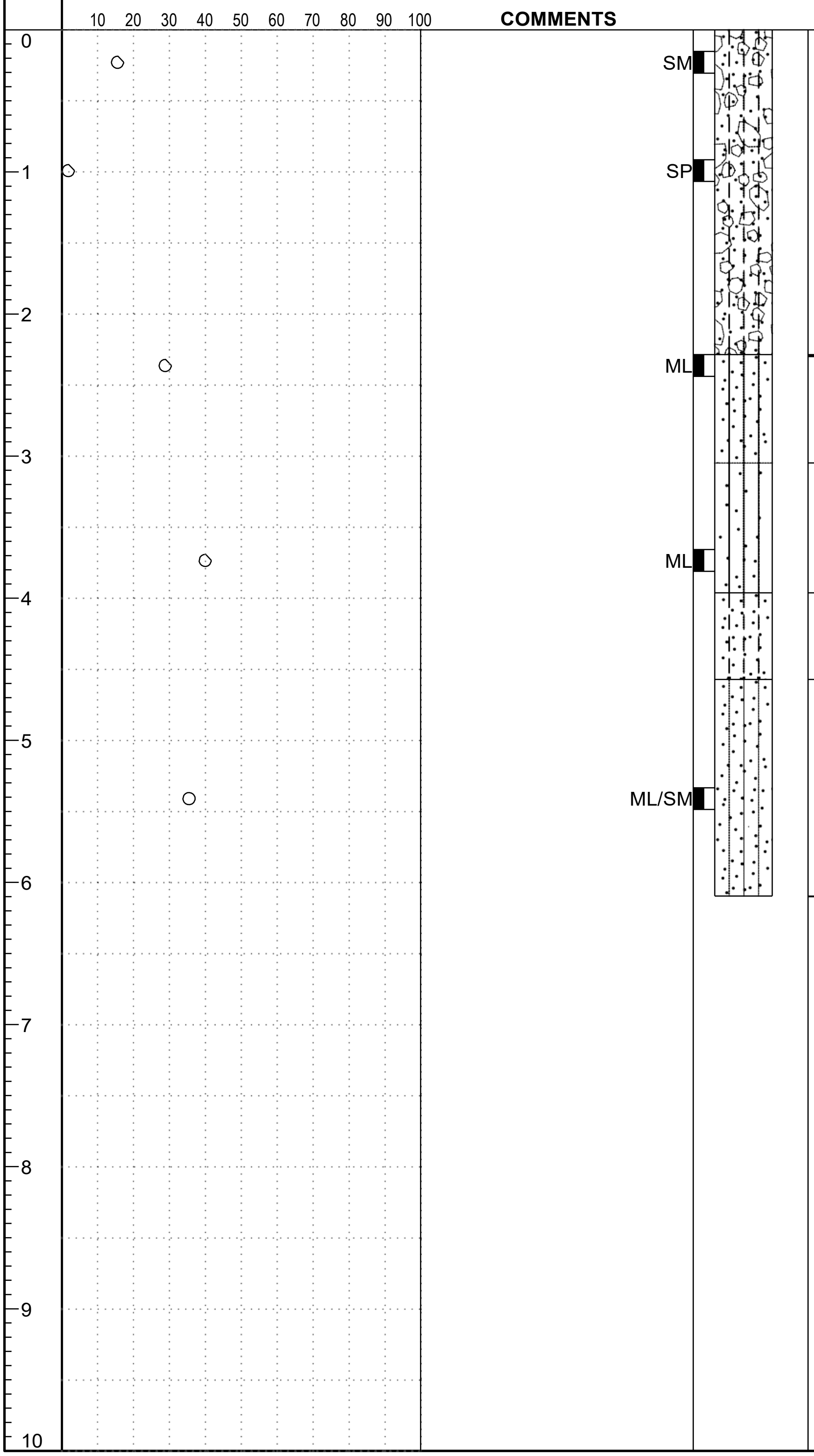
SAMPLES
◧ Disturbed
■ Undisturbed
☒ No Recovery

UNDRAINED SHEAR STRENGTH (kPa)
◆ Peak
◇ Residual
◆ Remolded

GRAIN SIZE (%)
▲ Passing #200 sieve
△ Passing #4 sieve

SOIL HEADSPACE READING (ppm)
✱ GASTECH reading
✲ PID reading

DEPTH (m) | COMMENTS | SOILS DESCRIPTION



Brown, moist SAND with some silt and gravel (DIKE FILL).

Brown-grey, moist to wet SAND and SILT to sandy SILT with a trace of organics.

Very soft, brown-grey SILT with some sand and traces of clay and organics.

Grey, moist SAND with some silt.

Grey, wet SILT and SAND with a trace of organics.

End of hole at required depth.
No water observed upon completion of drilling.

# APPENDIX D: MILLER-LILLOOET DIKE PARTIAL UPGRADE

30 Gostick Place | North Vancouver, BC V7M 3G3 | 604.980.6011 | www.nhcweb.com

nhc
northwest hydraulic consultants ltd

NHC Ref. No. 3004610

30 January 2020

**Pemberton Valley Dyking District**
1381 Aster Street
Pemberton, BC
V0N 1B0

**Attention:** **Mr. Steve Flynn**
Operations and Maintenance Manager

**Via email:** Steve@pvdd.ca

**Re:** **Pemberton Valley Flood Mitigation Planning**
**Proposed Typical Section for Miller-Lillooet Dike Partial Upgrade Project**

Dear Mr. Flynn:

Following our 16 January 2020 conference call, Pemberton Valley Dyking District (PVDD) requested recommendations with respect to a typical dike cross-section for partial upgrading of a section of the Miller-Lillooet Dike. The proposed project is described in PVDD's Community Emergency Preparedness Fund (CEPF) application and in NHC's 10 December 2019 report "Pemberton Flood Mitigation Planning – UBCM Community Emergency Preparedness Fund - Structural Flood Mitigation 2019 Grant Funding Application – Final Report".

The primary objective of the project is to reduce the risk of a dike breach for a 1,400 m long section of the dike downstream from the railway bridge on the right bank of the Lillooet River. For this river reach, recent model studies have shown the dike to be very low, which could overtop and breach from less than a 1:50 AEP flood (approx. 20% chance of this happening in the next 10 years). Because of the dike's proximity to the Village, a breach in this section could result in rapid flooding of residential areas with high velocities and deep water. Given the very limited times for safe evacuation (i.e. in the order of 15 minutes after initiation of the breach) there is a significant potential for loss of life.

To achieve an acceptable level of risk mitigation for the Lillooet River Valley, the Village of Pemberton, Squamish Lillooet Regional District, Lil'wat First Nation and PVDD are working towards a comprehensive integrated floodplain management plan. Ideally, as one component of this work, the entire Miller-Lillooet dike should be considered for upgrading to provincial standards. These standards would include raising the dike crest to the current 1:200 AEP profile plus a freeboard allowance, designing to meet slope stability, seepage control and seismic requirements, plus adding erosion protection. However, the CEPF funds, while intended for "structural projects", are very limited in comparison to the high costs of upgrading a long dike to provincial standards. Therefore, for local authorities with limited cost sharing funds, only partial dike upgrades can be considered when applying to the CEPF program.

Given the limited funding opportunities, but in recognition of the need to at least marginally improve a critical 1,400 m long section of dike, PVDD's current funding application proposes to raise the dike crest by approximately 0.5 m to the 1:100 AEP flood level profile, without freeboard.

This letter outlines key design considerations for the partial upgrade, provides recommendations for dike geometry and briefly discusses *Dike Maintenance Act* (DMA) approvals (seismic guidelines) and funding limitations.

# 1 DESCRIPTION OF EXISTING WORKS

## 1.1 Previous dike upgrade

In 2002, a 3.2 km long section of the Miller-Lillooet Dike (which includes the proposed project area downstream of the railway bridge) was upgraded by the PVDD (KWL Project No. 713-003 "Area 4 Dyke Upgrading", Record Drawings 25 February 2003). The dike was raised by approximately 0.5 m on average, with both waterside and landside slopes constructed at 2H:1V, and a minimum crest width of 4.0 m. The dike is now about 3 metres high with respect to the landside toe elevation.

The 2003 fall flood nearly overtopped this section of raised dike just before midnight on 18 October 2003. The 2002 dike raise project was crucial in preventing a dike breach, major flooding of the Village and keeping people safe, as no evacuations had been undertaken.

Although the 2002 dike raise project prevented a catastrophe in 2003, the existing dike cross-section is relatively narrow and steep in comparison to provincial standards. This raises concerns over dike stability and the potential for a seepage/piping failure of the existing dike in future floods, in addition to overtopping.

## 1.2 Geotechnical Conditions

An overview geotechnical study of the Pemberton Dyking District's Dikes was completed by Thurber Engineering Ltd (Letter Report dated 31 October 31 2019). Of the 10 boreholes that were drilled and logged, one (TH 19-02) was located in the dike near the middle of the proposed partial upgrade project. The Thurber letter report states:

> "The soil profile encountered in THs 19-02 and 19-03 generally comprised 1.5 m to 1.8 m of dike fill consisting of sand with some silt overlying sand with zones of sandy silt to silty sand extending to the maximum depth investigated." (max. depth of the hole was approx. 6 m)

Relevant geotechnical advice from Thurber includes:

- A recommendation that seepage control measures are needed if a 2.5H:1V landside slope is to be used (rather than the standard 3H:1V landside slope without special seepage control measures).
- "The test hole logs indicate that there are granular soils that may be susceptible to liquefaction present under the Pemberton Valley dikes. Based on our experience with past dike seismic assessments, we anticipate the earthquake return period initiating liquefaction could be in the range of 500 to 1000 years."

A detailed seismic assessment of the Miller-Lillooet Dike has not been completed. However, given the potential susceptibility of the dike foundation materials (natural soils) to liquefaction in a large earthquake it is possible that the subject section of the Miller-Lillooet dike may not meet the allowable displacements outlined in the provincial guidelines ( "Seismic Guidelines for Dikes " prepared for MFLNRO by Golder Associates, 2014). Further discussion is provided below.

# 2 DESIGN RECOMMENDATIONS

## 2.1 Typical Design Section Considerations

Key design considerations for this project include:

- Overtopping – only a small dike raise can be considered due to funding availability.
- Stability and seepage – provincial dike geometry standards should be met with seepage control measures as determined by geotechnical analyses.
- Seismic design – consideration of the seismic guidelines for dikes is required.
- Rights of way – additional rights of way are required beyond the landside toe of the dike.
- Project phasing - the project may need to be phased due to funding limitations.
- Erosion protection – additional riprap may be required - (e.g. "LOC 12" in NHC's draft Dike Condition Assessment – erosion protection is not addressed in this memo)

A sketch of the recommended typical design section is provided in **Figure 1** (see attached). Four cross-sections shown on the KWL 2003 record drawings, are also included. These are compared with cross-sections cut from the hydraulic model DEM, based on 2016 Lidar. Minor horizontal and vertical adjustments were made to compensate for variations in datum and georeferencing. The cross-sections are not identical, with the Lidar elevations generally being higher. These variations may be due to the Lidar not accurately representing bare-earth elevations but including some vegetation. The comparison emphasizes the importance of a detailed ground survey before dike design drawings can be prepared and accurate fill volumes estimated.

**Figure 1** also shows the typical design section at the four cross-sections. The key features and rationale for the proposed upgraded section are as follows:

- **Crest Elevation** – to 1:100 flood level. From Figure 11 in NHC's 10 December 2019 report the dike typically requires a raise of about 0.5 m, but the actual raise amount should be confirmed by a detailed plot of a recent dike crest ground survey with the new flood profile.

- **Crest width of 4.5 m** – because the dike has no freeboard for the modelled 1:100 level, emergency flood fighting will likely be required. Therefore, a slightly wider than the minimum crest width of 4.0 m is suggested to facilitate equipment access and emergency work. The additional 0.5 m width adds a relatively small amount to the dike cross-section area and fill quantities. (Increasing the crest width further to facilitate future dike raising would significantly increase quantities and costs).
- **Water side slope of 2H:1V** – the existing dike/adjacent riverbank is protected by riprap for most of the project length, however the condition and requirements for additional rock needs further review.
- **Landside slope of 2.5H:1V** – minimum slope with seepage control measures (e.g. toe drain). Stability and seepage design to be confirmed by geotechnical analysis. (Note: a similar design was utilized for the nearby 2014 Ayers Dike upgrade project.)
- **Rights of Way** - the present right of way boundary (as shown on the 2003 record drawings) is located near the toe of the existing dike, but in some sections the dike extends beyond the boundary. Significant additional rights of way would ultimately be required, assuming that temporary permission for construction can be obtained. A minimum 7.5 m wide ROW will need to be added to allow for the extended embankment and for maintenance equipment to travel along the toe of the dike. Consideration should also be given to acquiring sufficient rights of way to allow future dike upgrading to provincial standards.

Dike materials and construction methods have not been addressed in this letter. In addition to geotechnical design for the proposed cross-section, the materials zoning in the embankment should anticipate possible future upgrading to the 1:200 plus freeboard geometry. To minimize costs, local materials should be sourced provided that acceptable permeability, compaction and drainage characteristics can be achieved.

A detailed cost estimate for constructing the recommended partial upgrade is not yet available, and costs may be highly dependent on the suitability of local materials. Should the funds be insufficient to complete the proposed 1,400 m length of dike, it is recommended that the work be phased, starting at the railway bridge, then proceeding downstream. A second phase to complete the project should be initiated as soon as further funding is available. It is strongly recommended that the dike landside slope not be steepened beyond 2.5H:1V to reduce material quantities and costs in an effort to extend the length of dike raised.

Based on the DEM (2016 Lidar) and assuming a 25% allowance for compaction and waste, a minimum fill volume of 16,600 m$^3$ was estimated. Considering the uncertainty associated with the dike survey information and following ground grubbing and clearing, the actual volume required may be considerably larger, perhaps approaching 25,000 m$^3$.

## 2.2 Seismic Guidelines and Dike Maintenance Act (DMA) Approval

A general requirement to be eligible for CEPF funds for projects that involve major upgrades for "High Consequence Dikes" is that the project must be permittable (i.e. obtain DMA approval) and must address the provincial "Seismic Guidelines for Dikes" (2nd Edition, Golder Associates, 2014).

As noted above, a detailed seismic assessment of the subject section of dike and foundation soils has not been completed. However, the overview geotechnical study indicated that potentially liquefiable granular soils are present. Depending on density of these soils, the guidelines' displacement criteria could potentially be exceeded if liquefaction occurs during large seismic events. Given the potential funding amount in the current application and the limited project scope, explicit design and construction of the project section to meet the maximum allowable seismic displacement criteria could be unviable.

A suggested rationale to address the seismic guidelines and current project approval issues is to acknowledge that the immediate public safety concerns can be at least partially addressed by this project while still working towards the broader objective that new and upgraded flood protection infrastructure should be seismically resilient. Completing the project now would achieve some risk reduction benefits in the short term, but also recognizing that this work is only part of a longer term and ongoing effort towards a comprehensive integrated flood management plan.

**Key Benefits of The Partial Upgrade Project**

- The project will help to reduce the high life safety risk related to a probable breach of the low dike section in close proximity to populated residential areas; and
- The project will "flatten" the landside slopes of the dike and make the existing dike less vulnerable to seepage/piping type failures.

**Partial Upgrade Project Scope within Long Term Context of Major Dike Upgrading**

- The project can be considered as a "minor upgrade" to the Miller-Lillooet Dike because of its limited scope:
    - The project involves partial raising of a 1.4 km long "low" section of a 12 km long dike. (Other sections of the same dike upstream of the railway bridge are also low and could overtop and breach, but because of the railway embankment across the floodplain, the floodwaters would take more time to reach parts of the Village, allowing more time to evacuate the most densely populated areas.)
    - The dike crest level is to be raised from less than a 1:50 AEP flood level to a 1:100 AEP flood level without freeboard (typically 0.5m).
- Full upgrade of the complete Miller-Lillooet-Pemberton dike should ideally be completed to the 1:200 level including freeboard. Necessary planning and pre-design work includes:
    - Completion of a detailed dike seismic assessment (and geotechnical review) of the entire 12 km long dike. If some sections do not meet the displacement criteria, options for modification of the cross-section (e.g. flattening side-slopes, overbuilding etc.) and possible re-alignment and set-back could be considered. Given the long length of the dike, extensive ground improvement to meet seismic criteria would not be feasible.
    - Completion of conceptual designs and cost estimates.
    - Review of "transfer of risk" impacts and mitigation of these effects.
    - Consideration of a new "Village Set-back Dike" option as an alternative to major upgrading of the Miller-Lillooet dike.
    - Refine options and apply for funding for a major structural upgrade project. (Required funds may be at least an order of magnitude higher than funds available through CEPF.)

## 2.3 Proposed Partial Upgrade Project within Context of an Integrated Flood Management Plan

Through the Pemberton Valley Emergency Management Committee, work is ongoing in the following areas as part of an integrated flood management planning effort:

- Improving river flow monitoring and forecasting.
- Working on emergency response and community preparedness. Updated and detailed response plans are including notification and evacuation procedures for areas potentially impacted by potential dike breaches.
- Reviewing, updating, and implementing floodplain development planning and regulations based on the recently completed floodplain mapping.
- Monitoring and managing gravel/sediment influx to diked reach.

# 3 CLOSURE

We trust that this memo is of assistance to the PVDD. Please let us know if you have any questions.

Sincerely,

**Northwest Hydraulic Consultants Ltd.**

| **Prepared by:** | **Reviewed by:** |
|---|---|
| *"Original signed by"* | *"Original signed by"* |
| Neil Peters, P.Eng.<br>Senior Flood Management Engineer | Monica Mannerström, P.Eng.<br>Principal |

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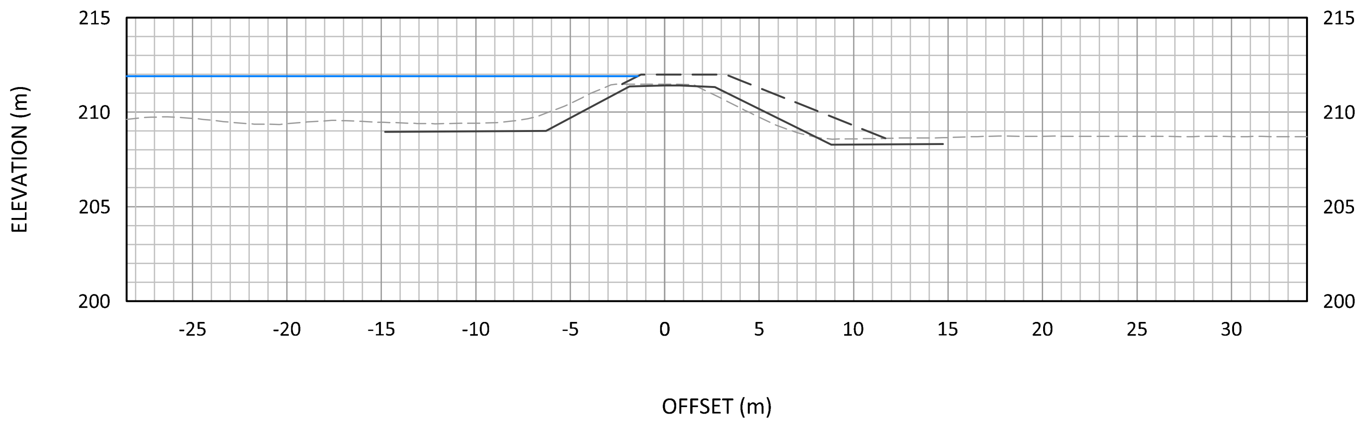
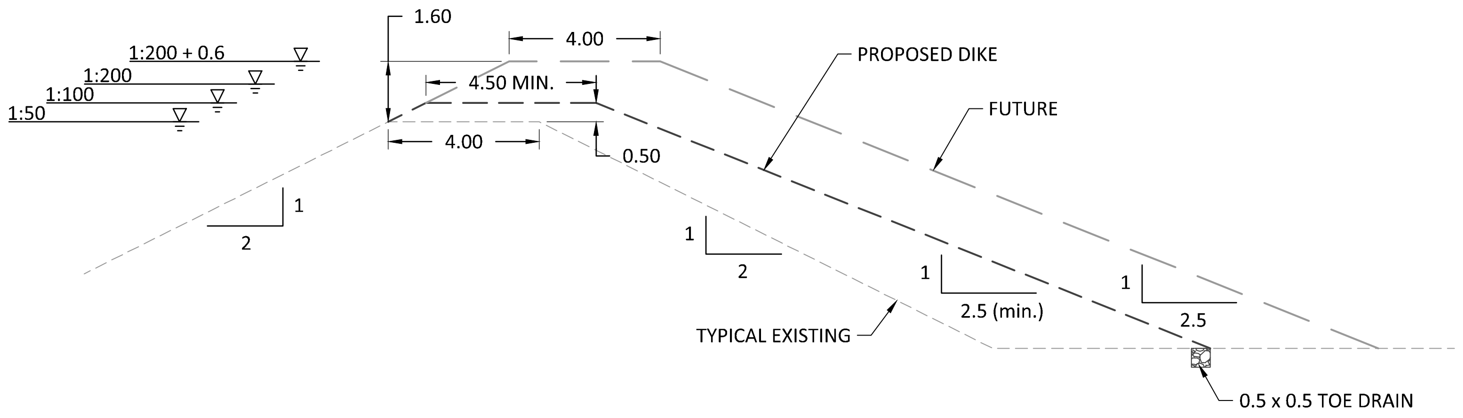
SECTION 1 - KWL STA. 6+816.64





TYPICAL SECTION (LOOKING DOWNSTREAM)
SCALE = 1:200

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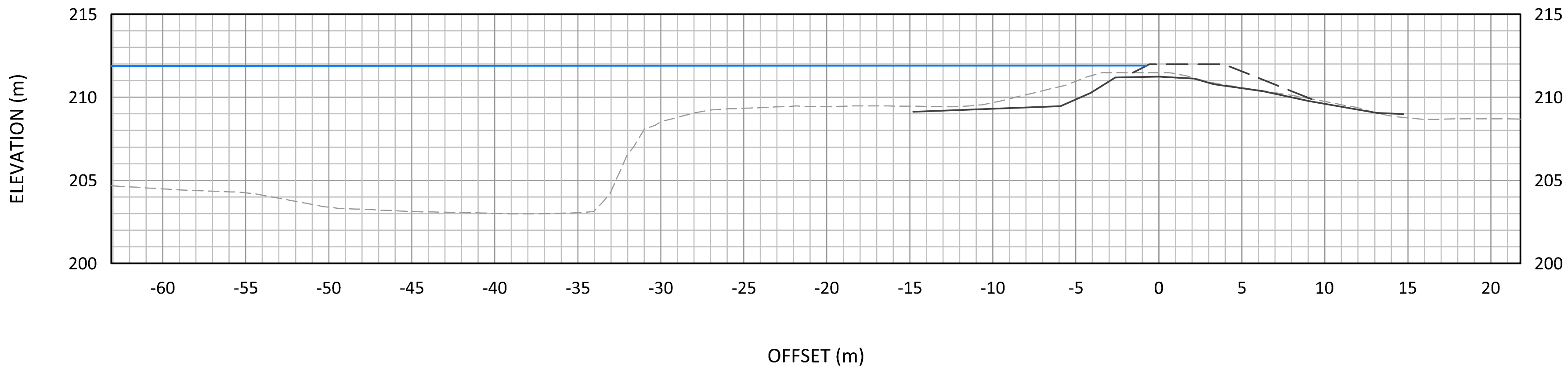
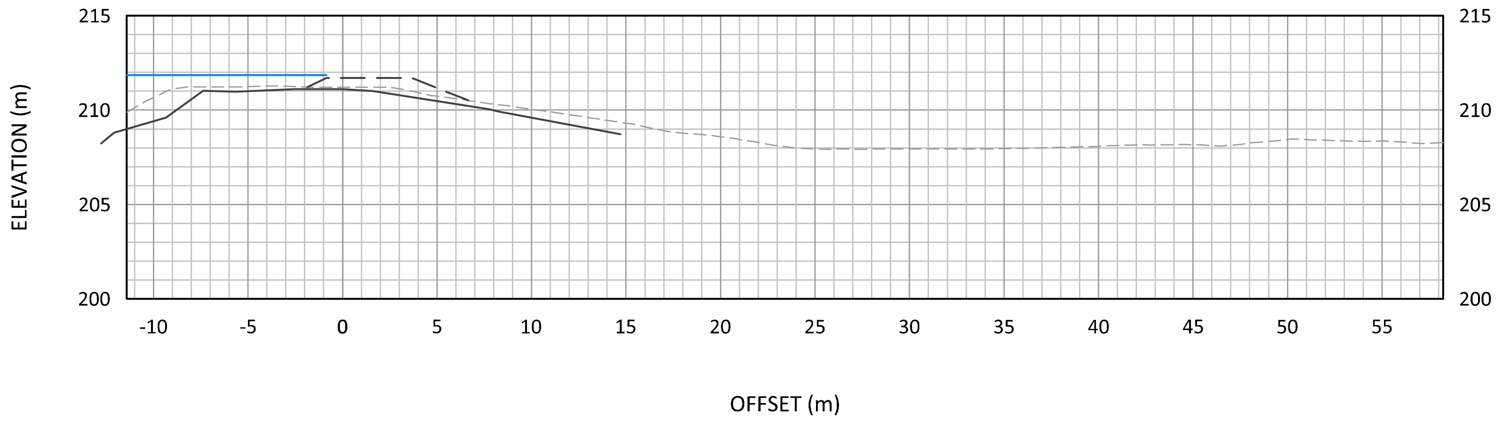


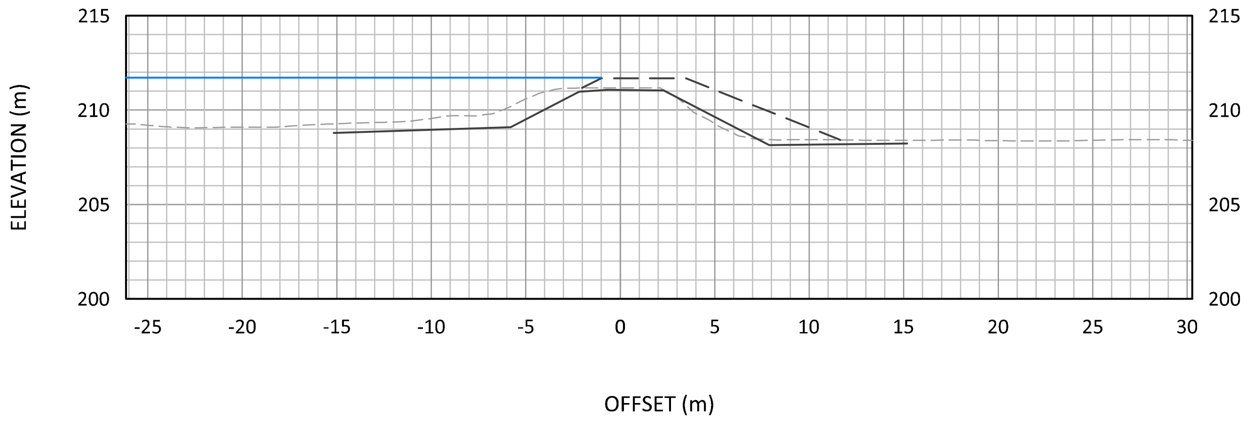
## LEGEND

| | |
|---|---|
| GROUND ELEVATION (2016 LIDAR) | - - - - - - |
| AS BUILT (KWL 2003) | ——— |
| ESTIMATED 100-YR LILLOOET RIVER WATER SURFACE | ——— |
| PROPOSED IMPROVED DIKE | — — — — — |

SECTION 3 - KWL STA. 7+062.23



SECTION 4 - KWL STA.7+170.85



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REVISIONS

| DRAWING INFORMATION | |
|---|---|
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| DRAWN BY | |
| CHECKED BY | |
| SHEET SIZE | B (11" x 17") |

PEMBERTON VALLEY
FLOOD MITIGATION PLANNING

COMPARISON OF MILLER-LILLOOET DIKE CROSS-SECTIONS

PROJECT NUMBER 3004610-8
DRAWING NUMBER 3004610-8-001
SHEET NUMBER
1
REVISION

# APPENDIX E: RETURN ON INVESTMENTS ESTIMATES

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# 1 RETURN ON INVESTMENT ESTIMATES

## 1.1 Objective

The (Pemberton Valley Diking District) PVDD is interested in working with community partners to evaluate flood mitigation options. This included three proposed dike projects:

1. Upgrade the Miller-Lillooet-Pemberton Dike
2. Build a new Village Set-back Dike
3. Build a new Mt. Currie Set-back Dike

For each of these dike alignments a high level cost estimate was developed. In addition, avoided losses were calculated using available information and spatial analysis. The mitigation measure costs and avoided losses were then used to calculate the return on investment (ROI) ratios for each option. This was done to support the PVDD in considering the relative costs and benefits of structural flood mitigation. These ROI calculations are approximate and intended for comparative purposes only.

## 1.2 ROI Approach

A commonly used method, as outlined by Infrastructure Canada's (INFC) Disaster Mitigation and Adaptation Fund (DMAF) program was selected for the analysis (INFC, 2018). Generally, a ROI calculation requires two main components, the calculation of returns and investments.

The 'returns' portion of the ROI ratio includes **direct, indirect, tangible**, and **intangible** avoided costs including **economic, social, environmental**, **heritage**, and **cultural** asset damage (INFC, 2018). For this report the returns considered were direct tangible avoided costs only. With the inclusion of indirect and intangible costs the returns would be higher. The 'investment' portion typically includes project costs eligible for funding. For this report the investment portion includes high level estimate of the costs to upgrade or build mitigation measures.

INFC (2018) provides the following formulation:

$$ROI = \frac{Cost\ of\ potential\ damages\ during\ the\ asset\ life\ cycle}{Mitigation\ Project\ Costs}$$

**Equation 1 Basic ROI equation**

where…

$$\begin{matrix}\mathit{Cost\ of\ potential\ damages} \\ \mathit{during\ the\ asset\ life\ cycle}\end{matrix} = \begin{matrix}\mathit{Estimated} \\ \mathit{Annual\ Damages}\end{matrix} \times \begin{matrix}\mathit{Remaining\ life\ span} \\ \mathit{of\ asset}\end{matrix}$$

And

$$\mathit{Estimated\ Annual\ Damages} = \frac{\mathit{Total\ estimated\ cost\ of\ damages}}{\mathit{Frequency\ of\ hazard}}$$

In this report ROI will be expressed as a percentage return and a ratio. For comparison, within the DMAF program, projects that result in an ROI higher than **2:1** or **200%** may be eligible for funding.

## 1.3 Flood Mitigation Options

The 200 year return period flood with freeboard was used to assess avoided damages. An assessment of avoided damages with climate change would include a more severe flood hazard and therefore higher avoided losses.

### 1.3.1 Upgrade the Miller-Lillooet-Pemberton Dike

The first option is an upgrade to the Miller-Lillooet-Pemberton dike. The high level cost estimate for this measure is $22 Million and the approximate alignment can be seen in **Figure 1.**

**Figure 1: Miller-Lillooet Dike Upgrade Approximate Alignment**

The cost estimate for this upgrade is based on the extent of the existing dike and typical costs for dike upgrades. The extent of the flood hazard, buildings and other infrastructure in this area can been seen in **Figure 2**.

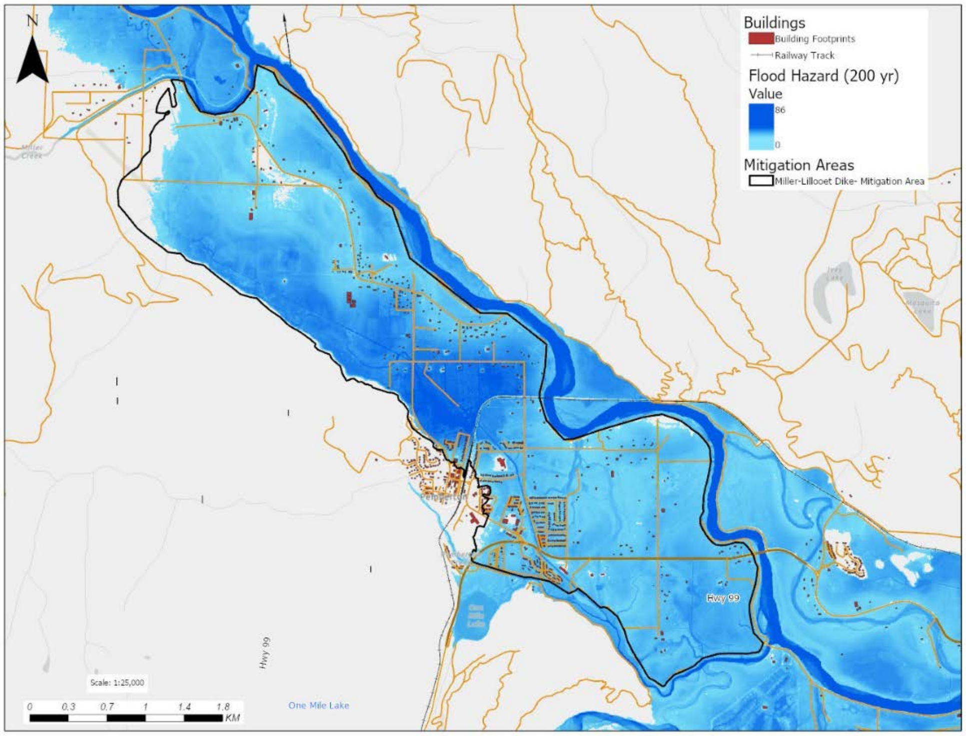

**Figure 2: Miller-Lillooet-Pemberton Dike Structural Flood Mitigation Area**

### 1.3.2 Build a New Pemberton Village Set-back Dike

Another structural mitigation option is to build a new Village set-back Dike. The high level cost estimate for this measure is $19 Million and the approximate alignment can be seen in **Figure 3**.

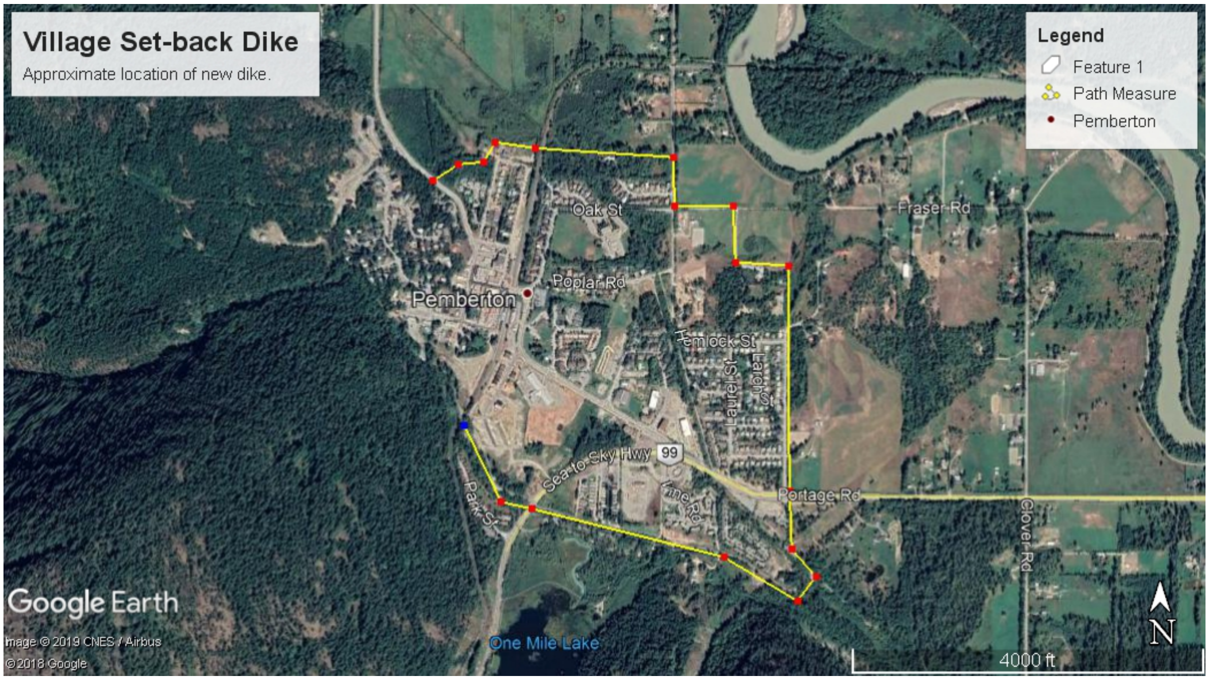

Figure 3: Pemberton Village Set-back Dike Approximate Alignment

The cost estimate for this upgrade is based on the total length for a new dike in this area and typical construction costs. The extent of the flood hazard, buildings and other infrastructure in this area can been seen in **Figure 4**.

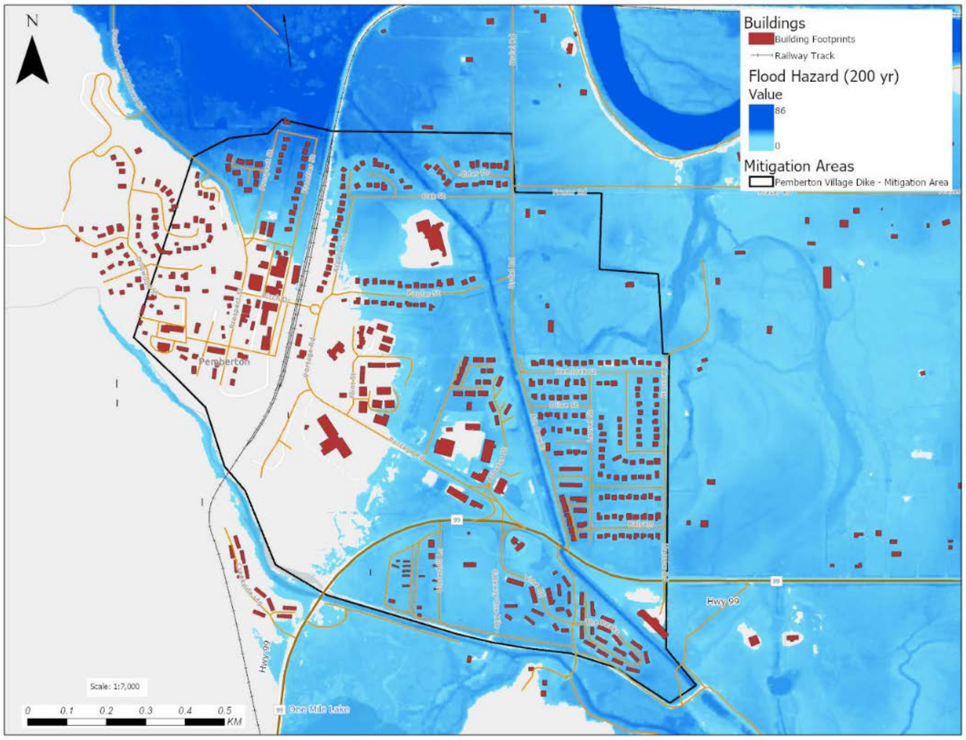

Figure 4: Pemberton Village Set-back Dike Structural Flood Mitigation Area

### 1.3.3 Build a New Mt. Currie Set-back Dike

Another structural mitigation option is to build a new Mt. Currie Set-back Dike. The high level cost estimate for this measure is $7 Million and the approximate alignment can be seen in **Figure 5**.

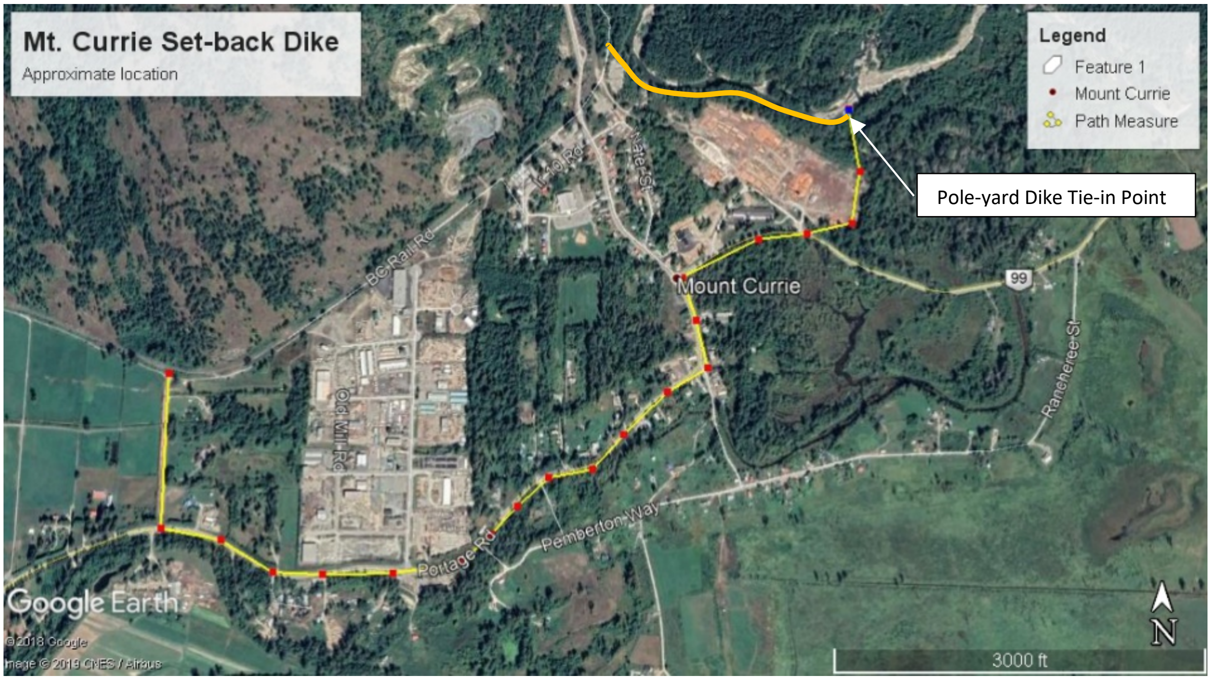

**Figure 5: Mt. Currie Community Set-back Approximate Alignment**

The cost estimate for this dike is low compared to its total length as it would tie in with an existing dike and is assumed to be cost-shared with MOTI. The extent of the flood hazard, buildings and other infrastructure in this area is shown in **Figure 6**.

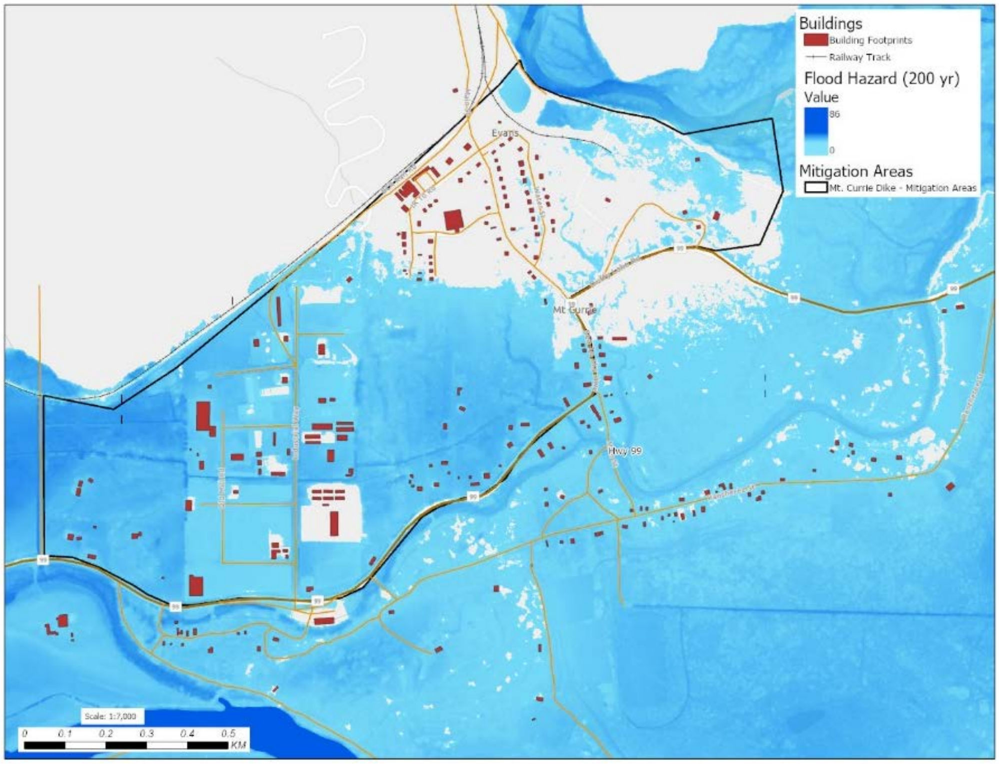

**Figure 6: Mt. Currie Community Set-back Dike Structural Flood Mitigation Area**

## 1.4 Returns (Benefits or Avoided Damages)

As mentioned in Section 1.3 the 200 year return period flood event with freeboard for current conditions was used to assess returns on investment in structural mitigation. A raster file representing flood extent and depth information was used to identify the assets that would be affected by flooding. For this assessment direct tangible losses were considered for buildings, road transportation, rail transportation, agriculture, environmental contamination, and cultural assets.

### 1.4.1 Buildings

Flooding can damage building structures and contents. Avoided losses for buildings were estimated for each mitigation measure considering the following:

- Buildings footprints were obtained from a Microsoft database derived from satellite image processing and used with minimal corrections (Microsoft, 2019)

- Depths were obtained from the output of hydraulic modelling for the 200-year flood event with freeboard for current conditions.

- Average property values were used for this first high level estimate. A more detailed analysis using BC Assessment Authority data would improve this estimate.

- A depth-damage curve obtained from US Federal Emergency Management Agency's (FEMA) Hazus program (FEMA, 2009b) was selected (see **Figure 7**). The curve selected is for a two story residential building with no basement as this is a common building type in the study area and curves for buildings in the study area are similar.
- The effect of flood duration was not included in this estimate.

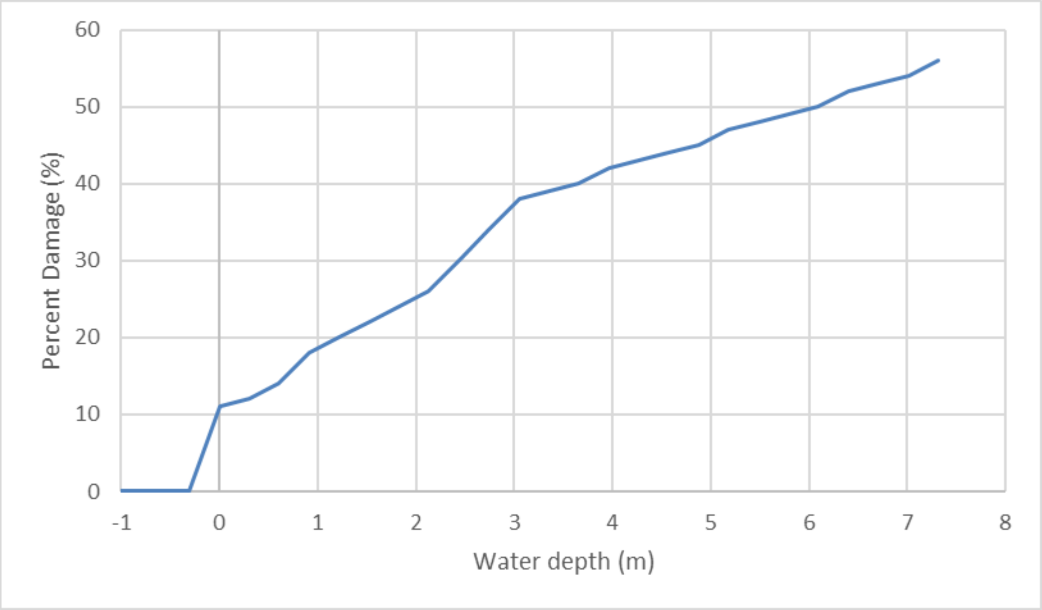

**Figure 7: Depth-damage relationship (FEMA, 2009a)**

Using the depths extracted at the centroids of buildings and the selected depth damage curve, avoided losses for buildings were calculated. These results are summarized in **Table 1**.

**Table 1: Summary of avoided losses for buildings**

| Dike Options | Affected Buildings | Avoided Losses |
|---|---|---|
| Upgrade the Miller-Lillooet-Pemberton Dike | 639 | $160 M |
| Build a new Village Set-back Dike | 319 | $142 M |
| Build a new Mt. Currie Set-back Dike | 86 | $106 M |

A sensitivity analysis was also performed for this calculation to determine the effect that freeboard has on the avoided losses for the buildings calculation. For the Miller-Lillooet Dike and the Village Set-back Dike, the addition of freeboard increases the ROI by 37% and for the Mt. Currie Set-back Dike the addition of freeboard increases the ROI by 59%.

### 1.4.2 Road Transportation

Avoided losses for road transportation were not calculated for this ROI  assessment as the diking options would not prevent an interruption of transport through this area.

Diking would, however, improve access for local evacuation via road and likely reduce the time and effort required for local recovery.

### 1.4.3 Rail Transportation

Avoided losses for rail transport were not calculated for this ROI assessment as the diking options would not prevent an interruption in rail service through this area.

Diking could, however, potentially help to avoid some damage to the rail bed and avoid embankment damages.

### 1.4.4 Agriculture

Floods can damage top soil, agricultural buildings, equipment, and livestock. The Pemberton valley has many active farms and the majority of the land is within the Agricultural Land Reserve (ALR). However, not all of the ALR designated land is being used for active commercial agriculture. This assessment of potential avoided agricultural losses used the latest Land Use Inventory Report for the Pemberton Valley (Ministry of Agriculture, 2009) and loss estimates from a previous assessment for agricultural flood losses in the Fraser River Valley (FVRD, 2016). For this loss estimates a rate of $13,000/ha was selected. This represents a short duration flood which is appropriate as the duration of the 200 year event in this area would be in the order of days, whereas the flood events on the Fraser River would be in the order of weeks.

The loss estimates for each mitigation area are summarize in **Table 2** and were assessed for areas identified as being actively used for agriculture.

**Table 2: Summary of avoided losses for agriculture**

| Dike Options | Area within ALR | Area of Active Agricultural Land | Type of Agricultural Activities | Avoided Losses |
|---|---|---|---|---|
| Upgrade the Miller-Lillooet Pemberton Dike | 8.48 km$^2$ | 6.88 km$^2$ | • Agritourism (2 parcels)<br>• Apiculture (1 parcel)<br>• Beef (2 parcels)<br>• Crops under cover (1 parcels)<br>• Grains, cereals and oilseeds (1 parcel)<br>• Horse Farm (10 parcels)<br>• Forage (19 parcels)<br>• Pasture (10 parcels)<br>• Potatoes (1 parcel)<br>• Sheep (1 parcel) | $8.9 M |
| Build a new Pemberton Village Set-back Dike | 0.12 km$^2$ | 0.00 km$^2$ | • Land in the ALR but no active agricultural use | $0.0 M |
| Build a new Mt. Currie Set-back Dike | 0.38 km$^2$ | 0.027 km$^2$ | • Pasture (1 parcel) | $0.04 M |

These estimates used the best available information for a high level desktop study, however, there are several limitations. The loss numbers provided were estimated for a different location and the farm characteristics would be different. Also, the Land Use Inventory report was produced 10 years prior to this study and the type of agriculture or areas in active use may have changed.

### 1.4.5 Environmental

Floods can cause contaminants to spread, therefore the avoided losses from environmental contamination should be considered. Contamination sources identified in the mitigation areas were considered. High level remediation costs from contamination were estimated using the Canadian Parliamentary Budget Officer report on Federal Contaminated Sites Costs (Office of the Parliamentary Budget Officer, 2014).

It was assumed that these sites would be on average Class 2 sites which is medium risk. These types of sites are reported to have an average remediation cost of $73,145. The total avoided losses from environmental contamination are summarised in **Table 3**.

**Table 3: Summary of avoided losses due to environmental contamination**

| Dike Options | Quantity of Potentially Contaminated Sites | Avoided Losses |
|---|---|---|
| Upgrade the Miller-Lillooet-Pemberton Dike | 6 sites | $0.44 M |
| Build a new Village Set-back Dike | 6 sites | $0.44 M |
| Build a new Mt. Currie Set-back Dike | 2 sites | $0.15 M |

A more detailed assessment of the sources of contamination could refine the class estimate and localized data could refine the cost estimate.

### 1.4.6 Cultural Assets

Cultural sites can be of value for current practices and also have archeological value. There are many cultural assets in the inundation areas but relatively few are inside the identified dikes.

At this level of assessment, the areas have been identified spatially but further characterization would be needed to assign avoided loss to these sites. In addition, structural mitigation does not always have a benefit for cultural sites because access to water is sometimes an important characteristic of the site.

**Table 4: Summary of cultural areas in mitigation areas**

| Dike Options | Number of Areas |
|---|---|
| Upgrade the Miller-Lillooet-Pemberton Dike | Two areas identified |
| Build a new Pemberton Village Set-back Dike | One area identified |
| Build a new Mt. Currie Set-back Dike | Two areas identified |

While avoided losses are not assessed quantitatively at this stage, they should be considered as part of mitigation planning decision making.

## 1.5 Summary

Direct tangible avoided losses were calculated for buildings, agricultural, and environmental losses for three potential dike alignments and used to calculate the ROI for each mitigation area as listed in Table 5.

**Table 5: Summary of Avoided Loses and ROI for Long-Term Structural Mitigation Measures**

| Dike Options | Cost of Measure | Avoided Losses During Asset Life Cycle | ROI (ratio) |
|---|---|---|---|
| Upgrade the Miller-Lillooet-Pemberton Dike | $22 M | $45 M | 2.0:1 |
| Build a new Pemberton Village Set-back Dike | $19 M | $36 M | 1.9:1 |
| Build a new Mt. Currie Set-back Dike | $7 M | $27 M | 3.8:1 |

The ROI calculations show that building a Mt. Currie-set back Dike would have the highest ROI at **3.8:1.** This is primarily influenced by the lower construction cost for this option as existing road and diking infrastructure could partly be used to build this diking option. In addition, there are avoided losses from buildings, agriculture, and environmental contamination in this area.

The second best option based on the ROI calculation would be the upgrade to the Miller-Lillooet-Pemberton Dike with **2.0:1**. In this case the cost of this option is the highest but the avoided losses are also the highest with buildings, agriculture, and avoided agricultural assets benefiting from additional protection. This measure has the greatest impact on avoided losses for agriculture.

Finally, the ROI for the Pemberton Set-back Dike is the lowest at **1.9:1** and for comparison would not satisfy the DMAF ROI threshold requirement. The cost for this measure is high as it would primarily be a new structure with limited tie in to existing raised infrastructure. This study only included direct intangible avoided losses and with indirect and intangible losses such as loss of business and disruption of services this ROI would be higher.

In summary, while this assessment was high level it provides a starting point to consider structural flood mitigation for PVDD structures. As the construction cost estimates and the avoided loss estimates are improved and expanded on these ratios will likely change. Finally,  if a method was applied that included indirect and intangible avoided losses then the ratios would be considerably higher.

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