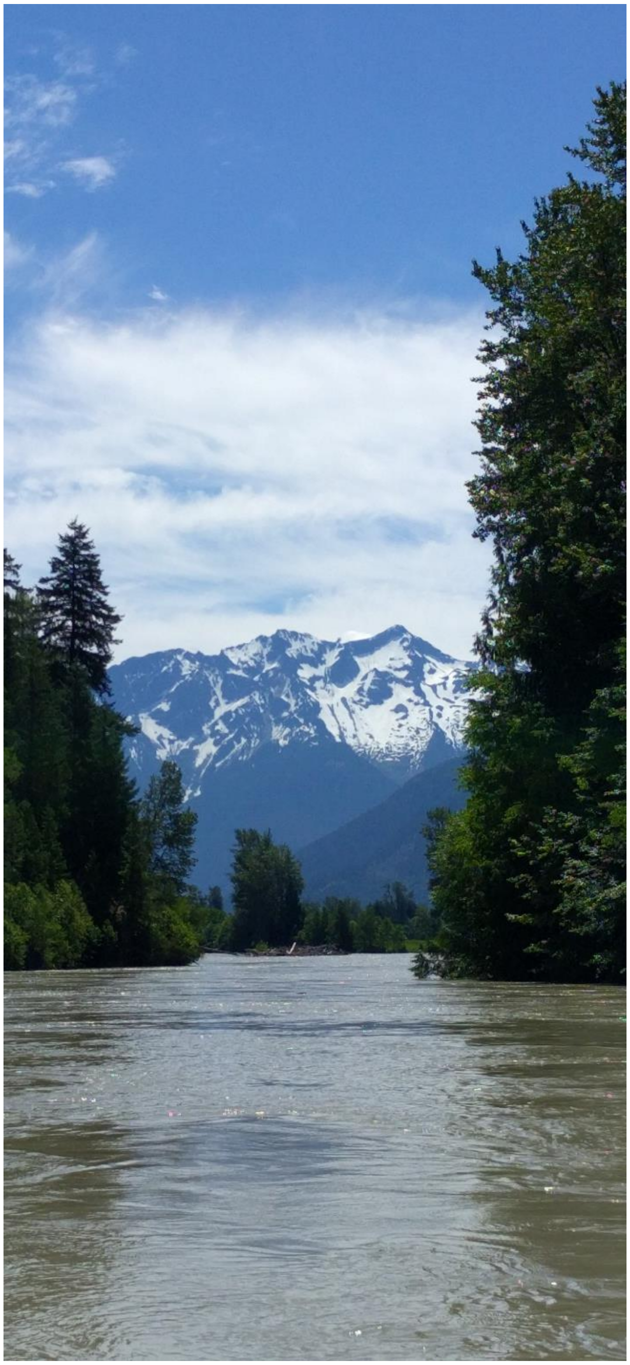


LILLOOET RIVER FLOODPLAIN MAPPING

FINAL REPORT

Prepared for:

Pemberton Valley Dyking District Office
1381 Aster St
Pemberton, BC V0N 1B0

Prepared by:
Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3

22 November 2018

NHC Ref. No. 3002903

northwest hydraulic consultants
water resource specialists

LILLOOET RIVER
FLOODPLAIN MAPPING

FINAL REPORT

Prepared for:

Pemberton Valley Dyking District
Pemberton, BC

Prepared by:

Northwest Hydraulic Consultants Ltd.
North Vancouver, BC

22 November 2018

NHC Ref No. 3002903

nhc

Report Prepared by:

29 August 2018

Vanessa Bennett, MASc., EIT
Water Resource EIT

Joel Trubilowicz, PhD, EIT
Environmental Data Scientist

Wil Hilsen, P.Geo
Associate

Report Reviewed by:

29 Aug 2018

Monica Mannerström, P.Eng
Principal

Neil Peters, P.Eng
Senior Floodplain Management Engineer

Malcolm Leytham, PhD, P.E.
Principal Hydrologist

DISCLAIMER

This report has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **PEMBERTON VALLEY DYKING DISTRICT** for specific application to the **LILLOOET RIVER FLOODPLAIN MAPPING 2017/2018**. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation, and was prepared in accordance with generally accepted engineering practices.

Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by **PEMBERTON VALLEY DYKING DISTRICT**, its officers and employees. **Northwest Hydraulic Consultants Ltd.** denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.

CREDITS AND ACKNOWLEDGEMENTS

Northwest Hydraulic Consultants Ltd. (NHC) would like to thank the Pemberton Valley Dyking District (PVDD) for initiating this study, making available extensive background information and providing advice and support through-out the project. Key PVDD representative was Mr. Steve Flynn, Operations and Maintenance Manager. Ryan Wainwright, Emergency Program Manager with Squamish Lillooet Regional District; Ernest Arman, COO with Lil'wat First Nation; and, Sarah Toews, Emergency Program Manager with Village of Pemberton, provided additional guidance.

The following NHC personnel participated in the project:

- Surveys (Wil Skitmore, Aaron Snyder, various field staff)
- Geomorphic Analysis (Andrew Nelson, Wil Hilsen, David McLean)
- Hydrologic Analysis (Joel Trubilowicz, Piotr Kuras, Malcom Leytham)
- Hydraulic Modelling (Vanessa Bennett, Chris Long)
- Mapping and GIS (Dawn Lasprugato, Madalyn Ohrt, Sarah North)
- Project Review (Neil Peters)
- Project Management (Monica Mannerström)

Highmark Land Surveying and Engineering Ltd. (Highmark) was retained as a subconsultant to assist with surveys of land features as required.

EXECUTIVE SUMMARY

Understanding Flood Hazards in the Pemberton Valley

The Pemberton Valley is prone to flooding - this was already recognized by early Lil'wat inhabitants thousands of years ago and European settlers as they started to arrive at the beginning of the last century. Flow records are available for the Lillooet River for almost 100 years and interestingly show an increase in flood peaks since about the late 1970's.

It is not unusual for British Columbian rivers to have long periods of above or below average floods, this is the result of normal climate variations. However, on the Lillooet this increase in peak flows has been accompanied by a shift in the timing of annual floods. Instead of generally being caused by snowmelt in the spring time, annual peak floods are now more consistently caused by heavy rains in the fall or early winter. The flood flows are the result of intense low-pressure weather systems, or atmospheric rivers. When originating over the Hawaiian tropics, these storms are often referred to as the Pineapple Express, bringing warm, high moisture air towards British Columbia's coastline. The storms may linger for several days and are particularly troublesome when preceded by early snowfall, leading to rapid melt in combination with heavy rains. This shift in timing of the annual flood peak may be permanent and climate change impacts are foreseen to further increase flood flows in the future.

In the 1940's and 50's, the Prairie Farm Rehabilitation Administration introduced measures to reduce flooding in the Valley. The Lillooet River was straightened, bypassing natural bends in several locations; some dikes were constructed and Lillooet Lake was lowered by modifying the lake outlet. In spite of the alterations, the river continued to flood. The Pemberton Valley Dyking District (PVDD) was formed and took on the upgrading and expansion of dikes along the Lillooet River and its main tributaries. Prior to and following the flood of record in 2003, with a peak flow of 1,490 m^3/s, PVDD has completed multiple projects in cooperation with federal, provincial and local governments, and First Nations. These projects have involved raising, widening and lengthening several dikes, protecting river banks from erosion, preventing log jams from building up and removing sand and gravel from the Lillooet River, Miller Creek, Birkenhead River and Pemberton Creek to help maintain sufficient channel capacity to convey flood flows. This work has significantly reduced flood impacts over the past several decades.

PVDD carrying out sediment removal to restore channel capacity.

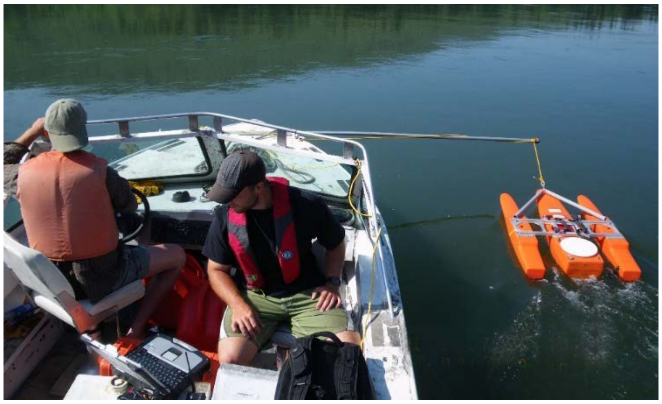
In 2010, a large landslide occurred on the side of Mount Meager, about 65 km upstream from Pemberton. The slide caused a temporary channel blockage in Meager Creek and Lillooet River but fortunately the material gradually dispersed without resulting in a sudden outburst flood. Subsequently, PVDD commissioned the installation of an early warning system on the Lillooet River to alert against future channel blockages and potential outburst floods, should another large slide occur in the upper valley. Material from the slide is now making its way through the Lillooet River system, affecting the channel stability and the amount of flow the river can carry within its channel. This slide material, in combination with potential increases in flood peaks, means that the available floodplain mapping (prepared by the provincial government in 1990) and the updated dike design profile from 2002 are no longer valid.

Upper Lillooet River showing Meager Slide deposits in the river channel.

Floodplain Mapping – What Is Involved?

Floodplain mapping is highly useful for estimating the extent and depth of different magnitude floods, developing appropriate flood emergency response measures, and planning for future flood resistant development and infrastructure. PVDD, in consultation with other local governments and Lil'wat First Nation, recognized the need for updating the design profile and preparing up-to-date floodplain maps for the Valley. The Dyking District successfully applied for funding from Emergency Management BC, facilitating this important project to go ahead. Northwest Hydraulic Consultants Ltd. (NHC) carried out the work as described in the Lillooet River Floodplain Mapping Final Report, August 31, 2018. The project has made several major advances in knowledge and provides significant new tools to support flood management in the Pemberton Valley. The Final Report describes the work in detail, with main components and related benefits summarized here.

To support the hydraulic modelling and development of mapping, NHC developed a Digital Elevation Model (DEM) of the Valley, including the river channels. Floodplain topography was made available by the Province in the form of Lidar (Light Detection and Ranging) surveys; NHC surveyed by boat the bathymetry of the Lillooet River from Lillooet Lake to just upstream of the Forest Service Road Bridge and the tributary rivers. The two sets of surveys were converted to a consistent datum (CGVD2013) and combined in the DEM. Considerable effort was required to convert all historic information to this datum as various reference elevations have been used in the past.



NHC surveying on the river.

Considering the major channel changes that have taken place following the Mount Meager Slide, NHC carried out extensive fieldwork and geomorphic investigations to fully understand the Lillooet River sediment issues and their impacts, particularly those related to the changing flow capacity of the river channel. This work is described in the Geomorphic Atlas included as an appendix to the main report. Sediment supply will decrease over time but will remain high for several decades. The slug of coarse sediment moving down the river has increased channel instability in the upper river; the sand and fine gravel has already reached the depositional zone downstream of Ryan River confluence. Since 2011, the annual average channel bed elevation over the lower 35 km of the river has increased by about 0.4 m. As the coarse material enters the study reach, the channel bed will potentially infill an additional 0.5 m by 2025, further increasing flood levels.

NHC undertook hydrologic analyses to estimate the Lillooet River flows corresponding to the 50, 100 and 200-year flood events, including the 200-year flood incorporating projected climate change impacts by the end of the century. In view of the observed significant changes in timing and magnitude of peak flows, NHC based flood estimates on post-1975 flow records rather than the entire historical period. A 40+ year period is considered statistically significant for estimating the 200-year flood and resulted in much higher estimates than those previously developed by others.

The current 50-year flood estimate is slightly higher than the flood-of-record in 2003, and the current 200-year flood estimate is 39% higher than the value used for the 2002 profile update. Given the shift from spring freshet to fall/winter flood peaks, the higher design flows are considered to be more realistic than previous estimates and, therefore, the new estimates were used for updating the floodplain mapping and design profile. Previous studies assumed that the 50, 100 and 200-year tributary floods would occur during regional events with the Lillooet flood of the same return period, but that the timing of the peaks would differ. We took a different approach, instead estimating tributary flows (Ryan River, Miller Creek, Pemberton Creek, Green River and Birkenhead River) likely to coincide with the Lillooet design flows.

A numeric hydraulic model uses a DEM as input and then calculates water levels corresponding to certain inflows and boundary water levels, in this case Lillooet Lake. Past Lillooet studies used 1D hydraulic model software for simulating flood levels. Considerable improvements have been made to software products and computing power has increased significantly. NHC developed a leading-edge 2D model of the rivers and floodplain. The model has several advantages over previous 1D models, allowing for more detailed representation of flood waters. The model was calibrated and validated to observed water levels and flows and then used to simulate the 50, 100, 200 year and 200 year + climate change floods.

The simulated flood profiles allowed comparison with surveyed dike crest elevations to estimate the flows when dikes may start to overtop. Some overtopping is likely at the 50-year flood and the present diking will not adequately protect against the 200-year flood. The present work generated animations of floods progressing through the valley as the result of dike overtopping and breaching. This information is particularly useful for planning emergency response. In some locations warning time is minimal and the animations form a key tool for planning. The model will allow simulation of potential future up-grades to specific dikes such as the "Miller-Lillooet-Pemberton Ring Dike" and assessment of impacts to adjacent areas.

Three types of map products were produced:

- Designated floodplain maps depicting 200-year flood levels plus a freeboard allowance of 0.6 m.
- Flood depth maps for the 50, 100 and 200-year floods.
- Flood hazard maps showing a Hazard Rating based on flood depths and flow velocities.

The designated flood maps show the extents of flooding and include Flood Construction Levels (FCLs), the minimum level for construction. The Village of Pemberton, the Squamish Lillooet Regional District and Lil'wat First Nation have the authority to designate the maps as official floodplain mapping for their areas. The flood extents are fairly similar to the 1990 maps but FCLs are considerably higher due to: 1) the increased 200-year flood flow; 2) the reduced channel flow capacity due to the Meager slide; and, 3) the more accurate modelling methods applied. The flood depth and hazard maps are primarily intended for emergency response planning.

Moving Forward

The Pemberton Valley is now one of relatively few communities in BC with up-to-date floodplain maps, providing valuable opportunities for improving flood safety and emergency response in the Valley. By sharing the results and educating key authorities, stake holders and the public, PVDD will help reduce potential loss-of-life and flood damages during future extreme flood events.

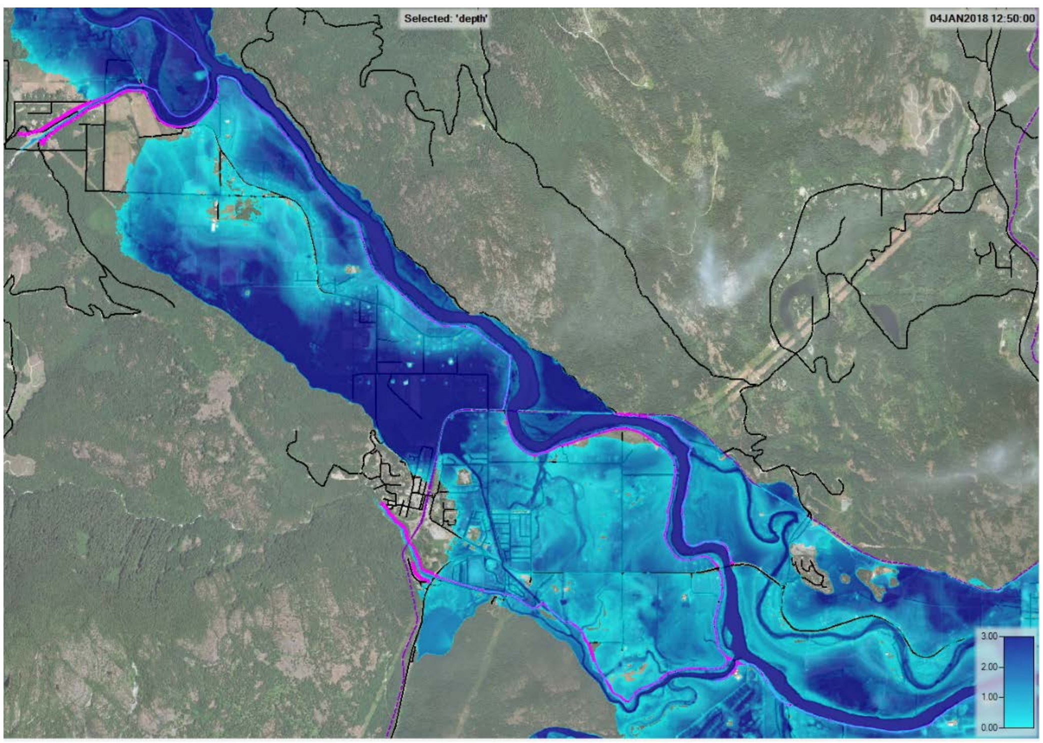
Planning new development away from high hazard areas and implementation of the Lillooet River updated FCLs will lead to more flood resilient development. Access and egress routes requiring improvement can readily be identified and the location of temporary evacuation areas determined. Substantial dike upgrades are likely to be costly and a dialogue regarding tolerable flood risk should be initiated. Consideration should also be given to relocating or floodproofing existing housing and other development in extreme flood hazard areas.

As the material from the Meager Slide moves through the river system, it is critical that the current sediment management program be intensified. Preferably, DFO and the province should grant a standing agreement for regular removals of sand and gravel from key locations in the river. The feasibility of installing a sediment trap upstream of the Forest Service Road Bridge should be explored.

It is clearly important that WSC continues to maintain their primary gauge on the Lillooet River near Pemberton and that the stage-discharge relationship be kept up-to-date. Gauges on the tributaries should be reinstalled, the Birkenhead gauge being particularly important. The water level gauge installed by NHC at the Forest Service Road Bridge provides important emergency notification in the event of an upstream channel blockage and should be monitored and maintained. The provincial River Forecast Centre needs to be aware of the increased flood vulnerability of the Valley.

We recommended that tributary 200-year floods also be modelled to develop corresponding FCLs on the tributaries. Modelling the Birkenhead River is a priority for the Lil'wat First Nation.

The Lillooet River channel is highly dynamic and the hydraulic model and mapping will need to be updated over time. Considering the ongoing aggradation, the river channel should be monitored and re-surveyed every 5-10 years and the hydraulic model updated as required. During future flood events, high water marks should be obtained to allow for future model calibration.



Progression of 200-year Lillooet River flood. Still image from model animation.

TABLE OF CONTENTS

APPENDICIES

APPENDIX A: SURVEY DATA
  Appendix A.1: Spatial Data Collected
  Appendix A.2: Vertical Datum Memo
  Appendix A.3: Spatial Data Deliverables

APPENDIX B: GEOMORPHIC ATLAS

APPENDIX C: PROFILE AND CROSS SECTION COMPARISON

APPENDIX D: HYDRAULIC DATA
  Appendix D.1: Design Profiles for Lillooet River and Tributaries
  Appendix D.2: Mesh Sensitivity Plots

DESIGNATED FLOODPLAIN MAPS

FLOOD HAZARD MAPS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background Information

The Pemberton Valley is located in the Coast Mountains roughly 160 km north of Vancouver and extends from Lillooet Lake up to the confluence of Meager Creek. It includes the Village of Pemberton, Mount Currie and Pemberton Meadows. Pemberton Village currently has a population of about 2600 people with the local economy dependent on farming, logging and tourism. The climate is warm and dry in the summer and generally wet in the winter.

Historically, Pemberton Valley has been inhabited by the ancestors of the Lil'wat Nation. Hudson's Bay traders first came through in 1827 looking for a new fur trading route from Kamloops to Fort Langley. It was either from these traders or through earlier Native traders that the people along the Lillooet River obtained their first cultivated potatoes, which later became the main crop of the area. After the goldrush, the farming settlement grew and eventually a railway was built (1914) which allowed for easier access. Permanent settlement remained a challenge as frequent spring and fall floods resulted in significant losses (Decker et al., 1978).

The Prairie Farm Rehabilitation Administration initiated the straightening and diking of the Lillooet River and its tributaries (Ryan River and Miller Creek) as well as the lowering of Lillooet Lake. Pemberton Valley Dyking District (PVDD) was formed in 1947 to manage flood control and drainage in Pemberton Valley. This made more land available for farming which in turn brought in more settlers in the late 1940s and 1950s (Decker et al., 1978). Over the next few decades, the Lillooet River underwent extensive anthropogenic change, largely confining the channel to the east valley wall.

1.1.1 Historical Flooding

There have been five significant floods in the past 78 years, four of them in the past 37 years, causing damage to the Pemberton area. The largest floods typically occur in the fall and are associated with rain-on-snow events. The valley was flooded in the fall of 1940 when a poorly constructed dike breached. The flooding covered the entire valley, impacting buildings, livestock and vegetation. The flood in November of 1981 had a slightly lower flow magnitude.

In the fall of 1984, Pemberton suffered another severe event and residents had to be evacuated. It was the largest flood on record for the Lillooet River at the time (1,310 m3/s max. instantaneous flow estimated at gauge 08MG005 near Pemberton). The dikes in the Miller Creek area were over-topped and failed as well as in several other areas, including Ryan River and Upper Pemberton Creek. Peak flood levels were reached almost 26 hours after the dikes overtopped (KWL, 2002).

An unusual "summer rainfall" flood event occurred in late August 1991 when heavy rain fell across southwestern BC. The Lillooet River and several tributaries experienced major floods and Lillooet Lake reached a historic high. The maximum instantaneous flow of 1,410 m3/s at Pemberton became the new "flood of record".

The flood of 2003 was another fall flood, when a warm front caused prolonged rainfall in the area setting rainfall records. The flood peaked during the night and set a new all time high of 1,490 m3/s at the WSC gauge near Pemberton, becoming yet another flood of record. In adjacent areas, the flood washed out Highway 99 at Rutherford Creek, cutting off Pemberton from Whistler and the Lower Mainland. Unprotected areas of the valley were inundated and flood waters came up to the crest of several dikes near Pemberton (KWL, 2005). A few dikes were breached.

An increasing trend in peak flows has been observed over time and is discussed in the hydrology section of this report (Section 4).

In 2010, there was a large landslide on Mount Meager that impacted Meager Creek, Capricorn Creek and Lillooet River, causing a temporary blockage. It was the largest landslides in Canadian history and there was concern that the blockage would breach suddenly, causing an outburst wave down the Lillooet River channel. However the blockage eroded gradually over 3 days and there was no resulting flood wave (Guthrie et al., 2012). The landslide has impacted, and will continue to impact, the sediment supply to the Lillooet River, potentially affecting the flow capacity of the channel. The importance of understanding the implications of the slide on future flood levels was recognized and considerable effort was expended to explore the geomorphology of the study reach (Section 3 and Geomorphic Atlas in Appendix B).

More recently, Pemberton Valley experienced a large flood in November of 2016 (peak flow of 956 m3/s at the gauge near Pemberton, preliminary estimate). While not as large as the 2003 flood, it still caused extensive flooding in unprotected areas of the valley (Figure 1-1). Water Survey Canada (WSC) conducted discharge measurements at the peak of the event which subsequently allowed WSC to update the stage-discharge relationship for their gauge on the Lillooet River near Pemberton (08MG005).

Figure 1-1 FSR Bridge and Dike during the peak of the 2016 flood. (Photo by Steve Flynn, PVDD)

1.1.2 Previous Floodplain Mapping Studies

Several floodplain mapping and hydraulic modelling studies have been completed for the Pemberton Valley. The floodplain was originally mapped in 1973 by the Ministry of Environment, Lands and Parks, Water Management Division and was further revised in 1980. Following the 1984 flood, the maps were updated in 1990. After the 1991 flood, the design profiles for the river were again updated in 1995 by the Ministry of Environment, Lands and Parks, Water Management Division. It was deemed that the actual floodplain mapping did not need to be updated at that time. The design flood profiles were further updated in 2002 by KWL but mapping not produced.

In accordance with the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) guidelines, PVDD is responsible for maintaining dikes and other flood protection works from the top of Pemberton Meadows to Lillooet Lake, excluding those on Lil'wat First Nation lands. The

Dyking District identified a need for updated flood mapping and design profiles for the valley. With the apparent increase in sedimentation within the river and observed larger floods, a review of the valley geomorphology, hydrology and hydraulics is imperative to improve the safety of the population in the valley. With funding from Emergency Management BC (EMBC), PVDD retained NHC to carry out a comprehensive floodplain mapping study of the approximately 50 km reach of the Lillooet River from the top of Pemberton Meadows to Lillooet Lake.

1.2 Project Objectives

The primary objectives of the project are to: 1) create a series of new modernized flood hazard maps for the Pemberton Valley Floodplain; 2) develop an official 200-year Designated Floodplain Map; and 3) update the design profile for the river (see Figure 1-2 for River details and extents). The new design profile and mapping will allow dikes to be upgraded to the provincial standard, Flood Construction Levels (FCLs) to be set for new construction, and emergency response plans to be updated. The mapping will also provide hazard information for community planning, to help reduce future flood risks in a rapidly developing area. Recent large flood events (2016 and 2003) demonstrated that the valley is subject to a high degree of flood hazard. Because of the limited emergency response time and probability of dike failure, large floods can potentially lead to loss-of-life as well as substantial economic, environmental and social losses.

The design profile was revised in 2002 but is now considered out-dated due to the changes that have taken place in the river channel, partly as a result of the Meager Creek slide and because peak flows over recent years have increased.

PEMBERTON VALLEY DYKING DISTRICT

nhc
northwest hydraulic consultants
30 Gostick Place
North Vancouver, B.C. V7M 3G3
Canada
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

DATA SOURCES: PVDD, Lilwat First Nation, GeoBC, MFLNRO, NRCAN, Esri

SCALE - 1:51,318

0 1 2 3 KM

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Engineer	GIS	Reviewer
XXX	MSN	XXX

Job Number	Date
3002903	26-JUN-2018

LILLOOET RIVER FLOODPLAIN MAPPING STUDY AREA REFERENCE MAP

Figure 1

\\MAINFILE-VAN\Projects\Active\3002903 Lillooet River Flood Maps\95 GIS\3002903_VCCB_Map_Overview_R1c_Dikebreach.mxd

1.3 Terms of Reference

The following project requirements and river study reaches were listed in the terms of reference:

- *50 km of the Lillooet River from just upstream of Lillooet Forest Service Bridge to Lillooet Lake;*
- *12 km of the Birkenhead River;*
- *15 km of the Ryan River;*
- *3 km of Miller Creek;*
- *8 km of Green River; and,*
- *6 km of Pemberton Creek.*

Mapping methods must conform to current guidelines and standards, including those under development, namely:

- *APEGBC Professional Practice Guidelines for Flood Mapping in BC);*
- *National Guidelines (under development with expected release 2017/18) and*
- *MFLNRORD Flood Hazard Area Land Use Management Guidelines (2004 and 2018 update).*

To achieve the objectives, the tasks include, but are not limited to:

1) *Obtaining Channel and Floodplain data, including but not limited to:*
    a) *Currently available topographic, land use and cadastral information;*
    b) *Currently available LIDAR and orthographic data;*
    c) *Bathymetry data (surveys required);*
    d) *Data must be provided to PVDD and the Province of BC once project is completed.*
2) *Conducting both field and desktop geomorphological reviews and assessments of channel stability to determine aggradation/degradation trends in the Lillooet River and tributaries. The reviews and assessments to include, but not be limited to:*
    a) *Current channel sedimentation locations and assessment of impacts to flood flows and conveyance of Design Flood event.*
    b) *Future sediment sources from landslides and assessment of the likelihood and magnitudes of future sediment deposition.*
    c) *Assessment of freeboard considerations.*
3) *Conducting hydrologic review, analyses including recommendations for future considerations. Review and analysis to include, but is not limited to:*

a) *Literature review of the history of flooding in Pemberton Valley including reports on determination and quantifying the design flood.*

b) *Investigating the WSC Lillooet River near Pemberton (08MG005) gauge and comparing it to new gauges in the area.*

c) *Reviewing the historic stage-discharge relationships for the Lillooet River gauge.*

d) *Determining Lillooet Lake flood Levels based on recorded levels and lake discharge rating curves.*

4) *Carrying out frequency analyses and determining the 100, 200 and 500 year return period peak flows and associated flow hydrographs for the Lillooet River and tributaries.*

5) *Conducting hydraulic analyses for (tentatively) 100, 200 and 500 year return period scenarios consisting of, but not limited to:*

   a) *Establishing two dimensional hydraulic model to compute flood profiles;*

   b) *Incorporating climate change scenarios and modifying hydrographs accordingly, then map to current conditions;*

   c) *Determining flood water level profiles for each return period;*

   d) *Identifying dike over-topping locations for each return period;*

   e) *Determining dike breach locations and breach parameters;*

   f) *Digital model and results must be provided to PVDD and the Province of BC once project is completed.*

6) *Undertaking one-and two-dimensional coupled hydraulic modeling to simulate dike breach scenarios at up to 10 key locations along the diked portions of the Lillooet River and tributaries, locations to be supplied by the PVDD. This is to determine the inundation extents, depth of flows, velocities and flood durations in the floodplain for the 100, 200 and 500 year return period flow scenarios. This includes, but is not limited to:*

   a) *Testing, calibration and validation of hydraulic models. Models can be open source.*

   b) *Determining the dike breach location that creates the "worst case scenario" resulting in greatest inundation extent, depth of flow, highest velocities and longest flood duration in the flood plain and along the river bank and dike. This is for each of the flow scenarios.*

7) *Developing a series of composite envelope flood hazard maps for each return period that demonstrates the worst case scenario of inundation showing area, water level, velocity, flood duration and dike breach location that could occur at any location along the dikes. This is to include, but not limited to:*

   a) *Producing flood hazard maps for each scenario. Mapping to be compatible with the Federal NEMS management system. (Note: Mapping must be provided to PVDD, Public Safety Canada and the Province of BC once project is completed.)*

b) *Producing a Flood hazard map for the 200 year design flood scenario. This map is intended to become the "designated" floodplain map. (Note: Mapping must be provided to PVDD, Public Safety Canada and the Province of BC once project is completed.) This map to include:*

   i. *the design flood water level profile;*
   ii. *dike crest elevations, dike extents that are vulnerable to overtopping;*
   iii. *flood extent, depths, velocities and flood durations;*
   iv. *flood construction levels (FCL) including freeboard allowance;*
   v. *hydrometric gauge locations;*
   vi. *critical infrastructure and assets (dikes and right of ways, flood boxes and pumping stations, roads, railways, hospitals, airports, municipal buildings, sewers and sanitary and utility buildings, emergency services, etc.) and any other information useful for flood emergency planning and response purposes.*

8) *Develop a rating curve for the gauge located on the Lillooet River 25 km north of Pemberton at the Forestry Bridge in order to determine discharge data from this location and; correlate the discharge data from the Forestry Bridge gauge with the discharge data from the WSC Lillooet River gauge (WSC 08MG005) in order to assist with river behavior forecasting and provide redundancy to improve gauge/data reliability.*

9) *Preparing a report to document all tasks and deliverables including, but not limited to, those listed above. Report must include, but is not limited to a discussion and recommendations on:*

   a) *Climate change impacts and associated hydrologic and hydraulic impacts to Pemberton Valley;*
   b) *Future sedimentation trends;*
   c) *Raw data types, source, dates, accuracy and limitations;*
   d) *Modeling type, methodology, accuracy and limitations;*
   e) *Considerations of future modelling and mapping and updating thereof;*
   f) *Summary of discharge data;*
   g) *Considerations on future emergency response and preparedness;*
   h) *Flood Mitigation Planning.*

Some of the tasks were modified during the project to better suit PVDD's requirements. The design event return periods were changed from 100, 200 and 500 years to 50, 100, and 200 years. PVDD determined that a 50 year scenario was more valuable as flow estimates have significantly increased.

A complete 2D model was used rather than a linked 1D and 2D model. For dike breach modelling, breach locations were chosen based on worst case scenarios for the valley, with a focus on the Lillooet River. In order to show the progression of flooding due to a given breach, breach mapping was presented in series of eight timed snapshots. Also, a video recording of each breach model run is included in the electronic deliverables for the project.

Due to the large extent of flooding occurring during the 200-year flood, the dike extents vulnerable to overtopping were not shown on the 200-year Designated Floodplain Map (i.e. almost all of the dikes are overtopped). However, a critical threshold table was created within the report to show where and at what flow a dike (at its current surveyed elevations) could be expected to start overtopping.

The 200-year Designated Floodplain Map was based on 2D modeling of a 200-year event on the Lillooet River with tributary flow hydrographs adjusted so that the flow at the Lillooet River gauge near Pemberton just reached the 200-year peak magnitude as determined by hydrological analyses. Therefore the 200-year mapping and FCL's are only provided for the lowest reaches of the tributary rivers and streams, where they are located within the Lillooet River floodplain. Additional future work is required to prepare floodplain and hazard mapping for the tributary floodplains and alluvial fan hazard areas.

While it is recognised that extreme flood events from landslide generated outburst floods can occur along the Lillooet River and its tributaries, such events were not specifically dealt with and are considered to be outside the scope of the present work. As per APEGBC, 2017, using a flood magnitude corresponding to the 2,500 year flood would likely be appropriate for modelling an outburst flood on the Lillooet River but was not pursued as part of this project. Emphasis was instead placed on understanding sediment issues and potential impacts on future flood levels and bank erosion as outlined in the Geomorphic Atlas (Appendix B).

1.4 Report Outline

The report contains 9 sections. In addition to the introductory Section 1, Section 2 describes the topographic, bathymetric and data collected during the summer of 2017. The geomorphic review is outlined in Section 3 and the hydrologic analysis is presented in Section 4. Section 5 describes the hydraulic analysis carried out and Section 6 explains the development of flood mapping. Conclusions and recommendations are summarized in Section 7, with references listed in Section 8.

There are 4 appendices. Appendix A describes the vertical datum for the project and the issues with datums in the valley. It outlines how the bathymetric survey data were collected and with what instruments. Also described are dike crest surveys and culvert surveys collected by Highmark. Information about the surveys, as well as the survey data, is included.

Appendix B contains the Geomorphic Atlas which describes the geomorphology of the Lillooet River from Meager Creek down to the mouth of the River. Appendix C contains the profile and cross section comparison for historical sections along the Lillooet River and tributaries.

Appendix D contains the hydraulic profiles for the Lillooet River and tributaries as well as the sensitivity plots developed during the evolvement of the model mesh.

2 TOPOGRAPHIC AND BATHYMETRIC DATA

Key spatial data layers acquired or developed for this project are tabulated in Appendix A.1. These included:

- Orthophoto imagery;
- Lidar topographic data;
- Bathymetric and topographic survey data;
- Locations of flood control structures (dikes);
- Locations of bridges and culverts;
- Land cover and land use data, used to develop surface roughness mapping;
- Administrative boundaries and cadastral boundaries;
- Infrastructure data, such as roads, railways, and other key infrastructure; and
- Highwater mark locations and elevations.

Orthophoto imagery for the study area was captured by the Province in 2016 and was made available to the PVDD. Lidar topographic data, was collected by the Province in 2016 and by McElhanney (for PVDD) in 2009. The 2016 data was primarily used for the project, with the 2009 information only applied to fill data gaps. All other topographic and bathymetric data were surveyed by the NHC-Highmark teams. Land cover and land use data was delineated from the orthophoto imagery. Administrative and cadastral boundaries were available from provincial records, similarly key infrastructure information. Highwater mark locations were provided by PVDD and surveyed by NHC.

2.1 Vertical Datum

Several vertical datums are in use for current and historic data in the Lillooet River study area. These include CGVD2013, the new vertical datum for Canada, and three versions of CGVD28, the previous standard vertical datum for Canada. Vertical datums are described in detail in Appendix A.2. Vertical datums for key datasets used in this project are summarized in Appendix A.1.

The CGVD2013 datum was used for modelling and mapping for this project, for the following reasons:

- Canada has now adopted CGVD2013 as official datum. The province is in the process of migrating to this new datum.
- The 2016 Lidar data was collected in this datum.
- There is uncertainty about the use of the CGVD28 datum in the Pemberton area for previous surveys that used provincial Water Resource Service (WRS) benchmarks that were not readjusted to newer federal benchmarks. Adopting CGVD2013 will avoid future confusion.

2.2 River Bathymetry Surveys

2.2.1 GPS Control Surveys

A static survey style was adopted for the Lillooet River control network. Two base receivers were left to log at either end of the project over the course of one day. Two more roving receivers were used to do short 1.5 hrs occupations. The longer full day occupations were submitted to NRCAN PPP GPS post processing service. The corrected results were inserted into the control network as survey grade start points. Raw observables from the full day static and shorter roving, or fast-static, occupations were uploaded into Trimble Business Center and processed with the dual frequency baseline processor. This achieved centimetre grade accuracy. A network adjustment constrained at either end of the control network, using the full day occupation results, was calculated to tighten control point results. Table 2-1 shows resultant calculated baselines from the control survey occupations. Overall accuracy once the network adjustment was applied was +/- 0.02 m horizontally and =/- 0.02 m vertically.

Table 2-1 Resultant calculated baselines from the control survey occupations

Observation	Solution	H. Prec. (m)	V.Prec. (m)	Elipsoid Dist. (m)	ΔHeight (m)
NHC1778-NHC1979	Fixed	0.004	0.018	20180.044	-21.705
NHC1778-NHC381	Fixed	0.005	0.022	10510.470	-12.572
NHC381-NHC1191	Fixed	0.006	0.010	6248.797	7.939
NHC1204-NHC381	Fixed	0.006	0.012	4926.535	-0.402
NHC1979-NHC1204	Fixed	0.006	0.011	4974.847	9.558
NHC1930-NHC1917	Fixed	0.004	0.019	6405.319	2.946
NHC1778-NHC1191	Fixed	0.005	0.008	4305.135	-4.664
NHC1930-NHC1191	Fixed	0.005	0.009	25564.373	24.926
NHC1930-NHC1204	Fixed	0.004	0.024	16478.455	17.403
NHC1979-NHC1917	Fixed	0.006	0.009	5792.696	-4.906

2.2.2 Bathymetric Surveys

Bathymetric surveys were conducted over a 46 km reach on the Lillooet River starting at Lillooet Lake. Tributaries including: Birkenhead River (12 km), Green River (8 km), Pemberton Creek (2 km), Miller Creek (2.5 km) and Ryan River (14 km) were also surveyed. To achieve an acceptable channel DEM of all these reaches a zigzag pattern was used with 50 m longitudinal spacing. The Ryan River spacing was decreased to 30 m due to its narrow channel width. Historical section locations, as provided by PVDD, were also surveyed along the Lillooet and all tributaries. Background files of the longitudinal spacing, historical sections and LIDAR data channel boundary were used to ensure coverage and efficient data collection. Long profiles, of bed and water surface elevations, paired with acoustic Doppler current profiler (ADCP) discharge measurements were also conducted on each reach. The majority of the surveys were conducted in June and July 2017. Deficiencies and add-ons were surveyed in Sept. 2017.

NHC crews began each day setting up GPS base stations, with long range radios, on control points established during the control survey. Check points were tied in daily to confirm coordinate reliability and geodetic parameters of the survey gear. Once onboard the shallow draft jet boat used for the work, a GPS and sounder patched through a laptop running Hypack 2017 were setup and tested for position, sounding and synchronization reliability. Points generated by independent bed shots were compared to points generated by the bathymetry software. All these comparisons were within +\-0.05 cm. Once QA/QC was completed the rest of the day was spent collecting channel bathymetry for the DEM and historical sections.

The river conditions during June and July 2017 were quite high and fast. This complicated the surveying by boat in certain areas. Moving bed, high turbidity and woody debris conditions in the water column caused the data to be 'noisier' than expected.

Areas not accessible by boat, due to too much woody debris or shallow depths, were waded and surveyed with GPS rovers as ground points. GPS ground surveys were also conducted on important targeted bars, defined by the hydraulic modelling team.

Bridge structure surveys were collected by setting temporary GPS control. A total station was set up on this geodetic control and used to collect bridge deck, low chord and bridge pier locations.

Hypack 2017 Single Beam Editor was used to process the very large amount of bathymetry data collected. Viewed in profile, each bathymetry file was reviewed for outliers, checked for GPS reliability and then finally smoothed over an average of 5 measurements. The smoothing routine was an attempt to address some of the noise inherent in the sounding data. All bathymetry data was exported into time-stamped tabular format, for import into GIS and DEM integration.

All other survey information was compiled in Trimble Business Center software filtered with QA/QC measures and then exported into time-stamped tabular format.

2.2.3 Survey Equipment

The following survey equipment was used:

- Trimble R10 and R8 GNSS RTK GPS rover receivers
- Nikon Nivo 5 total station
- Trimble R10 GNSS RTK GPS base receiver w/ Trimble TDL 450 35 watt radio
- Trimble TSC3 and TSC2 controllers w/ Trimble Access field software
- Trimble Business Center desktop software
- Ohmex Sonarmite 200 kHz sounder sounding at 2 Hz
- Panasonic CF31 Toughbook w/ Intel I5 processor
- Hypack 2017 hydrographic software

2.2.4 Accuracy Considerations

Based on industry standards the following survey accuracies were achieved:

- Trimble R8/R10 GPS RTK receivers - +/-0.05 m
- Ohmex Sonarmite sounder - +/- 0.02 m
- Nikon Nivo Total Station - +/- 0.02 m

Typically, the overall bathymetry survey accuracy is in the order of 10-15 cm for the multi-sensor kinematic (moving collection) setup applied. However, with the challenging river conditions on the Lillooet, specifically during data collection under mobile bed conditions, the accuracy may be as low as +/- 30 cm in some locations. Ground surveys using GPS have a normal accuracy of +/- 0.05 m. Total station surveys, such as of the bridge structures, would also have +/- 0.05 m accuracy.

2.2.5 Coordinate System Details

In summary, specific coordinate system details are:

- Horizontal Datum: Nad83 CSRS 2002
- Projection: UTM Zone 10 North
- Vertical Datum: CGVD 2013
- Geoid Model: CGG2013

2.3 Dike Crest Surveys

To expedite ground surveys, NHC retained Highmark as a subconsultant. Highmark surveyed dike crest centrelines and elevations from August to November 2017. These surveys were conducted using RTK GPS, kinematic post-processed GPS and total station. All surveys were provided to NHC in the selected coordinate system.

Based on provincial mapping of dike locations, the following dikes were surveyed:

Table 2-2 List and description of dikes surveyed for study

Name of Dike	River/Stream	DMA Regulated	Diking Authority	Description
Smuks Dike	Lillooet River	YES	PVDD	0.4 km long - Ties Pemberton Meadows Road to high ground across Salmon Slough
Forestry Road Dike	Lillooet River	YES	PVDD	3.0 km long – Extends from Forest Service Road Bridge to Smuks Dike
Orphaned Pemberton Meadows Berm	Lillooet River	NO		Listed as orphan works, but PVDD maintains
Hungerford Dike	Lillooet River	YES	PVDD	2.5 km long – Downstream extension of Pemberton Meadows Berm – “open” at downstream end
Ryan Dike	Ryan River	YES	PVDD	9.4 km long– Upstream end ties into high ground near quarry. Downstream end ties into Pemberton Meadows Road just south of Erickson Road
Strobl Dike	Ryan River	YES	PVDD	0.6 km long – Upstream end ties into high ground. Downstream end ties into Pemberton Meadows Road
Boneyard Dike	Miller Creek and Ryan River	YES	PVDD	2.7 km long – Upstream end on Ryan River ties into Pemberton Meadows Road. Upstream end on left bank of Miller Ck ties into high ground
Miller-Lillooet Dike	Miller Creek and Lillooet River	YES	PVDD	12 km long - Major dike protecting the highest density development in the Pemberton area. (Part of Village Ring Dike System)
Adventure Ranch Dike	Lillooet River	YES	PVDD	0.2 km long - Highway 99 to Airport Road (Part of Village Ring Dike System)

Name of Dike	River/Stream	DMA Regulated	Diking Authority	Description
Pemberton Creek Dike	Pemberton Creek	YES	PVDD	4.5 km long - connects with Adventure Ranch/Airport Road Dike. (Part of Village Ring Dike System)
Creekside Village Training Berm	Pemberton Creek	YES	PVDD	0.36 km long
Ayers Dike	Lillooet River	YES	PVDD	1.4 km long – includes the "North Arm Plug"
Pemberton Ck Right Bank	Pemberton Creek	NO		0.3 km - Downstream end connects with Airport Road Dike
Airport Road Dike	Lillooet River	NO		0.5 km long - Upstream end connects to Adventure Ranch Dike and is part of Village Ring Dike System. 3 km long - Dike continues on downstream side of Pemberton Creek Confluence.
Nesuch	Lillooet River	NO		7.6 km – Mt Currie First Nation works
Poleyard Dike	Birkenhead River	YES	PVDD	0.7 km long

Note: Names are based on PVDD titles, the names may vary slightly from the provincial dike database (MFLNRO, 2018)

The spatial data deliverables are listed in Appendix A.3. NHC imported survey points and field photo point locations to GIS, and digitized dike centrelines with elevations embedded based on the survey data. GIS files are included in the data deliverables provided with the report.

2.4 Culvert Surveys

For modelling catastrophic flooding (50, 100 and 200 year events) only major openings (underpasses) were included in the hydraulic model. To facilitate future drainage assessments, PVDD requested that an inventory of culverts be prepared, summarizing culvert locations, lengths, diameters and inlet/outlet invert elevations. This work was completed by Highmark and is summarized in Appendix A.1 and provided in the data deliverables.

3 GEOMORPHIC ASSESSMENT

3.1 Overview

Present day geomorphology of the Lillooet River valley has been influenced by landform changes from past periods of geologic and glacial activity and are dominated by post-glacial erosion of the steep mountain slopes and fluvial processes. The mountains ridges rise between 1,500 to 2,000 m above the valley bottom, which originally formed by glacial processes and is covered with a thick layer of alluvium overtop glacial sediment. The Lillooet River is aggrading on a geologic time scale and there is an absence of river terrace features on the valley floor.

The Lillooet River headwaters lie within the Mount Meager volcanic complex, which last erupted approximately 2,400 years ago (Friele, Jakob, and Clague 2008). The steep slopes are relatively unstable, erodible, and prone to landslides. Historically, large landslide events originating from the Mount Meager Complex have occurred numerous times either due to volcanic activity or from collapsed unstable ground. These events have altered the channel morphology and sediment load in lower reaches, and some have been tied to channel impoundments in the upper Lillooet River and pronounced increases in sediment supply rates.

The Lillooet River carries a high sediment yield and the channel is very dynamic. It is important to understand the geomorphic processes because over time these may change the channel morphology, sediment load in the lower river reaches, and capacity for conveyance of flood flows. The Capricorn Creek landslide that occurred on Mount Meager in 2010 is a recent and important geomorphic control, therefore the geomorphic review included an examination of the slide deposit and channel features in the upper Lillooet River and assessment of channel morphology and sedimentation patterns over a distance of 85 kilometers upstream of Lillooet Lake (River Kilometer or RK 85).

Sections 3.2 to 3.7 summarize the geomorphic assessment that was carried out for this project. More detailed information is presented in the Geomorphic Atlas (Appendix B).

3.2 Field Investigations

The majority of the geomorphic field investigations were conducted during the last week of August 2017. Flows at the time fluctuated between approximately 180 and 280 m^3/s with daily variability attributed to snow melt intensity. Field data focussed primarily upon observation and interpretation of landforms and channel features between the Mount Meager slide zone and Lillooet Lake, and sub-surface and surface sediment sampling to map grain size distribution and sediment lithology over 82 km of the channel. Bathymetric surveys described in Section 2.2 were also used to support a comparison of historical cross sections to evaluate channel changes, aggradation rates and bedload transport rates.

An overflight was conducted on 12 October 2017 to collect updated and detailed orthophotos of the river when the flow was relatively low and clear (approximately 36 m^3/s) which provided good visibility of bed forms in the channel. High resolution (approximately 35 cm pixel resolution) orthophotography was collected in the Upper Lillooet River to supplement the physical sampling and for comparison with historical orthophotography to map channel changes.

3.3 Assessment of Sediment Supply Changes Over Time

3.3.1 Mount Meager Slide Deposit

The 2010 Mount Meager landslide deposited approximately 4.9 X 10^7 m^3 of sediment on the valley bottom, near the confluence of Meager Creek and the Lillooet River (Guthrie et al. 2012). The rate of fluvial evacuation of sediment from the deposit was evaluated by comparing a 2010 digital elevation surface model, that was developed from a photogrammetric analysis of satellite imagery just after the slide (5 m resolution GeoEye, dated 22 August and 21 September 2010), with LiDAR data collected in 2015 (provided by John Clague, SFU and Brian Menounos, UNBC). The differences between the two surfaces indicates that 5.0 X 10^6 m^3 of sediment was eroded from the slide deposit. The 2010 DEM and the orthophotos collected by NHC in 2017 were interpreted to estimate a total erosion of 5.9 X 10^6 m^3 of the slide material between the time that the slide occurred and the acquisition date of the 2017 orthophotography.

In a fluvial system the rate of sediment mobilization of a slug of material in a channel decreases over time as the most accessible and mobile deposits are carried away, the channel slope over the slug decreases, the deposits become more stable as the larger lag deposits form an armour layer, and as vegetation becomes established (Nelson and Dubé 2015). Using the grain size distribution data from the sediment samples collected from the Mount Meager slide deposit, a theoretical pattern of exponential decay in sediment yield following landscape-scale disturbances (Nelson and Dubé 2016) was applied to estimate the expected future sediment loading to the Lillooet River. Application of this theoretical approach yields an estimated total erosion of 7.5 X 10^6 m^3 of the slide material, which is 1.6 X 10^6 m^3 more than the estimate derived from the comparison of existing topographic data.

Grain size distribution of the slide deposit samples show 19% +/- 2% silt and clay, 37% +/- 7% sand, 41% +/- 7% gravel and cobble, and 3% +/- 2% boulder. Gravel and cobble sized material will move as bedload and would be expected to have the biggest impact on the reaches immediately downstream of the slide, whereas the sand would rapidly move through the system and travel as far as the diked, lower reach. Silt and clay are not present in appreciable quantities in the river bed, and once eroded these materials move as wash load and are transported to Lillooet Lake and would have little influence on channel geomorphology. Table 3-1 presents the estimated past and future rates of fluvial remobilization of sediment from the slide material, which deposited in Meager Creek and in Lillooet River, extending almost 2.5 km downstream of the confluence.

Table 3-1 Estimates of past, present, and future rates (m^3yr^{-1}) of fluvial remobilization of the slide deposit

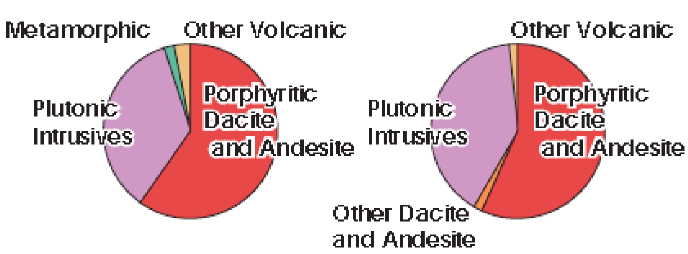
Material Size	Post-slide (2010 – 2015)	Present (2017)	Next Decade (2027)	Future Decade (2037)
Sand	410,000	370,000	300,000	230,000
Gravel	450,000	410,000	320,000	250,000

Note: Post-slide (2010 – 2015) values are based on estimated erosion rates from the surface model comparison. Present and future rates are based on the theoretical pattern of exponential decay in sediment yield.

3.3.2 Sediment Lithology

The lithology of gravel in the 2010 Meager Landslide deposit includes a disproportionate concentration of a distinct porphyritic rhyodacite. Figure 3-1 shows the distribution of lithologies observed from the Mount Meager slide deposits. The relative concentration of this material is used as a 'tracer' to identify slide-derived sediment farther downstream.

Sediment samples collected in 2017 have been compared to samples collected in 2001 (KWL 2001). There is a clear increase in the proportion of volcanic lithology relative to 2001 and the 'tracer' is observed in abundance to RK 55, indicating a substantial volume of coarse sediment (gravel and cobble) from the slide has prograded at least this far downstream. Between RK 45 and RK 25 there is an increased proportion of 'other volcanic' lithologies, which indicates a substantial proportion of coarse sediment in the lower river originated from areas along the north valley wall where this type of rock is exposed. Likely much of this sediment is remobilized from the channel floodplain upstream of the Forest Service Road (FSR) bridge. Downstream of RK 15, the 'tracer' is absent in gravel sized sediment which indicates it has not yet been transported as far downstream as the Highway 99 bridge.



The chart on the left is observed on the Meager Creek fan and the chart on the right is observed on a coarse lag deposit where the river has eroded into the slide deposit, approximately 82 km upstream of Lillooet Lake.

Figure 3-1 Distribution of lithologies observed from the Mount Meager slide deposits.

3.3.3 Sediment Grain Size Distribution

Coarse sand and fine gravel composition of the channel bed material in the Upper Lillooet River has increased substantially between 2001 and 2017. Figure 3-2 presents the grainsize distribution of sediment samples collected along the Lillooet River in 2001 and 2017, between RK 27.7 and RK 64.6. All of the samples other than RK 27.7 show a marked increase in the composition of gravel and sand, which suggests that the main 'slug' of sand and gravel has not yet reached the depositional reach downstream of the Ryan River.

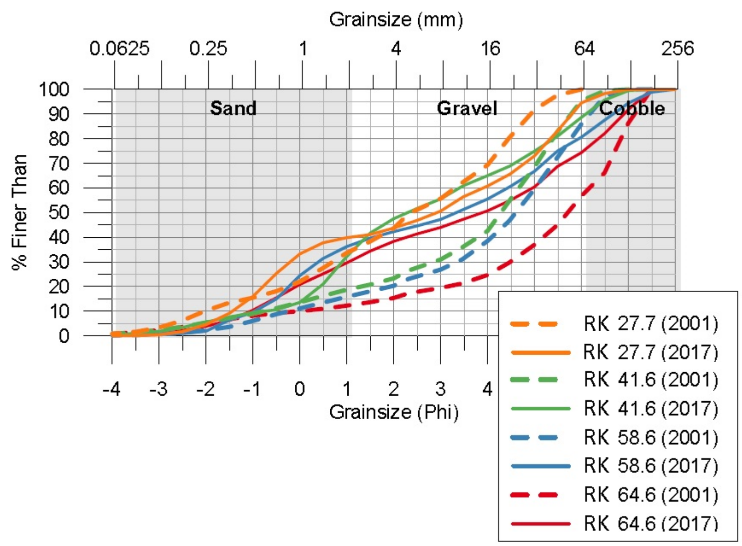


Figure 3-2 Grainsize distribution

3.4 Assessment of Channel Morphology

Channel morphology is the study of the channel planform, cross-section, and longitudinal profile to understand the relationship between the spatial and temporal channel form and channel processes. Over time, the morphology of Lillooet River is changing in response to natural changes in the flow and sediment regime, as well as substantial channel alterations that occurred in the mid-1940s to straighten the channel and lower the outlet elevation of Lillooet Lake. Geomorphic responses including bed degradation and channel narrowing started immediately following the channel alteration and continued for several decades.

Weatherly and Jakob (2014) describe that 38 km of dykes were constructed, the river was straightened and shortened by 4.9 km and the outlet of Lillooet Lake was lowered by 2.5 m during the late 1940s and early 1950s. The further describe channel degradation of between 3 m to 4 m in the channel reaches upstream of the 'cut' and up to 2 m in the reaches downstream over the period 1945 to 1969, and a 50% reduction in the average channel width between 1947 and 1994. Figure 3-3 shows a plan view of the Lillooet River valley bottom along the most prominent straightened channel reach known as the McKenzie Cut. The former path of the Lillooet River is visible on the floodplain.

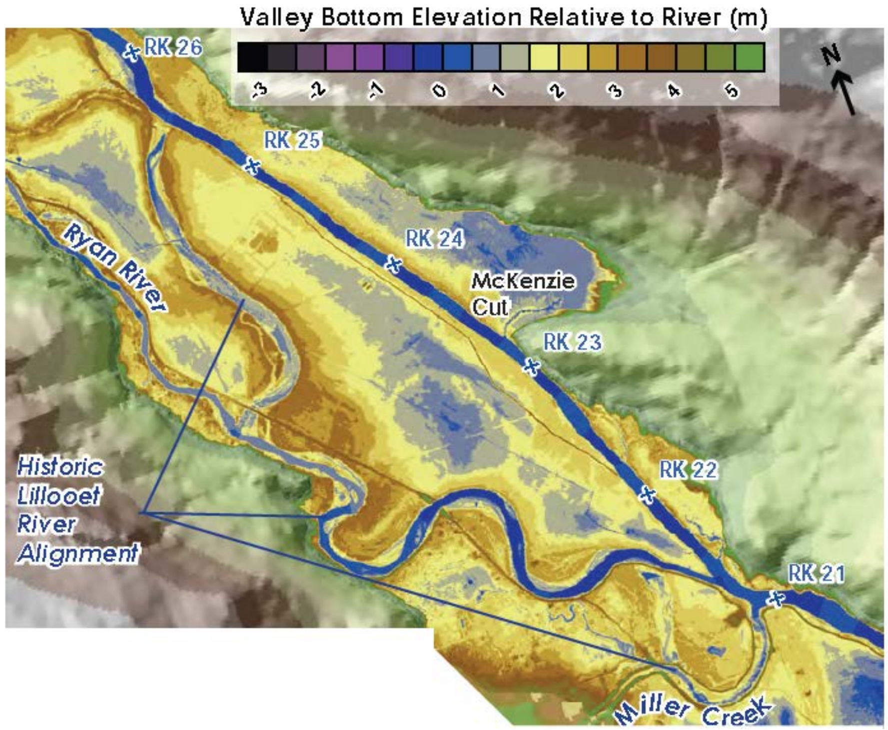


Figure 3-3 Lillooet River valley bottom, showing the McKenzie cut-off and former river alignment.

3.4.1 Observed Channel Change in the Upper Lillooet River

Lateral channel migration and vertical incision is actively recruiting sediment from the 2010 Meager Creek landslide deposit, both directly from the bed and banks and through mass failures of the slide material. Large volumes of coarse sediment have been introduced to the downstream braided reach that extends between RK 78 and RK 54, and substantial volumes of sand have been transported farther downstream.

Upstream of RK 71, the effects of proximal sedimentation since the 2010 Mt. Meager slide have had considerable and extensive channel impacts. These include growth of active channel bars that protrude up to 1 m above the surrounding floodplain, lateral channel instability and widening, loss of vegetated islands and die off of large areas of the riparian forest (compared with air photos from 2013), which is caused by higher water levels associated with channel aggradation. Large pockets of sand are being temporarily stored within the braid plain.

The effects of coarse sediment accumulation are evident downstream of RK 70, although a declining intensity of floodplain tree kill suggests aggradation is less extensive compared to the channel zone farther upstream. Substantial channel widening is evident and a large number of forested islands have been eroded, which suggests the leading edge of the coarse sediment 'slug' has passed through this reach. Depositional lobes of sediment, large accumulations of wood debris, and channel shifting within the braided floodplain occur upstream of RK 55 and there is a lack of characteristic impacts farther downstream. This suggests that the location of the leading edge of the coarse sediment 'slug' is near RK 55.

3.4.2 At-a-Station Change in Bed Elevation

Because channel bed changes cause a corresponding change in water level, long term data records at gauging stations or channel monitoring locations can be used to quantify change over time at that particular location in the channel (i.e. at-a-station change). Historical cross sections at RK 34 are presented in Figure 3-4 to illustrate how the channel bed changed since 1945. Compared with the 1945 data (transposed from Weatherly and Jakob 2014), the 2000 and 2011 channel bed is generally lower by 2 m to 3 m, although there is little difference between the 2000 and 2011 bed. Since 2011 the bed has aggraded up to 2 m.

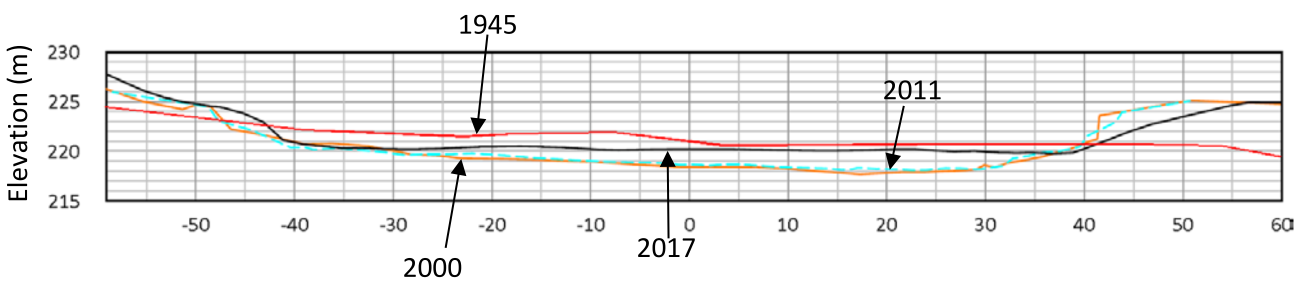


Figure 3-4 Historical Cross Sections at RK 34.

Stage-discharge analysis is a useful indicator of bed level trends on the Lillooet River because the WSC gauge has been in-place since 1914 at a location with relatively stable banks, Water level (stage) at the WSC gauge has varied in a complex manner over the last several decades (Figure 3-5). However, it appears that a relatively stable stage-discharge relation existed from 2000 to 2010, suggesting the channel was approaching equilibrium. Since the 2010 landslide event, the specific gauge values are trending upwards. Figure 3-6 shows stage during a 100 m^3/s flow at the WSC gauge, between 1914 and 2018. Prior to the onset of channel modifications, bed aggradation occurred at a rate of approximately 0.015 m per year. The channel rapidly degraded by over 0.5 m in the first few years following the channel modifications then degraded by between 0.021 to 0.028 m per year over the next five or six decades before levelling off in the early 2000s. Since the 2010 landslide the channel has aggraded at a rate of 0.04 m per year.

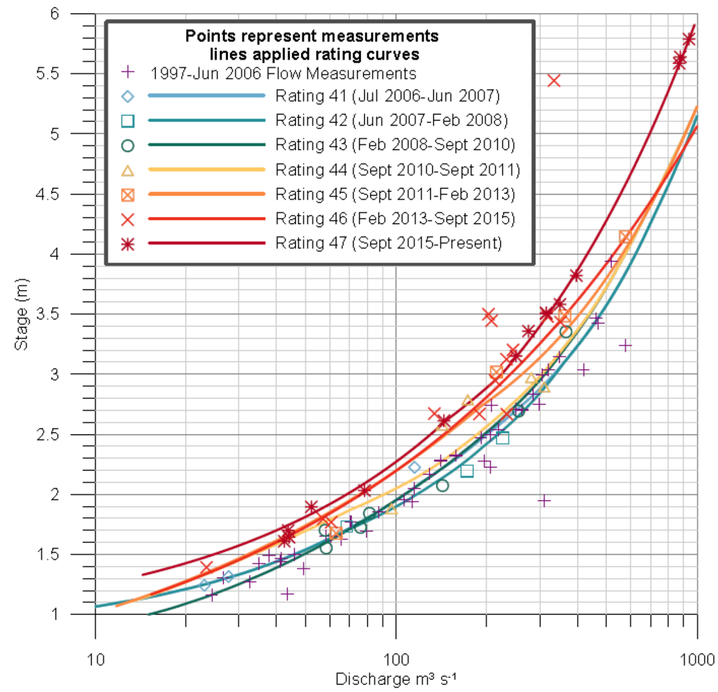
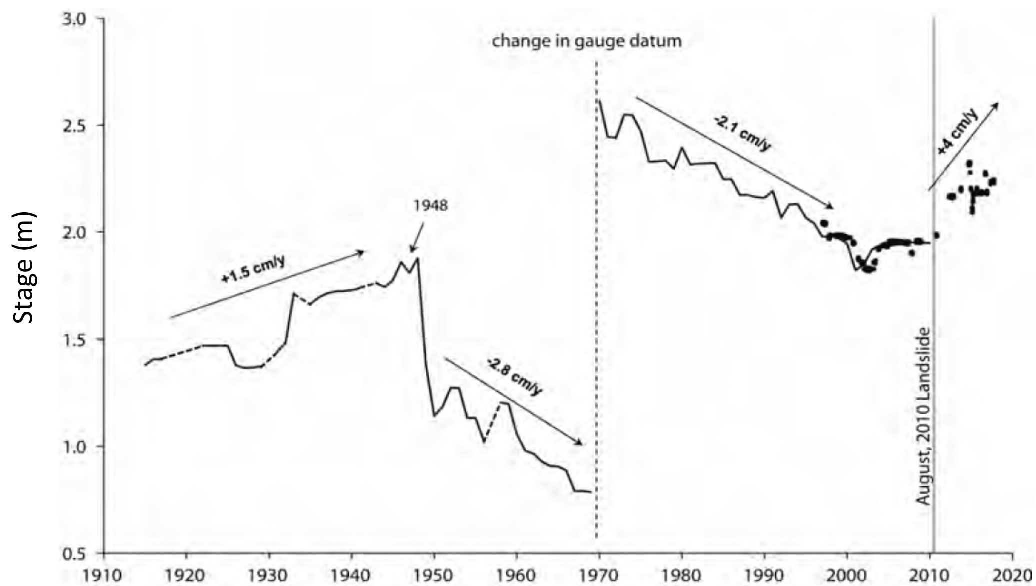


Figure 3-5 Rating curves from specific gauge analysis for Lillooet River WSC station 08MG005



Note: River stage (m) at 100 m^3/s between 1914 and 2018 (after Weatherly and Jakob 2014). Data since 2009 was appended by NHC.

Figure 3-6 Specific gauge analysis for Lillooet River WSC station 08MG005

3.4.3 Longitudinal Change in Channel Bed Elevation

Average bed elevation is a useful measure to show the effects of sediment aggradation in a channel, and is computed by integrating the cross section bed elevations to include the deepest parts of the channel, the top of exposed gravel bars, and all other inflection points within the active channel boundary. Average bed elevations were computed using cross section survey data from 2000, 2011, and 2017. Figure 3-7 shows the average channel bed elevation over the entire reach has increased an average of about 0.4 m since 2011. In the reach between the CN Rail Bridge and WSC Gauge the bed is increasing in the order of 0.07 m/year, with more substantial increases at localized accumulation zones. This amounts to an increase in average bed elevation of about 0.5 m by 2025. More substantial bed height increases (as much as 1.2 m) have occurred in the reach that extends upstream of the Ryan River confluence to RK 35, which has resulted in a steepening of the channel gradient.

The effects observed to date in the diked reach (downstream of RK 30) represent the initial response of the channel due to the arrival of the fine gravel and sand component of the sediment slug. The impacts from the coarse fraction of the sediment load will become increasingly apparent over the next several decades.

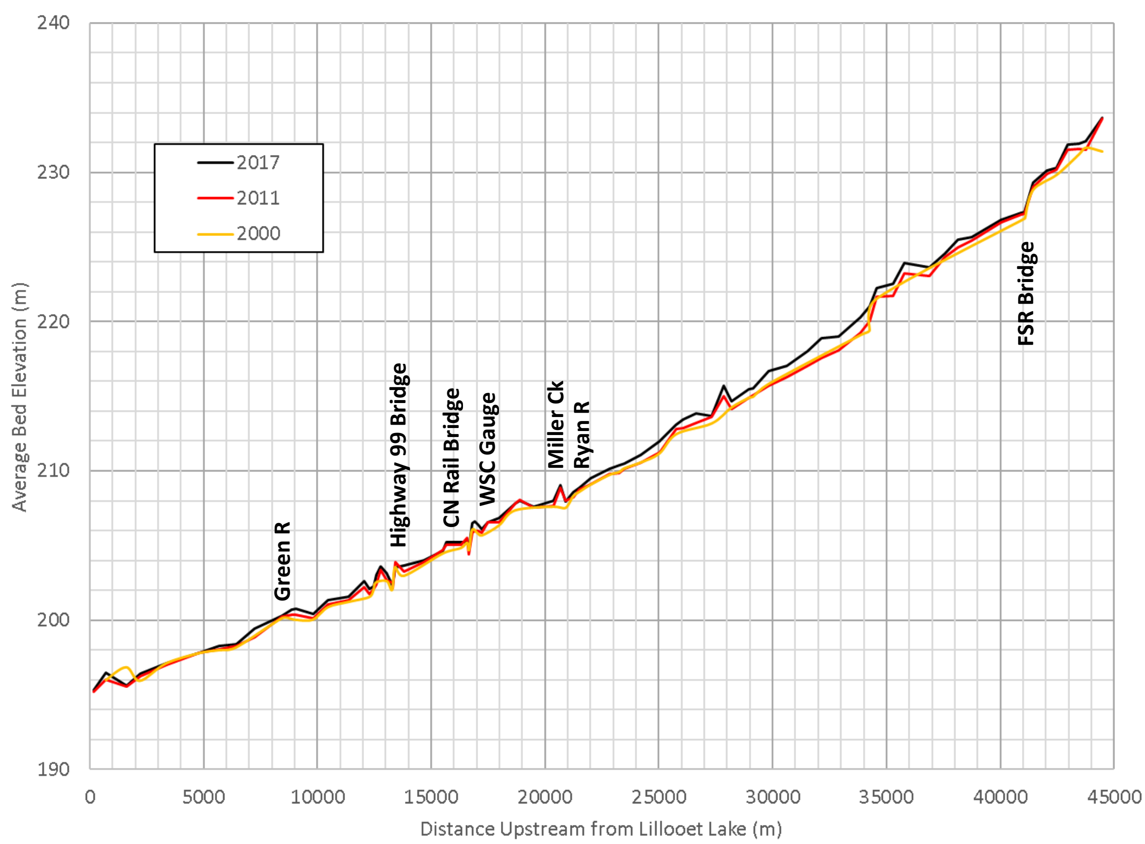


Figure 3-7 Longitudinal plot of Lillooet River average bed elevation for 2000, 2011, and 2017

3.5 Updated Sediment Budget

3.5.1 Cross Section Comparison

Eighty four cross sections were surveyed between Lillooet Lake and RK 44 in 2011 to update the survey that was completed in 2000 and to provide a 'baseline' for evaluating future channel changes from post-landslide sedimentation. In 2017, the channel was surveyed in more detail so that an elevation model of the channel could be developed. Cross section data from the 2017 elevation model were extracted at each cross section, and the end-area volume of the change in cross sectional area at each section for 2000, 2011, and 2017 was computed. Cross section plots are provided in Appendix C.

Figure 3-8 shows the cumulative aggradation along the Lillooet River between the Green River confluence and RK 35. The volumetric approach used for estimating sediment yield has considerable uncertainty (+/-50%), however, there is a clear trend toward a substantial increase in sedimentation rates since 2011. The estimated cumulative aggradation rate has increased from about 40,000 m^3/year between 2000 and 2011 to 170,000 m^3/year between 2011 and 2017. Assuming bed material is not carried downstream of the Green River confluence and accounting for sediment removals within this period, the bed material transport rate is estimated to be approximately 180,000 m^3/year, which is more than a fourfold increase.

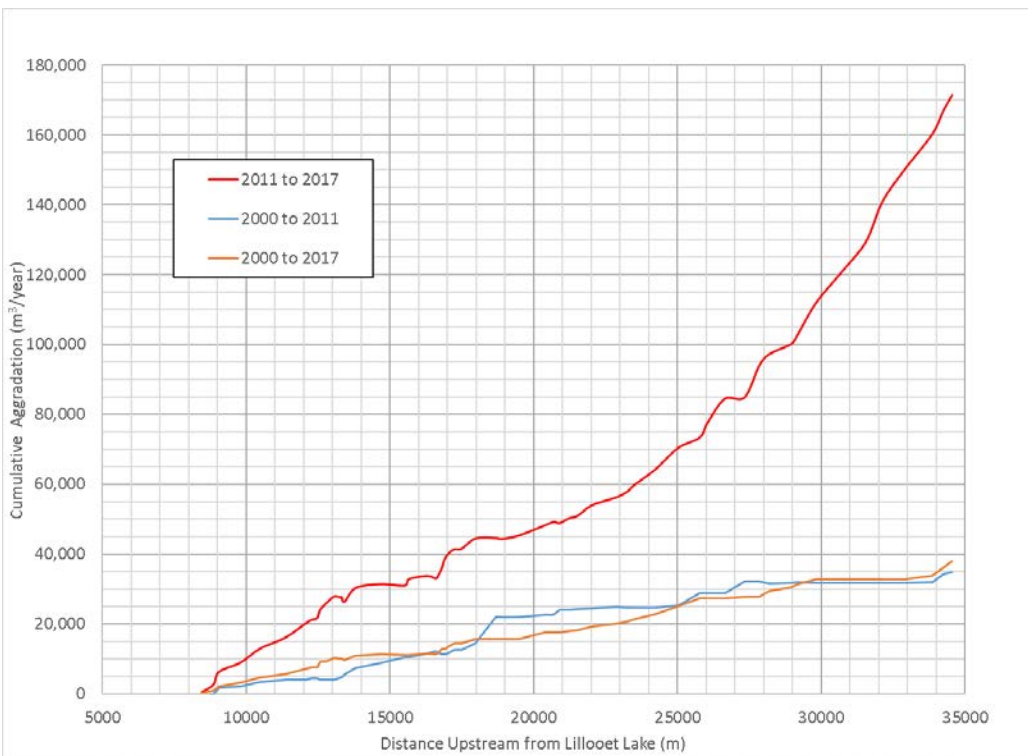


Figure 3-8 Cumulative aggradation based on analysis of cross section's from 2000, 2011, & 2017

3.5.2 Conceptual Sediment Budget Since the 2010 Landslide

A conceptual sediment budget can be used to understand the primary system components and includes sediment sources, the pathways by which sediment is delivered, and storage elements where sediment is deposited. Sediment storage occurs at many time scales, and can last a matter of days or months for sediment that is stored within the active channel, or decades to centuries for sediment that is deposited on the floodplain and remains in-situ until it is remobilized by bank erosion. Tributaries that join the channel will introduce water and sediment to the system.

Ryan River and Miller Creek join the Lillooet River near RK 21, adding approximately 30% to the contributing catchment area. The Upper Ryan River is steep and carries a high sediment load, and has a stepped longitudinal profile that is characteristic of rivers flowing through glacially-sculpted landscapes. Approximately 15 km upstream of its confluence with the Lillooet River the Ryan River flows into the Lillooet River floodplain and its slope is reduced from approximately 5% to 0.1%. Much of the cobble and gravel load is deposited in this reach. Bed material in the lowest reach of the Ryan River is dominated by highly embedded gravel finer than about 45 mm, which suggests the Ryan River is not likely a substantial source of gravel to the Lillooet River.

The average annual bedload of Miller Creek is estimated to be approximately 6,500 m^3/year, which is about 4% of the estimated bedload being delivered from the Upper Lillooet River. Miller Creek flows across an alluvial fan about 3 km upstream of its confluence with the Lillooet River, and its slope drops from about 10% to 0.2% over a distance of a few kilometers. The basin is susceptible to debris flood events that can suddenly release tens of thousands of cubic metres of material to the fan, and could result in a sediment load that is much higher than average. A debris flow basin and sediment trap was constructed approximately 2.2 km upstream of the confluence and is regularly maintained, however, sediment removals occasionally occur near Pemberton Meadows Bridge, approximately 1 km upstream of the confluence, in response to high flow events that fill in the sediment trap and carry sediment farther downstream.

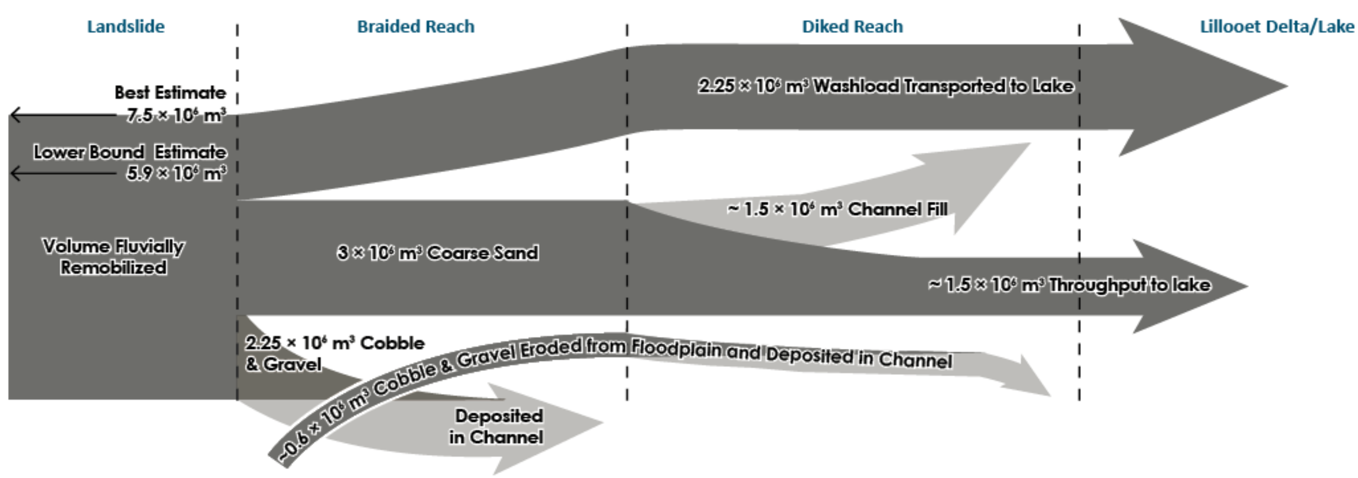


Figure 3-9 presents a conceptual sediment budget for the period between the 2010 landslide and September 2017 when the channel surveys were completed, and illustrates key sediment exchanges interpreted from available evidence. As described in Section 3.3.1, the best estimate total volume of fluvially remobilized sediment is based on a theoretical exponential decay in the rate of erosion of the slide material and the lower bound estimate is based on the comparison of the post-slide and 2015 surface models and estimated bank erosion volumes between 2015 and 2017. Estimates are subject to substantial uncertainty (ranging from +/- 20% for the best constrained to order-of-magnitude for the least constrained), however, the figure provides a visual means of understanding the general movement pattern of sediment that is being remobilized from the 2010 slide deposit. Of the total sediment being eroded from the slide, approximately 30% of this material is carried in suspension as washload and transported through the system to Lillooet Lake and has little geomorphic effect on the river.

About 40% of the material is coarse sand and granules, half of which is likely being transported to the lake and half of which is depositing in the lower 40 km of the river. The introduction of the sand fraction of the slide material has dramatically reduced the grain size distribution of the bed material throughout the braided reach. This has increased the mobility of the bed material, which in turn has increased lateral migration rate and channel width. Increasing instability in the braided reach (e.g. bank erosion) may contribute in the order of 10% of additional material to the system, which is then transported and deposited farther downstream in the channel.

The remaining 30% of the material is moving more slowly through the system as 'slug' of material. This material moves through the system as bedload and is working its way through the braided reach upstream of the FSR Bridge. Geomorphic changes associated with the coarse sediment slug are described in more detail in Section 3.4.1.

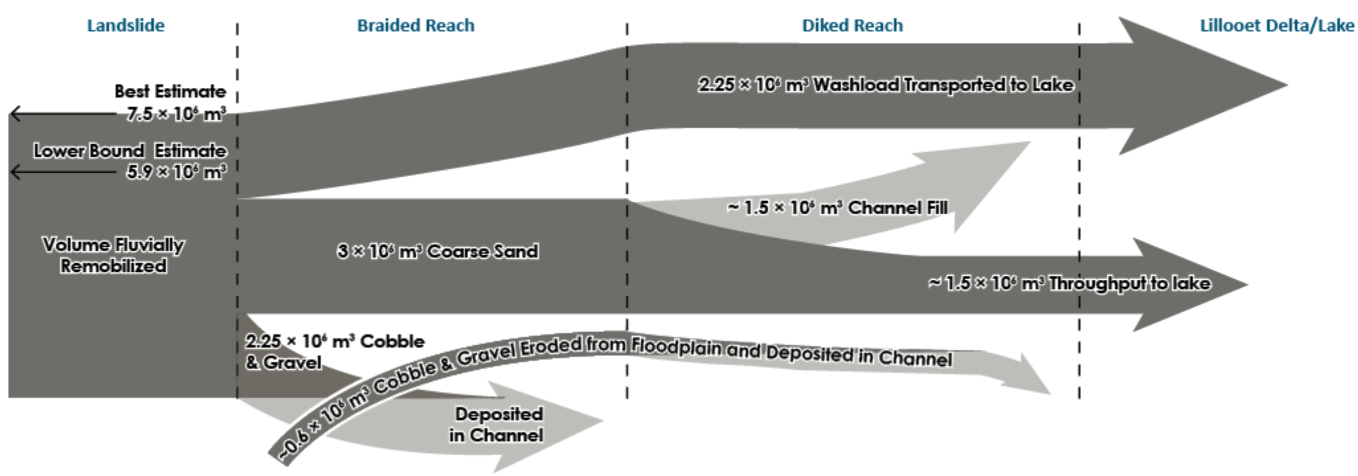


Figure 3-9 Conceptual sediment budget for the period between the 2010 landslide and June 2017.

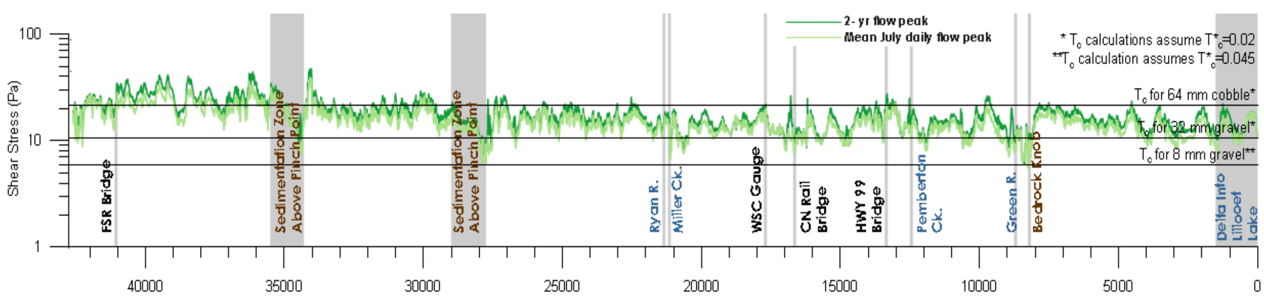
3.6 Sediment Transport

Bedload sediment transport depends, fundamentally, on the relationship between the grain size distribution of the bed material and hydraulic force applied by the flow. Upstream of the FSR Bridge, the Lillooet River has become finer grained but the channel has widened. Higher concentrations of sand in the channel bed reduces the critical shear stress required to move the larger sized material. Conversely, wider channels will generally be shallower which will reduce the hydraulic force applied to the channel bed.

Sediment transport calculations were completed to illustrate the magnitude of change in sediment transport rate based on the change in grain size distribution between 2000 and 2017. Assuming static hydraulic conditions for both years and applying the grain size distribution for each year, the computed gravel transport rate is several orders of magnitude higher for the 2017 grain size distribution. Calculations were also carried out to assess changes in channel width, keeping grain size static and the results show an order of magnitude reduction in transport rates. The key finding is that sediment from the landslide deposit has increased the fine sediment composition of the bed material, which will substantially increase the transport rate of gravel-sized sediment into the diked reach of the river.

Shear stress was computed, using the 2-D model NHC developed for this project, for a mean July daily peak flow and a 2-year peak flow to illustrate the potential for sediment mobilization under typical conditions.

Figure 3-10 shows sediment up to and including cobble sizes is capable of being moved through the Upper Lillooet River into the depositional reach, downstream of Ryan River and Miller Creek confluences, and very coarse gravel (>32 mm) is capable of moving through the depositional reach where it will start to accumulate in the channel. Medium gravel (> 8mm) is capable of being moved all the way to the lake. Computed shear stress falls below the critical threshold at a few locations, notably around RK 35 and RK 28, which are localized sediment accumulation zones located upstream of channel constrictions. Flows that increase above the 2-yr level will remobilize a portion of the material that was deposited on the bed and on bars.



Note: Tc is the threshold shear stress necessary to initiate mobilization of bed sediment. Shear stress values that lie above the Tc indicate where sediment will become mobile and values that lie below will become immobile

Figure 3-10 Shear stress plot for 2-yr peak and mean July daily peak flows.

Academic studies have examined the movement of sediment slugs in the Nooksack River, WA, USA (Anderson and Konrad 2016 and USGS 2018) and have established a relationship between the sediment wave in that system and the channel gradient. Although the exact relation is expected to vary between different rivers, there may be similarities with the Lillooet River because they have a similar size and physiographic setting. Based on the rate of progress of the sediment slug on the Lillooet River and applying the relationship developed for the Nooksack River, the sediment wave is predicted to reach the FSR Bridge sometime around 2023 and would reach the WSC gauge in two decades.

3.7 Effect of Sedimentation on Flood Levels

Sediment supply from the 2010 Meager Creek landslide will decrease over time but 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 substantial increase in the concentration of sand in the channel has reduced the flow force required to move the larger fraction of the channel bed, which will decrease the stability of the channel bed.

Sediment accumulation observed in the diked reach below RK 30 represents the initial response of the channel to the increased sediment supply. The impacts from the coarse fraction of the sediment load will become more apparent over the next few decades as it works its way through the system and continues to cause channel changes in the braided reach upstream of the FSR bridge and as sediment continues to accumulate in the dike reaches. The precise nature, location, and type of impacts from the altered sediment regime are hard to predict, however, it is anticipated that it will have a direct impact on the flood conveyance capacity of the channel. Localized increases in channel velocity and scour potential are also anticipated as material builds up at gravel bars and other depositional zones. These changes will increase the potential for dike overtopping and failure of dike armour.

Based on the present rate of infilling, the reach upstream of the Highway 99 bridge could infill up to 0.5 m by 2025. The effects of sedimentation on flood levels were assessed by artificially increasing the bed height of the channel in the 2-D numerical model that was developed for the project and running the model for the 200-year flow condition to determine the impact on water level. The 'sample' reach included a 1 km long section of the channel extended upstream from the Highway 99 bridge. The entire channel bed was increased by 0.5 m and each end of the artificially raised bed was gradually tapered to match the pre-existing channel bed. The model computed a corresponding 0.3 m increase in water level. The simulation indicates that future sedimentation will have a substantial impact on flood levels, and without a substantial sediment management program in place aggradation of the channel bed will reduce the effectiveness of the dikes.

4 HYDROLOGIC ANALYSIS

The hydrology of the BC Coast Mountains is complex, both in terms of annual water cycle and the processes that generate peak flows. The BC Coast Mountains experience heavy winter precipitation, primarily in the form of mid-latitude frontal storms, which bring rain to lower elevations and snow to higher elevations. Additionally, atmospheric river storms can bring extremely heavy rainfall, high winds, and warm temperatures across all elevations; these storms can cause large scale rain-on-snow flooding along the west coast of North America (Neiman et al., 2008; Spry et al., 2014).

Depending on elevation, latitude, aspect, and glacierization, watersheds in the BC Coast Mountains can be typified as snow dominant, rainfall dominant, rain-snow hybrid, snow-glacier, or rain-snow-glacier hybrid (Eaton and Moore, 2010). Watersheds in this region may even change their type from year to year. Fleming Et al. (2007a) found evidence of all of these watershed types within the Georgia Basin, and found that watersheds could switch their dominant runoff generation processes between years, depending on short (e.g. El Niño Southern Oscillation), medium (e.g. Pacific Decadal Oscillation) and long term (e.g. climate change) climate variabilities.

The hydrology of the region surrounding Pemberton is typical of the eastern side of the BC Coast Mountains. Obedkoff (2003) considered the Eastern Coast Mountains, from the central coast of BC (south of Bella Coola) to the BC-Washington border, as one contiguous hydroclimatic region. As opposed to the watersheds on the western edge of the coast mountains, eastern watersheds are typified by a relatively greater influence of snow fall and snow melt due to higher elevation and somewhat cooler temperatures, and less rainfall both due to the cooler temperatures and some terrain shading effects. These watersheds can be heavily glacierized, as is the case in the upper headwaters of the Lillooet River. Most of the major icefields of the BC Coast Mountains are located in Obedkoff's Eastern Coast Mountain region.

Though Eastern Coast Mountain watersheds, and the watersheds surrounding Pemberton, BC, have an annual runoff cycle that is primarily dominated by snowmelt, peak flows can still be generated by multiple processes and at multiple times of year, including heavy fall rainfall, rain-on-snow flooding (either in the fall or in the spring during the freshet), and by purely snow melt during rapid warming. Glacier coverage complicates this further, adding the potential for peak flows in the late summer, when heavy rainfall occurs on exposed glacier ice. This is the case of the August 1991 flood, which is the flood of record in many watersheds in the region surrounding Whistler, BC.

That peak flows can be caused by many different processes, can vary based on climate modes at multiple scales, and vary widely from watershed to watershed, makes estimation of flood return periods difficult, even when long flow records exist. The statistical assumption underlying flood frequency analysis is that the peak flow series can be represented by a single distribution. The hydrologist then chooses which distribution (e.g. Gumbel, generalized extreme value, log-Pearson type III, etc.) best fits the observation data. However, when floods are generated by multiple different physical processes, this assumption is violated. It would be more appropriate to assume that each type of flood generation processes is part of its own separate distribution, and fit each one separately. However, due to the rarity of some types of flood processes (e.g. the rain on glacier flood), there is rarely enough data to do this.

Mixed distributions, using parameters from two different groups, are also a possibility. Waylen and Woo (1982) used a mixed-Gumbel distribution, where the parameters of two separate fits (fall/winter floods and spring/summer floods) are used to represent the flood frequency distribution. However, this is likely only appropriate when the two flood types are fairly evenly distributed.

Keeping in mind these potential issues, we performed a regional flood frequency analysis for the 15 gauged WSC watersheds in the Eastern Coast Mountain region from Obedkoff (2003), along with the unlisted (by Obedkoff) watersheds on the Lillooet River: 08MG003 – Green River, 08MG025 – Pemberton Creek, 08MG026 – Fitzimmons Creek and those watershed nearby Pemberton, BC: 08GA072 – Millar Creek, 08ME027 – Hurley River, and 08GA071 – Elaho River. We used these 20 watersheds to create regional curves for the required design return periods. A map showing the spatial extent of the watersheds used in the regional analysis is shown in Figure 4-1 and watershed summary information is shown in Table 4-1.

4.1 Gauged Site Analysis

4.1.1 Trend Analysis

A positive or negative trend in a peak flow series can be evidence of changing of the dominant flood generation process over time. We first investigated both the potential for trends in the peak flow series and changes in flood generation processes visually. Figure 4-2 shows the time series of all observed instantaneous annual peak flows for all of the regional WSC gauges. These series are colored by their season of occurrence, split as in Waylen and Woo (1982), where September – March is considered Fall/Winter, and April – August is considered Spring/Summer. While quite simple, this illustrates how flood generation processes may be changing over time on a range of watersheds. The reader should particularly note the panel for the Lillooet River at Pemberton, the primary gauge of interest to this study. This watershed experienced all (at least when data was available) peak flows in the Spring/Summer prior to 1975. It is presumed that these peaks were driven primarily by snowmelt during the spring freshet. Post-1975, more peak flows have been generated during the winter months, and typically these have been higher peaks. We can presume that these winter peak flows have been primarily caused by major rain-on-snow floods, which cause most of the largest fall and winter floods in the BC Coast Mountains. Note that this assumption is not always true; the 1991 flood, a rain-on-glacier flood, occurred on August 31, and hence is classified into the Spring/Summer category.

Years 1975/1976 is generally considered to be a turning point in the Pacific Decadal Oscillation (PDO), a medium term climate oscillation that affects hydrology along the Georgia Basin, from the ‘cold phase’ to the ‘warm phase’ (Fleming et al., 2007b). Thus, it is possible that the PDO shift moved the peak flow regime of the Lillooet River near Pemberton from a strictly snow dominant regime to a more hybrid rain-snow regime. Fleming et al (2007b) state that this warm PDO phase continued until at least 1998. However, we do not notice a shift back towards only snow dominant flood events after 1998. It is possible that more recent PDO shifts are negated by the underlying recent warming trend for the Lillooet River. The peak flow regime from 1975 to the present appears to be a relatively constant hybrid rain/snow regime.

Along with visually examining the peak flow records, we performed a formal statistical trend test. We did this for two reasons. First, fitting flood distributions depends on the assumption of stationarity within a peak flow series. If a dataset has a trend, either positive or negative, unexpected results can occur. Despite the cautionary notes in the previous section of other assumptions about the peak flow series, it is still prudent to formally check a peak flow series for the presence of a trend (either positive or negative). Second, EGBC (2018) recommends that design flows be increased with a 20% safety factor to account for climate change when an increasing trend is found in the observation series. When a trend is not found, a 10% increase is recommended.

We performed the non-parametric Mann-Kendall trend test on peak flow data from each of the regional watersheds. The Mann-Kendall τ statistic indicates whether a series has a positive or negative trend, and the P value indicates the significance level. We considered a significance value < 0.05 to be a notable result. The results of the test are listed in Table 4-1. Based on this test, two gauges were found with a significant positive trend, and two were found with a significant negative trend. Both stations with negative trends (Atnarko River and Bella Coola River) were removed from the regional analysis, along with the positive trending Klinaklini River.

The second station with a positive trend was the Lillooet River near Pemberton. As this gauge is the primary gauge in the floodplain study model domain, we could not remove it from the analysis. Instead, we tested the effect of only using the post-1975 data (after the expected PDO shift) for our flood frequency analysis. A Mann-Kendall trend test on this post-1975 data did not show a statistically significant trend ($\tau = 0.119$, $P = 0.313$). This result supports the idea that, even after shifting away from the PDO warm phase in the years around 1998 to 2000, the Lillooet river has remained as a hybrid rain/snow peak flow regime watershed from 1975 up to the present day. We used this post-1975 Lillooet River dataset for all the flood frequency analysis moving forward with the assumption that removing the pre-1975 data would result in estimates that are more representative of the modern peak flow regime of the Lillooet River at Pemberton.

We used only observed instantaneous peaks for the regional gauge analysis. Though peaking factors have often been used to extend peak flow records (based on ratios from peak daily to peak instantaneous) the ratio is likely to vary between flood generation processes (summer melt or winter rain-on-snow). Thus, we deemed it most appropriate to only use actual instantaneous observations in the regional flood frequency analysis.

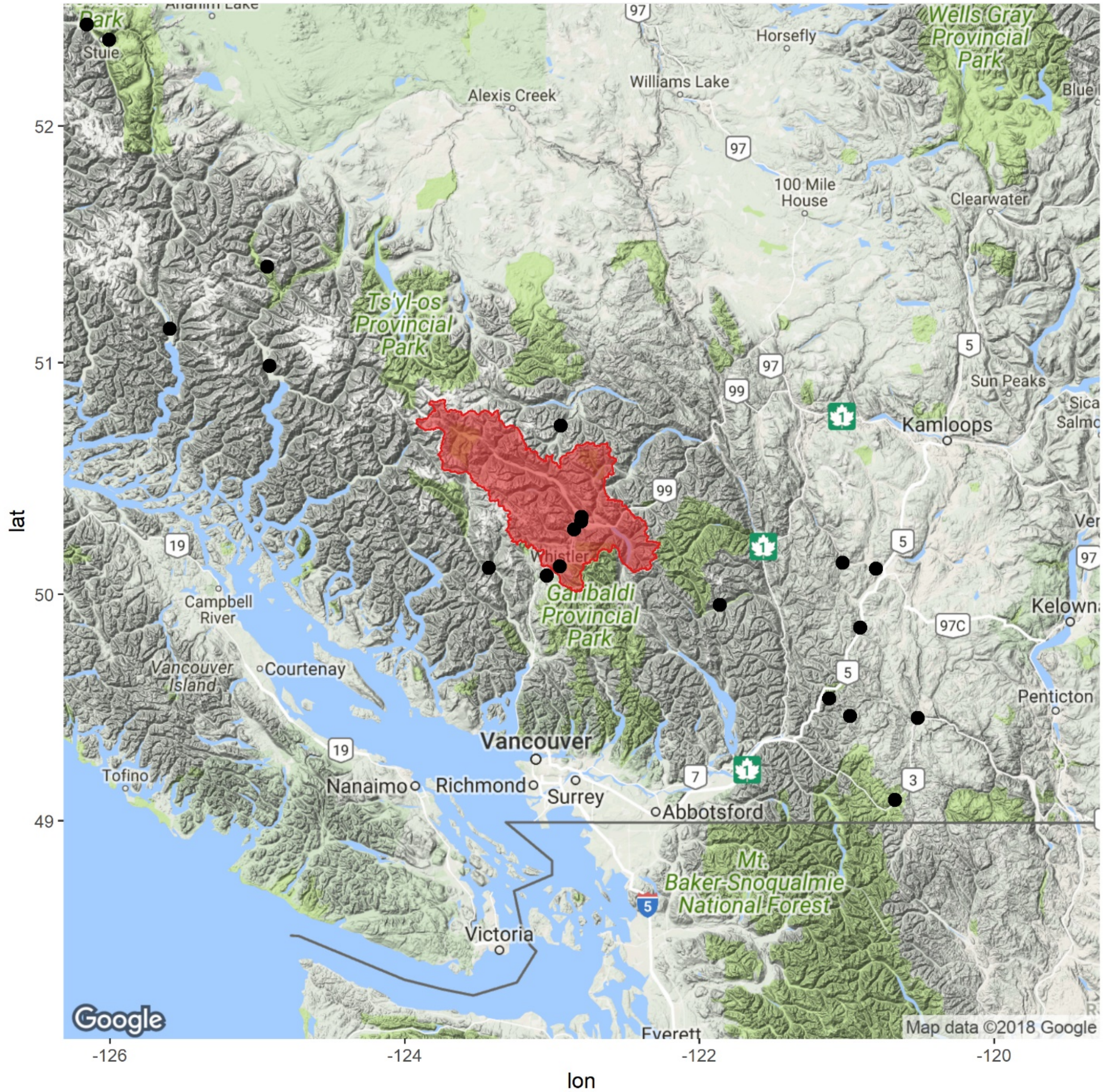


Figure 4-1 WSC stations and study watershed used in the regional peak flow analysis

Table 4-1 Summary information and results for WSC gauges used in regional peak flow analysis

Name	WSC ID	Area (km^2)	Record length (yr)	M-K τ	M-K P
ATNARKO RIVER NEAR THE MOUTH	**08FB006**	**2550**	46	**-0.250**	**0.015**
BELLA COOLA RIVER ABOVE BURNT BRIDGE CREEK	**08FB007**	**3720**	44	**-0.215**	**0.041**
CHEAKAMUS RIVER ABOVE MILLAR CREEK	08GA072	297	33	-0.080	0.525
COLDWATER RIVER AT MERRITT	08LG010	917	10	-0.244	0.371
COLDWATER RIVER NEAR BROOKMERE	08LG048	316	48	-0.012	0.915
COQUIHALLA RIVER BELOW NEEDLE CREEK	08MF062	86	40	0.183	0.098
ELAHO RIVER NEAR THE MOUTH	08GA071	1200	32	-0.099	0.436
FITZSIMMONS CREEK BELOW BLACKCOMB CREEK	08MG026	90	14	-0.100	0.660
GREEN RIVER NEAR PEMBERTON	08MG003	855	19	-0.041	0.833
HOMATHKO RIVER AT THE MOUTH	08GD004	5680	57	0.104	0.259
HURLEY RIVER BELOW LONE GOAT CREEK	08ME027	312	20	0.242	0.144
KLINAKLINI RIVER EAST CHANNEL (MAIN) NEAR THE MOUTH	**08GE002**	**5780**	35	**0.457**	**0.000**
LILLOOET RIVER NEAR PEMBERTON	**08MG005**	**2100**	57	**0.212**	**0.020**
MOSLEY CREEK NEAR DUMBELL LAKE	08GD007	1550	19	-0.070	0.700
NAHATLATCH RIVER BELOW TACHEWANA CREEK	08MF065	712	36	-0.026	0.834
PEMBERTON CREEK NEAR PEMBERTON	08MG025	32	18	0.341	0.053
SIMILKAMEEN RIVER ABOVE GOODFELLOW CREEK	08NL070	408	37	-0.122	0.295
SPIUS CREEK NEAR CANFORD	08LG008	775	38	0.117	0.308
TULAMEEN RIVER AT PRINCETON	08NL024	1780	38	-0.028	0.811
TULAMEEN RIVER BELOW VUICH CREEK	08NL071	253	38	-0.102	0.372

Note: Mann-Kendall (M-K) trend test results are shown in right column. Stations in bold indicate significant trends at 95% confidence level ($P < 0.05$), either in the positive ($\tau > 0$) or negative ($\tau < 0$) direction. Length of the instantaneous peak flow record is shown.

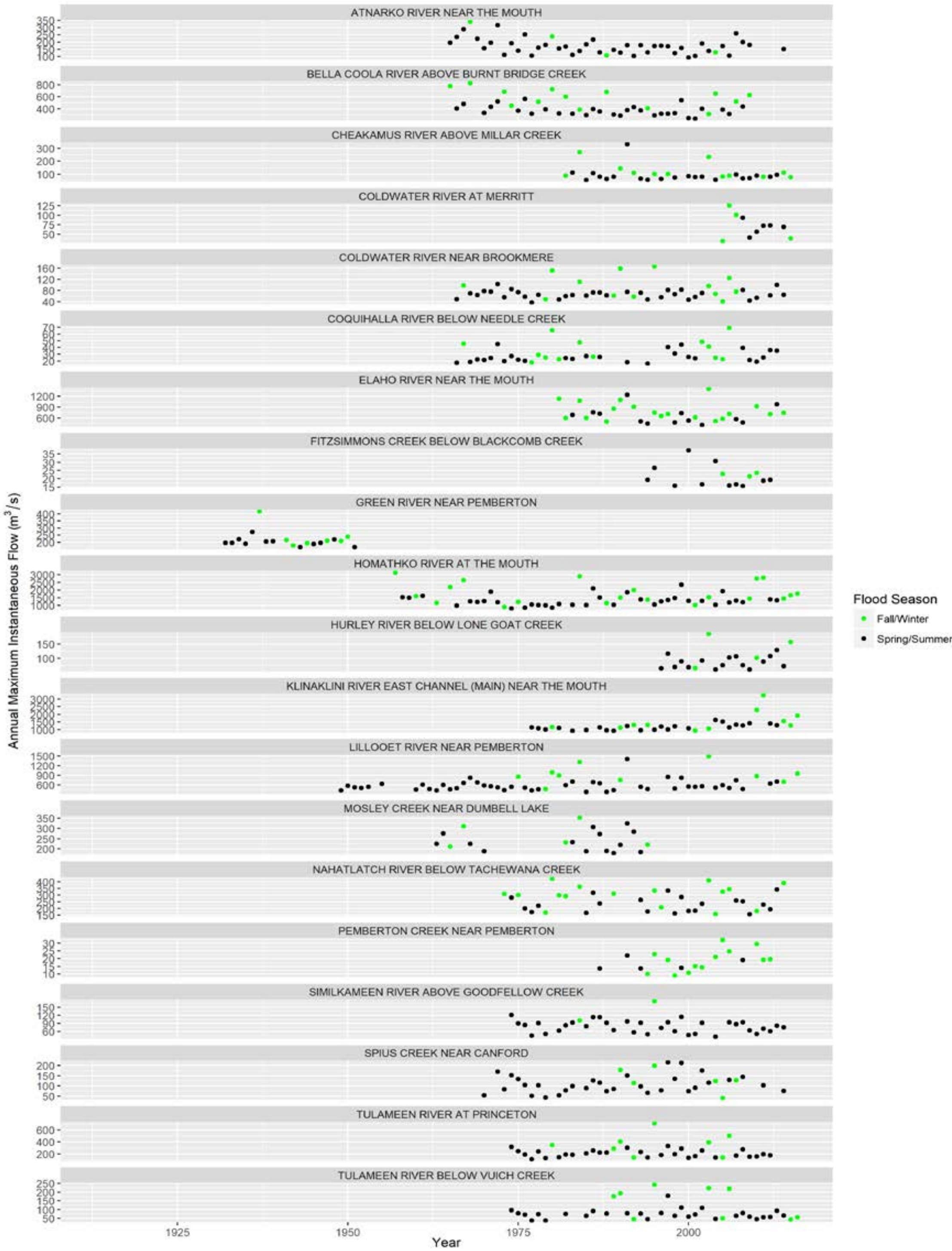


Figure 4-2 WSC instantaneous peak flow records used for regional analysis.

4.1.2 Regional Frequency Analysis

We fit the Generalized Extreme Value (GEV) distribution to instantaneous peak flow observations at all regional WSC gauges using the method of L-moments in the statistical language 'R' (Hornik, 2016). We used bootstrap resampling (1000 samples) from the fitted distribution to determine 90% confidence intervals of each GEV distribution fit[1]. Results are shown in Figure 4-3 for non-exceedence probabilities up to 0.998 (a 500-year return period). The 90% confidence bands are shown in light red. Additionally, observed peaks are colored by their season of occurrence, and results indicate a mixture of both winter and spring floods, with the majority of the floods of record (10 of 17) occurring during winter. The reader should particularly note the results for the Lillooet River at Pemberton, where the majority of peaks occur in the Spring/Summer season, but the top three largest floods all occurred in the fall/winter season. Elimination of the pre-1975 record from this gauge results in notably larger peak flow estimates than when using the full record. Given the recent occurrence of multiple large floods on this system, we feel that accounting for this apparent shift in the peak flow regime via only using the most recent data is warranted, and will help to produce more appropriate design flows for the system. Also, note the Pemberton Creek results, indicating a different peak flow regime (with nearly all peak flows occurring in fall/winter) than the rest of the watersheds used in this analysis.

[1] http://headwateranalytics.weebly.com/blog/flood-frequency-analysis-in-r

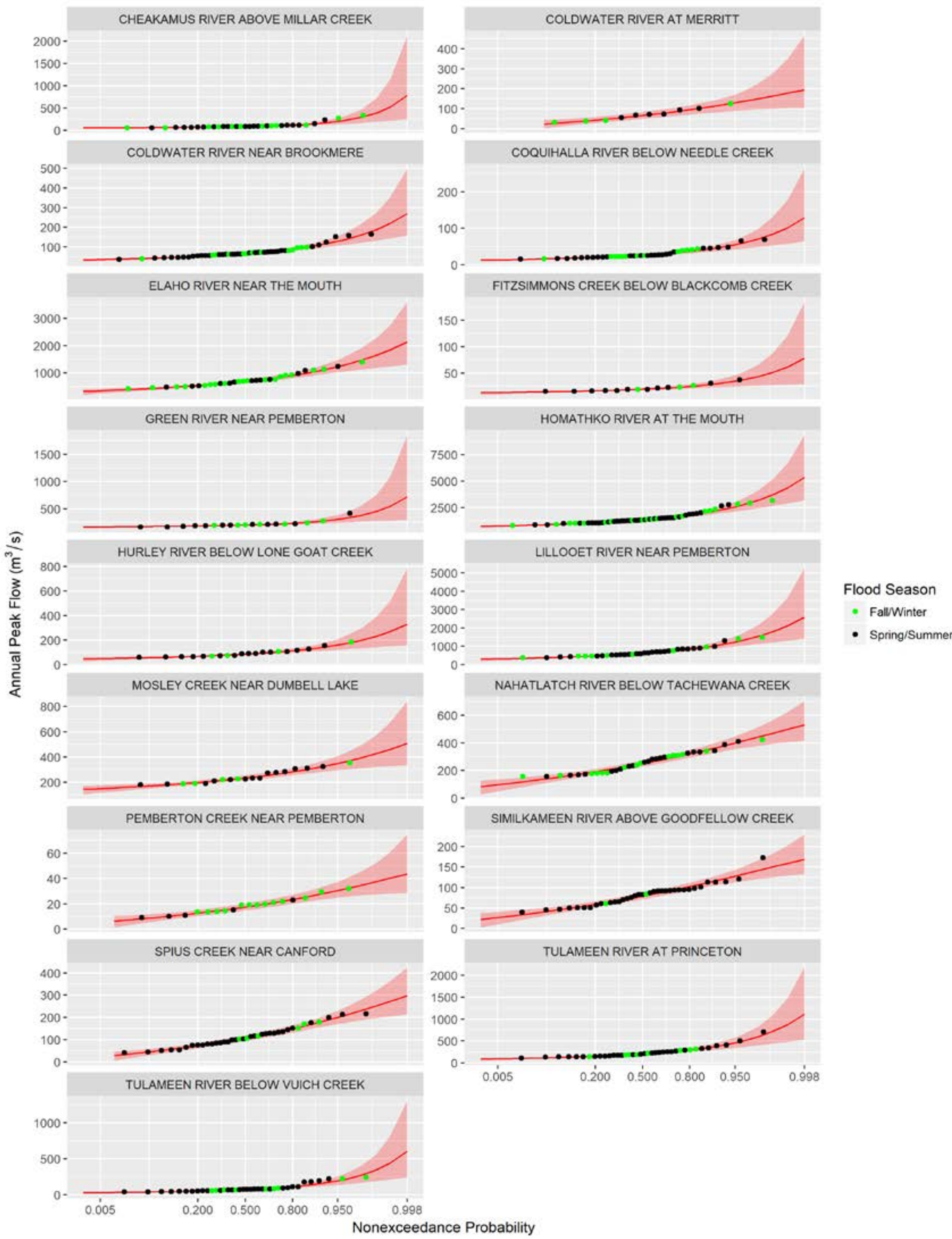


Figure 4-3 Generalized Extreme Value (GEV) distribution fits for all WSC sites used in the analysis.

After calculating flood flows using the GEV distribution for all 17 regional sites, we created regional models, of area vs peak flow, for each of the desired return periods (2, 5, 10, 20, 50, 100, 200, and 500 year) in order to estimate peak flows on ungauged watersheds. Power models were fit to the regional data of the form:

$$Q = a \cdot A^b$$

where Q is the peak flow estimate, A is the catchment area (km^2), and the values of coefficients a and b are shown in Table 4-2. The fitted models are shown in log space in Figure 4-4. These models are used to estimate design flood levels at all watersheds without active gauging (NA in the gauging column in Table 4-3.

Table 4-2 Fitted power law coefficients.

Return Period (Yr)	Nonexceedance probability	a	b
2	0.5	0.571	0.857
5	0.8	0.790	0.852
10	0.9	0.965	0.849
20	0.95	1.163	0.845
50	0.98	1.477	0.839
100	0.99	1.762	0.834
200	0.995	2.098	0.829
500	0.998	2.637	0.822

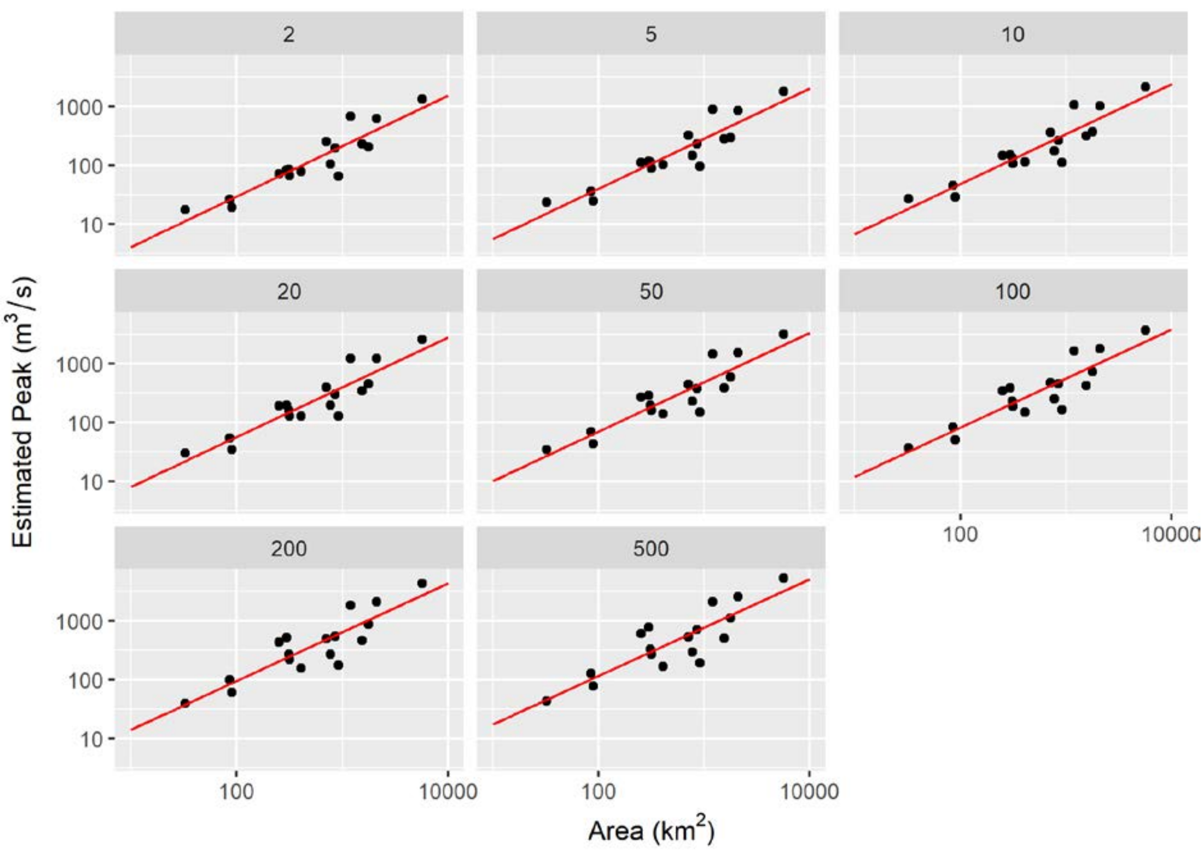


Figure 4-4 Power models (red) fit to all regional peak flow estimates. Panels indicate return periods

4.2 Peak Flows On Ungauged Sites

After performing the frequency analysis on gauged watersheds and fitting regional power law models, we used the results to estimate flood flows along the floodplain model reaches. The hydraulic model required flood flow estimates at the upper end and along reaches of Lillooet River, Green River, Ryan River, Birkenhead River, Pemberton Creek, and Miller Creek. To estimate these design flows, we delineated the subbasins in Figure 4-5. Watersheds were divided into areas upstream of the model reaches and area along each of the model reaches so that they could be input as such within the hydraulic model. The subbasins are summarized in Table 4-3. Depending on their locations relative to WSC gauges (the 08MG005 – Lillooet River Near Pemberton and 08MG025 – Pemberton Creek Near Pemberton gauges), we estimated design flows in these subbasins a number of different ways which are elaborated in the following sub-sections. The flowchart in Figure 4-6 illustrates the different methods for estimation that were used.

nhc

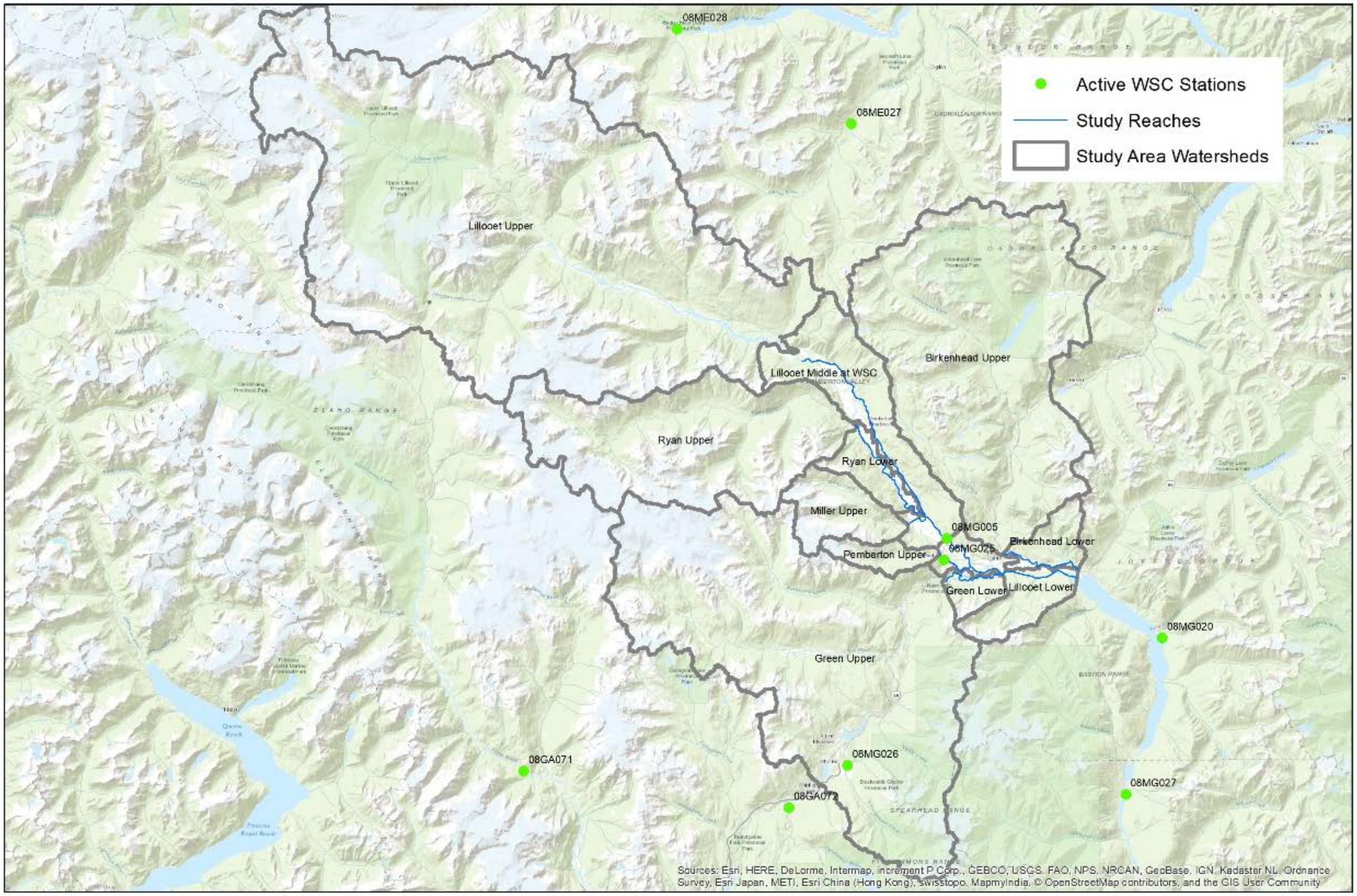


Figure 4-5 Watersheds used to estimate reach inflows.

Table 4-3 Ungauged subbasin summary

ID	Name	Area (km^2)	Downstream ID	Gauging
1	Birkenhead Lower	38	NA	NA
2	Birkenhead Upper	646	1	NA
3	Green Lower	24	5	NA
4	Green Upper	850	3	NA
5	Lillooet Lower	80	NA	NA
6	Lillooet Middle at WSC	162	5	Abv 08MG005
7	Lillooet Upper	1439	6	Abv 08MG005
8	Miller Upper	73	6	Abv 08MG005
9	Pemberton Upper	30	5	Abv 08MG025
10	Ryan Lower	41	6	Abv 08MG005
11	Ryan Upper	375	10	Abv 08MG005

Note: Downstream ID indicates the subbasin that a basin flows into. A downstream ID of NA indicates that the subbasin is at the lower end of the model domain.

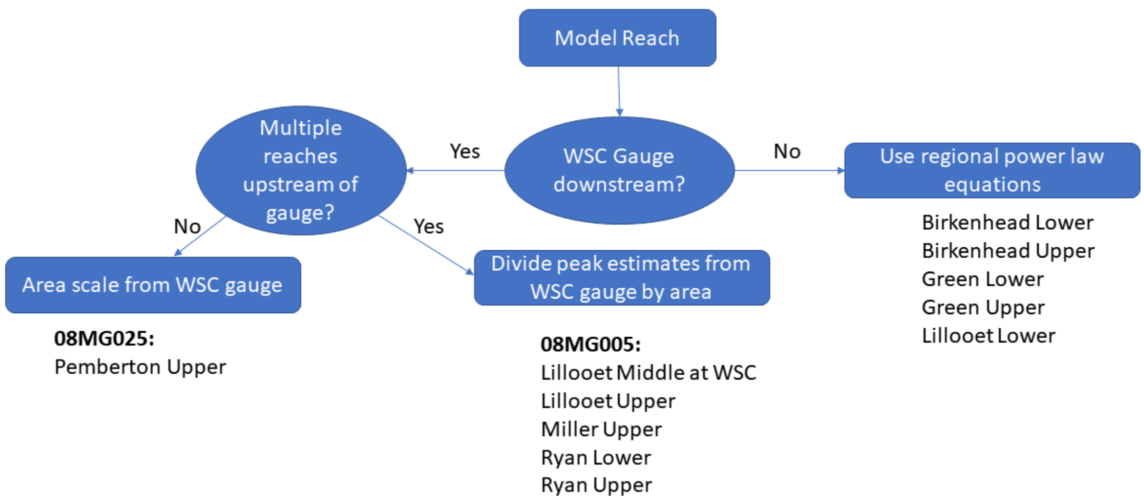


Figure 4-6 Flowchart of estimation methods for design peak flows at each study reach.

Table 4-3 and Figure 4-6 show that five subbasins are upstream of the WSC Lillooet River at Pemberton (08MG005) gauge. In order to best achieve a flow similar to the fitted peak flows at the WSC gauge location within the model (the 'Estimate' column in Table 4-4), we took the peak flow estimates at the WSC gauge and divided them based on the fractional area of the total WSC gauge (2100 km^2). As opposed to using the regional curve for all of the subbasins separately, this method allows the hydraulic model to receive the closest flow possible to the 'true' fitted peak flows at the 08MG005 location within the model domain.

Similarly, we used the fitted peak flow estimates for the Pemberton Creek near Pemberton gauge (32 km^2) scaled linearly to the Pemberton Upper (30 km^2) ungauged model boundary. As noted in Section 4.1.2, Pemberton Creek appears to experience a different peak flow regime than most of the watersheds in the regional analysis, with very few peak flows in the spring and summer months. Hence, we felt it more accurate to characterize the design events based on this gauge than the full region.

Table 4-4 Peak flow estimates for the WSC Lillooet River at Pemberton gauge (08MG005).

Return Period (Yr)	Nonexceedance probability	Lower 90% C.I.	Estimate	Upper 90% C.I.
2	0.5	566	620	689
5	0.8	746	849	967
10	0.9	874	1031	1223
20	0.95	992	1223	1539
50	0.98	1127	1540	2158
100	0.99	1223	1810	2815
200	0.995	1312	2118	3677
500	0.998	1432	2594	5278

Notes:

1) *Upper and lower 90% confidence intervals, determined via bootstrap resampling of the GEV distribution, are shown along with the actual estimate.*
2) *For comparison, the 200-year estimate using the entire flow record is approximately 1600 m^3/s vs 2118 m^3/s above.*

4.3 Hydrographs For Unsteady Flows

For a two dimensional hydraulic floodplain model, the instantaneous design flows were then converted to flood hydrographs. The most recent major flood events occurred in the region in October 2003, September 2015, and November 2016. We performed two-dimensional hydraulic modelling of two of the previous flood events (2016 and 2003) along with 50, 100, 200 and 200 year + Climate Change flood flows.

High resolution (hourly or less) flow measurements during the flood events were only available at the primary gauge, 08MG005 – Lillooet River at Pemberton[2]. Additionally, only preliminary hourly data were available for the 2015 and 2016 events. Approved hourly data were available for the 2003 event.

Due to limited data availability, we used the hourly storm hydrographs at the Lillooet River gauge for the 2003 and 2016 events, and scaled them according to the design flows for each subbasin. The assumption of a similar response at a wide range of watershed sizes has support on a physical basis. Jones and Perkins (2010) found that large scale rain-on-snow events, particularly the type that cause floods in the

[2] WSC reported that high flows were outside of the range of confidence for rating curves on the 08MG025 – Pemberton Creek and 08MG026 – Fitzimmons Creek gauges during the 2015 and 2016 flood events.

Pemberton and other coastal regions, tend to have a similar response at a wide range of catchment sizes. The atmospheric river storms that tend to cause these major flood events typically bring nearly isothermal atmospheric conditions, thus rain falls and snow melts at similar rates over large elevation and area ranges. This synchronized melt means that runoff response will be quite similar at a range of catchment size and implies similar peak to volume ratios across watershed sizes.

4.3.1 Individual Event Hydrographs

The 2003 flood is the largest flood with data available on the Lillooet River. The peak instantaneous flow was 1490 m^3/s (Figure 4-7), corresponding to just under a 50 year flow based on the estimates from Table 4-4. Thus we used this hydrograph as the shape of the 50 + year design flows along with the 2003 event itself. We created hydrographs that included the full day of the peak flow itself, along with flows ±3 days from that day. The storm hydrographs were created as follows:

1) We converted the hourly hydrograph into a unitless hydrograph, with peak value of 1 at the maximum value on the curve (i.e. when the WSC gauge measured 1490 m^3/s).

2) For subbasins above the WSC gauge, we divided this unitless hydrograph by fractional area of the full area above the gauge.

3) We then multiplied all of the unitless hydrographs above the gauge by the 1490 m^3/s peak flow.

4) For all model reaches below the 08MG005 WSC gauge (this includes all reaches in the right column of Figure 4-6 and the Pemberton Upper reach) we multiplied the step 1 unitless hydrograph by each subbasin's corresponding 50-year design flow. As shown in Figure 4-7, the design flows for the Pemberton Upper reach were based off the frequency analysis from 08MG025, whereas the right column gauges were based off the regional power law equations.

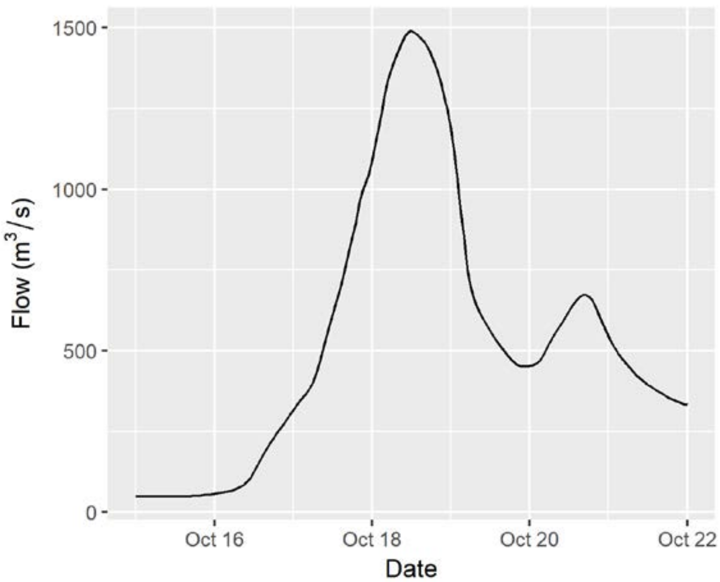


Figure 4-7 Approved hourly data for the October 2003 flood event at the 08MG005 gauge

The 2016 flood peaked at 956 m^3/s[3] (Figure 4-8) corresponding to a flood between the 5 and 10 year level. We performed the same procedure for the 2016 event, with a unitless hydrograph based off the 2016 preliminary hourly data. The procedure was identical to the 2003 procedure except we used 10 year flows in step 4. The design hydrographs are shown in Figure 4-9.

[3] 956 m^3/s is a preliminary, unapproved, peak flow result from WSC. Based on inspection of the manual gauging during the 2016 event, we felt this was the best estimate available, even if it remains preliminary. Hence, we used it as a representative flow for the 2016 event.

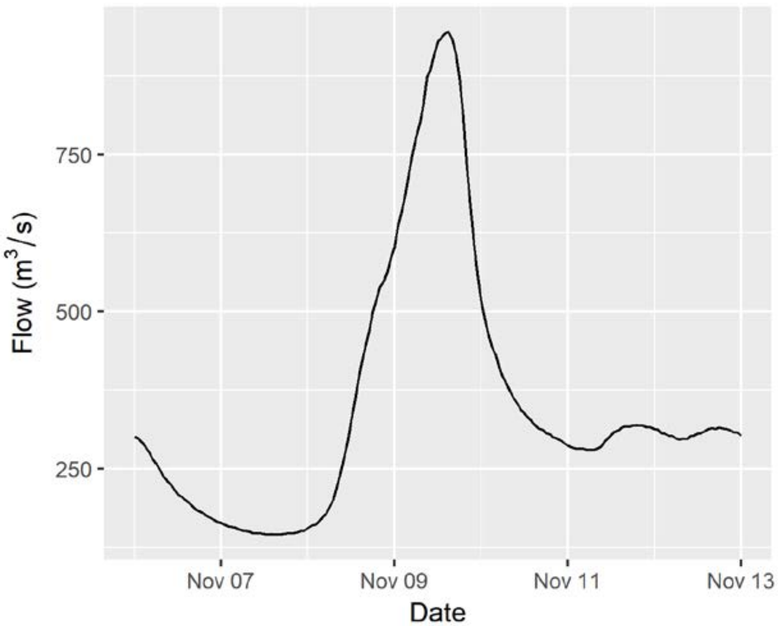


Figure 4-8 Preliminary hourly data for the November 2016 flood event at the 08MG005 gauge

4.3.2 Design Flood Hydrographs

For the 50, 100, 200 and 500 year flows, we used the 2003 unitless hydrograph and fractional unitless hydrograph (described in previous section) for watersheds above the WSC gauge. We then based all flows above the gauge off of the design flows estimate as in the flowchart in Figure 4-6. Design hydrographs are shown in Figure 4-9. This figure illustrates that the Lillooet Upper reach is the most dominant water source into the model area. This area has both the largest watershed area and furthest to travel through the hydraulic model area.

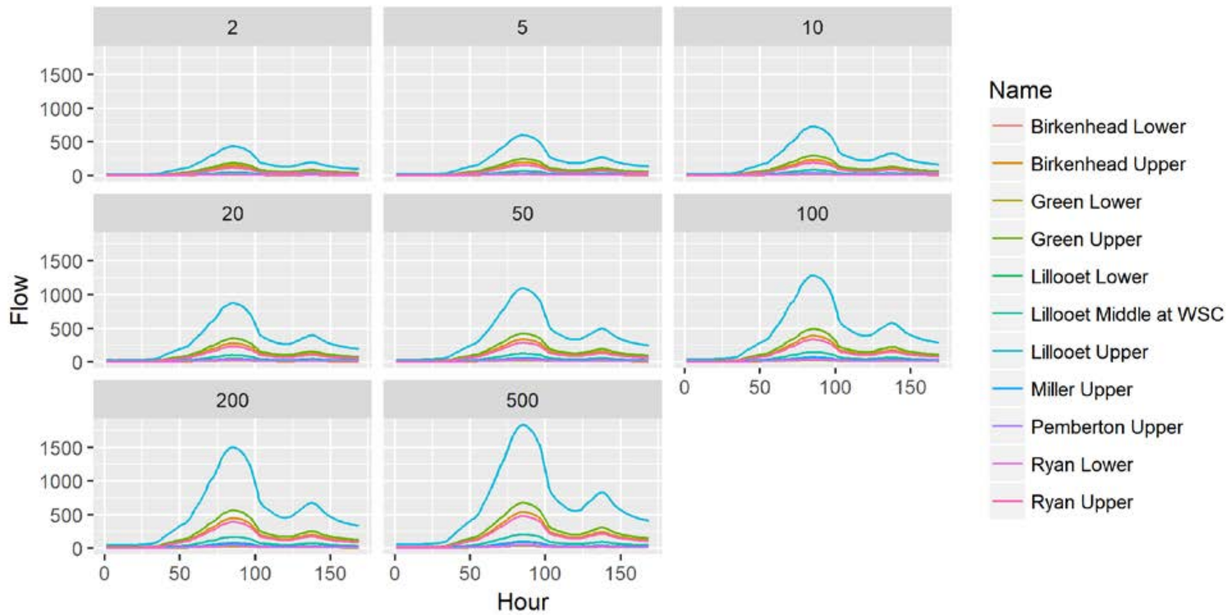


Figure 4-9 Design hydrographs for all model subbasins.

4.3.3 Iterative Hydrograph Routing

While the research of Jones and Perkins (2010) suggests similar response at a range of watershed scales during rain-on-snow, thus supporting the idea of similar (or the same) hydrograph shapes within the different subbasins, there is some desynchronization that results from routing these floods through various lengths of model reaches. The most significant of these are the flows generated in the “Lillooet Upper” subbasin, which are the largest flows and the flows that have to travel the furthest through the hydraulic model. Figure 4-9 illustrates that the flows generated in the Lillooet Upper watershed are the largest of the model domain; however, other reaches may also have some effect. In order for peaks from this reach to arrive at the WSC gauge location at the same time as peaks from nearer reaches, some modification of hydrograph timing was introduced.

As the hydraulic model is a detailed routing model already, the best way to do this was for the hydraulic modeler to adjust the timing of the hydrographs so that the peak flows at the WSC gauge in the hydraulic model correspond to the intended design flows. This was performed iteratively on the 2016 flood. We found that an adjustment of 5.5 hours ahead for the Lillooet Upper reach, 0.5 hours ahead for the Lillooet Middle reach, and 4 hours ahead for the Ryan Upper reach was required for the peak flows to arrive at the WSC gauge approximately simultaneously. After these timing adjustments were found with the 2016 flood event, we applied the same timing offsets to all other unsteady hydrographs (design floods, design floods with climate change, and the 2003 flood) used in the hydraulic model.

4.4 Climate Change

EGBC (2018) recommends a 10% increase in design peak flows to account for climate change when no trend is evident in the record, and a 20% increase when a trend is evident. Section 4.1.1 notes that we did find a trend toward increasing flows in the long term record of the 08MG005 – Lillooet River at Pemberton gauge. Additionally, the straddling of the peak flow regime between snowmelt, mixed rain/snow and rain dominant implies that the Lillooet River around Pemberton may be particularly sensitive to climate change.

Radic et al (2015) predicted that fall atmospheric rivers, are expected to occur more often in a changing climate. Hence, we applied a 20% factor of safety increase to design flows for all model reaches. Table 4-5 gives the design peak flows for all individual model reaches (the maximum value from the hydrograph estimated as in 4.3.2) and the corresponding increases due to climate change. After timing offsets for routing, all values of the unsteady hydrographs were increased by 20% for the climate change design flows.

Table 4-5 Design peak flows for model reaches and increases to account for climate change (CC).

Model Reach	50-yr	50-yr + CC	100-yr	100-yr + CC	200-yr	200-yr + CC
Birkenhead Lower	32	38	37	44	43	52
Birkenhead Upper	336	403	389	467	448	538
Green Lower	21	25	25	30	29	35
Green Upper	423	508	489	587	563	676
Lillooet Lower	58	70	68	82	80	95
Lillooet Middle at WSC	119	143	140	168	164	197
Lillooet Upper	1061	1273	1247	1496	1459	1750
Miller Upper	54	64	63	76	74	88
Pemberton Upper	32	38	35	41	37	44
Ryan Lower	30	36	35	42	41	50
Ryan Upper	276	332	325	390	380	456

4.5 Design Flow Comparison

A comparison of NHC's flow estimates and KWL (2002) values is provided in Table 4-6. NHC's focus was on modelling the Lillooet River design flows corresponding to the 50, 100, 200 year and 200 year + climate change floods. As described previously, NHC estimated flows with a combination of regional curves, using 17 selected stations, and individual site estimates.

Table 4-6 Comparison of Flows used for Lillooet River 200-year Flood

River	NHC Flow (m^3/s)	KWL Flow (m^3/s)
Lillooet at WSC Gauge	2118	1520
Ryan	421	654
Miller	74	222
Pemberton	41	64
Green	592	727
Birkenhead	491	735
Total	**3737**	**3922**

The 200-year flow estimate (present climate conditions) of 2118 m^3/s at WSC Station 08MG005, corresponding to the sum of ‘Lillooet Upper’, ‘Lillooet Middle’, ‘Miller Upper’, ‘Ryan Upper’ and ‘Ryan Lower’ in Table 4-5, is considerably higher than KWL’s estimate of 1520 m^3/s. This increase is the main reason for the higher design flood levels reported in Section 5.4.1. and occurs primarily due to our elimination of the pre-1975 record for the Lillooet River gauge.

Downstream of ‘Lillooet Middle at WSC’, the present estimates are lower than KWL’s 2002 values. For example, the flow estimate for Birkenhead Lower + Upper of 491 m^3/s is much less than the 200-year Birkenhead flood by KWL (2002) of 735 m^3/s. This is due to our use of the regional regression equations. Regional regressions (in this case power law) provide a smoothed best fit for all sites within the region. Smooth regional curves may not always be appropriate for design on a single site, but when they are intended to complement a 200 year flow on the main stem of the Lillooet River, we feel they are representative. How exactly a 200 year flood would be distributed will vary and NHC’s approach reflects the idea that coincident 200 year floods on all tributaries of the river would have a return period much longer than 200 years for the region as a whole.

5 HYDRAULIC ANALYSIS

A hydraulic model was developed to simulate the 50, 100, 200 year and 200 year + climate change Lillooet River design floods and estimate corresponding flood levels and extents within the study area. This section describes the various tasks carried out and results obtained. Key steps included: 1) development of a Digital Elevation Model (DEM) to represent the channel and floodplain geometry; 2) development of a hydraulic model using suitable software; 3) calibration and validation of the model; 4) performing model runs and reviewing results; 5) modelling dike breaches and reviewing results; and, 6) reviewing model limitations.

5.1 DEM Development

The DEM, or model geometry, was built by combining the 2017 channel surveys, the 2017/2018 dike surveys, and the 2016 and 2009 LiDAR[4]. The DEM prioritized most recent channel/ dike surveys and the 2016 LiDAR. The 2009 LiDAR was only used to fill any voids in the 2016 floodplain topography, typically limited to the outer edges of the DEM (less than 30% of the final terrain).

The DEM for the river channels was derived from the bathymetric surveys (Section 2.2) and the additional data listed in Appendix A.1. The US Bureau of Reclamation Bathymetric Interpolation Tool was employed to interpolate a continuous surface from the surveyed points. Breaklines were used liberally to shape the channel topography as needed. In areas of sparse data (such as upstream of Km 44 on Lillooet River, downstream of Km 0 on Lillooet Lake[5], upstream of Km 2.5 on Miller Creek, upstream of Km 10 on the Birkenhead River and upstream of Km 4 on Pemberton Creek) the riverbed was interpolated using available data and professional judgement. Dikes were introduced into the digital terrain by linearly interpolating surveyed dike crest elevations and assigning a uniform width of 6 m.

5.2 Model Software and Development

Lillooet River flows are partly confined by dikes, roads and valley walls. There are secondary channels in the mid- and upper-reaches that have aggraded but become active during flood flows. Channel meander remnants from the channel-straightening in the 1950's may also carry some flow. Shallow bars and islands in the upper-reaches are frequently overtopped during high flow events, adding channel roughness and complexity to the hydraulics. Many of the dikes are expected to overtop during extreme flow events. Tributary channels provide additional complexity and confluence configurations are influenced by flow magnitudes.

The project Terms of Reference suggested using a linked 1D/2D model for the hydraulic analysis. In NHC's experience, full 2D modelling is preferable, providing more accurate representation of hydraulic

[4] The LiDAR data and ortho photos supplied by PVDD was collected in 2009 by McElhanney. The LIDAR and orthophotos supplied by the Province of BC was collected from mid-June 2016 to mid-September 2016, see Appendix A for more details.

[5] Lillooet Lake bathymetry was provided by PVDD. Lillooet Lake surveys were undertaken in April 21-22 2009 by Bazett Land Surveying under the direction of KWL (KWL, 2009).

conditions, particularly for complex river systems such as the Lillooet. In consultation with PVDD, it was agreed that a full 2D model be developed for the project.

NHC is familiar with a number of viable software options such as HEC-RAS2D, TELEMAC2D and MIKE21. Based on our previous experience, we recommended using the HEC-RAS (River Analysis System) software developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) for this project. Version 5.0.4 Beta 1 was released in January of 2018 and was used to develop the initial model. When the full 5.0.4 was released in May of 2018, the initial model was converted to the newer version and the calibration/validation and design runs finalized.

Model development involves inputting into the selected software the channel and floodplain geometry as represented by the DEM, relevant roughness coefficients for all surfaces, and any hydraulic structures such as bridges.

A secondary step is developing appropriate boundary conditions for calibrating and validating the model, as well as for the required model runs. For this project, boundary conditions included Lillooet Lake water surface elevations and inflow hydrographs for the upper ends of the Lillooet River and the tributaries as developed in Section 4.

5.3 Calibration and Validation

Model calibration is a critical step of hydraulic model development. It involves gradual refinement of model parameters to ensure simulated water levels match observed levels for a particular flood event. Typically, model parameters include channel roughness, floodplain roughness, and timing of hydrograph routing, but can also include approximation of channel blockages, scour, or degradation that may have occurred during a particular event. Once the coefficients have been fine-tuned, the model is used for simulating a second independent flood event with known flows and observed water levels to validate that the calibrated model is suitable for events other than just the calibrated event.

For the Lillooet River, the amount, spatial extent, and accuracy of flow and water level data from past floods somewhat limit the model calibration and validation. The 2016 flood was used for primary model calibration and the 2017 data obtained during the river surveys were used for model validation. For general comparison, the 2003 flood was also modelled but considering the geomorphic changes over the past 15 years, the flood was not used for calibration. The calibration, validation and comparison model runs are described below.

5.3.1 Roughness Coefficients

Hydraulic roughness coefficients, represented by Manning's n-values, strongly influence the computed profile. Care must be exercised to assign appropriate values based on observed highwater marks, technical literature and professional judgement.

For a 1D model the roughness factors account for friction losses resulting from surface roughness, vegetation, channel irregularities (variations in cross section size and shape), obstructions (stumps, roots, logs, isolated boulders) and channel alignment (degree of meandering). In a 2D model much of the friction losses (variations in channel shape and alignment) are accounted for in the momentum equation and consequently Manning's n-values are generally lower.

The Lillooet River was divided into reaches with similar channel bed material, sectional geometry, and plan form. Each reach was then assigned an initial roughness value for the in-channel portion of the reach. These initial roughness values were assigned based on field observations of channel bed composition and verified with values referenced in the literature (A Strickler, 1923; Bathurst, 1985; Brownlie, 1981; Engelund and Hansen, 1967; Jarrett, 1984; Limerinous, 1970; Maynord, 1991; van Rijn, 1984; Wong and Parker, 2006).

The overbank portion of the model mesh was assigned roughness values using aerial imagery and professional judgment. The adopted overbank roughness values are listed in Table 5-1

Table 5-1 Overbank Roughness values used in hydraulic modelling

Overbank Category	Manning's Roughness Coefficient (n)
Agriculture	0.041
Heavy Vegetation	0.100
Heavy Vegetation (banks)	0.075
Medium Vegetation	0.065
Light Vegetation	0.045
Island Vegetation	0.066
Grass	0.027
Lake or ponded water	0.044
Islands	0.042
Dikes	0.025
Residential development	0.091
Commercial development	0.092

Following the calibration process, the Manning's n channel roughness coefficients listed in Table 5-2 were adopted.

Table 5-2 Channel roughness values used in hydraulic modelling

River	Reach	Manning's Coefficient (n)
Lillooet River:	Mouth to Ryan River	0.025
	From Ryan River to Km 35	0.030
	Upstream of Km 35	0.039
Ryan River:	Lillooet River to Km 8	0.030
	Km 8 to Km 12	0.040

River	Reach	Manning's Coefficient (n)
	Upstream of Km 12	0.050
Miller Creek:	Lillooet River to Km 2.3	0.032
	Upstream of Km 2.3	0.080
Pemberton Creek:	Lillooet River to Km 3.5	0.029
	Upstream of Km 3.5	0.050
Green River:	Lillooet River to Km 6.5	0.030
	Upstream of Km 6.5	0.050
Birkenhead River:	Mouth to Km 8	0.030
	Upstream of Km 8	0.045

5.3.2 High Flow Calibration

For optimum calibration results, observed high water marks (HWMs) should be obtained at flows approaching the design flow magnitude. HWM observations should also be recent, corresponding to the channel and floodplain geometries used in the model. Considering the channel changes that have taken place since the flood of record in 2003, the event was deemed unsuitable for calibration despite having extensive highwater information at a very high flow (1490 m^3/s) . There is also uncertainty regarding the vertical datum used for surveying the 2003 HWMs and the data was consequently used for a general comparison with simulated values.

To better represent current conditions, the model was calibrated to the November 2016 flood (956 m^3/s), having a 5 to 10-year return period. HWM observations were sparser than in 2003 and were based on observations by PVDD as surveyed by NHC. The 2016 HWM dataset spans the majority of the Lillooet within the study reach but has limited coverage from KM 25-35. There are a few HWMs on the Ryan River but none on the other tributaries. Model boundary conditions for the calibration were based on scaling of the observed flow at WSC gauge 08MG005 and the observed Lillooet Lake level at WSC gauge 08MG020.

A comparison of 2016 observed and final simulated water surface elevations (WSEs) is plotted in Figure 5-1. As shown in the figure, the model somewhat over-predicts water levels. The agreement between observed and simulated water levels has a mean absolute error of 0.19 m. The difference between 2016 HWMs and simulated peak water levels is attributable to:

- Uncertainty in the HWM values. The 2016 HWMs were observed and surveyed after the flood had receded. The HWMs are variable; in some instances showing large differences in flood levels for the same location (up to 0.5 m). The HWMs may not accurately reflect the highest water levels experienced during the 2016 flood.
- The channel bed during the 2016 flood was potentially lower than those surveyed in 2017. It is expected that the bed scoured during the peak of the flood with sediment depositing along the bed as the flood receded. The model is based on the summer 2017 channel bed, surveyed at a lower discharge.

Despite the model potentially over-predicting water levels to some degree, the channel roughness values were not further adjusted for the following reasons:

- The extent of the simulated flooding matches the oblique air photos captured during the 2016 flood event.
- The roughness values selected are at the low end of plausible values for the channel form, bed texture, and channel slope based on referenced literature and past modelling experience.
- There is some uncertainty with the accuracy of the 2016 HWMs.
- The model assumes a fixed bed and scour during high floods cannot specifically be modelled.

5.3.3 2017 Validation

For model validation, NHC selected the flow conditions observed during the 2017 field surveys, specifically on June 27. Ample water level data was available for this day, as a long profile was surveyed starting above the FSR Bridge and ending at the mouth of the river, at Lillooet Lake. The river was flowing at approximately 380 m^3/s (at WSC 08MG005) during the survey, dropping slightly over the course of the day.

Figure 5-1 shows the observed and simulated profiles. The two profiles agree reasonably well, although there is some tendency for over-estimation in the model (mean absolute error of 0.17 m). The comparison of water levels also includes WSC 08MG005. The gauge was surveyed to geodetic datum (+204.874) to allow for direct comparison. Differences between the modelled and observed profiles can be attributed to:

- Variations between simulated and actual Lillooet flows. The assumed inflow at the upper end of the model was scaled based on data collected at the WSC gauge, using the same scaling method as for the 2016 calibration and may have resulted in some flow variations.
- Variations between simulated and actual tributary flows. The local inflows for the tributaries during the time of the survey were not specifically known and were scaled using the same method as described in Section 4.

5.3.4 2003 Comparison

For a general comparison, the 2003 Flood was also simulated with the model. Results are included in Figure 5-1. Based on a visual comparison, the simulation provides a reasonable match to the 2003 HWMS but again the model seems to over-predict water levels somewhat. The differences between observed and the simulated water levels are likely due to:

- Bed level changes. The 2003 Flood occurred 15 years ago and the channel has aggraded since then (Section 3). During the flood, the channel bed likely lowered from general and local scour. The model geometry has a fixed bed.

- Uncertainty in datum. The HWMs were surveyed in a local unspecified datum and the assumed conversion may be incorrect.

- Potential discrepancies in observed water levels. The HWMs were surveyed after the flood receded. The HWMs vary for a particular location and may be affected by local features.

5.3.5 Calibration Summary

Although the calibration, validation and comparison runs all indicate the model may to some extent over-predict water levels, the model was adopted for simulating the required design runs. Results may be somewhat conservative, in essence increasing the available freeboard, but considering the complexity of the system, potential material depositions, channel blockages and other uncertainties, the model is deemed representative.

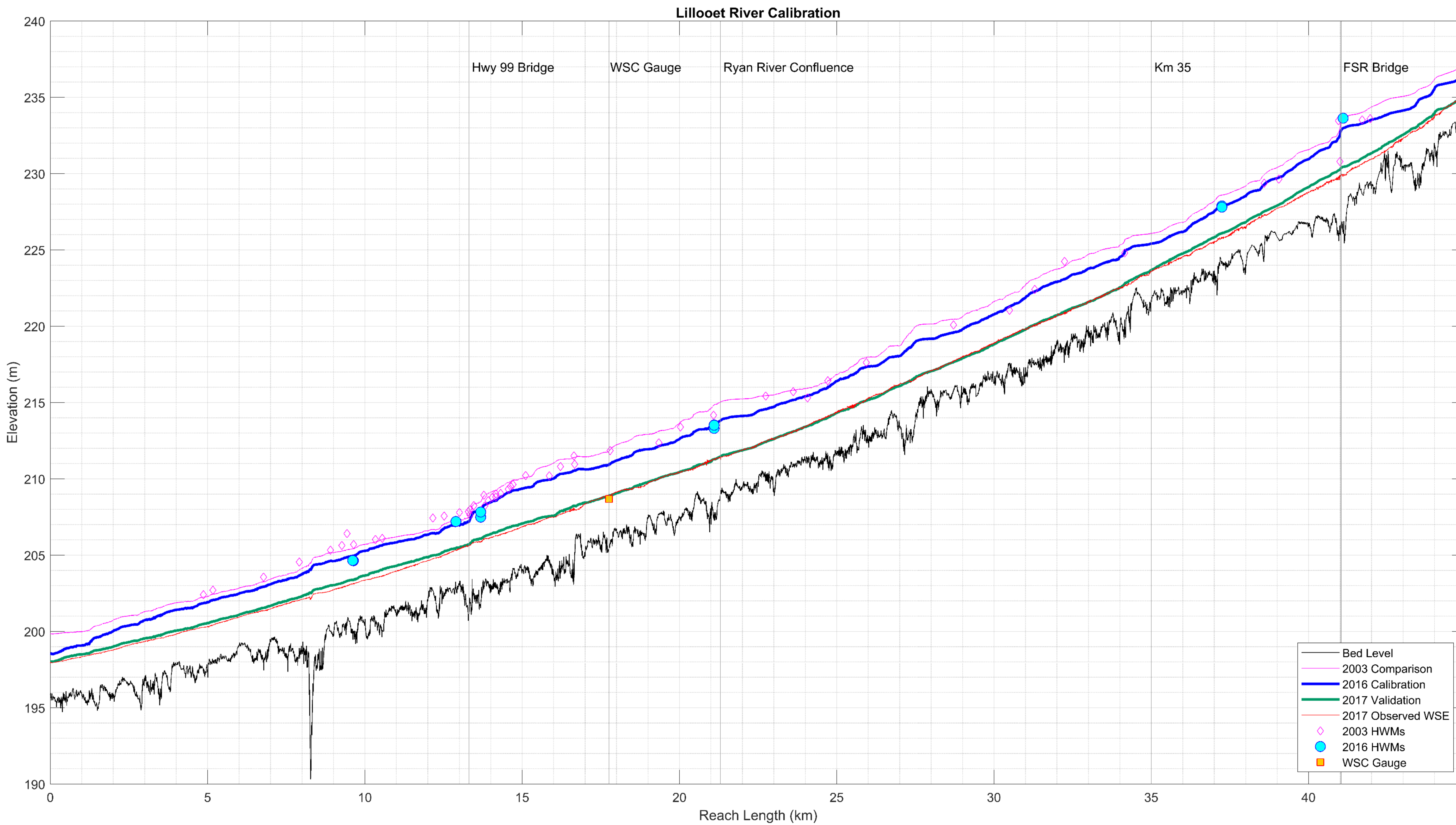


Figure 5-1 Calibration Profile Plot of Lillooet River

5.4 Model Runs and Results

In BC, floodplain mapping is typically developed for the 200 year flood. In addition to the 200 year Lillooet River flood, the 50 and 100 year floods were also modelled, as well as the estimated end-of-century 200 year flood, increased due to climate change impacts.

As noted in Section 4.5, the tributary flows used in the modelling correspond to flows coincident with the 50, 100 and 200 year floods on the Lillooet River, rather than 50, 100 and 200 year floods on each tributary. Combining, say the 200 year flood of each tributary with the Lillooet River 200 year flood, would result in unrealistic and overly conservative results. The floodplain mapping developed in Section 6 is specifically for the Lillooet River and additional modelling would be required to develop mapping for the individual tributaries.

To develop floodplain maps, design profiles must first be simulated using the calibrated hydraulic model. For the Lillooet River designated mapping, the present diking was assumed to be intact although extensively over-topped. This condition results in the highest flood levels in the main channel and is the modelling condition described in this section. However, once a dike is overtopped, it is likely to breach and separate dike breach modelling was performed to estimate overbank flow velocities and flood hazards for breached conditions. The analysis of dike breaches is described in Section 5.5.

5.4.1 Boundary Conditions

To simulate the selected design floods, appropriate boundary conditions (inflows and lake levels) had to be specified.

Estimated 50, 100 and 200 year design flows at WSC gauge 08MG005 are listed in Table 5-3. Also included, is the 200 year flood estimate corresponding to the end of the century. The gauged flows were scaled (Section 4) to represent inflows at the upstream end of the Lillooet study area and at the tributaries.

Table 5-3 Peak flow estimates for the WSC Lillooet River at Pemberton gauge (08MG005).

Return Period (Yr)	Flow Estimate (m^3/s)
50	1540
100	1810
200	2118
200+Climate Change	2542

The downstream boundary condition, or the Lillooet Lake level, was set at the coincident return period (i.e. the 50 year design flow was run with the 50 year lake level). The climate change scenario was run with a 200 year lake level. Lake levels are listed in Table 5-4.

Table 5-4 Peak lake level estimates for the WSC Lillooet Lake gauge (08MG020).

Return Period (Yr)	Lake Level Estimate (m) (CVGD 2013)
50	199.653
100	199.933
200	200.199

To convert WSC lake records to a consistent datum, NHC surveyed the lake gauge (subtract 169.55 m to convert to local datum). Annual peak lake levels included in the frequency analysis covered roughly the same period as the flow analysis (1971 to 2016). Temporal variability of the yearly water level series was fitted using the GEV (method of weighted moments). The results of the frequency analysis are in Table 5-4. The 200 year water level has a 95% confidence interval of approximately 1m.

The coincident return period lake level was used as the downstream boundary conditions in the previous modelling as well (KWL, 2002). However, a direct comparison could not be made with present lake level estimates as the previous datum could not reliably be converted.

5.4.2 Model Geometry

The model geometry developed for the calibration/validation/comparison runs was unaltered for the design runs and was assumed to be representative for all the design runs. No allowance for bed scour or localized deposition was introduced. Similarly, no debris blockages or avulsions were considered and dikes were assumed to maintain their present configuration even if overtopped. It was recognized that the diking would be almost entirely overwhelmed during the 200 year flood and experience some overtopping even during the 50-year flood. The modelling focussed on large, catastrophic events and the floodplain drainage network, incorporating culverts, canals or ditches, was not modelled in detail.

Floodplain mapping corresponding to the design runs is described in Section 5.6.

5.4.3 Critical Threshold for Dike Overtopping

The 200 year flood simulation confirmed that dikes are extensively overtopped. For emergency response and to determine which dikes are most vulnerable, PVDD requested that threshold flows for dike overtopping be estimated using the model. Table 5-5 provides approximate flows at WSC gauge 08MG005 when each dike overtops. Two flows are listed; when the dike is about to overtop and when it is significantly overtopped. Significant overtopping is defined as more than 20 cm of water overflowing the dike.

Table 5-5 only considers the dike locations where initial overtopping occurs (with the exception of Miller-Lillooet A and C Dike). The table does not account for flows that back-water areas from behind dikes or dikes that are overtopped from the land-side (such as Adventure Ranch Dike, Airport A Dike, Pemberton Creek Left Bank). According to the modelling, many dikes are overtopped at the 20 year flood and all dikes are overtopped at the 50 year flood.

Table 5-5 Critical Threshold for Overtopping Dikes

Dike	Location on Dike Referenced to Distance from Mouth of River (See Figure 1-2)	River on which dike breach occurs	Flow at WSC Gauge when Dikes are Imminent to Overtopping (m3/s)	Flow at WSC Gauge when Dikes are Significantly Overtopped (m^3/s)
Ayers Dike	Km 14.5- 15	Lillooet	1090	1250
Airport Road Dike B	Km 10 – 11 Km 12.4	Lillooet	750	820
Forestry Road Dike	Km 43.5 – 44	Lillooet	980	1120
Hungerford Dike	Km 24.5 – KM 25	Lillooet	940	1060
Boneyard Dike	Km 1 (Where the dike intersects Pemberton Meadows Highway)	Ryan	1080	1170
Miller-Lillooet A Dike	KM 19 – 20 Lillooet	Lillooet	1260	1340
Miller-Lillooet A Dike	KM 0.6 – 1.0	Miller	1340	1360
Miller-Lillooet C Dike	KM 13 – 14	Lillooet	1320	Not significantly overtopped
Miller-Lillooet C Dike	KM 14.5 – 15.5	Lillooet	1300	Not significantly overtopped
Miller-Lillooet C Dike	KM 16 – 17	Lillooet	1340	Not significantly overtopped

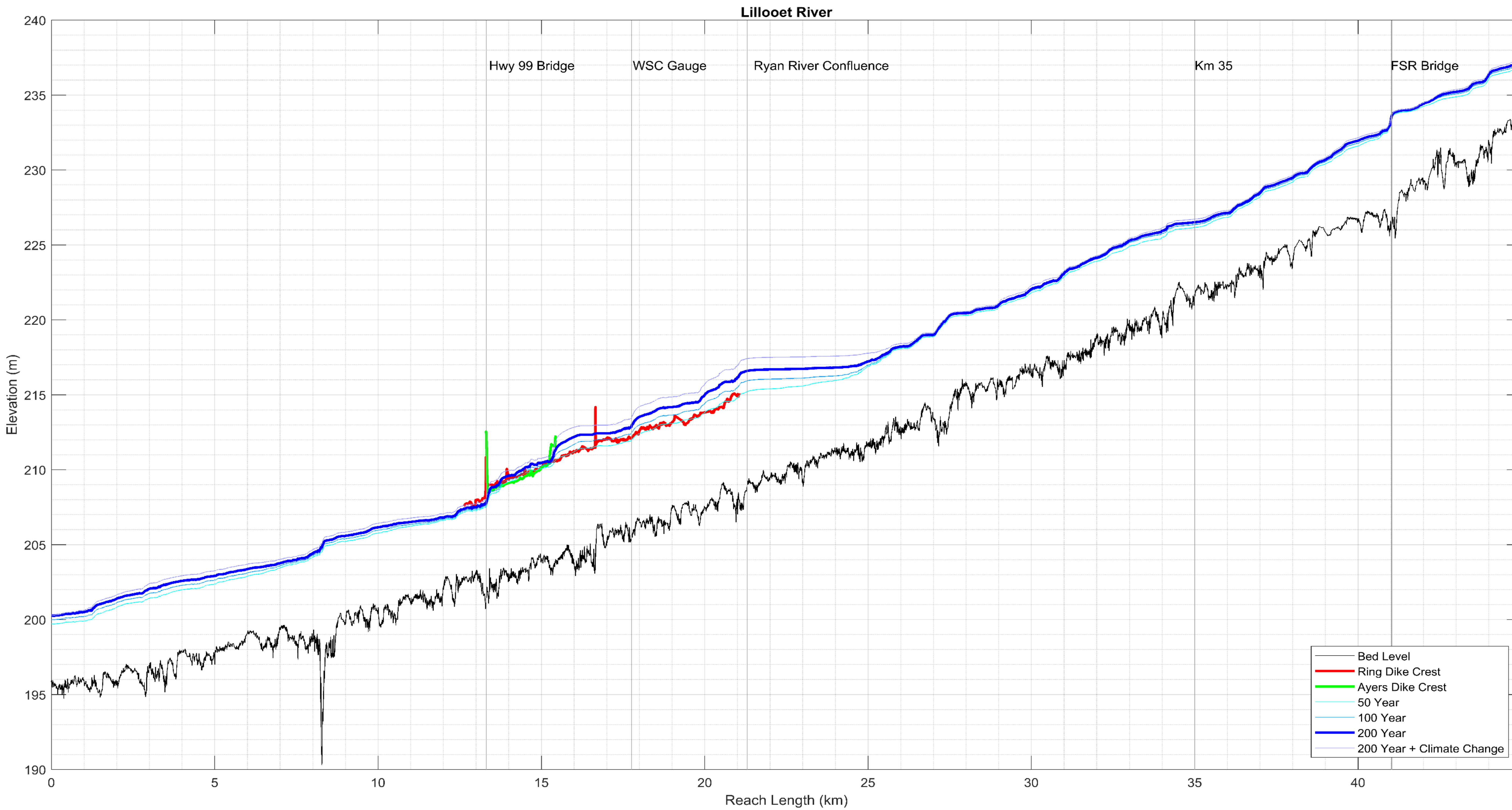
Nesuch	Km 4 and 9.5 – 10 (Where dike intersects Lillooet Lake road)	Lillooet	800	850
Orphaned Pemberton Meadows Berm	Km 31 – 31.5	Lillooet	1060	1200
Orphaned Pemberton Meadows Berm	Km 25.5	Lillooet	900	1070
Poleyard Dike	Km 10	Birkenhead	1400	Not significantly overtopped (for the Birkenhead River flow corresponding to a 1:200 Lillooet River Flood)
Ryan Dike	Km 13 – Km 14	Ryan	800	920
Smuks Dike	Km 44.5 (North end of dike)	Lillooet	1050	1160

5.4.4 Design Profiles

For potential dike upgrades, simulated design flood profiles are plotted in Figure 5-2 and

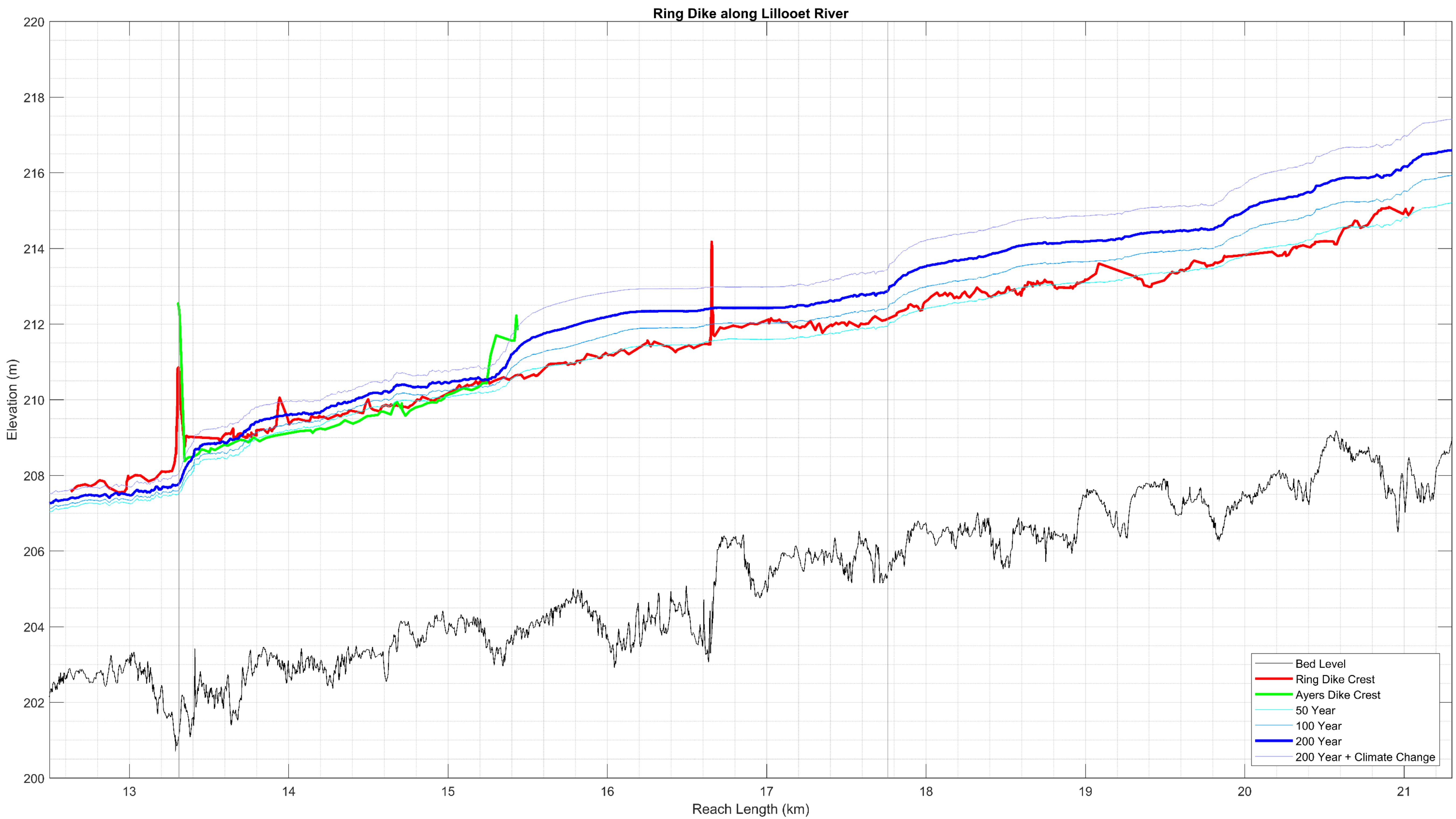
Figure 5-3. The profiles represent the water surface elevation at the centre of the river channel during the peak of the flood. Additional profiles of the Lillooet River and the tributaries can be found in Appendix D.1.

For the simulations, the main “ring dike” sections protecting the centre of the Village of Pemberton (comprised of the Miller-Lillooet Dike, the Adventure Ranch Dike, the Airport A Dike and downstream sections of the Pemberton Creek Dike) were assumed to be raised to contain the flow. Therefore, the flood profile shown is an appropriate basis for estimating the required height of these dikes for a 1:200 flood event (freeboard must also be added).



Note: The simulation was completed assuming that the ring dike was infinitely high and not

Figure 5-2 Lillooet River Design Profile



Note: The simulation was completed assuming that the ring dike was infinitely high and not

Figure 5-3 Lillooet River Design Profile from Km 12.5 to Km 21.5

5.4.5 Rating Curves

PVDD Gauge at Forest Service Road Bridge

In 2014 PVDD retained NHC to install a water level gauge at the FSR bridge (roughly at km 41) to provide an early flood warning system for potential channel blockages caused by a landslide. If gauge levels suddenly drop or increase, an automatic alert is sent to key organizations in the Pemberton Valley. NHC has obtained a number of discharge measurements at the gauge to develop a rating curve for the site. However, measurements have so far been obtained at relatively low flows (less than about 375 m^3/s). To extend the rating curve to higher flows and improve the predictability of flood conditions, stage-discharge values were extracted from the model.

Figure 5-4 shows the model rating curve at the gauge location. It was extracted for flows up to the point when water overtops the Lillooet Forestry Service Road, which occurs at roughly 800 m^3/s (at the location where the Forestry Road Dike ties into the Forestry Service Road). For greater flows, the water bypasses the bridge and the rating curve abruptly changes shape, the shape becoming a function of breach conditions.

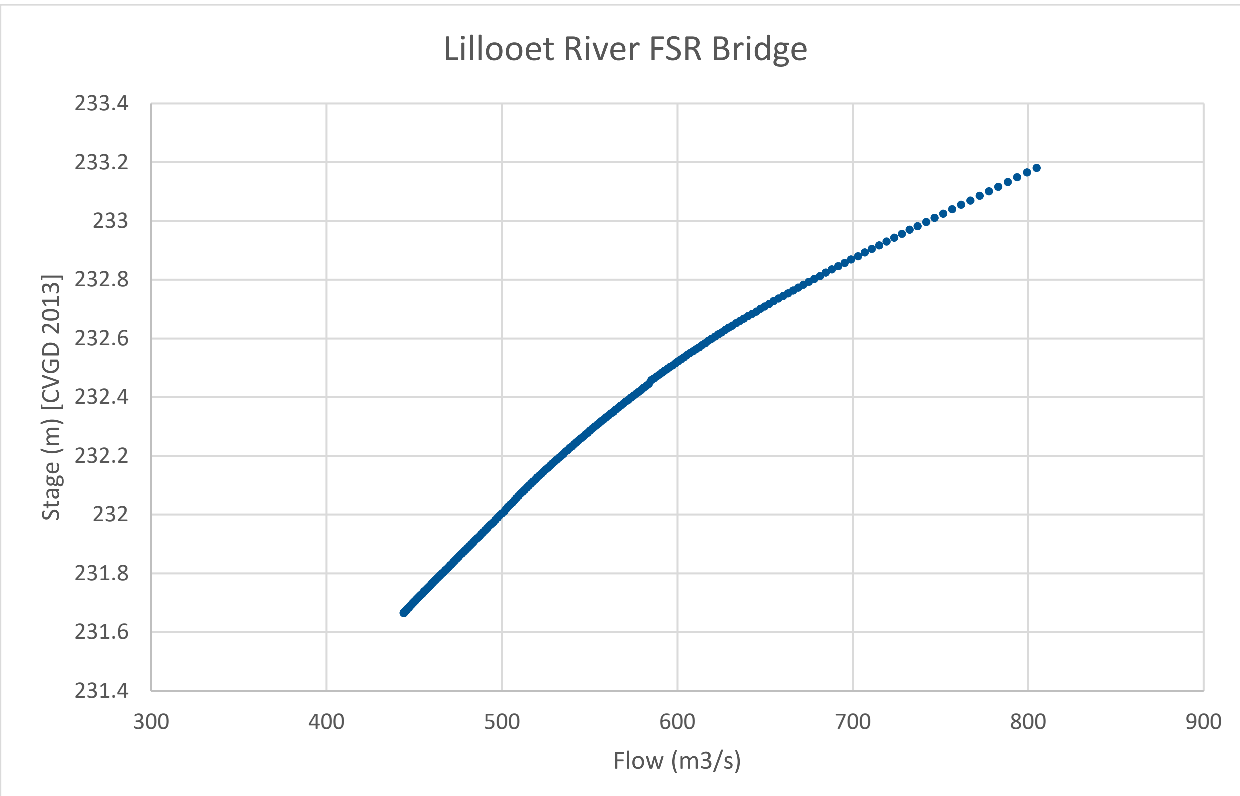


Figure 5-4 Rating curve at Lillooet River FSR bridge at roughly Km 41 created from model

Water Survey of Canada Gauge 08MG005 Near Pemberton

Considering the amount of flow that crosses the floodplain at the WSC gauge near Pemberton, a rating curve was not developed using the model at this location. However, WSC has developed an approximate rating curve for this location based on estimated historic flows. The previous rating curve and the new rating curve (post 2016 flood data included) are shown in Figure 5-5. The curve has shifted over time, likely due to geomorphic changes as discussed in Section 3. The curve is shown in WSC's local datum at that gauge, to convert to CVGD2013 add 204.874 m.

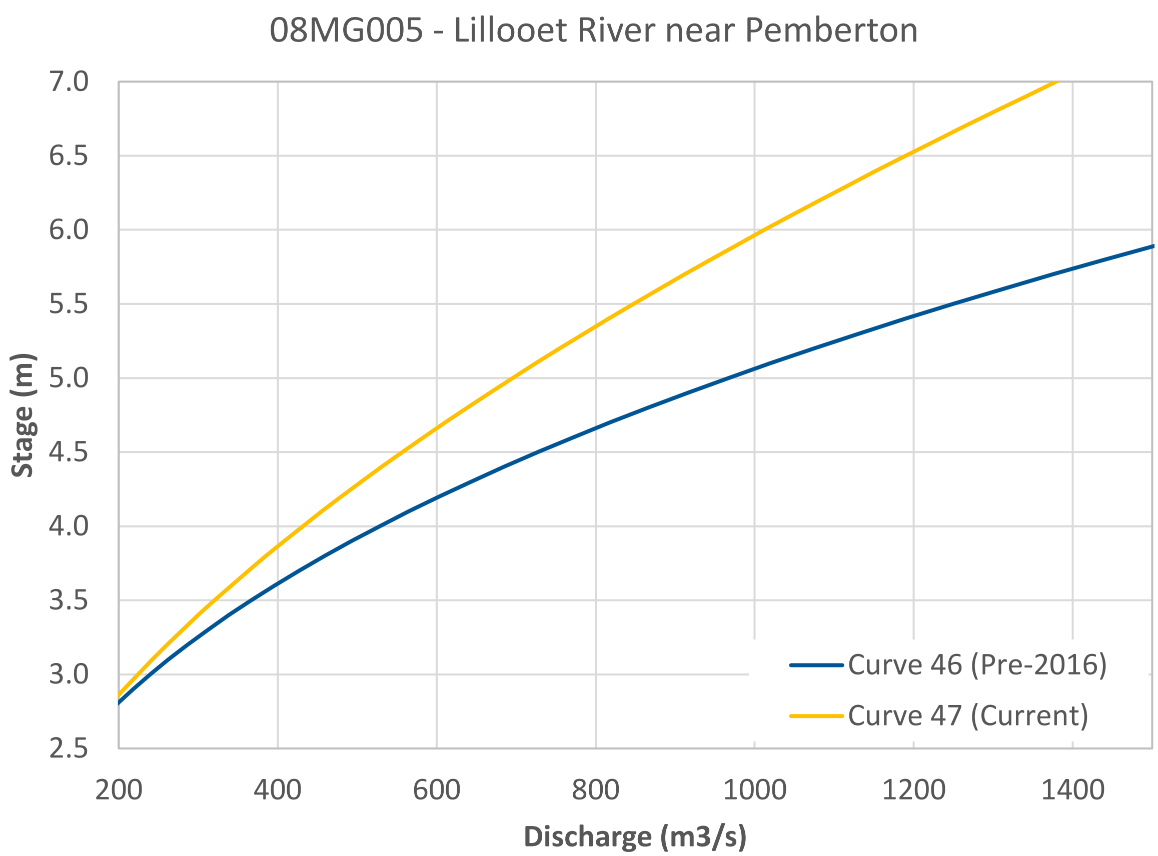


Figure 5-5 WSC Gauge – 08MG005 rating curve showing pre-2016 curve and current curve

5.4.6 Model Sensitivity

Model sensitivity analyses were carried out to determine the effects of changing model parameters on water levels, flow depths, and inundation extents. The sensitivity analyses included analysis of the impacts of varying the following parameters within a credible range:

- Grid cell size,
- Channel roughness values, and
- Overbank roughness values.

For the Lillooet River and the tributaries, the grid cell size was varied from 20 m, to 10 m and down to 5 m in the channel. The floodplain cell size was 40 m for all simulations. The WSE at several locations across the model was recorded for each simulation and compared to the simulation time. Results are provided in Appendix D.2. Based on the results, it was determined that a 10 m channel cell size was an appropriate compromise between accuracy and simulation run time for the Lillooet River, as there was little advantage gained from further reducing the cell size. The tributaries were simulated with 5 m grid cells in the channel because of their narrower width.

The roughness conditions were tested with upper and lower limits of +/- 15%. Results are provided in Figure 5-6 and Figure 5-7. When the roughness parameters were universally increased by 15% (channel and floodplain), water surface elevations observed on the floodplain were 10-20 cm higher. The WSE increase within the channel was typically less than 10 cm. Similar results were found for the roughness decrease of 15%. There was only a small change in the channel WSE and a more significant change on the floodplain (10-20 cm).

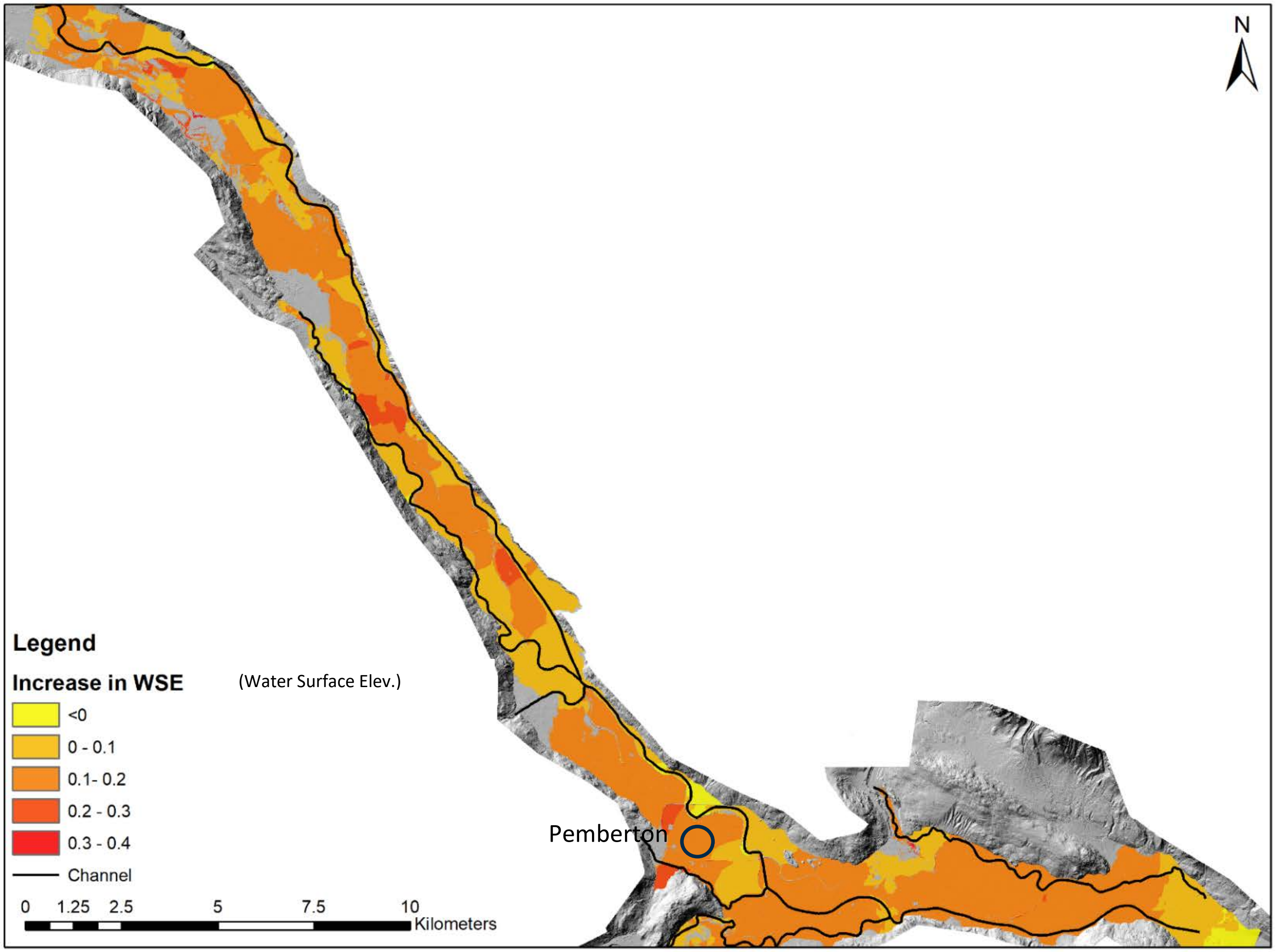


Figure 5-6 Roughness sensitivity map of WSE's when model roughness is increased by 15%.

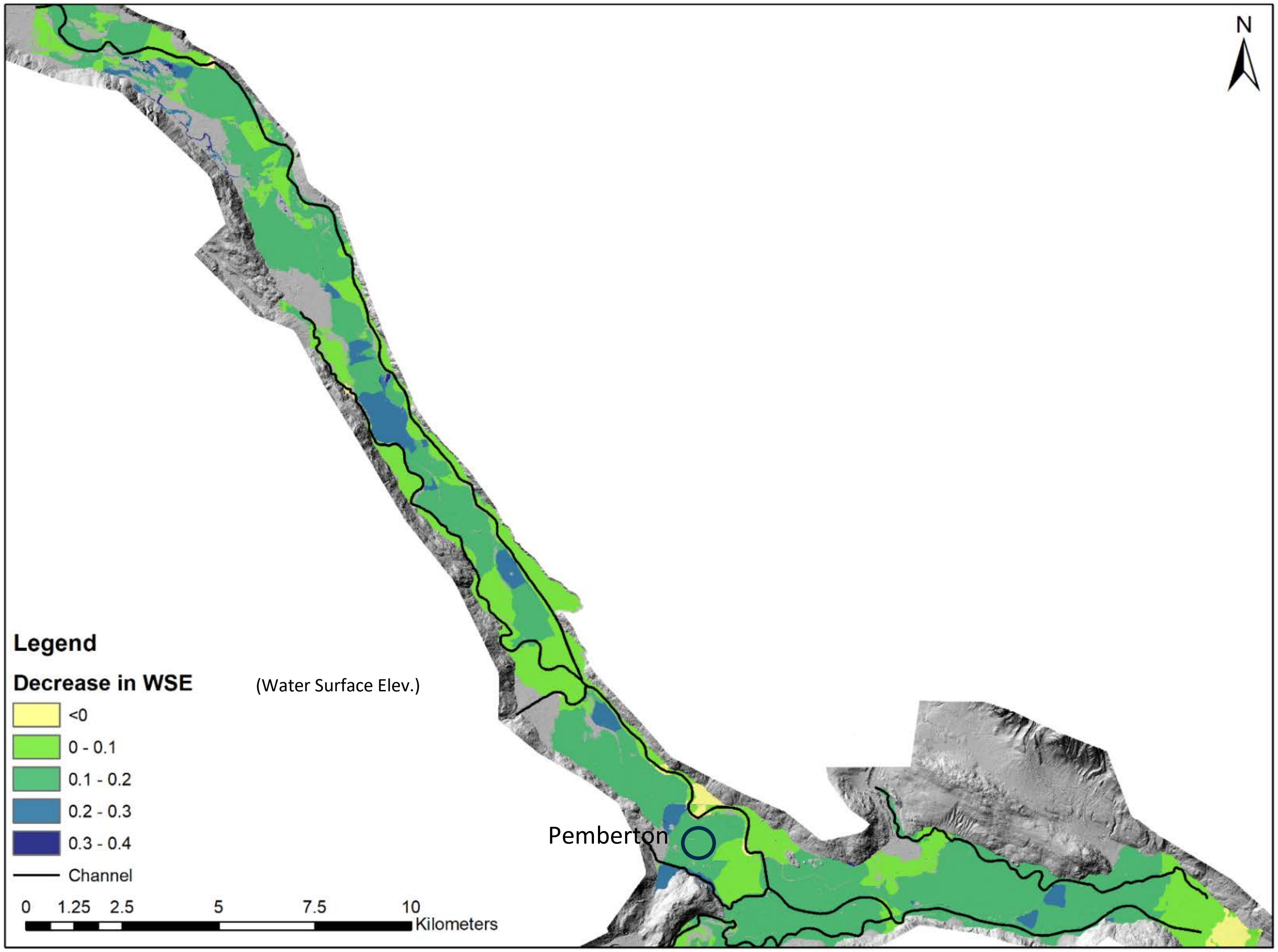


Figure 5-7 Roughness sensitivity map of WSE's when model roughness is decreased by 15%.

5.4.7 Progression of the 200 Year Flood Simulation

An animated video of the simulated 200 year flood was developed and provided to PVDD as a digital file. To prepare for emergency response measures it is important to have an understanding of the possible sequence of floodplain inundation, dike overtopping and impacts on access routes. Please note that the pattern and sequence of flooding could vary significantly from the simulated event shown in the video, and would depend on tributary inflows, dike breach locations and many other factors.

Highway 99, a key access/egress route for the area, becomes extensively inundated during the 200 year flood. The first location to overtop is near the mouth of the Birkenhead River. The 200 year lake level is the cause of highway inundation early on during the flood. Next, water overtops the highway east of Mount Currie, where the road bends along the Birkenhead River, cutting off access to the east. The Birkenhead River is the cause of flooding in this area. The Lillooet River first overtops the highway directly east of the Highway 99 Lillooet River Bridge. East of the bridge water begins to spill over the road and into the floodplain cutting off Mount Currie's access to the west. This may occur when the flow at the WSC gauge is approximately 1150 m^3/s. Highway 99 through Pemberton becomes inaccessible as the area dikes breach or overtop. Dike breaching is described in Section 5.4.7.

In some instances, dikes and other raised features such as railway embankments can cause water to pond, aggravating flood hazards. The area just north of the railway in Pemberton, on the west side of the valley, has potential for significant ponding. The water in this location may get deep (as much as 5 m) and new development in this area should either be restricted or be floodproofed to above the railroad elevation. Another location of concern is the south eastern area protected by Pemberton Creek Left Bank Dike, Airport Road Dike, and Adventure Ranch Dike. The water here would naturally flow back into the Lillooet River but the dikes prevent it from draining and consequently water ponds until it is high enough to flow over the dike. Again, planning of any new development in these areas should take this into consideration, especially if the dike is raised in the future. Further information on flood hazards can be found in Section 6.3.

5.5 Dike Breach Modelling

The Pemberton Valley dikes and their main features were tabulated in Section 2.3. The hydraulic modelling showed that during the simulated 200 year flood, the flood flow overtops nearly the complete length of each Lillooet River dike. For the floodplain and hazard mapping, overtopped dikes were assumed to remain intact as this typically results in the highest water levels. However, in practice, an overtopped dike is likely to breach due to erosion of the crest. Therefore, dike breach modelling was carried out to develop an understanding of the flood progression and timing of inundation resulting from localized failures. It is emphasized that dikes may fail well before overtopping due to seepage, piping, slippage or other modes of failure. These other types of failures were not modelled.

For an overtopping failure, the process is generally initiated by a head-cutting erosion process on the downstream side of the embankment as a shallow stream of water flows over the dike crest. As the depth of flow increases above the dike crest, the surface vegetation is generally removed and the embankment starts to erode very rapidly. Once water levels on both sides of the embankment equalize or the breach invert reaches the elevation of the floodplain, the rate of erosion slows down or stops.

For overtopping failures of the Pemberton Valley dikes, a final breach bottom width of 100 m at the elevation of the floodplain and an estimated breach formation time of one hour were used. The final shape of the breach was assumed to be trapezoidal in shape with 2H:1V side slopes. This assumed configuration is roughly based on observed failures during the 2003 flood (Ayers Dike and Ryan River Dike).

5.5.1 Dike Breach Scenarios

Conceivably, a nearly infinite combination of dike breach locations and sequences could occur. To manage the modelling effort, the breach modelling scenarios were selected based on the most likely and most severe dike breach locations. Breach modelling was completed for the following locations as shown in Figure 5-8::

1) Breach #1 Forestry Road Dike - Approx. 800 m downstream of tie-in to Pemberton Meadows Road
2) Breach #2 Miller-Lillooet Dike A – near Miller Ck Confluence
3) Breach #3 Miller-Lillooet Dike A – Approx. 1500 m downstream of the Miller Ck Confluence
4) Breach #4 Miller-Lillooet Dike C Approx. 500 m downstream of rail bridge
5) Breach #5 Ayers Dike – Near the entrance to the former north arm channel (near Lillooet River km 15)

Dike breach modelling was limited to the Lillooet River dikes as the tributaries were modelled using flows less than the 200 year return period magnitude.

For protecting the Pemberton Village, the Miller-Lillooet Dike, Adventure Ranch Dike, Airport Road Dike A and the Pemberton Creek Left Bank Dike are critical. These dikes are referred to as the Pemberton Ring Dike. To investigate dike breaches in the valley, the Ring Dike was assumed to be raised sufficiently to contain flows. This ensures that the dike breach modelling only simulates flows from the breaches rather than from overtopping. Other dikes were not assumed to be raised as they are discontinuous or do not tie into high ground.

The following dike breach results are all based on individual model runs and listed assumptions. The actual pattern, extent and timing of flooding that could occur may vary. The details, locations and sequences of the five dike breach scenarios are as follows and resulting “snap-shots” are shown in Figure 5-9 to Figure 5-13:

1) Breach #1 Forestry Road Dike - Approx. 800 m Downstream of Tie-in to Pemberton Meadows Road:

a. The southeast area, near and west of the Lillooet River Forest Service Road, is impacted by backwater flowing northwest (up valley) over the Lillooet River Forest Service Road.

b. Pemberton Meadows Road is overtopped where it joins Smuks Dike and significant flows enter Salmon Slough. This occurs well before the Forestry Road Dike is overtopped at the Breach #1 location.

c. Breach #1 appears not to worsen the flooding in this area by much as the Smuks Dike and Pemberton Meadows Road are overtopped first.

2) Breach #2 Miller-Lillooet Dike A – near Miller Ck Confluence (north-east corner of ring dike)

   a. Pemberton Meadows Road becomes impassable almost immediately.

   b. For approximately an hour after the initiation of the breach, Pemberton Meadows Road influences the pattern of flooding, and contains much of the flow between the road and the river dike.

   c. Within about 2 hours of the breach, significant flood flows reach the Village and there is deep ponding west of the railway embankment, which acts as a temporary barrier to the flow.

   d. Given the modeling assumptions, low lying areas east of the railway embankment could be flooded within 3 to 5 hours of the breach.

   e. A dike breach at site #2 ultimately will flood the entire Lillooet floodplain on the land side of the Miller-Lillooet ring dike.

   f. After the breach has eroded to its assumed maximum width of 100 m, a large proportion (approx. 30%) of the Lillooet River flow is flowing into the floodplain and is bypassing the WSC gauge.

3) Breach #3 Miller-Lillooet Dike – Approx. 1500 m downstream of the Miller Ck Confluence (east side of ring dike – near upper end)

   a. The flood sequence is similar to Breach #2

4) Breach #4 Miller-Lillooet Dike Approx. 500 m downstream of rail bridge (east side of ring dike – lower end)

   a. The breach site is at the location of a former (relic) channel of the Lillooet River, which has a low base elevation. The breach opening will be large even before it reaches its assumed maximum width of 100 m.

b. The former channel conveys flows very quickly towards the developed residential area in the vicinity of Hemlock St, Laurel St and Harrow Road.

c. Because of close proximity to the breach site and the presence of the relic channel, there is very limited time (i.e. less than 15 minutes) before fast flows enter the high density residential area.

d. The railway embankment acts as a barrier and may reduce flooding and flood depths upstream of the railway.

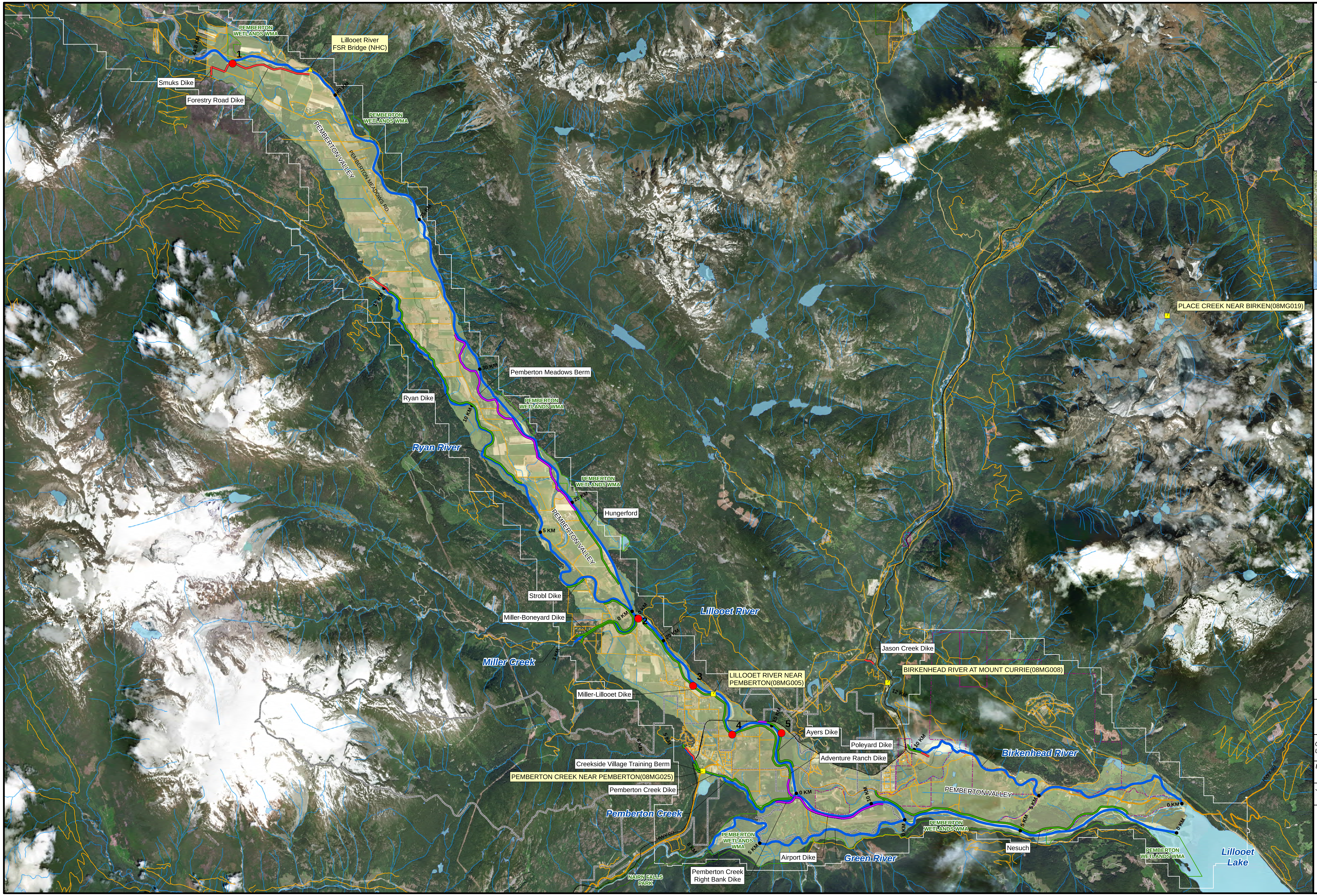
e. Highway 99 also acts as a temporary barrier, but is soon overtopped and the lower areas of the floodplain flood to at least the crest level of the downstream ring dike near the confluence of Pemberton Creek and Lillooet River.

5) Breach #5 Ayers Dike – Near Entrance to Former North Arm Channel

   a. Overtopping of the Ayers dike and initiation of the breach at this location is simulated to occur when the flow at the WSC gauge is approximately 1,100 m^3/s. At this flow, flooding is already extensive but it is generally confined to areas south of Highway 99.

   b. The breach results in flooding of areas north of Highway 99, with floodwaters reaching the industrial park and Mount Currie town site within a few hours.

The sensitivity of the time assumed to reach a full breach width of 100 m was tested by reducing the duration from one hour to 15 minutes for Breach #2 on the Miller-Lillooet Dike A. The results of the sensitivity test can be seen in Figure 5-14 and show that the simulated sequence of flooding is not very sensitive to a reduction in breach development time.



PEMBERTON VALLEY DYKING DISTRICT

nhc
northwest hydraulic consultants
30 Gostick Place
North Vancouver, B.C. V7M 3G3
Canada
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

- DIKE BREACH LOCATIONS
- MODEL NETWORK
- NHC HYDROMETRIC STATION
- WSC HYDROMETRIC STATION
- STANDARD DIKE
- NON-STANDARD DIKE
- OTHER FLOOD CONTROL WORKS
- 1990 FLOODPLAIN MAPPING
- STREAM
- LAKE
- MAJOR ROAD
- LOCAL ROAD
- OTHER ROAD
- RAILWAY
- FIRST NATIONS LANDS
- VILLAGE OF PEMBERTON
- BC PARK
- WILDLIFE MANAGEMENT AREA
- 2009 LIDAR EXTENTS

DATA SOURCES: PVDD, Lilwat First Nation, GeoBC, MFLNRO, NRCAN, Esri

SCALE - 1:51,318

0 1 2 3 KM

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

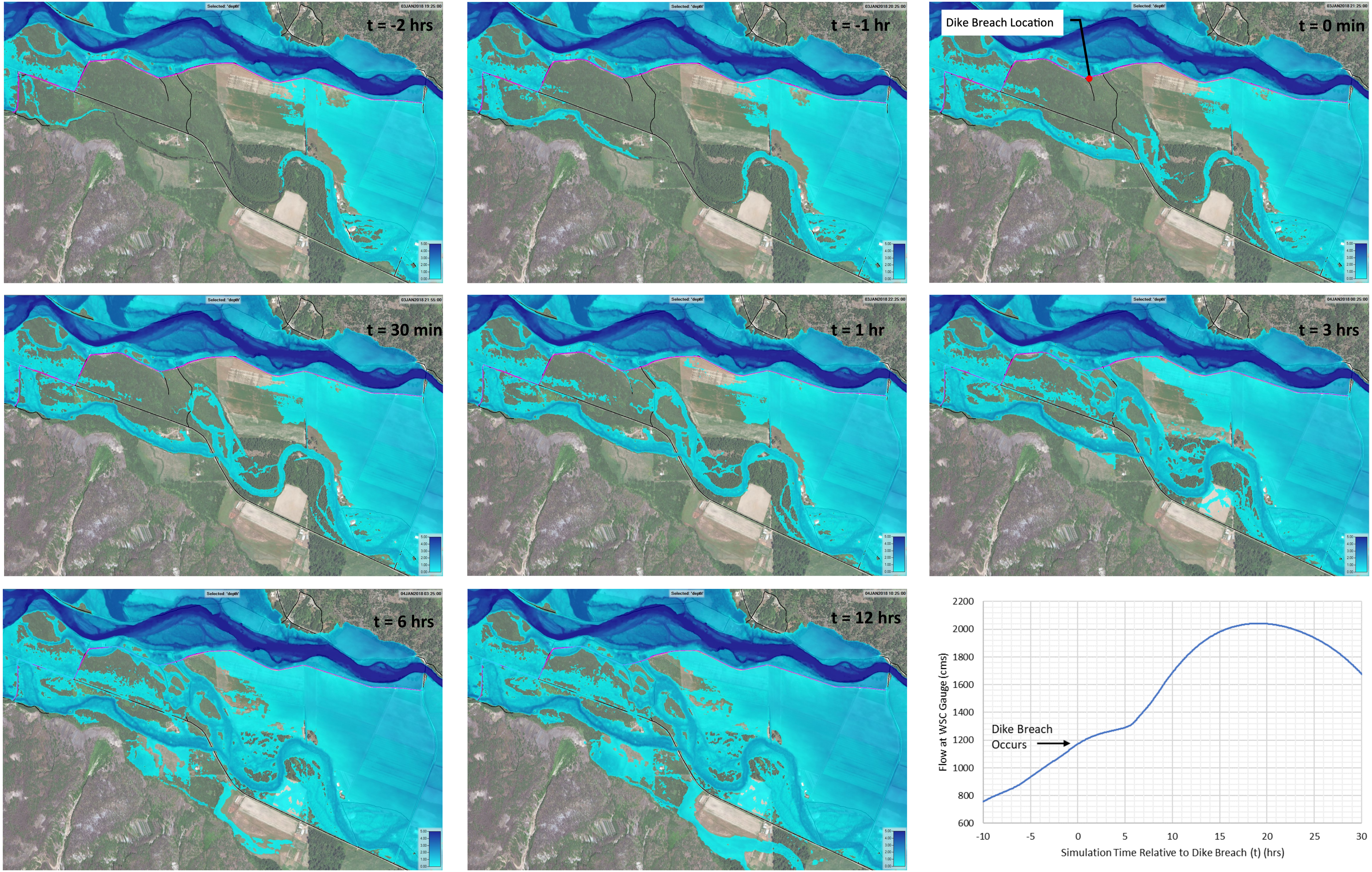
Engineer	GIS	Reviewer
VCCB	VCCB	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN MAPPING
DIKE BREACH LOCATIONS

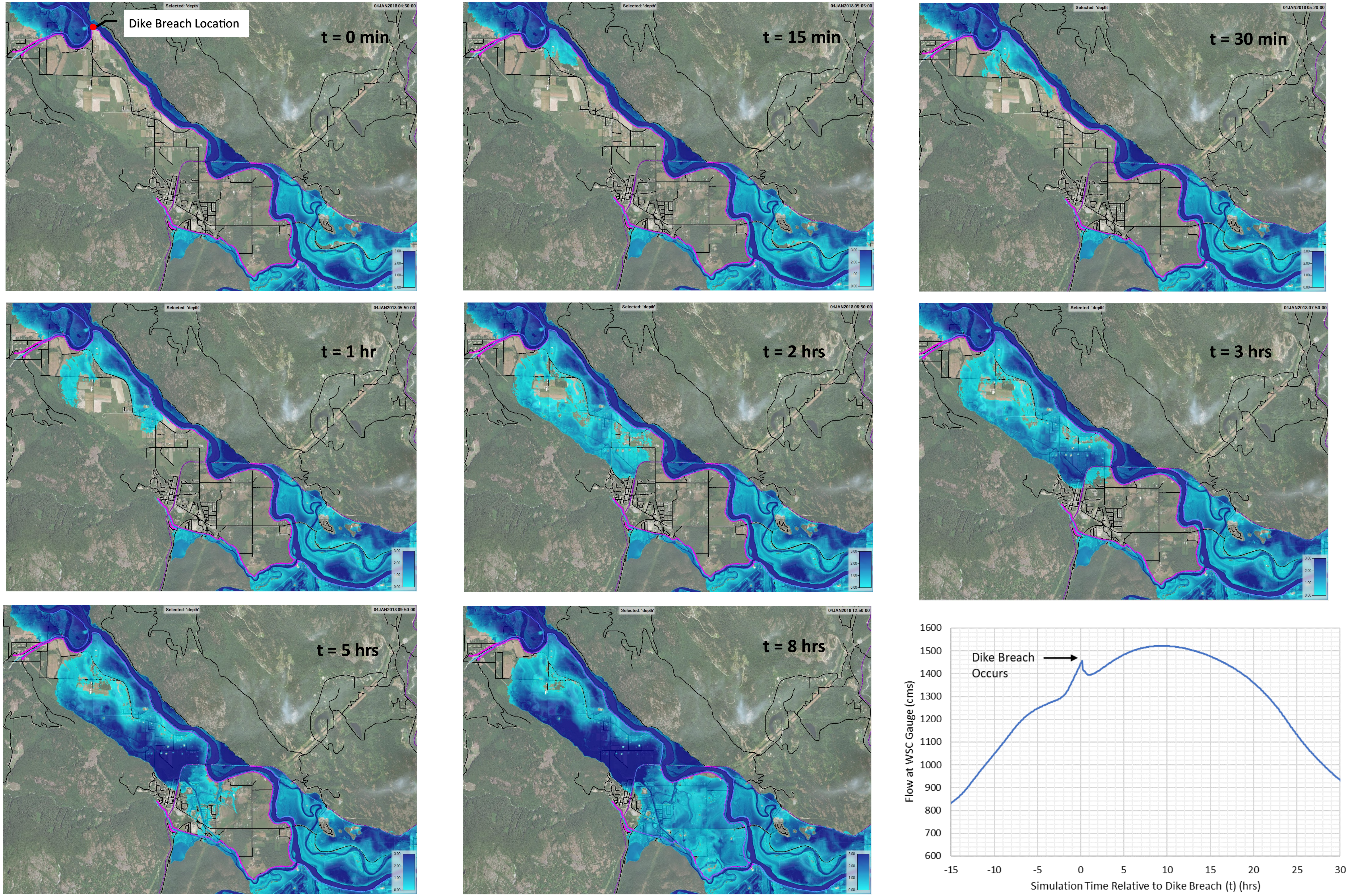
Figure 5-6

Dike Breach #1—Forestry Road Dike

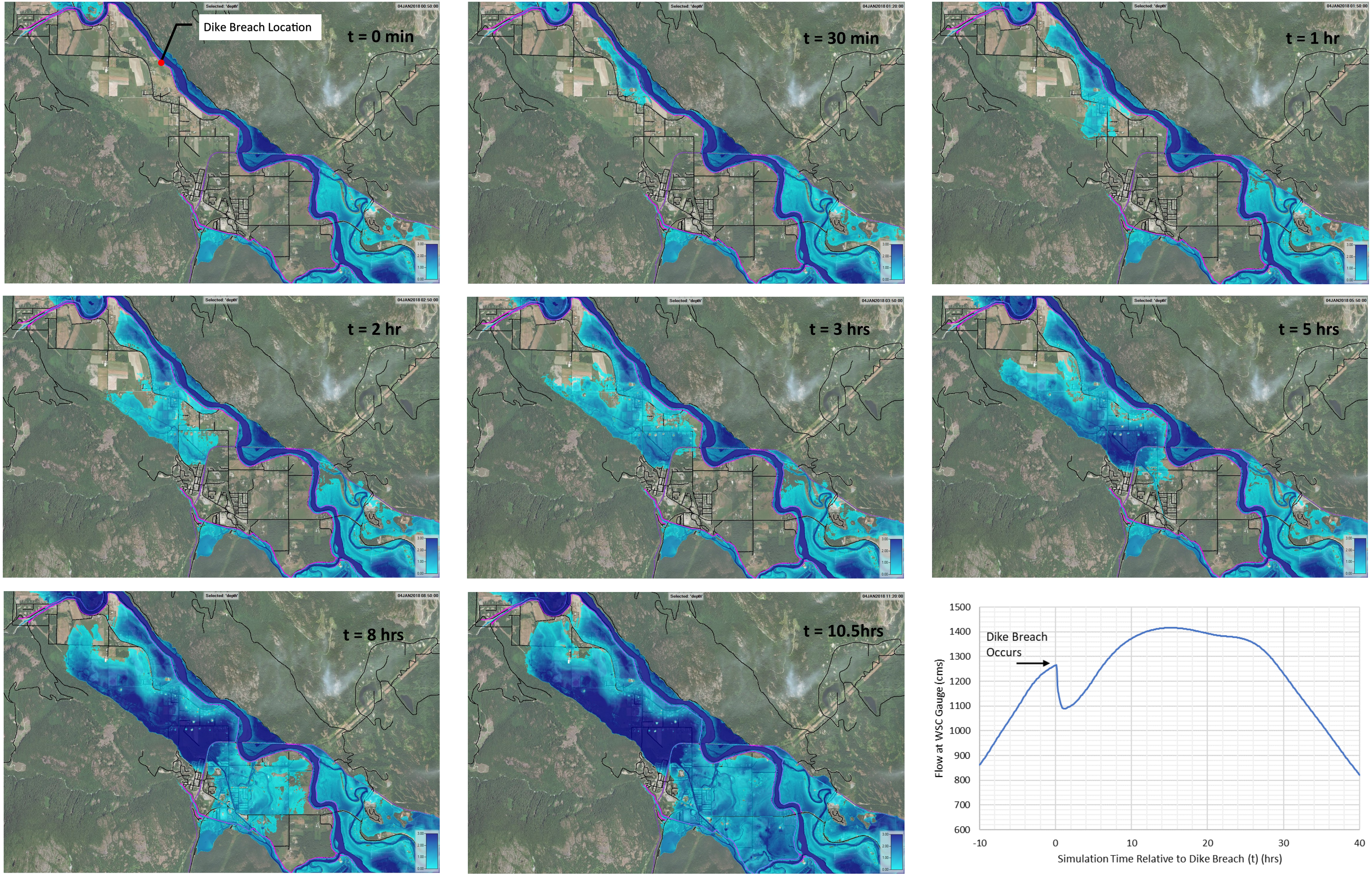


* Breach occurs approximately 5.5hr ahead of flow measured at WSC Gauge

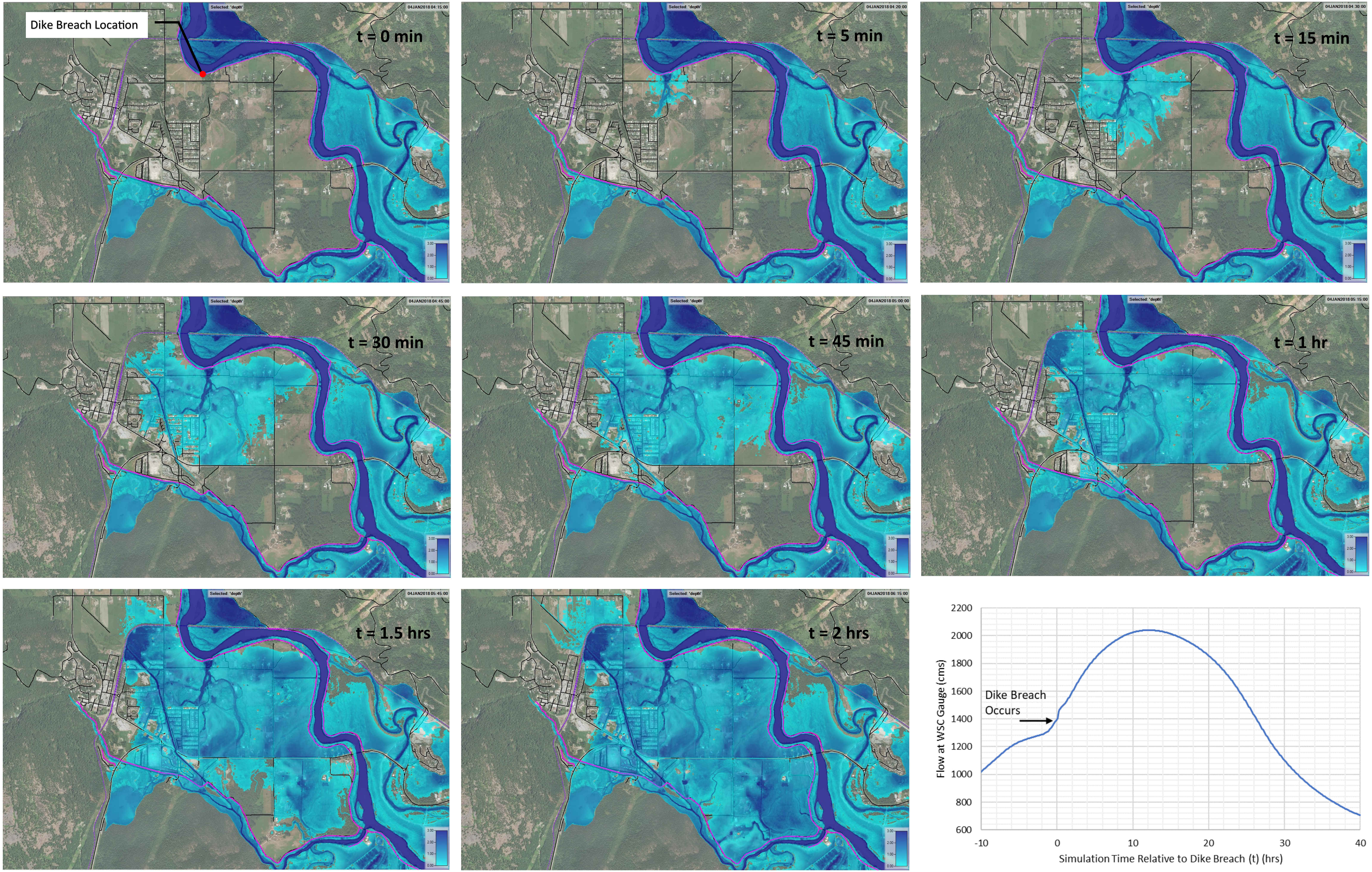
Dike Breach #2—Miller Lillooet A



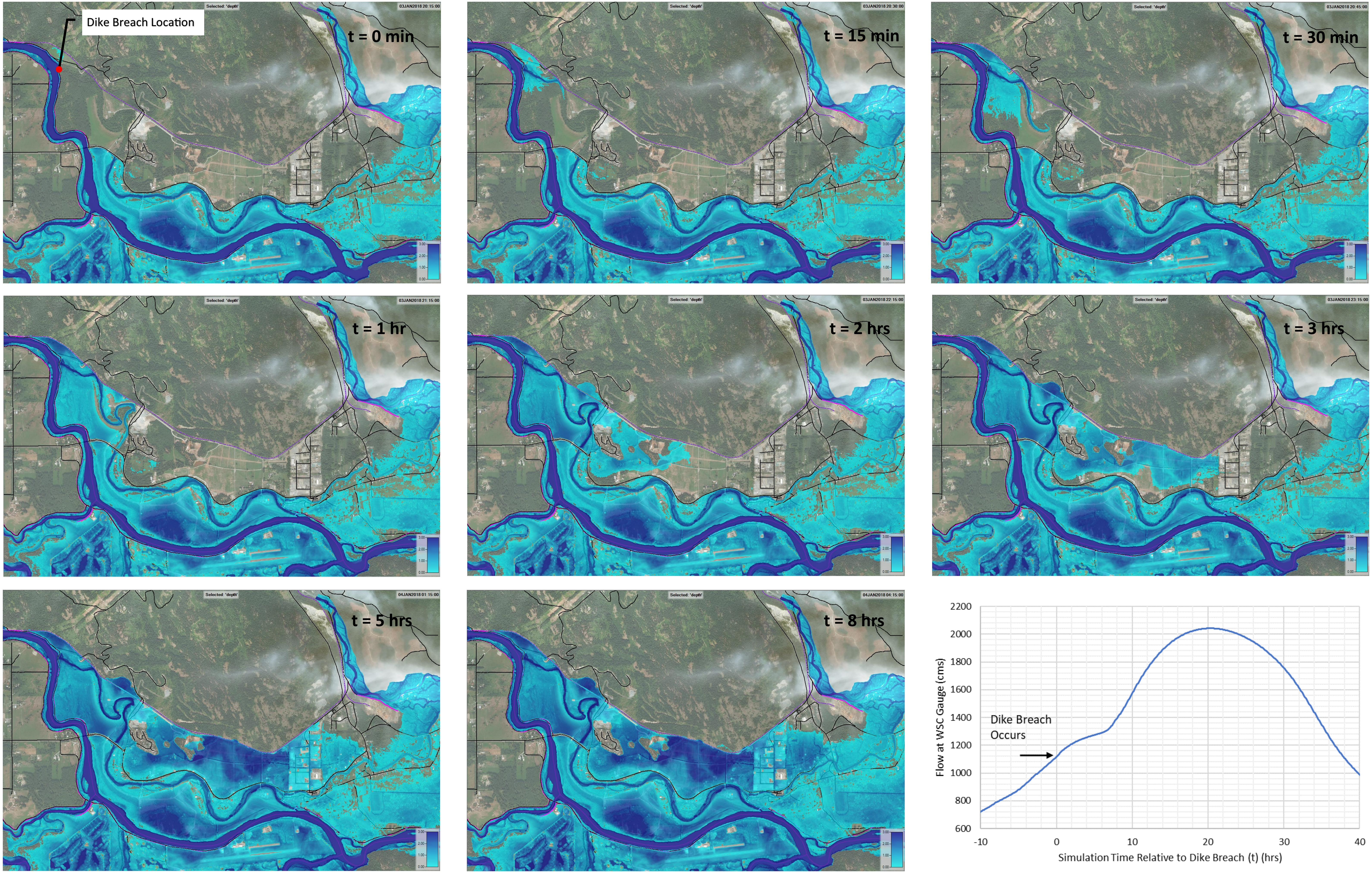
Dike Breach #3—Miller Lillooet A



Dike Breach #4—Miller Lillooet A



Dike Breach #5—Ayers Dike Breach



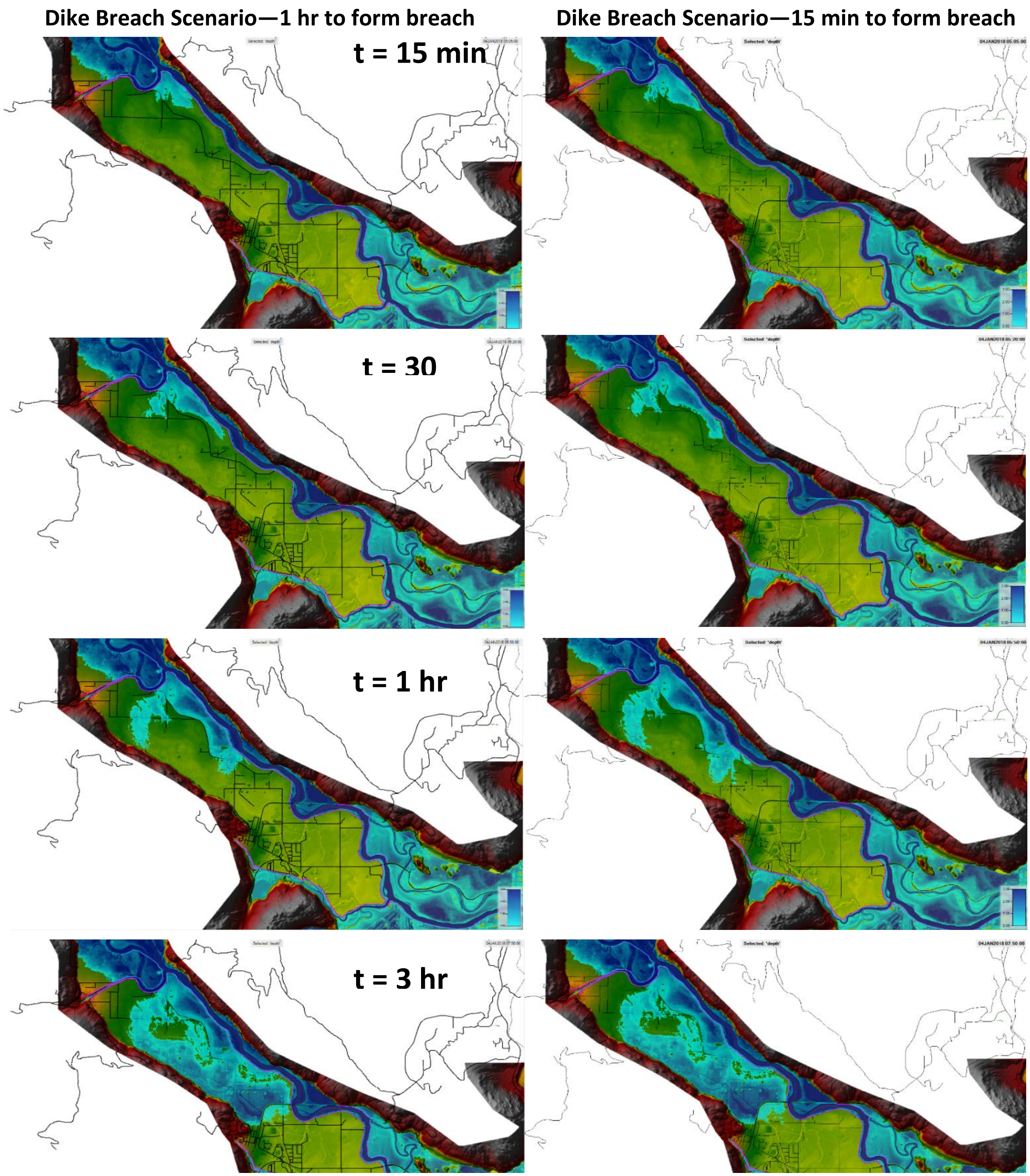


Figure 5-14 Dike breach sensitivity plot

5.6 Model Limitations and Uncertainties

Some uncertainty is associated with all hydraulic model outputs and consideration should be given to the associated accuracy and limitations. The output from the Lillooet River HEC-RAS2D hydraulic model is limited by the capabilities of the DEM, the hydraulic modelling and breach assumptions made.

5.6.1 DEM

The limitations and assumptions associated with the DEM include:

- The 2016 LiDAR surveyed by EMBC did not cover the full extents of Pemberton Valley so the 2009 LiDAR was used to fill in the gaps (roughly 30% of the entire DEM). The older LiDAR may contain inaccuracies caused by river channel shifts and other changes in the floodplain.

- Due to the high flow conditions during the bathymetric surveys making data collection quite challenging, the upper ends of the Lillooet River and tributaries had sparser survey data than the rest of the study reaches. Some interpolation was applied to develop the channel geometry.

- For all the channels, a smoothing algorithm and professional judgement was applied to develop the surface geometry between survey points.

- During the bathymetric surveys, the Lillooet channel bed was partly mobile, with dunes of material visible in the data. The mobile bed conditions likely introduced some inaccuracies.

- Although specified to contain bare-earth data, the LIDAR used for developing the DEM may contain some artificially high points, especially in areas where the vegetation is dense, creating unrealistic “dry spots” for some floodplain model runs.

- Culverts, ditches/canals and other drainage features were not specifically modelled.

5.6.2 HEC-RAS2D

For the 2D unsteady flow computations, the software used the full 2D Saint-Venant equations. The 2D computational cells were pre-processed in order to develop detailed hydraulic property tables based on the underlying terrain. (This allowed for larger cells to be partially wet with the correct water volume based on the modelled water surface and DEM resolution). Although RAS2D is a sophisticated modelling tool, it has several basic assumptions and limitations:

- The model assumes a fixed geometry for the channel and floodplain in spite of bank erosion, scour, deposition and potential avulsions taking place during high flows.

- The absence of blockages, such as debris jams at bridge crossings and debris plugs at floodplain openings, is assumed.

- Dike breaches, other than those specifically modelled, are assumed not to occur. For the breaches that have been modelled, actual breach locations, parameters and opening sizes may vary.

- The model is as accurate as its calibration. The 200 year design flood is considerably larger than the calibration event (2118 m^3/s vs 956 m^3/s) and the calibrated roughness coefficients may not be representative of the higher flow. Some overprediction was observed in the calibration but roughness coefficients were not reduced as it was felt that the values applied represent lower bound coefficients.

- At the start of a flood simulation, the model floodplain is assumed to be dry although there may already be water in the form of localized ponding and runoff from precipitation. Also, a multi-peaked hydrograph may cause more severe flooding than the event simulated.

5.6.3 Dike Breaching

Some limitations and assumptions associated with the dike breach modelling include:

- The dike breach results are based on individual model runs and specific dike breach locations. The dikes may breach in any location and multiple dikes may breach at once. The actual pattern, extent and timing of breach floods may vary significantly from those assumed.

- For detailed breach assessments, geotechnical modelling of the dikes is carried out to develop suitable breach parameters. The breach parameters specified for this project are based on historic breaches but parameters for future failures could vary (e.g. the breach could open faster or slower, wider or more narrow than specified).

5.6.4 Summary Statement

Although a number of limitations were identified with the different hydraulic modelling components, the results have followed state-of-the-art modelling procedures and are considered sufficiently accurate for updating the design profile, preparing up-to-date floodplain mapping and other required mapping products. It is recommended that the flood profile developed herein replace the previous flood profile by KWL (2002). Similarly, it is recommended that the floodplain mapping described in Section 6 replace the mapping from 1993.

6 FLOOD MAPPING

6.1 Flood Map Products

Three types of map products were produced:

- Designated floodplain maps depicting 200-year flood levels plus a freeboard allowance.
- Flood depth maps for the 50, 100 and 200 year floods.
- Flood hazard maps showing a Hazard Rating based on flood depths and flow velocities.

The approaches for developing the mapping and the maps produced are described below. A comparison with previous mapping (MFLNRORD, 1993) is included.

6.2 Designated Floodplain Maps

The simulated 200 year water surface was mapped at 1:10,000 scale on the 17 sheets (11”x17”) that are included in the map section of this report. Freeboard, discussed in Section 6.2.1, was added to the simulated water level surface, and the combined surface was then mapped over the DEM and projected across the floodplain to delineate flood extents. The maps show flood extents with and without freeboard allowance. With freeboard included, the maps indicate the minimum level for construction at a certain point within the floodplain, referred to as the Flood Construction Level (FCL). The maps include isolines or lines corresponding to equal FCLs, generally in 0.5 m or 1 m increments.

Local governments (i.e. the Village of Pemberton and the Squamish Lillooet Regional District) and the Lil’wat First Nation have the authority to regulate new development in flood hazard areas. The new mapping could be designated by the responsible authorities to become the official floodplain mapping for the Lillooet River.

A number of notes are included on the ”Key Plan”, outlining map usage and limitations, and these notes should be read carefully. The concepts described in notes No. 1 and No. 4 are highlighted briefly below.

> *Note No. 1: The 200-year flood extents and FCLs are only mapped for the Lillooet River. The tributaries were modelled with flood flows coincident with the 200 year Lillooet event rather than tributary 200 year floods. The tributary inundation areas corresponding with these lower flows are cross-hatched on the mapping.*
>
> *Note No. 4: The location of dikes, roads and other infrastructure are shown on the maps. For the modelling, dike crests were assumed to be at current elevations and to remain intact, although during the 200 year flood simulation, the flood flow overtopped nearly the complete length of each Lillooet River dike. During an actual event dike breaching would likely occur, but it is not possible to predict breach locations.*

In some areas, a dike breach could increase flood levels and velocities (and the hazard rating) above those shown on the maps. Therefore, for sites in the Lillooet River floodplain behind existing dikes, it is recommended that the FCL should be either the FCL shown on the map or 1.0 m above the surrounding natural grade, whichever is higher.

GIS deliverables for the flood mapping are described in Appendix A.3.

6.2.1 Freeboard Requirements

Freeboard is added to provide a safety factor. The freeboard accounts for local variations in water level (such as standing waves, super-elevation at the outside of river bends, local turbulence) and uncertainty in the flood level simulations. Historically in British Columbia, the minimum freeboard allowance applied has been the greater of 0.3 m above the instantaneous (peak) flood event or 0.6 m above the daily flood event. For some rivers, freeboard should be increased to 1 m or more, to address greater uncertainty in the assessment or concerns regarding sediment deposition, debris blockages or ice jams (MWLAP, 2004).

In recent years, a minimum freeboard of 0.6 m has been frequently used with an instantaneous event6, as suggested in recent provincial guidelines for sea dikes (MOE, 2011) and as discussed in the EGBC professional practice guideline for floodplain mapping (EGBC, 2017).

Considering the potential for bed level changes in the Lillooet River and the uncertainty of climate change on future flood flows, a minimum freeboard allowance of 0.6 m is recommended.

The PVDD, SLRD, Lil'wat First Nation and Village of Pemberton may wish to define a higher level of protection for certain infrastructure or facilities, such as dikes, major transportation routes, hospitals, emergency response centers, communications centers, residences for the elderly, or schools.

6.2.2 Comparison with Previous Designated Floodplain Maps

The previous floodplain mapping was based on 1D modelling and completed in 1990. Since the flood extents are fairly insensitive to flood flow magnitudes (Section 6.3), the previous and new maps have similar inundation areas. As expected, there are significant increases in present FCLs due to the higher design flood flow. There are also large changes in the isoline configurations as 2D modelling offers more detail on water level variations across the floodplain. Dikes and raised roads have a large influence on water levels and are accounted for in 2D models.

Specific FCL increases cannot be identified as there are substantial variations in the datum between the two sets of maps. A general comparison suggests the following FCL increases:

- 1.5 – 2 m near Industrial Way outside of Pemberton, not far from Mount Currie.
- 1.5 – 2 m near the airport.

[6] A brief set of examples of use of a minimum of 0.6 m freeboard above the instantaneous flood flow within BC include flood hazard study and mapping in Prince George, the lower Fraser River, Maple Ridge, Squamish, and North Vancouver (KWL, 2014, 2017; NHC, 2008, 2014, 2016).

- 0.5 m near One Mile Lake
- 0.5 – 1 m in the area south of Pemberton by Pemberton Creek Left Bank Dike (e.g. south of Highway 99)
- 0.5 – 1 m near Airport Road Dike A and near the south end of Clover Road
- 0.5 – 1.0 m at Pemberton Secondary School and Pemberton & District Community Centre
- 2 m in areas north and west of the railway embankment (e.g. Collins Road)
- 1.5 m Upper end of Pemberton Meadows
- 1.5 m at top end of Hungerford Dike.
- 1.5 m at location where Ryan River enters the valley.

A direct comparison of the new 200- year profile with the KWL (2002) profile is also difficult due to datum shifts.

6.3 Flood Depth Maps

The flood depth maps were developed using the water surfaces simulated in the model without a freeboard allowance. The DEM surface was subtracted from the water level surface to show the flood depths across the floodplain. The flood depth maps are shown on seven 11”x17”sheets at 1:20,000 scale, as included in the map section of this report.

The flood depth maps correspond to the 50, 100 and 200 year floods on the Lillooet River. The colour shading references the criteria listed in Table 6-1, adapted from the national standard in Japan (EXCIMAP, 2007).

Inundation durations were not mapped. Durations are highly sensitive to the flood hydrograph, dike breaching and drainage patterns experienced. For the depth mapping, dike breaches were not considered.

A comparison of the different return period flood depth maps show remarkably little increase in flood extents between the 50 and 200 year floods but significant increases in depth. This is to be expected, considering the valley is relatively flat and has steep valley walls. During floods with a return period exceeding 50 years, most of the valley floor is flooded. On the other hand, the increases in flood depths confirm that flood levels are quite sensitive to the flow magnitudes. Since the 200 year design flood adopted for this project is much higher compared to KWL’s (2002) value, the standard of diking is now lower than previously believed.

Table 6-1 Flood Depth Criteria

Flood Depth (m)	Description
0 to 0.5	Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5 to 1.0	Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0 to 2.0	Ground floor flooded; residents evacuate.
2.0 to 5.0	First floor and often roof covered by water, residents evacuate.
> 5.0	First floor and often roof covered by water, residents evacuate.

6.4 Flood Hazard Maps

For the flood hazard maps, a velocity surface was extracted from the model and (as per the Flood Hazard Rating equation shown in Table 6-2) multiplied by the depth surface to create a hazard rating surface. This surface was then mapped over the DEM as shown on the seven 11”x17”sheets at 1:20,000 scale in the map section.

Similar to the depth mapping, the 50, 100 and 200 year return period floods were mapped, assuming no dike breaching.

Table 6-2 lists the different levels of flood hazard based on the UK DEFRA/Environmental Agency (2005).

For many parts of the floodplain the hazard rating increases significantly from the 50 to 200 year flood. Some of the highest flood hazard ratings (i.e. “Significant” and “Extreme”) apply to relatively large areas of the lower part of the Valley from Lillooet River Km 25 (just upstream of the Miller Creek confluence) to Lillooet Lake.

Table 6-2 Flood Hazard Ratings

Hazard Rating depth * (velocity + 0.5) (m·m/s)	Degree of Flood Hazard	Description
< 0.75	Low	**Caution** "Flood zone with shallow flowing water or deep standing water"
0.75 to 1.25	Moderate	**Dangerous for some** (i.e. children) "Danger: flood zone with deep or fast flowing water"
1.25 to 2.5	Significant	**Dangerous for most people** "Danger: flood zone with deep fast flowing water"
> 2.5	Extreme	**Dangerous for all** "Extreme danger: flood zone with deep fast flowing water"

7 CONCLUSIONS AND RECOMMENDATIONS

Based on the project findings, the following conclusions and recommendations are provided:

7.1 Conclusions

1) A number of significant Lillooet River floods have occurred in the past (1940, 1984, 1991, 2003 and 2016). In the 1950s large-scale channel straightening and lowering of Lillooet Lake was carried out and over time, a number of dikes and berms have been built. Despite these flood protection measures, the Pemberton Valley continues to be at high risk of flooding. Considering apparent increases in peak flows and reduced channel capacity due to aggradation, flood hazards are expected to increase with time.

2) Previous floodplain mapping and flood profile work for the valley used a range of survey datum. Although, it was possible to convert some previous results to the present datum (CGVD2013), full comparisons were not feasible.

3) The Lillooet River carries a high sediment yield and the channel is very dynamic. The degradation trend observed from the early 1950s to 2010, largely as a result of the river straightening and lowering of Lillooet Lake, abruptly reversed after the 2010 Meager Creek slide. Since 2011, the annual average channel bed elevation over the lower 35 km of the river has increased by about 0.4 m, with more substantial increases in localized areas downstream of the Miller Creek confluence and in the reach that extends upstream of the Ryan River confluence to RK 35. In the reach between the CN Rail Bridge and WSC Gauge the bed is increasing in the order of 0.07 m/year, which amounts to an increase in average bed elevation of about 0.5 m by 2025. Hydraulic modelling of deposition in the 1 km reach upstream of Highway 99 suggest that a 0.5 m material accumulation may raise flood levels by about 0.3 m.

4) A key finding from the geomorphology assessment is that sediment from the landslide deposit has increased the fine sediment composition of the bed material, which in turn will substantially increase the transport rate of gravel-sized sediment into the diked reach of the river. Even without further major slides and new sediment inputs from the Mt Meager Volcanic Complex, a substantial amount of gravel is anticipated to continue to be transported into the lower reaches for a several decades.

5) The analysis of flow records at WSC Gauge 08MG005, Lillooet River near Pemberton, suggests a change in the flow regime starting roughly around 1975. Prior to 1975, the annual peak flow was typically freshet generated but over the past 45 years the extreme annual peaks tend to occur in the fall as a result of rain on snow events. This change in flow regime has caused a distinct increase in flood flows, suggesting that more representative flood estimates are obtained if pre-1975 flood records are excluded from frequency analyses. The current 200 year flood estimate of 2,120 m^3/s is 39 % higher than KWL's estimate of 1,520 m^3/s (KWL, 2002). As based on EGBC

guidelines and analyses of peak flow trends, climate change may increase the flood peak estimate to 2,540 m^3/s by the end of century.

6) The 2D hydraulic model developed for simulating the 50, 100, and 200 year Lillooet River return period floods, may somewhat over-predict flood levels. This is primarily because the model assumes a fixed bed, whereas the channel will scour during high flood events. On the other hand, the model assumes that the channel is free of debris blockages and material depositions, which could potentially increase flood levels. Actual flood levels may deviate from those simulated.

7) The hydraulic model showed that all existing diking would be overtopped during the 200 year flood. Overtopping may commence at the 20 year flood level, but by the 50 year flood level, the diking is extensively compromised. The dike breaches simulated would have significant impact on access/egress in the area. Flood flows would in many areas inundate the floodplain within a few hours. Corresponding flow velocities would be very high and flood hazard ratings are categorized as significant or extreme in many locations.

8) Although the hydraulic model has a number of limitations, it is a useful tool developed by applying state-of-the-art techniques. The simulated flood extents are similar to those developed for the 1990 floodplain mapping. However, flood levels are generally much higher and FCL isoline patterns vary. The depth mapping developed shows depths of over 2 m for extended areas, resulting in inundation of the first floor of most housing in the valley.

7.2 Recommendations

1) Administrative authorities, residents and other stakeholders in the Pemberton Valley must be informed regarding increased flood hazards.

2) An up-to-date emergency response plan should be prepared, taking into account the increased flood hazards. Depending on the location and nature of a dike breach, the response time before hazardous flows block roads and reach developed areas may be as little as 30 minutes (e.g. Miller Lillooet Dike C breach scenario, just downstream from rail bridge).

3) It is recommended that the designated floodplain maps be adopted for the Lillooet River and that the FCLs shown on the mapping be applied to future development.

4) Additional modelling and mapping should be carried out to determine the 200 year flood levels on each tributary and to develop designated mapping specific to the tributaries. The present simulations used tributary flows coincident with the Lillooet River design flow, not the 200 year tributary flows. Mapping Birkenhead River needs to be a high priority for Lil'wat First Nation.

5) It is recommended that the provincial River Forecast Centre be made aware of flood hazards in the Pemberton Valley and that the importance of accurate and timely forecasts be emphasized.

6) Flood protection measures in the area need to be improved. It is recommended that:

- PVDD identifies critical dike upgrades. It is recognized that raising all diking and berms to the 200 year standard would be prohibitively expensive and likely impractical. Careful consideration must be given to what dikes can be improved and to what standard without negatively affecting adjacent unprotected areas. Consideration should be given to setting dikes back from the river to increase flow capacities.

- Local authorities review the depth and hazard rating maps and identify areas where dike breaching and flooding would have major impacts on existing development. Consideration should be given to relocating or floodproofing housing and other development in critical areas.

- MOTI and other agencies identify areas where road and rail access/ egress can be improved to allow transport during high floods.

- The feasibility of installing sediment traps or sediment control structures upstream of the FSR Bridge be assessed.

- The effectiveness of the ongoing sediment management program in the lower reaches be reviewed and removal volumes increased. (The model simulations indicate that future sedimentation will have a substantial impact on flood levels, and without a rigorous sediment management program in place aggradation of the channel bed will reduce the effectiveness of the dikes.)

- Consideration be given to ensuring access to higher elevation areas in the valley that residents/ domestic animals can quickly be evacuated to.

7) The hydraulic model must be updated over time. Considering the significant aggradation taking place, the river channel should be monitored and re-surveyed every 5-10 years and the model updated as required. Major changes within the floodplain should be included in the model, such as raised dikes, roads or fill areas. (With a robust model readily available, updating portions of the DEM and hydraulic model is relatively straightforward.)

8) 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 reinstalled 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 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.)

10) Over time, apparent trends in observed peak flows should be monitored and potential changes in flows due to climate change be reviewed.

11) During large floods, high watermarks should be collected and corresponding flood flows observed to allow for future model calibration and validation updates.

8 REFERENCES

A Strickler (1923). Contributions to the Question of a Velocity Formula and Roughness Data for Streams, Channels and Closed Pipelines (Translation T-10).

APEGBC (2017). Flood Mapping in BC, APEGBC Professional Practice Guidelines, V1.0. [online] Available from: https://www.apeg.bc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx.

Ausenco-Sandwell (2011). Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use: Sea Dike Guidelines. Report prepared by Ausenco-Sandwell for BC Ministry of Environment. 59 pp.

Bathurst, J. C. (1985). Flow resistance estimation in mountain rivers. Journal of Hydraulic Engineering, 111(4), 625–643.

BC Ministry of Water, Land, and Air Protection (2004). Flood Hazard Area Land Use Management Guidelines. 72 pp.

Brownlie, W. R. (1981). Compilation of Alluvial Channel Data: Laboratory and Field. California Institute of Technology, Pasadena.

Decker, F., Fougberg, M., and Ronayne, M. (1978). Pemberton: The History of a Settlement. Pemberton Pioneer Woman, Pemberton, BC, Canada.

Eaton, B., and Moore, R. D. (2010). Regional Hydrology. Compendium of Forest Hydrology and Geomorphology in British Columbia (pp. 85–110). BC Ministry of Forests and Range, Forest Science Program.

EGBC (2018). Legislated Flood Assessments in a Changing Climate in BC, Version 2.0. [online] Available from: https://www.egbc.ca/getmedia/4264e239-5720-40c7-80fa-cf0f03eda400/V2-0-Leg-Flood-Assessments-in-BC-FINAL_2018-07-16-Web.pdf.aspx (Accessed 20 July 2018).

Engelund, F., and Hansen, E. (1967). A monograph on sediment transport in alluvial streams. Technical University of Denmark 0stervoldgade 10, Copenhagen K. [online] Available from: http://resolver.tudelft.nl/uuid:81101b08-04b5-4082-9121-861949c336c9 (Accessed 26 June 2018).

EXCIMAP (2007). Flood mapping: a core component of flood risk management - Atlas of Flood Maps: Examples from 19 Countries, USA and Japan. European Commission - Environment. [online] Available from: http://ec.europa.eu/environment/water/flood_risk/flood_atlas/ (Accessed 13 August 2018).

Fleming, S. W., Whitfield, P. H., Moore, R. D., and Quilty, E. J. (2007a). Regime-dependent streamflow sensitivities to Pacific climate modes cross the Georgia–Puget transboundary ecoregion. Hydrological Processes, 21(24), 3264–3287. doi:10.1002/hyp.6544.

Fleming, S. W., Whitfield, P. H., Moore, R., and Quilty, E. J. (2007b). Regime-dependent streamflow sensitivities to Pacific climate modes cross the Georgia–Puget transboundary ecoregion. Hydrological Processes, 21(24), 3264–3287.

Guthrie, R. H., Friele, P., Allstadt, K., Roberts, N., Evans, S. G., Delaney, K. B., Roche, D., Clague, J. J., and Jakob, M. (2012). The 6 August 2010 Mount Meager rock slide-debris flow, Coast Mountains, British Columbia: characteristics, dynamics, and implications for hazard and risk assessment. Natural Hazards and Earth System Sciences, 12(5), 1277–1294. doi:10.5194/nhess-12-1277-2012.

Hornik, K. (2016). The R FAQ. [online] Available from: www.r-project.org.

Jarrett, R. D. (1984). Hydraulics of high gradient streams. Journal of Hydraulic Engineering, 110(11), 1519–1539.

Jones, J. A., and Perkins, R. M. (2010). Extreme flood sensitivity to snow and forest harvest, western Cascades, Oregon, United States. Water Resources Research, 46(12), 21. doi:10.1029/2009WR008632.

KWL (2002). Engineering Study for Lillooet River Corridor. Final Report. Report prepared by Kerr Wood Leidal Associates Ltd for B.C. Ministry of Water, Land and Air Protection. 204 pp.

KWL (2005). Lillooet River - October 2003 Flood: High Water Mark Survey. Technical Memorandum. Report prepared by Kerr Wood Leidal Associates Ltd for B.C. Ministry of Water, Land and Air Protection. 11 pp.

KWL (2009). Pemberton Valley Dyking District - 2009 Lillooet Lake Survey and Compilation of Historica Survey Data: Overall Plan and Survey Notes.

KWL (2014). Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment - Floodplain Development Permit Area, Flood Construction Level Development and Use.

KWL (2017). District of Squamish Integrated Flood Hazard Management Plan - Final Report, October 2017. Prepared by Kerr Wood Leidal Associates Ltd. for District of Squamish. 251 pp. [online] Available from: https://squamish.ca/assets/IFHMP/1117/20171031-FINAL_IFHMP_FinalReport-compressed.pdf (Accessed 3 May 2018).

Limerinous, J. T. (1970). Determination of the Manning coefficient from measured bed roughness in natural channels.

Maynord, S. T. (1991). Flow resistance of riprap. Journal of Hydraulic Engineering, ASCE, 117(6), 687–696.

MFLNRO (2018). Flood Protection Structures in B.C. - Province of British Columbia. British Columbia. [online] Available from: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/dike-management/flood-protection-structures (Accessed 13 August 2018).

Neiman, P. J., Ralph, M. F., Wick, G. A., Lundquist, J. D., and Dettinger, M. D. (2008). Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West Coast of North America based on eight years of SSM/I satellite observations. 9(1), 22–47. doi:10.1175/2007JHM855.1.

NHC (2008). Flood Risk Evaluation and Flood Control Solutions, Phase 1. (34920). Report prepared by Northwest Hydraulic Consultants for City of Prince George.

NHC (2014). Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios (GS14LMN-035). Report prepared by Northwest Hydraulic Consultants for BC Ministry of Forests Lands and Natural Resource Operations. 202 pp.

NHC (2016). North Alouette and South Alouette Rivers Additional Floodplain Analysis: Phase 2 - Technical Investigations Completion Report. Report prepared by NHC for the City of Maple Ridge. 46 pp.

Obedkoff, W. (2003). Streamflow in the Lower Mainland and Vancouver Island, Aquatic Information Branch, Ministry of Sustainable Resource Management, Province of British Columbia. 186 pp.

Radic, V., Cannon, A., Menounos, B., and Gi, N. (2015). Future changes in autumn atmospheric river events in British Columbia, Canada, as projected by CMIP5 global climate models. Journal of Geophysical Research: Atmospheres, 120(18), 9279–9302.

van Rijn, L. C. (1984). Sediment transport, Part I: bed load transport. Journal of Hydraulic Engineering, 110(10), 1431–1456.

Spry, C. M., Kohfeld, K. E., Allen, D. M., Dunkley, D., and Lertzman, K. (2014). Characterizing pineapple express storms in the lower mainland of British Columbia, Canada. Canadian Water Resources Journal/Revue canadienne des ressources hydriques, 39(3), 302–323.

UK DEFRA / Environmental Agency (2005). Flood Risk Assessment Guidance for New Development - Phase 2: Framework and Guidance for Assessing and Managing Flood Risk for New Development (R&D Techincal Report FD2320/TR2). Technical Report. Defra / Environment Agency, Flood and Coastal Defence R&D Programme, London, UK. 384 pp. [online] Available from: http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/FD2320_3364_TRP_pdf.sflb.ashx (Accessed 13 August 2018).

Waylen, P., and Woo, M. (1982). Prediction of annual floods generated by mixed processes. Water Resources Research, 18(4), 1283–1286.

Wong, M., and Parker, G. (2006). Reanalysis and correction of bed-load relation of Meyer-Peter and Müller using their own database. Journal of Hydraulic Engineering, ASCE, 132(11), 1159–1168. doi:10.1061/(ASCE)0733-9429(2006)132:11(1159).

Appendix A: Survey Data

A.1 Spatial Data Collected
A.2 Vertical Datum Memo
A.3 Spatial Data Deliverables

SPATIAL DATA COLLECTED

				VERTICAL DATUM		
TITLE	DATE OF DATA	COVERAGE AREA	SOURCE	ORIGINAL	CONVERSION TO CGVD2013	COMMENT
Orthoimagery						
NHC 2017 Orthophoto	12-Oct-2017	Study Area	NHC	n.a.	n.a.	Collected during low flow conditions (approximately 36 cms); used for reference and for geomorphic assessment
EMBC 2016/2017 Orthophoto	Jun 2016 to Sep 2017	Study Area	GeoBC	n.a.	n.a.	Used as base image for flood maps
2009 Orthophoto	2009	Study Area	KWL for PVDD	n.a.	n.a.	Used for reference and for geomorphic assessment
2013 Air Photos	23-Aug-2013	Study Area	MFLNRORD	n.a.	n.a.	Used for geomorphic assessment
2010 Digital Globe Imagery	22-Aug-2010	Study Area	Google Earth	n.a.	n.a.	Used for geomorphic assessment
Survey (Topography and Bathymetry)						
NHC Combined Topographic & Bathymetric DEM for Hydraulic Modelling	various	Study area	NHC	CGVD2013	n.a.	Based on various sources listed below; intended for hydraulic modelling purposes only
NHC 2017 Bathymetric Survey	2017	Study area	NHC	CGVD28 HTv2.0	NHC converted using NRCan GPS-H	Incorporated in model DEM
NHC 2017 Topographic Survey	2017	Study area	NHC	CGVD28 HTv2.0	NHC converted using NRCan GPS-H	Incorporated in model DEM
Highmark 2017, 2018 Dike and Culvert Survey	2017 & 2018	Study area	Highmark	CGVD2013	n.a.	Incorporated in model DEM
Highmark 2017 Pemberton Creek Survey	2017	Pemberton Creek	Highmark	CGVD28 HTv2.0	Highmark converted	Incorporated in model DEM
Highmark 2017 Miller Creek Survey	2017	Miller Creek	Highmark	CGVD28 HTv2.0	Highmark converted	Incorporated in model DEM
EMBC 2016/2017 Lidar	Apr 2016 - Jul 2017	Study area	GeoBC	CGVD2013	n.a.	Incorporated in model DEM Metadata: average point density = 12 points per sq. metre; horizontal accuracy <= 65 cm; vertical accuracy <= 15 cm. Bare earth point cloud was used to derive a 1.0 m resolution DEM that was incorporated into the model DEM and used for mapping flood extents; bare earth Lidar has vegetation points filtered out however there are locations where the Lidar did not penetrate thicker vegtetation and as such there may be small articifical high points within the DEM.
UNBC 2015 Lidar	2015	Upstream of FSR bridge	UNBC (B.Menounos); J.Clague	CGVD2013	n.a.	Used for geomorphic assessment
NHC/Doug Bush 2014 Birkenhead River Survey	2014	Birkenhead River	NHC	CGVD28 HT97 (assumed)	NHC converted using Trible Business Centre and NRCan GPS-H	Incorporated in model DEM

				VERTICAL DATUM		
TITLE	DATE OF DATA	COVERAGE AREA	SOURCE	ORIGINAL	CONVERSION TO CGVD2013	COMMENT
KWL/Atek 2011 Lillooet River Survey	May 2011	Lillooet River	KWL	CGVD28 HTv2.0	NHC converted using NRCan GPS-H	Incorporated in model DEM
KWL/Atek 2011 Lillooet River Survey	Nov 2011	Lillooet River	KWL	CGVD28 HTv2.0	NHC converted using NRCan GPS-H	Used for reference
McElhanney 2009 Lidar	2009	Study area	PVDD	CGVD28 HTv2.0 (assumed)	not converted	Incorporated in model DEM, to fill gaps in 2016 Lidar DEM
KWL/Bazett Land Surveying 2009 Lillooet Lake Survey	April 2009	Lillooet Lake	PVDD	CGVD28 HTv2.0 (assumed)	NHC converted using NRCan GPS-H	Incorporated in model DEM
KWL 2006 Ryan River Survey	2006	Ryan River	KWL	CGVD28 (WRS benchmarks) (assumed)	not converted	Used for geomorphic assessment
KWL 2000 Lillooet River and Tribuaries Survey	2000	Lillooet River & Tribs	KWL	CGVD28 HTv2.0 (assumed)	NHC converted using NRCan GPS-H	Used for geomorphic assessment
Hydrometric Stations						
WSC Active and Discontinued Hydrometric Stations	various	Study area	DataBC	n.a.	n.a.	Location of WSC stations in the area
NHC Hydrometric Station	2017	Study area	NHC	n.a.	n.a.	Location of NHC-operated station on Lillooet River at FSR Bridge
Highwater Marks						
2016 Highwater Marks	2016	Study area	NHC	CGVD2013	n.a.	Surveyed by NHC based on PVDD information
2003 Highwater Marks	2003	Study area	NHC	CGVD28 HT97 (assumed)	NHC converted	Digitized by NHC based on KWL report
Flood Control Structures						
Dikes	various	Study area	DataBC, NHC	n.a.	n.a.	Provincially-mapped dikes, with alignments updated by NHC based on survey and Lidar
Raised Transportation Features	various	Study area	NHC	n.a.	n.a.	Roads and rail lines that act as flood control structures
Administrative Boundaries						
PVDD Administrative Boundary	unknown	Study area	SLRD	n.a.	n.a.	None
Village of Pemberton Boundary	unknown	Study area	DataBC	n.a.	n.a.	None
Lil'wat First Nation Boundary	2011	Study area	Lil'wat First Nation	n.a.	n.a.	Differs from boundary available from GeoBC
Transportation						
Roads - GeoBC Digital Roads Atlas		Study area	DataBC	n.a.	n.a.	
Rail Lines - National Railway Network		Study area	GeoGratis	n.a.	n.a.	
Land Cover / Land Use						
Land Cover	2009	Study area	NHC	n.a.	n.a.	Land cover digitized by NHC based on 2009 orthoimagery (as 2016 orthoimagery was not available at the time); required for roughness mapping in hydraulic model

30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: 604.980.6011
Fax: 604.980.9264

MEMO

To:	**3002903 Project File**	Date:	24-May-2018
From:	Sarah North – NHC	NHC Ref. No.	3002903
Re:	**Vertical Datums for PVDD Lillooet River Flood Mapping Study Memo**		

BACKGROUND

Several vertical datums are in use for the Lillooet River study area:

- CGVD2013 – the new vertical datum for Canada;
- CGVD28, represented by the HTv2.0 geoid model – the previous standard vertical datum for Canada;
- CGVD28, represented by the HT97 geoid model – an earlier version of CGVD28; and
- A variation of CGVD28 based on Water Resource Monuments.

CGVD2013

CGVD2013 is a new vertical datum for Canada, designed for modern positional instrumentation such as GPS. It is gradually being adopted across the country and the province. CGVD2013 will replace CGVD28 (HTv2.0). Natural Resources Canada (NRCan) and the BC government have information online:

- http://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9054
- https://www2.gov.bc.ca/gov/content/data/geographic-data-services/georeferencing/vertical-reference-system

The Province of BC is expected to officially adopt CGVD2013 on September 1st, 2018 (Brad Hlasny, email, 01-May-2018).

CGVD28 (HTv2.0)

The previous vertical datum was CGVD28, represented by the HTv2.0 geoid model (height transformation calculated in the 2002 epoch). This datum is still commonly used for many surveys in BC.

In BC, differences between CGVD28 (HTv2.0) and CGVD2013 are from a few centimetres up to 50 cm. Differences in the Lillooet area are around 35 cm.

northwest hydraulic consultants

30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: 604.980.6011
Fax: 604.980.9264

CGVD28 (HT97)

There was also an older geoid representation of CGVD28, called HT97 (height transformation calculated in the 1997 epoch). HT97 is rarely used for surveying in BC today. Vancouver Island is one place where HT97 benchmarks are commonly seen, but are gradually being phased out. Older generation federal benchmarks, in HT97, are still seen on the mainland as well.

Differences between HT97 and HTv2.0 can be as high as 20 cm (W.Skitmore, pers.comm.).

CGVD28 (WRS Benchmarks)

For the Pemberton area, there is an added complication. Surveys that refer to the CGVD28 datum may be using a different adjustment of the datum, which has a 20-30 cm difference from CGVD28 (HTv2.0). Johnathan Lunn of Highmark Land Surveying and Engineering Ltd. provided an explanation (J.Lunn, email, 23-Oct-2017):

> "…many surveys in the Pemberton area are controlled by Water Resource benchmarks (WRS) set by the Province in the late 80's based [on] the nearby federal benchmarks. These [WRS] benchmarks referenced the floodplain mapping used at that time, which was written into many of the restrictive covenants for flood construction by the SLRD and VoP. I believe a readjustment of the federal network occurred after this mapping was completed and the WRS monuments were not adjusted to match. This has led to a difference of approximately 20-30 centimetres from the previous adjustment depending on the WRS monument used. Most topographic surveys in the Pemberton area reference the WRS monuments rather than the federal benchmarks, and are still referred to as "Geodetic" or CGVD28 elevations even though they reference a different adjustment. This is the reason for the 60 cm [difference in comparison to CGVD2013] rather than 35 cm. Hopefully the SLRD and VoP will adopt the new datum in the future to eliminate the confusion."

DATUM CONVERSION METHODS

CGVD28 (HTv2.0) TO CGVD2013

NRCan provides information and a free software tool, GPS-H, for converting between CGVD28 (HTv2.0) and CGVD2013. The tool can be used online, or there is a version that can be downloaded and installed locally:

- http://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9054#_Toc372901507
- http://webapp.geod.nrcan.gc.ca/geod/tools-outils/gpsh.php

NHC has also developed a difference grid for BC that can be used to adjust between CGVD2013 and CGVD28 (HTv2.0) using GIS software.

northwest hydraulic consultants

30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: 604.980.6011
Fax: 604.980.9264

CGVD28 (HT97) TO CGVD28 (HTv2.0)

Conversion between HT97 and HTv2.0 can be done using Trimble Business Centre survey software, if the survey ellipsoid is known.

Alternately, NHC could develop a difference grid for conversion between HT97 and HTv2.0 using survey software and GIS software. This was not done, as it was not required for the current project.

CGVD28 (HT97) TO CGVD2013

NHC developed a difference grid for BC that can be used to adjust between CGVD2013 and CGVD28 (HT97) using survey software and GIS software.

CGVD28 (WRS BENCHMARKS) TO CGVD28 (HTv2.0) OR CGVD2013

There is no straightforward way to convert from CGVD28 (WRS Benchmarks) to a standard vertical datum.

Options include:

1. Resurvey the WRS Benchmarks to CGVD2013, then adjust the previous surveys using this information.
    - Would need to resurvey WRS Benchmarks that are referenced in the previous surveys.
    - Would need to know the original surveys of these benchmarks, to determine the difference.
    - Many of the WRS Benchmarks are difficult to locate in the field.
    - To date, NHC has not pursued this option.
2. Apply an approximate global shift to all the data, based on 20-30 cm difference between CGVD28 (WRS Benchmarks) and CGVD28 (HTv2.0) cited by J.Lunn.

PROJECT DATA

The CGVD2013 vertical datum will be used for this project, for several reasons:

- Canada has adopted CGVD2013. The province is in the process of migrating to this new datum.
- The 2016 Lidar data is already in this datum.
- There is confusion about the use of the CGVD28 datum in the Pemberton area, for surveys that used the WRS benchmarks that were not readjusted to the federal benchmarks. Adopting CGVD2013 should avoid further confusion in future.

A summary of vertical datums for key datasets used in this project is presented in Appendix X.

END.

TITLE	DATE OF DATA	COVERAGE AREA	SOURCE	Key Attribute Description	Description
Flood Mapping					
FCL Isoline	2018	Lillooet River (no tribs)	NHC	Isoline1 = contour created from wse grid Label = used for labelling with proper significant figures	FCL Isolines smoothed from W.S.E. grid with 0.6m freeboard added to it
200-year Flood Extents	2018	Lillooet River & tributaries	NHC	Type = distinguishes between flood inundation extents and areas of freeboard	200-year flood extents with areas of 0.6m freeboard
50-year Flood Hazard Grid	2018	Lillooet River & tributaries	NHC		depth x (velocity + 0.5) of 50-year event
100-year Flood Hazard Grid	2018	Lillooet River & tributaries	NHC		depth x (velocity + 0.5) of 100-year event
200-year Flood Hazard Grid	2018	Lillooet River & tributaries	NHC		depth x (velocity + 0.5) of 200-year event
50-year Depth Grid	2018	Lillooet River & tributaries	NHC		direct output from model
100-year Depth Grid	2018	Lillooet River & tributaries	NHC		direct output from model
200-year Depth Grid	2018	Lillooet River & tributaries	NHC		direct output from model
Tributary Areas	2018	Tributaries only	NHC		
Annotation					
Flow Direction Arrows	2018	Lillooet River & Tributaries	NHC	rotation = angle arrow points at	Digitized by NHC to use on designated floodplain maps, flood hazard maps, and flood depth maps
PVDD Annotation	2018	Lillooet River & Tributaries	NHC		Digitized by NHC to use on designated floodplain maps, flood hazard maps, and flood depth maps
First Nation Annotation	2018	Lillooet River & Tributaries	NHC		Digitized by NHC to use on designated floodplain maps, flood hazard maps, and flood depth maps
Dike Annotation	2018	Lillooet River & Tributaries	NHC		Digitized by NHC to use on designated floodplain maps, flood hazard maps, and flood depth maps
Stream Network Annotation	2018	Lillooet River & Tributaries	NHC		Digitized by NHC to use on designated floodplain maps, flood hazard maps, and flood depth maps
Cartography					
Strip Map Panel Index - 1:20,000	2018	Study Area	NHC	PageNumber = Panel ID Left = page to the left Right = page to the right Angle = text rotation Scale = scale of panel	Used for Designated Floodplain map book
Strip Map Panel Index - 1:10,000	2019	Study Area	NHC	PageNumber = Panel ID Left = page to the left Right = page to the right Angle = text rotation Scale = scale of panel	Used for Flood Hazard and Depth map books
Structures					
Flood Control Structures	Various	Study Area	DataBC, NHC	DikeName = name of dike	Provincially-mapped dikes, with alignments updated by NHC based on survey and Lidar

Raised Transportation Features	Variouis	Study Area	NHC		Roads and rail lines that act as flood control structures
Highwater Marks					
2016 Highwater Marks	2016	Study Area	NHC	CGVD2013	n.a.
2003 Highwater Marks	2003	Study Area	NHC	CGVD28 HT97 (assumed)	NHC converted
Survey (Topography & Bathymetry)					
NHC combined topographic & bathymetric DEM for hydraulic	various	Study Area	NHC		based on various sources listed in Appendix A - CGVD2013
NHC combined topographic & bathymetric DEM hillshade	various	Study Area	NHC		hillshade based on above topo

Appendix B: Geomorphic Atlas

Lillooet River Flood Mapping Study: Geomorphic Atlas

June, 2018

NHC Ref No. 3002903

Prepared for

Pemberton Valley Dyking District

Prepared by

Northwest Hydraulic Consultants Ltd.

North Vancouver, BC

Lillooet River Flood Mapping Study:

Geomorphic Atlas

Prepared for

Pemberton Valley Dyking District

Prepared by

Northwest Hydraulic Consultants

North Vancouver, BC

June, 2018

NHC Ref No. 3002903

Prepared by:

Andrew Nelson
30 August 2018
Andrew Nelson, M.Sc.
Staff | Geomorphologist

PROFESSIONAL PROVINCE OF W. P. HILSEN # 34522 BRITISH COLUMBIA GEOSCIENTIST
29 AUGUST 2018
Wil Hilsen, P.Geo
Associate | Geomorphologist

Reviewed by:

PROFESSIONAL PROVINCE OF D. G. McLEAN # 13220 BRITISH COLUMBIA ENGINEER
29-08-2018
David McLean, P.Eng., Ph.D.
Principal | Engineer

Monica Mannerström
Monica Mannerström, P.Eng., M.Eng.
Principal | Engineer

Introduction

NHC is working with the Pemberton Valley Dyking District to develop a series of new flood hazard maps for the Pemberton Valley. The Lillooet River carries a high sediment yield and is very geomorphically dynamic, therefore an important part of this study is an investigation of geomorphic processes along the river, as these may—over time—change the channel morphology, sediment load in the lower reaches, and capacity for conveyance of flood flows. A particularly important geomorphic control at the present time may be the very large Capricorn Creek landslide that occurred on Mount Meager in 2010, and so this atlas focuses on documenting changes related to this event.

The atlas starts with a brief summary of basin characteristics and a description of the volume and texture of sediment eroded from the landslide deposit, focuses on descriptions of approximately 5 to 10 km long channel segments, and concludes with plots of summary data describing patterns along the river.

Data Sources

Field Data

Fieldwork reported here was mostly conducted during the last week of August 2017. Flows at this time were relatively high, at Water Survey of Canada (WSC) gauge 08MG005 they fluctuated between about 180 and 280 m^3/s at gauge with daily variability in snow melt intensity. An overflight was conducted on 12 October 2017 to collect updated and detailed orthophotos of the river, the flow at this time was quite low, approximately 36 m^3/s, and water relatively clear, providing good visibility of bed forms in the channel. Channel survey, some results of which are presented here, was collected throughout summer 2017.

Geospatial Data

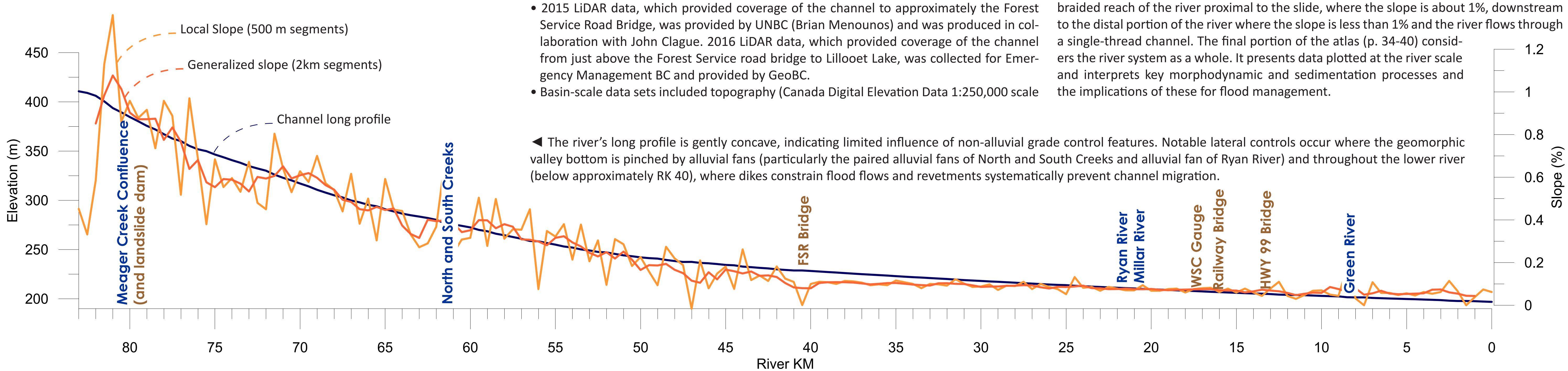
- Channel margins were digitized from aerial photos collected before the slide in 2009 (PVDD) and on 22 July 2010 (Digital Globe published in Google Earth) and after the slide on 23 August 2013 (MFLNRORD) and 12 October 2017 (NHC collected for this project). In addition an orthophoto from just after the landslide was reviewed in the area of the slide deposit.
- 2015 LiDAR data, which provided coverage of the channel to approximately the Forest Service Road Bridge, was provided by UNBC (Brian Menounos) and was produced in collaboration with John Clague. 2016 LiDAR data, which provided coverage of the channel from just above the Forest Service road bridge to Lillooet Lake, was collected for Emergency Management BC and provided by GeoBC.
- Basin-scale data sets included topography (Canada Digital Elevation Data 1:250,000 scale data), Landsat Imagery (1979-2018, accessed via the USGS's Landsat Look Interface), and geology (BC Columbia Digital Geology, Ministry of Energy, Mines and Petroleum Resources).

Historical Conditions

Information on historic geomorphic conditions provides a baseline for understanding changes resulting from the 2010 landslide. Much historical information is available from the work of KWL (2002), who completed a geomorphic investigation of the Lillooet River, based on fieldwork completed in November 2000 (survey) and 2001 (gravel sampling).

Atlas Organization

The first part of the atlas (p 2-3) considers the physiography of the whole Lillooet River basin. The second is organized geographically, starting with details of the 2010 landslide (p. 4-5) and then following the river from just above the 2010 Landslide dam downstream to Lillooet Lake, as shown on the index map below (p. 6-33). This moves from the steep, braided reach of the river proximal to the slide, where the slope is about 1%, downstream to the distal portion of the river where the slope is less than 1% and the river flows through a single-thread channel. The final portion of the atlas (p. 34-40) considers the river system as a whole. It presents data plotted at the river scale and interprets key morphodynamic and sedimentation processes and the implications of these for flood management.



◀ The river's long profile is gently concave, indicating limited influence of non-alluvial grade control features. Notable lateral controls occur where the geomorphic valley bottom is pinched by alluvial fans (particularly the paired alluvial fans of North and South Creeks and alluvial fan of Ryan River) and throughout the lower river (below approximately RK 40), where dikes constrain flood flows and revetments systematically prevent channel migration.

nhc

Physiography

The Lillooet River Basin drains approximately 3,100 km^2 of the Southern Coast Mountains of British Columbia. The basin is rugged and heavily glaciated, with characteristic relief of 1,500 to 2,000 m between ridges and the axial valley of the river and approximately 500 km^2 of glacier cover.

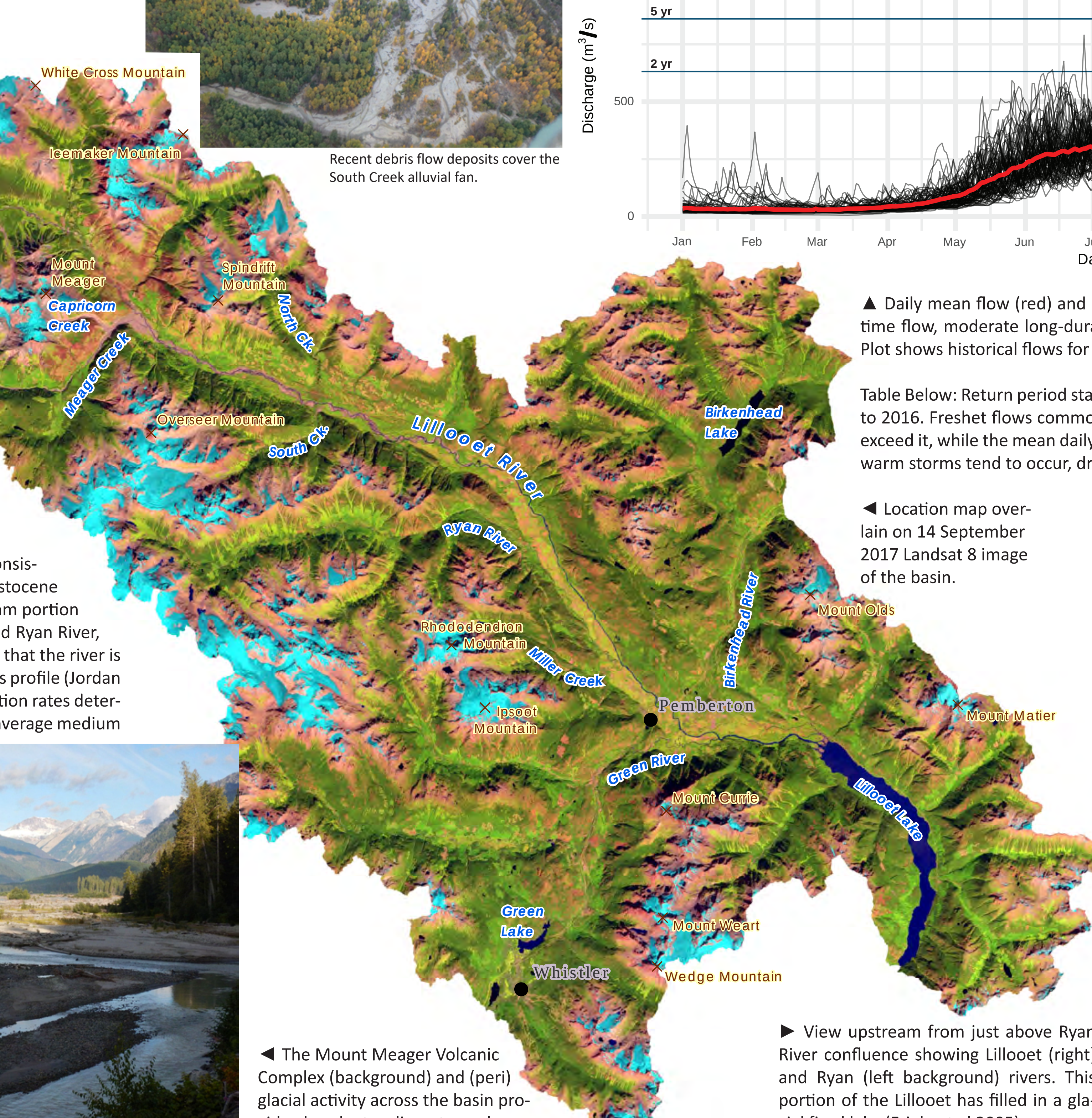
Most of the basin area is underlain by plutonic rocks, but quaternary volcanism at Mount Meager has produced an area of relatively erodible and unstable rock that is an important sediment source to the Lillooet River (Friele et al., 2005). Material derived from the Mount Meager volcanic complex has distinct lithology and geochemistry (Vogt, 2013) compared to the surrounding plutonic rocks, and so can be relatively readily traced downstream.

Jordan and Slaymaker (1991) combined observations of progradation of the Lillooet River Delta into Lillooet Lake with semi-quantitative inventory of major sediment sources along the river to develop a sediment budget for the system. They determined that the total yield was about 655,000 m^3/yr (plausible range from 273,000 to 1,037,000 m^3/yr) with the most important contributions from glaciers, debris flows, and extremely episodic but large landslides, mostly from the Mount Meager volcanic complex.

The Lillooet River flows through a glacially carved valley that has a very consistent width of slightly less than 2 km. The valley bottom lacks exposed Pleistocene glacial deposits and Holocene alluvial terraces (except in the most upstream portion of the river), but is instead covered by alluvium from the Lillooet River and Ryan River, and several large alluvial fans at the toe of steep tributaries. This indicates that the river is aggrading—on a geologic time scale—along the whole subject portion of its profile (Jordan and Slaymaker, 1991). Long-term (1,000-7,200 years ago) average aggradation rates determined from radiocarbon-dated drill cores have been 4.4 ± 1.3 mm/yr and average medium term (100-1,000 years ago) rates have been 3.4 ± 2.3 mm/yr (Friele et al. 2005).

In the early Holocene (approximatley 10ka), Lillooet Lake extended about 35 km upstream of its current location. But the Lillooet River delta has prograded into the lake at an average rate of about 6 m/yr, filling much of its volume (Friele et al. 2005). Periods of elevated aggradation and delta progradation rates (up to 15 m/yr) have been correlated to elevated sediment supply from mount meager due to eruptions or flank collapse landslides.

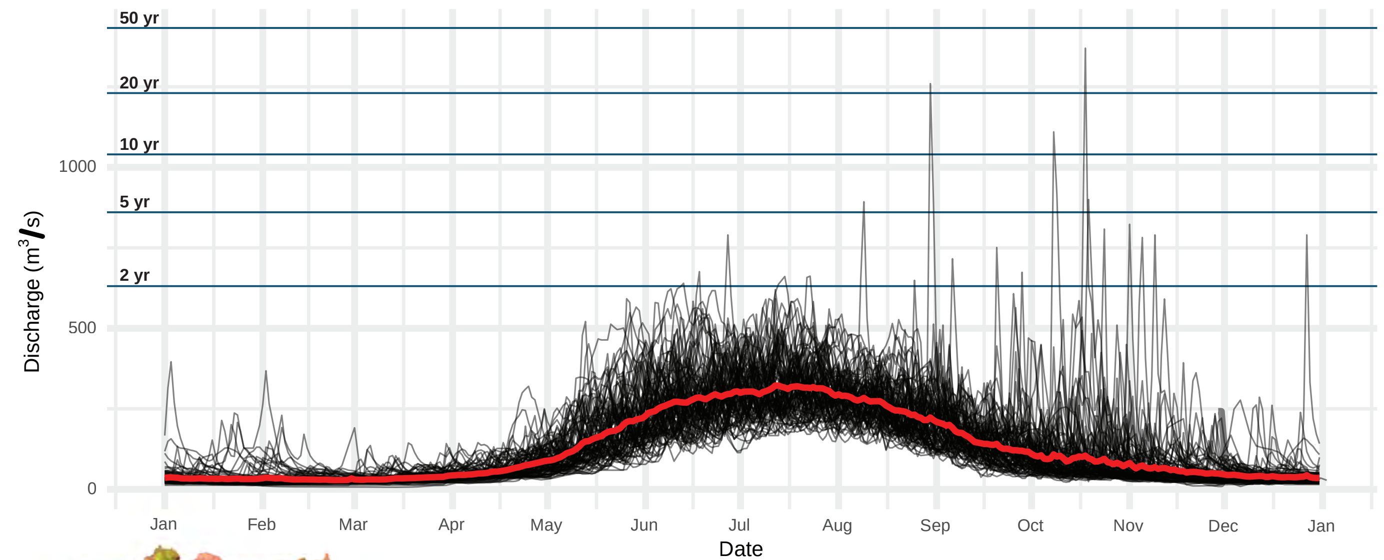
Recent debris flow deposits cover the South Creek alluvial fan.



◄ The Mount Meager Volcanic Complex (background) and (peri) glacial activity across the basin provide abundant sediment supply.

◄ Location map overlain on 14 September 2017 Landsat 8 image of the basin.

Hydrology



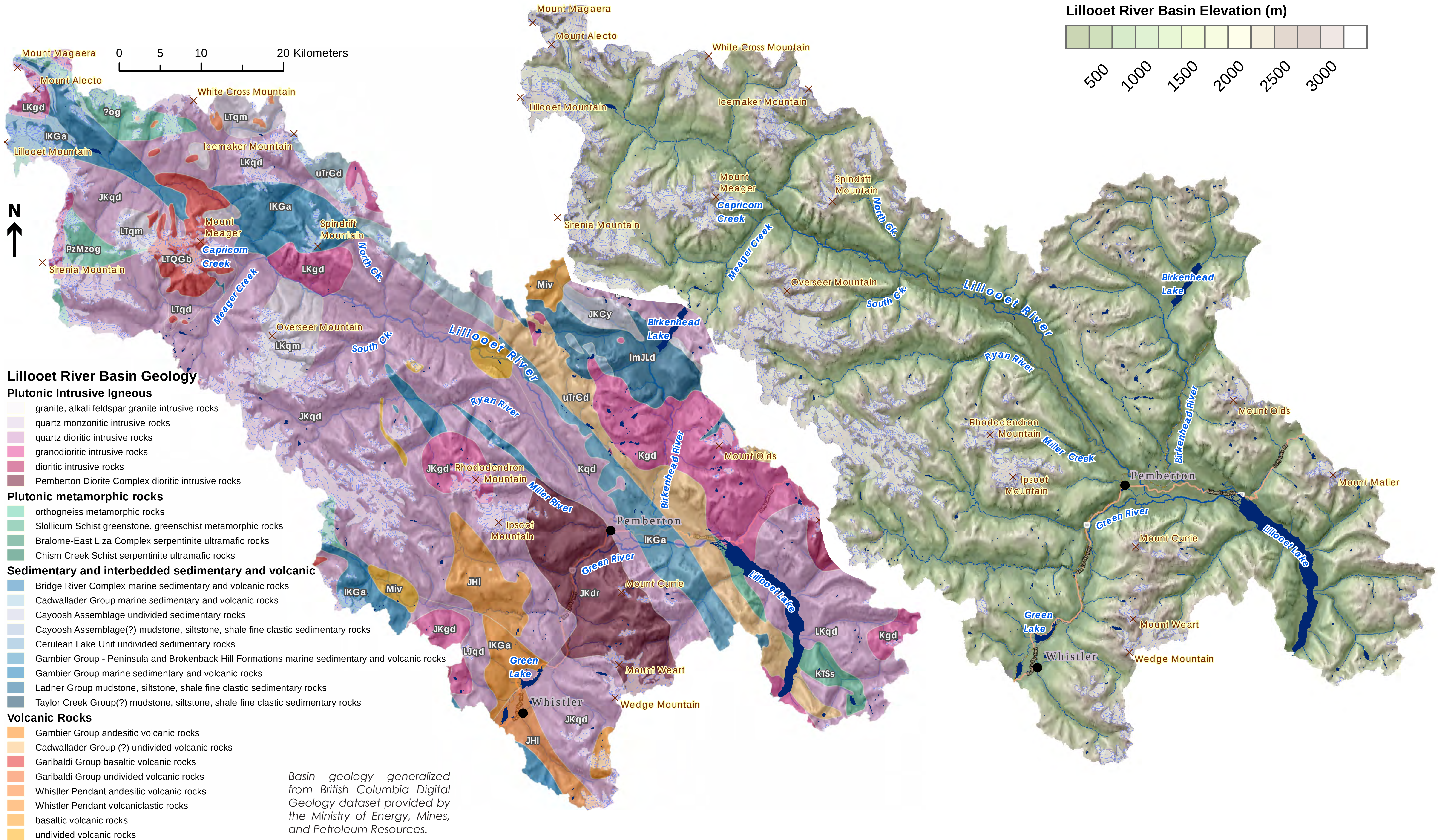
▲ Daily mean flow (red) and historic annual hydrographs showing pattern of low wintertime flow, moderate long-duration summer freshet high flows, and large autumn floods. Plot shows historical flows for WSC gauge 08MG005, Lillooet River near Pemberton.

Table Below: Return period statistics corresponding to 98 years of data recorded from 1914 to 2016. Freshet flows commonly approach the 2-year recurrence interval flow, but rarely exceed it, while the mean daily flow in autumn is lower but this is the period when wet and warm storms tend to occur, driving larger floods.

Lillooet River Flood Hydrology. Flows (m^3 s^{-1}) for gauge 08MG005.

Return Period (years)	Lower Bound (95% CI)	Best Estimate	Upper Bound (95% CI)
2	566	620	689
5	746	849	967
10	874	1031	1223
20	992	1223	1539
50	1127	1540	2158
100	1223	1810	2815
200	1312	2118	3677

► View upstream from just above Ryan River confluence showing Lillooet (right) and Ryan (left background) rivers. This portion of the Lillooet has filled in a glacial fjord lake (Friele et al 2005).



Basin geology generalized from British Columbia Digital Geology dataset provided by the Ministry of Energy, Mines, and Petroleum Resources.

nhc

Fluvial Remobilization of the 2010 Meager Landslide

The 2010 Meager Landslide mobilized about 4.9×10^7 m^3 of debris from the flank of Mount Meager and deposited this on the valley bottom near the confluence of Meager Creek and the Lillooet River (Guthrie et al. 2012). The rate of fluvial evacuation of sediment from the deposit was evaluated by comparing a surface developed by satellite photogrammetry from just after the slide—5 m resolution GeoEye from 22 August and 21 September 2010, described in Guthrie et al. (2012)—with LiDAR data collected in 2015. The difference between the two surfaces (below right) suggests that between 2010 and 2015, Meager Creek and the Lillooet River removed approximately 5.0×10^6 m^3 of sediment from the slide deposit. Some volume had already eroded from the slide mass prior to the acquisition of the satellite imagery from which the 2010 DEM was constructed. In the 2010 DEM, a channel 3 m deep through an area of about 74,000 m^2 is visible along the Lillooet River breaching the slide deposit and a channel about 5 m deep covering an area of about 75,000 m is visible along Meager Creek cutting through the main slide plug at the Capricorn Creek confluence. Combined, these add about 0.5×10^6 m^3 of material to the estimate of erosion from the slide deposit between its initial occurrence and 2015, for a total of 5.5×10^6 m^3.

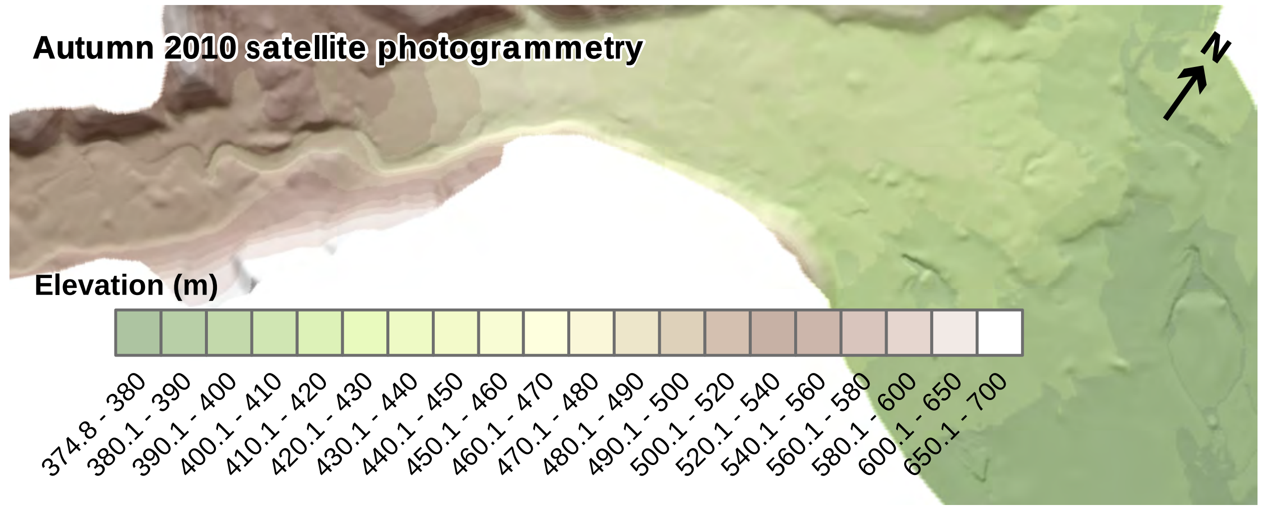
No detailed topographic data are available for 2017, but NHC collected a set of orthophotos, which can be used to evaluate lateral expansion of the area of post-slide fluvial erosion across the slide deposit. In conjunction with 2015 LiDAR data, these can be used to produce a minimum estimate of the volume of sediment eroded between 2015 and 2017. At least three additional factors may have contributed an additional volume of sediment—which may be quite substantial:

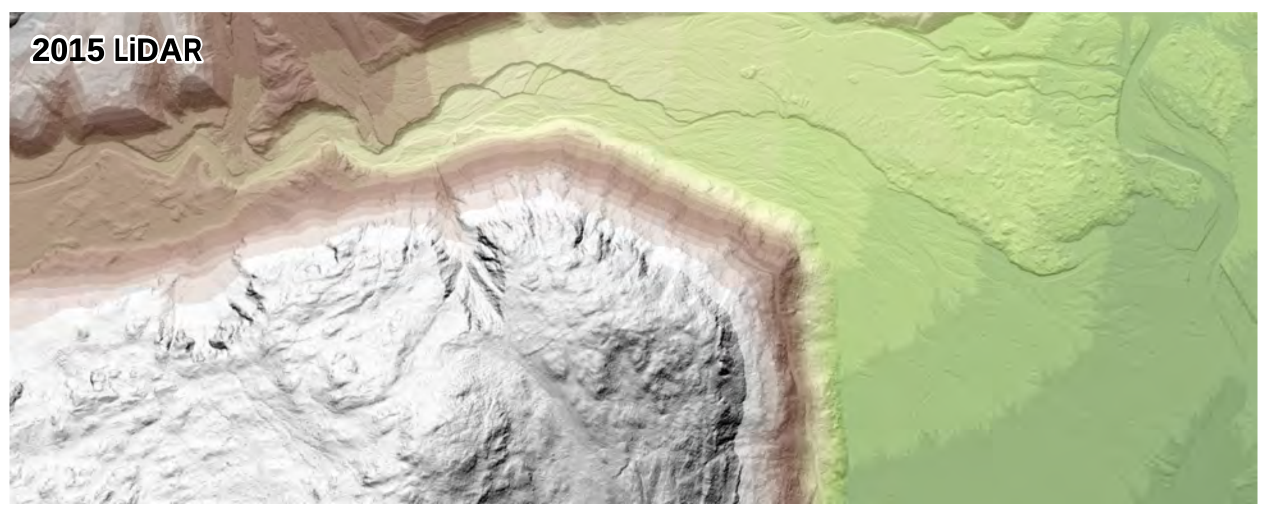
1) continued channel downcutting within the area eroded between 2010 and 2015,
2) contributions from mass failures of steep sidewalls cut into the landslide deposit around the channel, and
3) contributions from fluvial incision along Capricorn Creek.

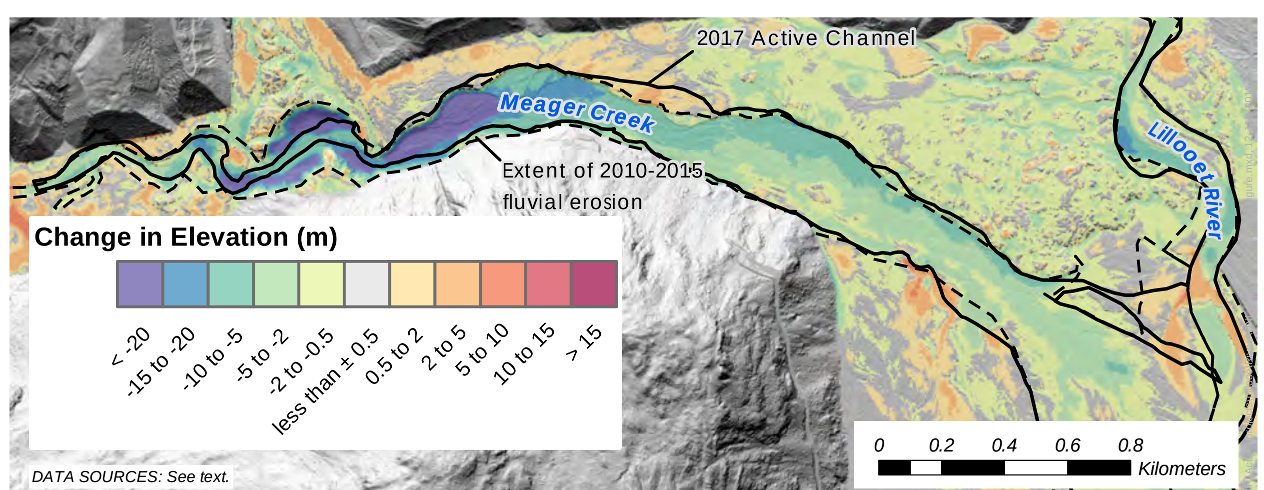
The volume of sediment contributed by lateral migration of Meager Creek and the Lillooet River was evaluated by mapping the margin of the channel and active floodplain in the 2015 LiDAR and 2017 aerial photo and estimating the height of sediment eroded from surrounding slide deposits and terraces based on offset between the elevation of those features and the active channel in the 2015 LiDAR. This calculation indicates that at least an additional 445,000 m^3 of sediment were evacuated from the slide deposit between 2015 and 2017, for a lower bound estimate of 5.9×10^6 m^3 of erosion since the slide occurred.

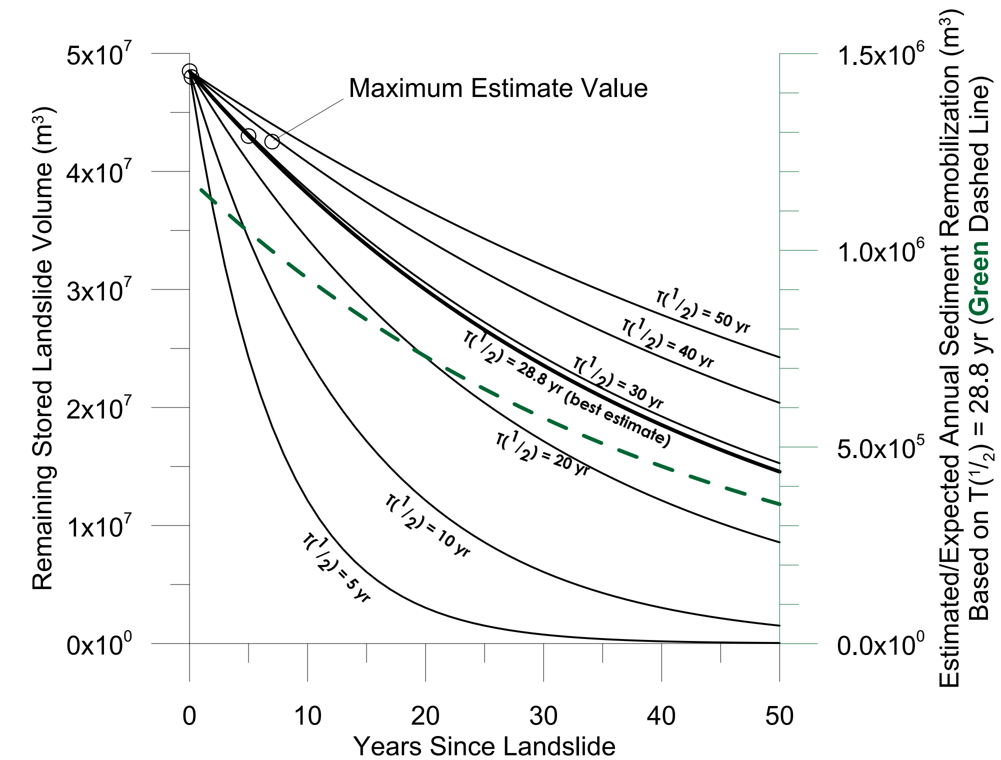
▲ View of landslide deposit looking upstream from confluence of Meager Creek (left) and Lillooet River (right).

Meager Creek cutting through landslide deposit at Capricorn Creek confluence.









A typical pattern of exponential decay in sediment yield following landscape-scale disturbances such as landslides provides a tool to help interpret the three estimates of sediment evacuated from the slide described above. As described by Nelson and Dubé (2016) and Croissant et al. (2017), sediment yield after landscape-scale disturbances typically decays exponentially over a period of decades to centuries. In established examples half-lives ($t_{1/2}$) for the remaining volume of material initially disturbed range from approximately 2.5 to 50 years, with most in the range of 5 to 25 years (Adams, 1980; Pearce and Watson, 1986; Major et al., 2000; Dadson et al., 2004; Koi et al., 2008; Hovius et al., 2011; Huang and Montgomery, 2012; Nelson and Dubé, 2016; Croissant et al., 2017). Half-life ($t_{1/2}$) is computed as

$$t_{1/2} = \frac{t \ln 2}{\ln\left[\frac{V_i}{V_f}\right]}$$

where the variable t represents the elapsed time of observation and V_i and V_f represent the initial landslide volume and landslide volume remaining in the upstream basin at the time of observation, respectively.

The pattern of exponential decay occurs because material mobilized by the disturbance becomes progressively more difficult for alluvial streams to reach as the most accessible deposits are carried away, channel slope over the slug decreases, and as deposits become stabilized through the formation of lag-armor deposits and establishment of vegetation (Nelson and Dubé, 2016).

The graph above illustrates the relation of the conceptual exponential decay model to observations of sediment remobilization from the Lillooet slide deposit. Using the best constrained estimate of total sediment remobilization—based on changed conditions between the 2010 DEM and when the LiDAR was acquired in 2015—gives a best estimate $t_{1/2}$ value of 28.8 yr which is well within the typical range but relatively slow, a result that may not be surprising given the very large volume of material in the 2010 landslide. Assuming continued exponential decay in the volume of stored sediment (and therefore rate of sediment remobilization) allows an estimate of the expected future sediment loading to the Lillooet River (dashed line in graph above).

Landslide Deposit Grain Size Distribution and Lithology

The grain size distribution of sediment remobilized from the landslide deposit controls how and where that material interacts with the Lillooet River downstream, and so it is very important to understand that distribution. Gravel and cobble sized material will move as bedload and would be expected to have the biggest impact in the reaches immediately downstream of the slide, while sand may rapidly move through the braided reach and have the biggest impact downstream through the diked reach of the river. Silt and clay are not present in appreciable quantities in the river bed and—once eroded—move as wash load with the flow and are transported directly into Lillooet Lake; therefore, they have minimal influence on the channel geomorphology.

The grain size distribution at four locations within the landslide diamicton was estimated by combining data from scaled photo-based pebble counts to characterize the coarser portion of the deposit (>22.4 mm) with bulk samples to characterize the finer portion of the deposit. The two data sources were combined by following the hybrid bulk sample approach of Rice and Hashenberger (2004) using 22.4 mm as the match fraction. Bulk samples were processed at the UBC geography sediment lab with sieving following a wet wash on the 63-micron sieve to remove silt and clay. The difference in mass between pre- and post-wash dry weight was used to determine the mass of material smaller than 63 microns (silt and clay).

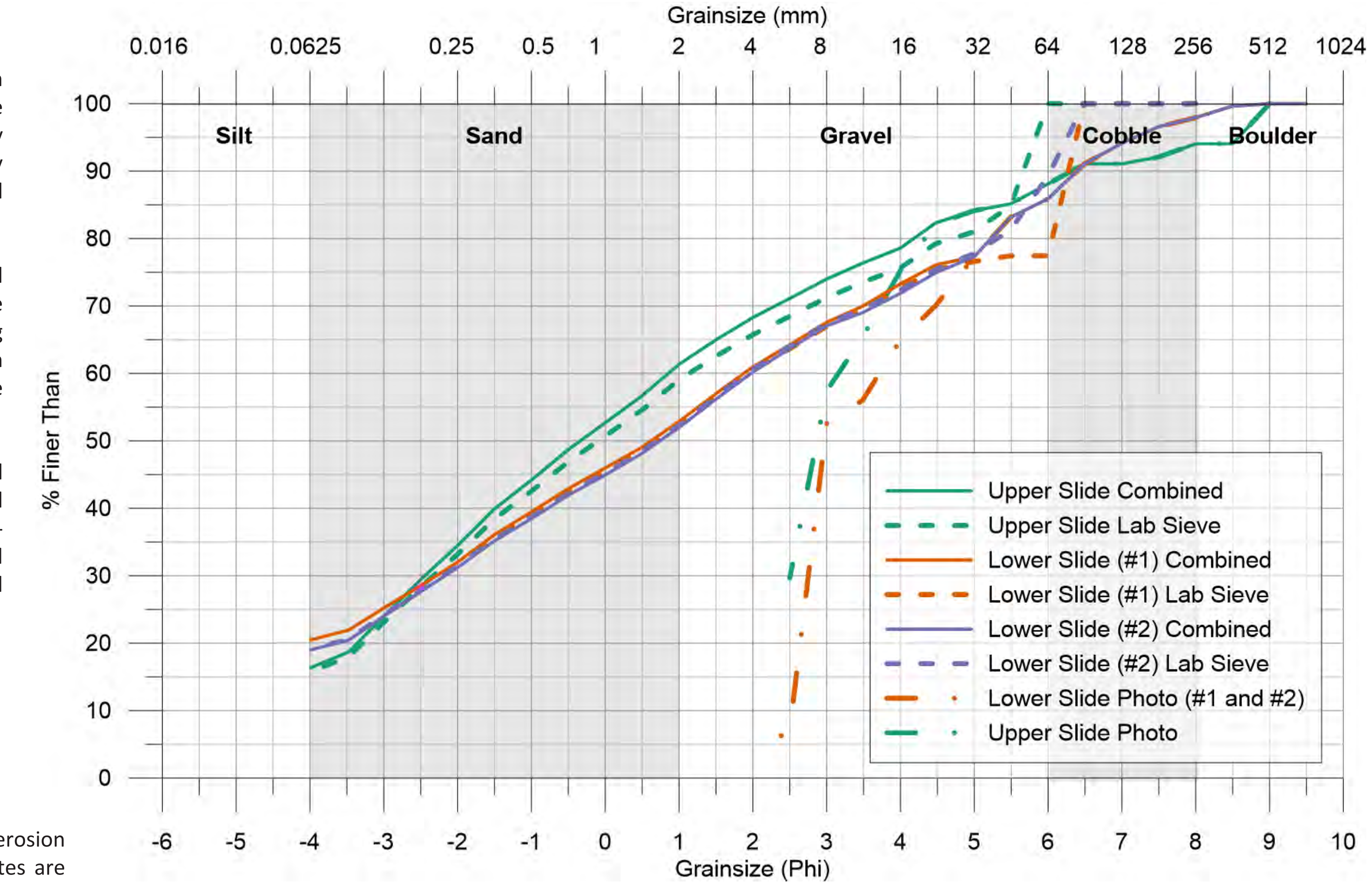
The cumulative distribution plots to the right show the resulting grain size distributions of the landslide diamicton samples. They all show relatively similar gradations, with 19±2% silt and clay, 37±7% sand, 41±7% gravel and cobble, and 3±2% boulder sized material (±1σ). Roberti et al. (2017) describe grain size distributions of the sand and finer fraction for three distinct facies within the slide deposit, and differentiated the silt and clay fractions for the material. They found that the pulverized block and mixed facies consisted of 70-85% sand with <5% clay and 10-20% silt, while a mixed facies consisted of of 65-75% sand with 5-10% clay and 15-25% silt, and the hydrothermally altered block facies consisted of 20-55% sand with 20-30% clay and 35-60% silt.

Assuming the landslide diamicton sediment remaining in the slide deposit is representative of that subsequently eroded by fluvial action, and an exponential decay curve with a $t_{1/2}$ value of 28.8 yr allows estimation of the grain size-specific sediment supply to the Lillooet River over time following the slide. These estimates, shown in the table to the right, indicate that the present rate of sand and gravel remobilization is reduced by about 15% from that in the post slide period.

Estimates of past and future rates ($m^3\ yr^{-1}$) of fluvial remobilization of the slide deposit.

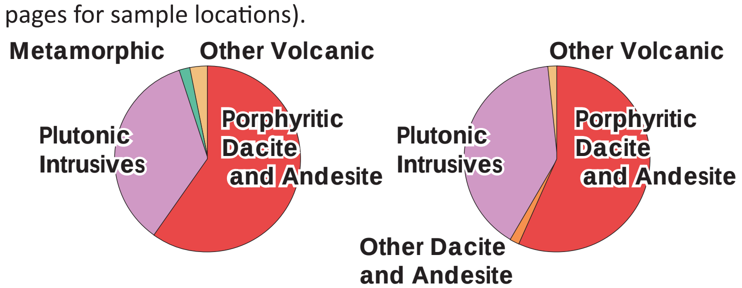
Material	2010-15	2017	2027	2037
Sand	410,000	370,000	300,000	230,000
Gravel	450,000	410,000	320,000	250,000

Note: Post-slide (2010 – 2015) values are based on estimated erosion rates from the surface model comparison. Present and future rates are based on the theoretical pattern of exponential decay in sediment yield.



▲ The lithology of gravel in the 2010 Meager Landslide deposit includes a disproportionate concentration of a distinct porphyritic rhyodacite; the relative concentration of this material can serve as a tracer for slide-derived sediment in the river downstream.

▼ The pie chart on the left shows distribution of lithologies observed on the Meager Creek fan and the chart on the right shows lithologies from a coarse lag deposit where the Lillooet River has eroded into the slide diamicton deposit at RK 82 (see following pages for sample locations).



▲ View up Meager Creek towards Capricorn Creek confluence. The 2010 Landslide came from the Capricorn Creek Drainage and then spread both upstream and downstream along Meager Creek. Downstream flow ultimately blocked the Lillooet River.

▲ Detail showing character of landslide diamicton at the lower slide diamicton sample site. The upper portion is minimally altered since deposition while the lower portion is a lag deposit following preferential removal of fines by the Lillooet.

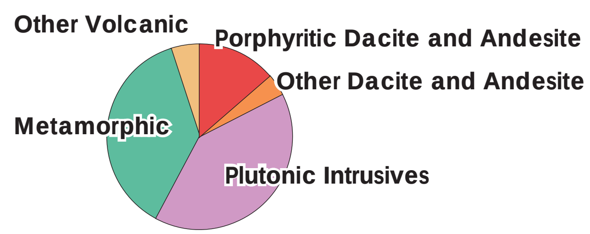
nhc

Deposition Upstream of the Landslide Dam: RK 82-85

- Clear indications of deposition on the Lillooet River upstream of the landslide deposit related to increased base level at the landslide dam and extend about 2 km upstream of the dam.
- Indications of deposition include inundation of floodplain forest, large deposits of sand, and active channel bars above the (now dead) established trees.
- The area of deposition covers about 27 ha, assuming an average depth of deposition of about 0.5 to 2 m suggests that about 135,000 and 540,000 m3 of bed material that otherwise would have been transported downstream has accumulated in the 10 years following the slide.

▼ View upstream from tree kill at RK 83 showing sediment blocking the Lillooet River channel, avulsion into standing forest, and high-water level relative to established conifers.

▲ View downstream towards 2010 landslide dam from approximately location of RK 82.55 pebble count.



◀ The lithology of gravel at the RK 82.55 pebble count location is dominated by basement rocks including metamorphic and plutonic intrusives. Volcanic rocks—mostly from the Meager Volcanic Complex—represent only about 23% of the gravel.

▲ Area immediately upstream of 2010 landslide dam.

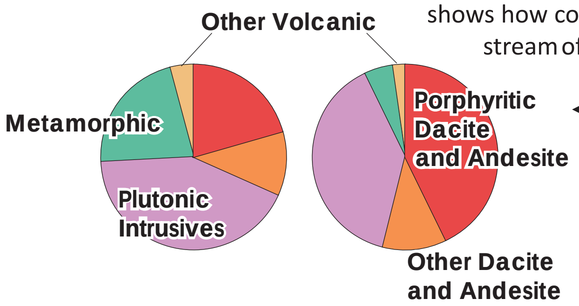
Fluvial Incision Through Landslide Dam and Proximal Sedimentation: RK 78-82

- Lateral channel migration and vertical incision are actively recruiting sediment from the landslide deposit along both Meager Creek and the Lillooet River. Sediment is derived both directly from the bed and banks and through mass failures in the slide deposit. The most active recruitment along the Lillooet River is between RK 81 and 82, while recruitment along Meager Creek continues a substantial distance up the fan.
- Extremely high turbidity was present in Meager Creek at the time of observation indicating active erosion through the slide deposit occurs even at moderate flows (in this case summer snowmelt).

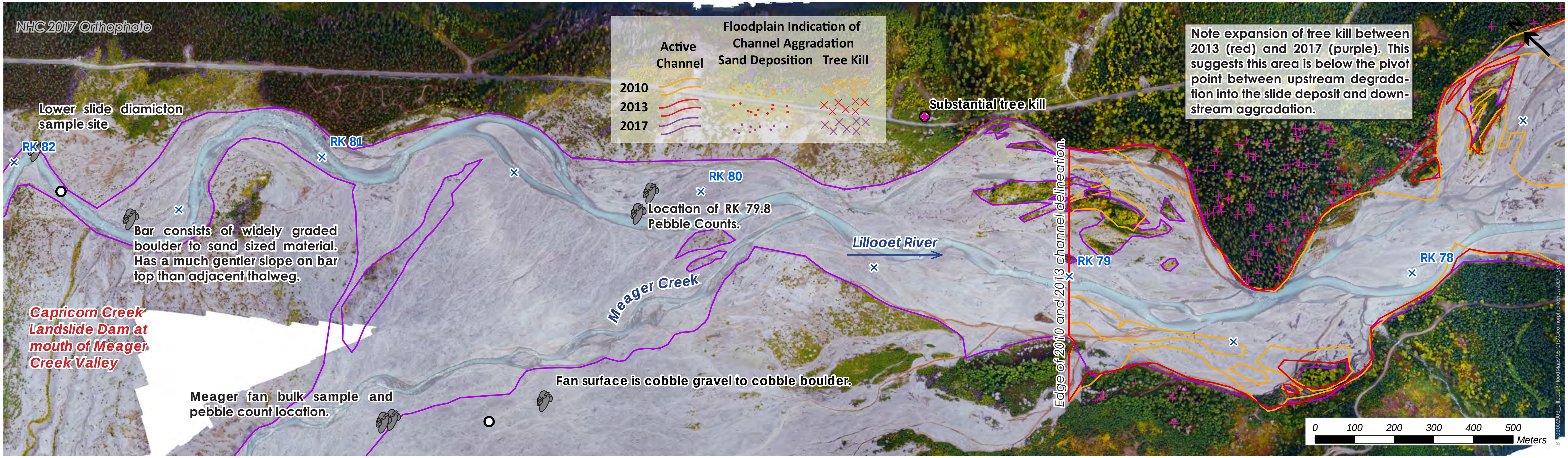
▲ Location of Meager Creek fan bulk sample, which targeted the unarmored material in the pictured escarpment along the margin of a paleo channel.

▲ Mass wasting failures of of the slide deposit are continuing to contribute sediment to the river even as the downcutting channel becomes increasingly armored. Channel hydraulics here suggest the bed is armored with boulder to cobble-sized sediment.

▲ Comparison of the lithology of two river bars in the lower part of the slide debris fan shows how coarse sediment connectivity from upstream of the slide has increased through time.



◀ The higher and older bar has a composition more similar to the slide deposit (right) while the lower and younger bar is more similar to the composition of river bars upstream of the slide.



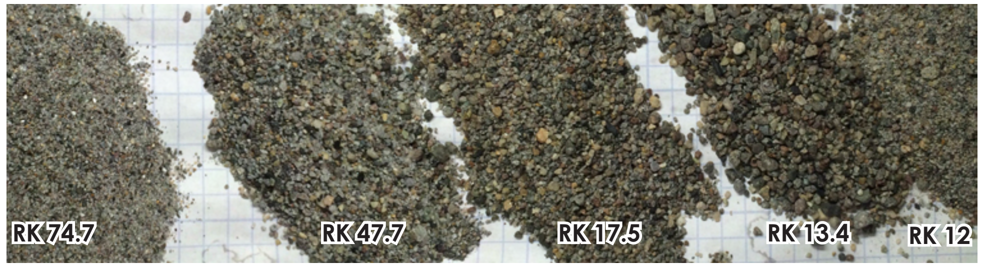
Proximal Sedimentation: RK 70-78

- Impacts of coarse (cobble and gravel) sediment remobilized from the landslide are apparent through this reach, indicating channel bed aggradation has occurred in response to downstream alluvial diffusion of the landslide sediment slug. Key impacts include:
  - Channel bank erosion, widening, and a loss of vegetated island area
  - Die off of large areas of riparian forest, including an increase in the area of die off between 2013 and 2017
  - A substantial increase in the concentration of landslide-derived volcanics in river bed material.
- Large sheets of blue-gray sand matching the minerology of the landslide-derived volcanics are stored in some localized areas of the braid channel network. These suggest high rates of sand transport through the reach. The overall volume of storage of this material is modest, and it does not impact hydraulic channel controls in this reach.

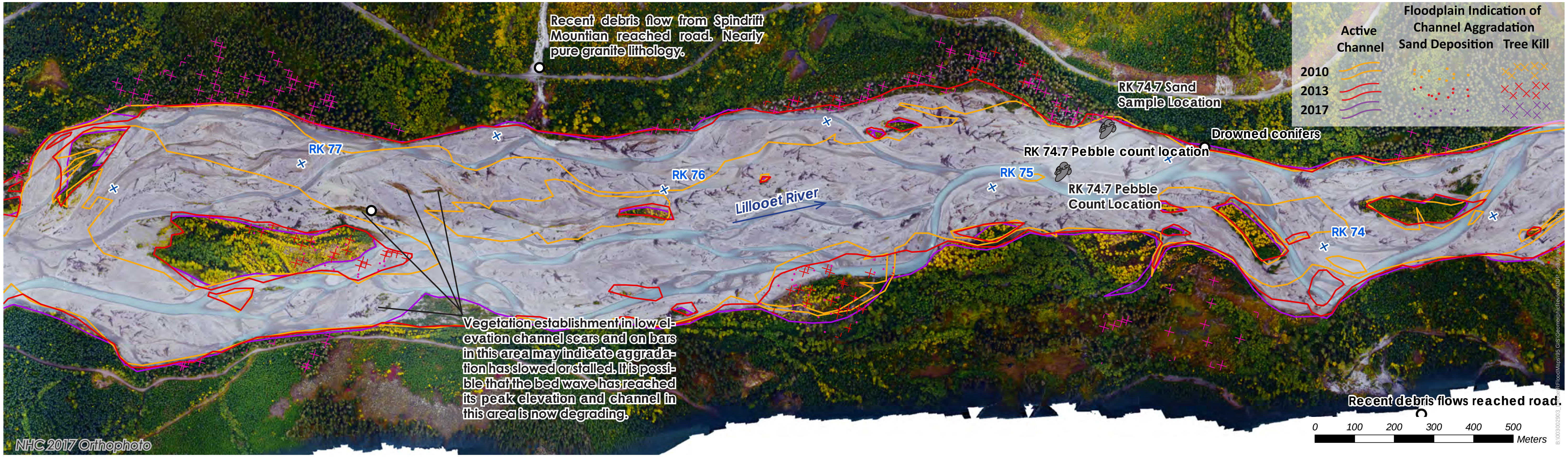
▲ Drowned conifer trees on left bank at RK 74.5, along with systematic riparian tree die off through whole reach, are clear indicators of substantial recent channel aggradation.

▲ This recent debris flow from the flank of Spindrift Mountain illustrates the dominant granodiorite intrusive igneous plutonic rocks from sediment sources along most of the length of the Lillooet River.

▲ Pocket of sand temporarily stored in the braid plain and location of RK 74.7 sample.



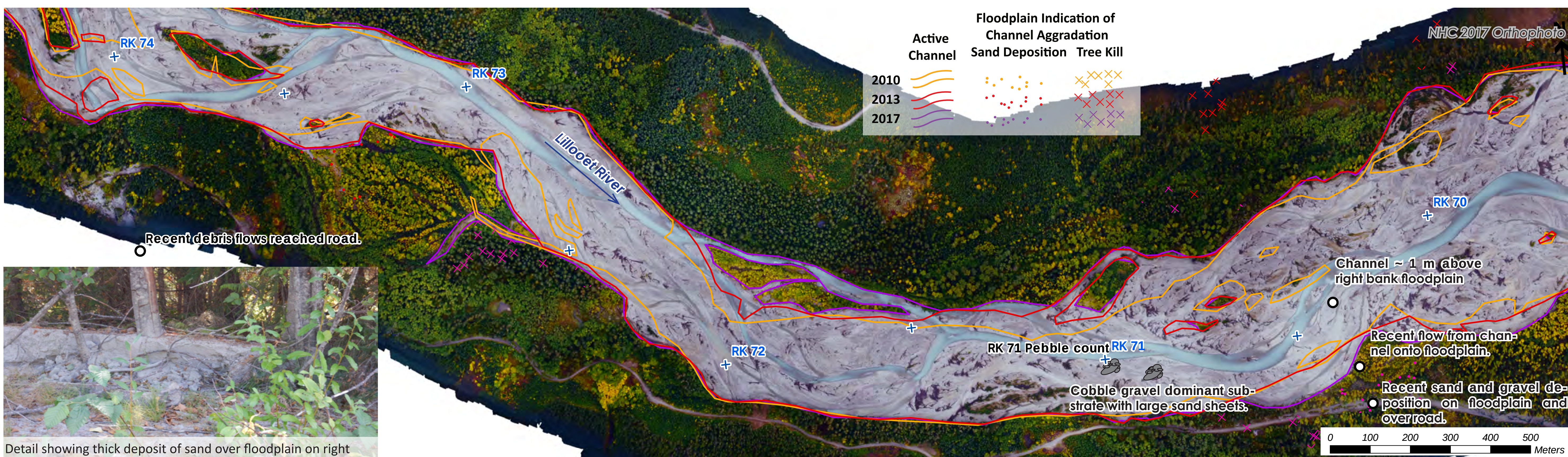
▲ Detail of sand samples from along the Lillooet River showing consistent minerology and dominance of blue-gray lithic fragments interpreted to be from the 2010 Meager Slide Dacite. The grain size distribution of individual samples reflects local hydraulic conditions at the depositional location rather than systematic sorting along the river. Grid cells are approximately 5.1 mm to a side.



▲ Large sand sheets on the right bank floodplain at approximately RK 70.75.

▲ Location of RK 71 pebble count.

▲ Growing active channel bars at approximately RK 70.4 are at grade with and up to 1 m above the surrounding floodplain. Ground observations show both conifer and deciduous (e.g. cottonwood) trees have died and the channel is aggressively migrating into the right bank in this area.



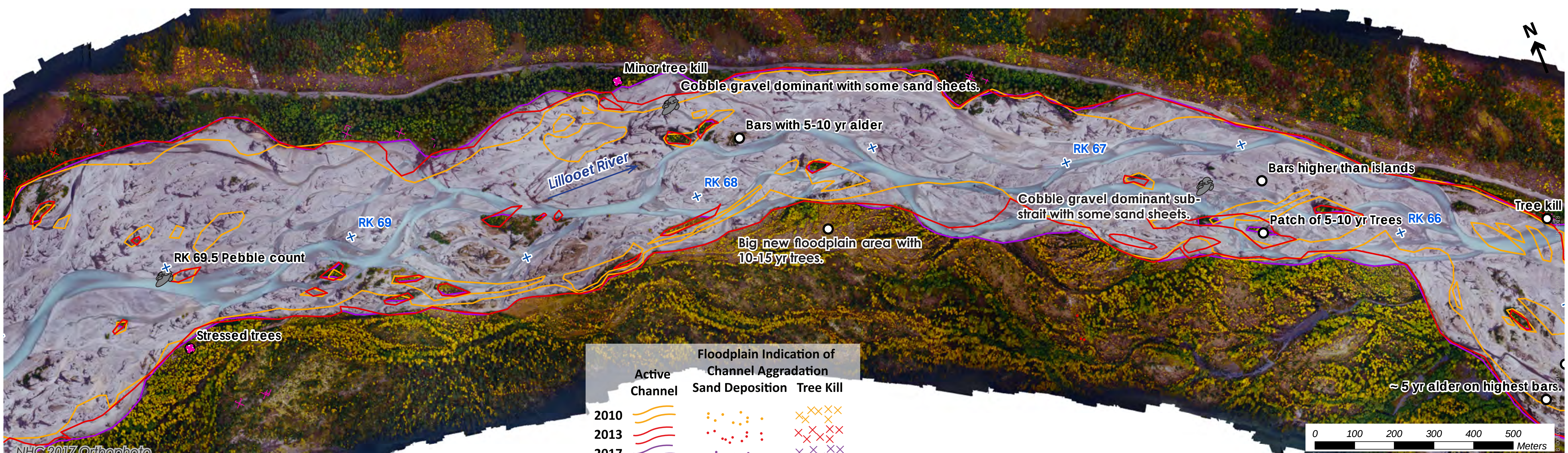
Detail showing thick deposit of sand over floodplain on right bank at approximatley RK 70.5

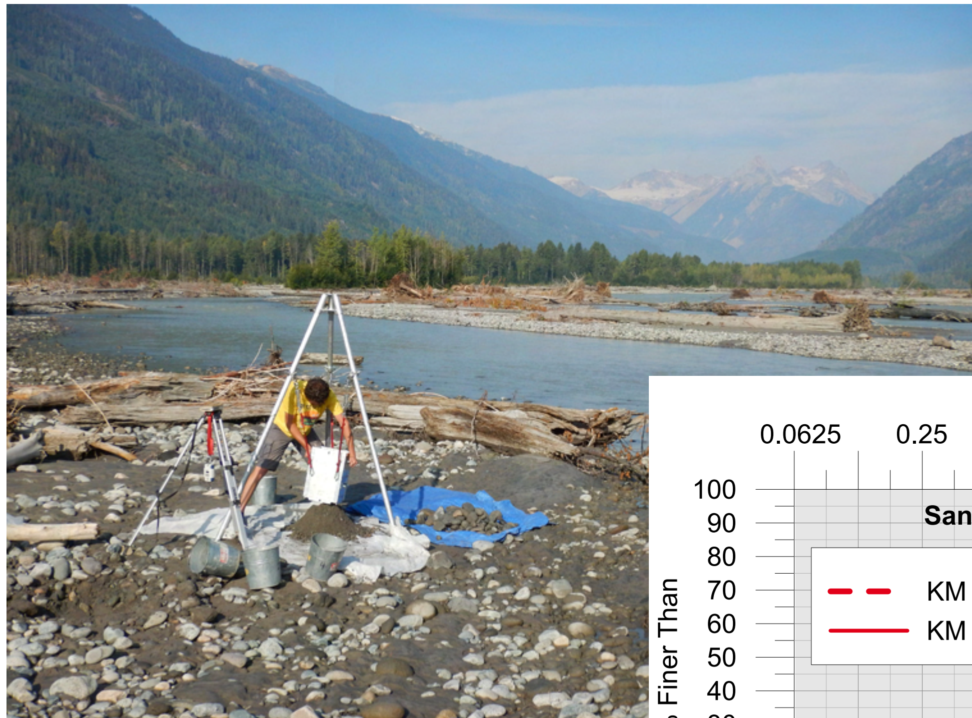
Gravel Front Advancement: RK 70-61

- Indications of coarse sediment accumulation described for the reach upstream continue through this reach. A declining intensity of floodplain tree kill suggests less channel aggradation has occurred here compared to upstream. Substantial channel widening is nonetheless evident, particularly between RK 63 and 66 where a large number of forested islands have been eroded. This suggests the leading front of the coarse slug has passed through the reach.
- Combined impingement of the North and South Creek alluvial fans at RK 61 may act as a hydraulic pinch point leading to backwater induced sedimentation in the reach upstream.
- Many of the highest bars through this reach are being colonized by approximately 5-year-old alder stands suggesting that these formed during a relatively large flood shortly after the 2010 landslide. It is unclear whether the mean and thalweg bed levels have changed more recently, but increasing extent of tree kill between 2013 and 2017 suggests that it likely has.
- Comparison of the bulk grain size distribution in 2001 and 2017 shows a major increase in the proportion of bed material composed of coarse sand and fine gravel. This change indicates both higher bedload transport capacity and competence through the reach.

◄ Location of RK 69 Pebble Count

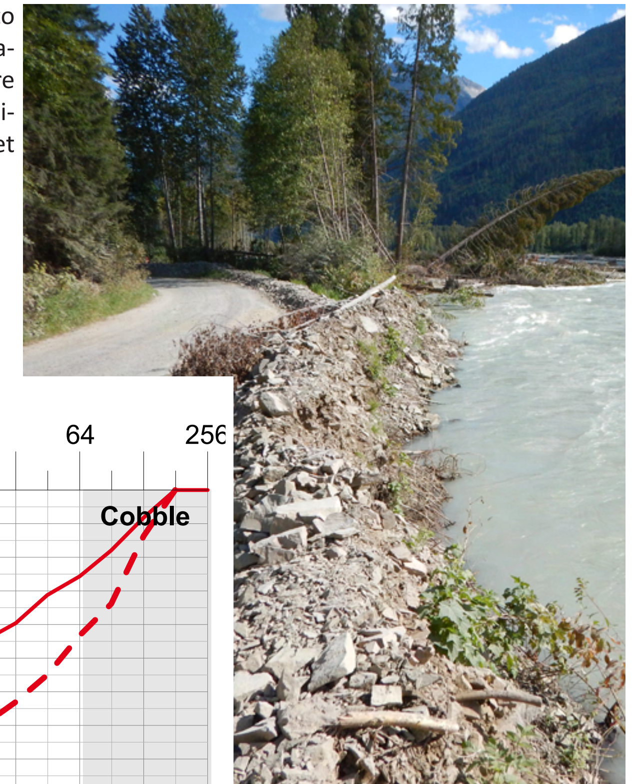
▼ Panorama showing conditions at approximately RK 68. Note in particular bars with ~5 yr age class Alder, sand sheet over dominant cobble gravel substrate, and wide active channel.

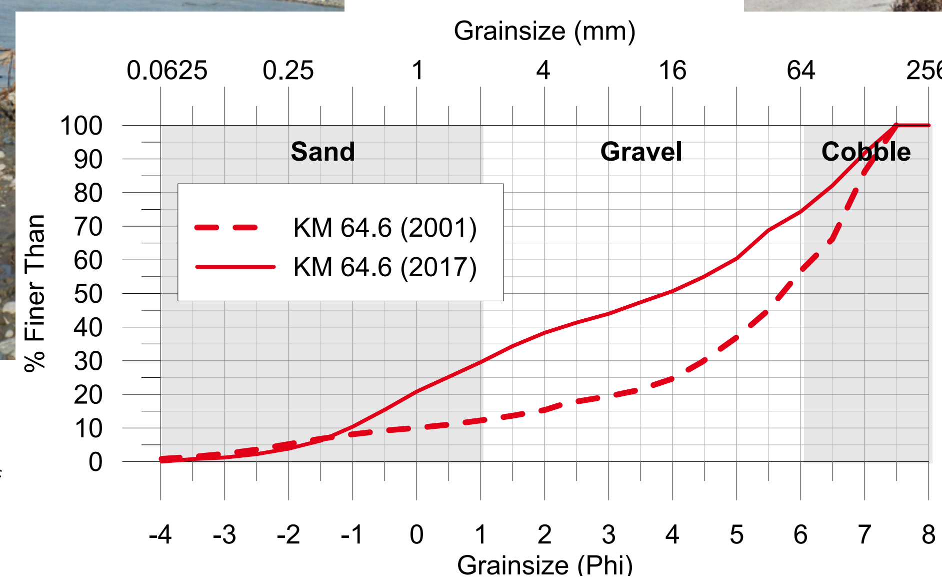




▲ Location of RK 64.6 Bulk Sample.

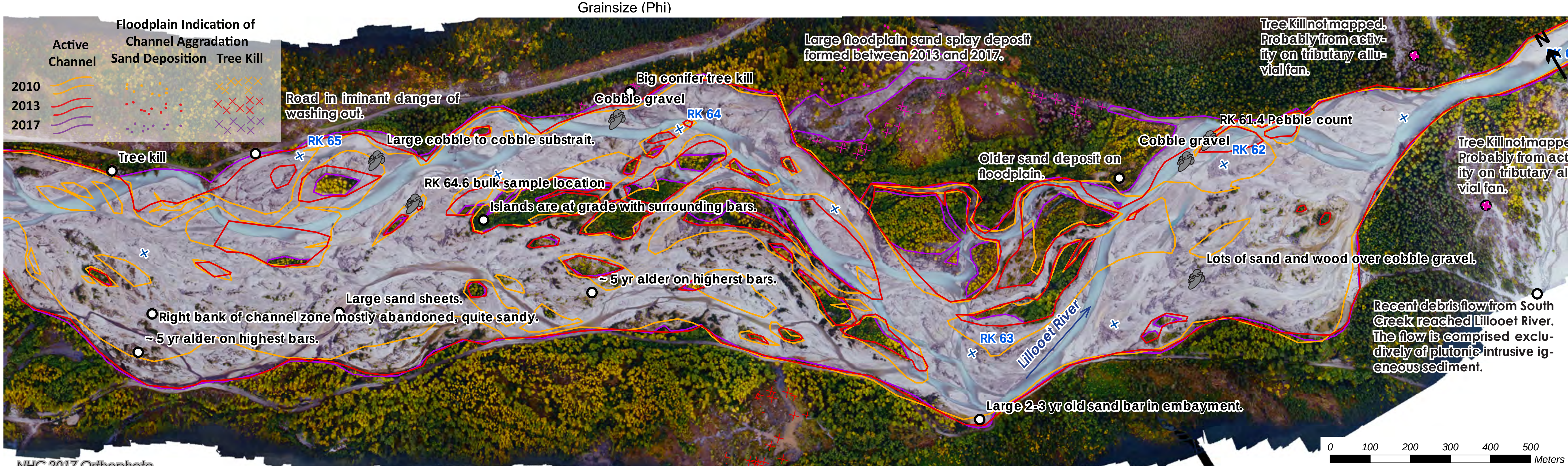
▶ Channel widening leading to aggressive lateral channel migration is impacting infrastructure along the river. Here lateral migration is impinging the Lillooet Forest Service road.





▶ Comparison of bulk grain size distribution at RK 64.6 in 2001 and 2017 shows a major increase in the proportion of bed material composed of coarse sand and fine gravel.

▲ The dominant channel avulsed from the right bank side of the group of islands between RK 63 and 65 to the left bank side of these islands between 2010 and 2013. A large volume of sand is now accumulating in this area.



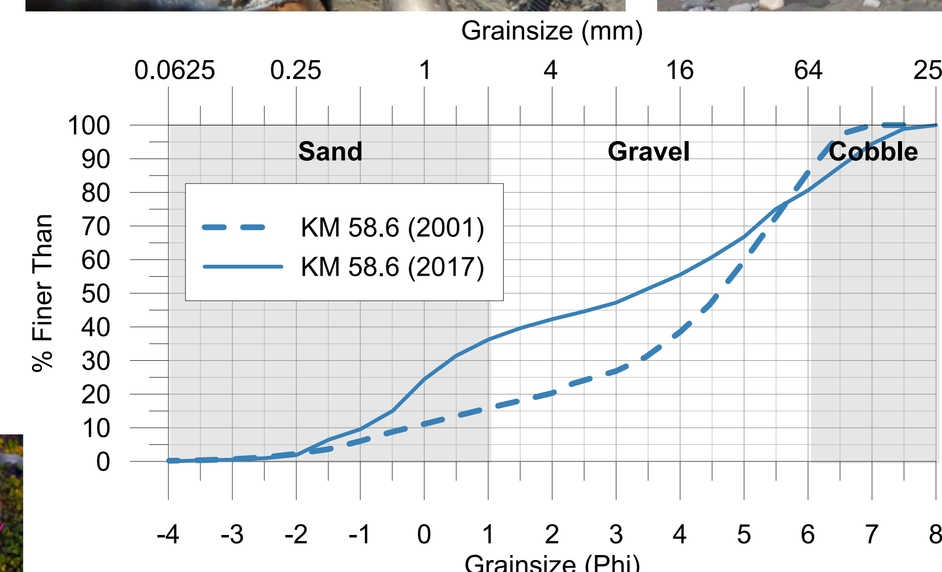
nhc

Leading Edge of Gravel Front: RK 61-54

- The characteristic impacts of coarse (cobble and gravel) sediment remobilized from the landslide described above transition from apparent in the upstream (alluvial) portion of the reach to nearly absent at about RK 55, suggesting that this is the approximate position of the leading edge of the coarse sediment slug.
- More change in channel planform has occurred between 2013 and 2017 than between 2010 and 2013 indicating that the leading edge of the gravel front entered this reach more recently and that instability is likely presently increasing.

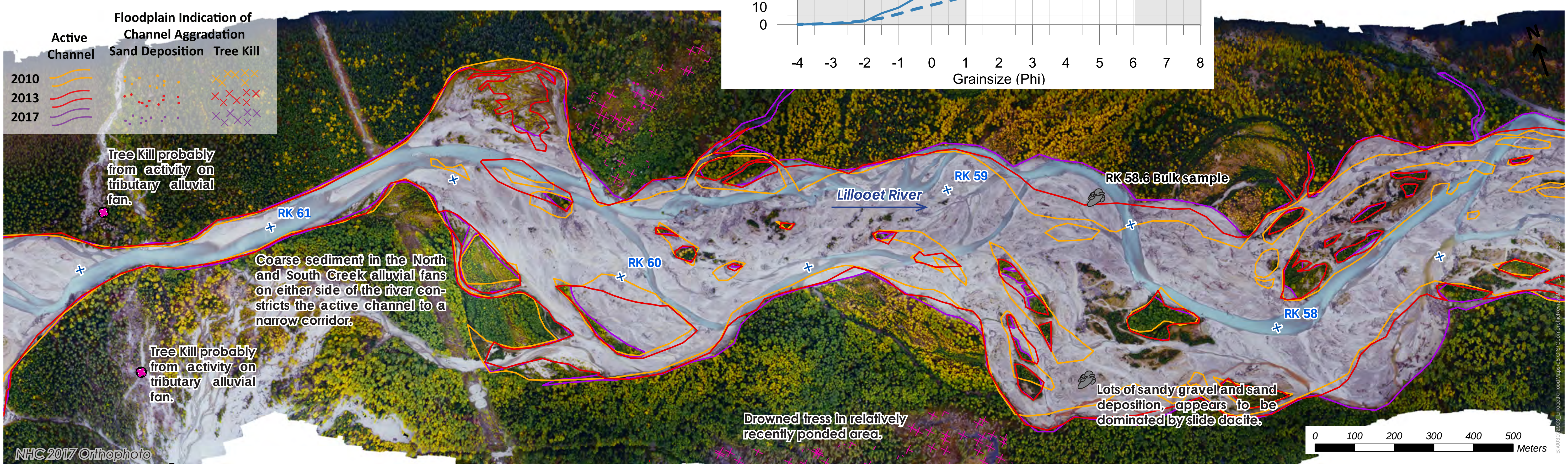
Coarse sand fills braid channels across the floodplain at RK 58.5.

► Detail showing characteristic braid channel coarse sand deposit.



▲ Location of RK 58.6 Bulk Sample. Note active channel migration into floodplain along the outside of the upstream bend.

◄ Comparison of bulk grain size distributions from 2001 and 2017 shows a major increase in the proportion of bed material composed of coarse sand and gravel.

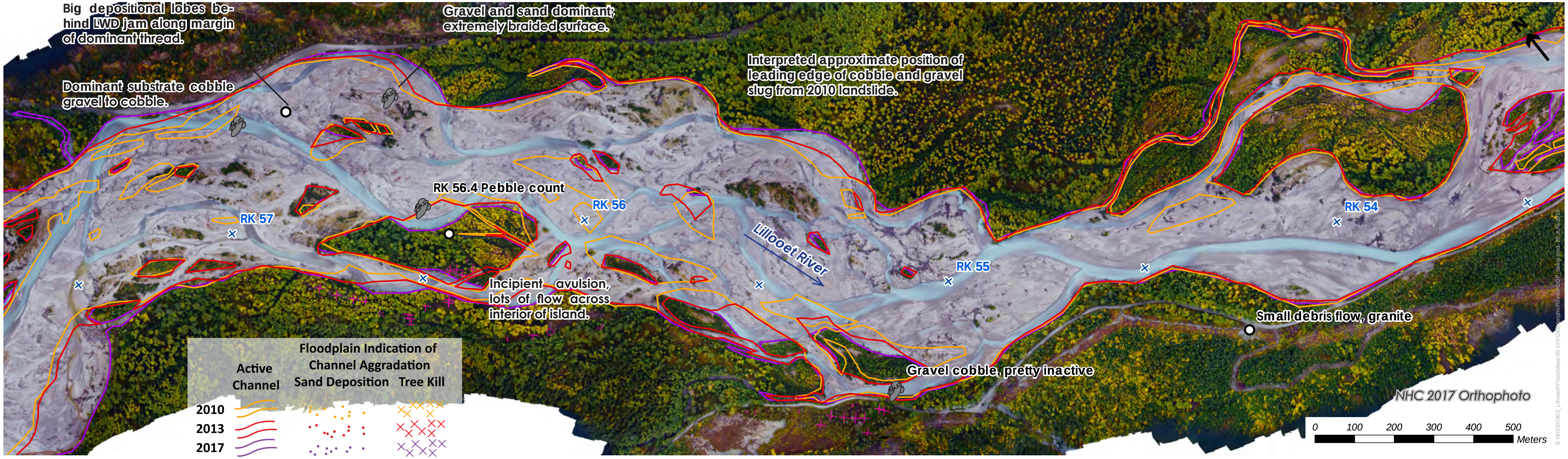


▲ Massive accumulation of large wood, much of it from recently eroded floodplain areas (as indicated by presence of needles), along left side of channel between RK 56.6 and 57.

▲ High water level and flow cutting across forested island indicate channel bed aggradation and an incipient avulsion. .

▲ Unusually coarse substrate observed in dominant channel at RK 57.

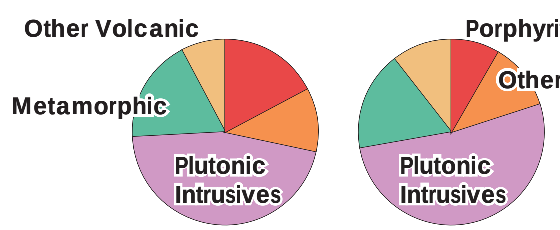
▲ Location of RK 56.4 Pebble Count



nhc

Transition from Braided to Wandering Morphology: RK 54-44

- As the Lillooet River transitions from a braided morphology upstream into a single thread channel downstream, it passes through an area with a wandering morphology where a single dominant thread meanders across a wide active channel zone.
- Channel migration in this area is characterized by meander amplification followed by cutoff avulsions that leave intervening forested islands. In the upstream portion of the reach meander erosion is clearly expanding the active channel zone, while downstream meander growth is (at least partially) compensated by reciprocal point bar accretion and vegetation establishment.
- Porphyritic Dacite is still abundant in this reach and the total proportion of gravel and cobble with volcanic lithology is substantially elevated above the pre-landslide condition, suggesting that some bedload material from the 2010 landslide is present in the reach.
- The proportion of gravel and cobble with other volcanic lithology is increasing substantially in this reach. This material is probably sourced from the older volcanic rocks that are locally present along the north valley wall (p. 3) and shows the contribution of gravel sources in this area to sediment accumulating in the channel downstream. Because no major tributaries join the river in this area, bank erosion into older channel deposits is the likely source of this material.



Lithology of pebble counts from RK 47.7 sample location (far left) and RK 46 sample location (left).

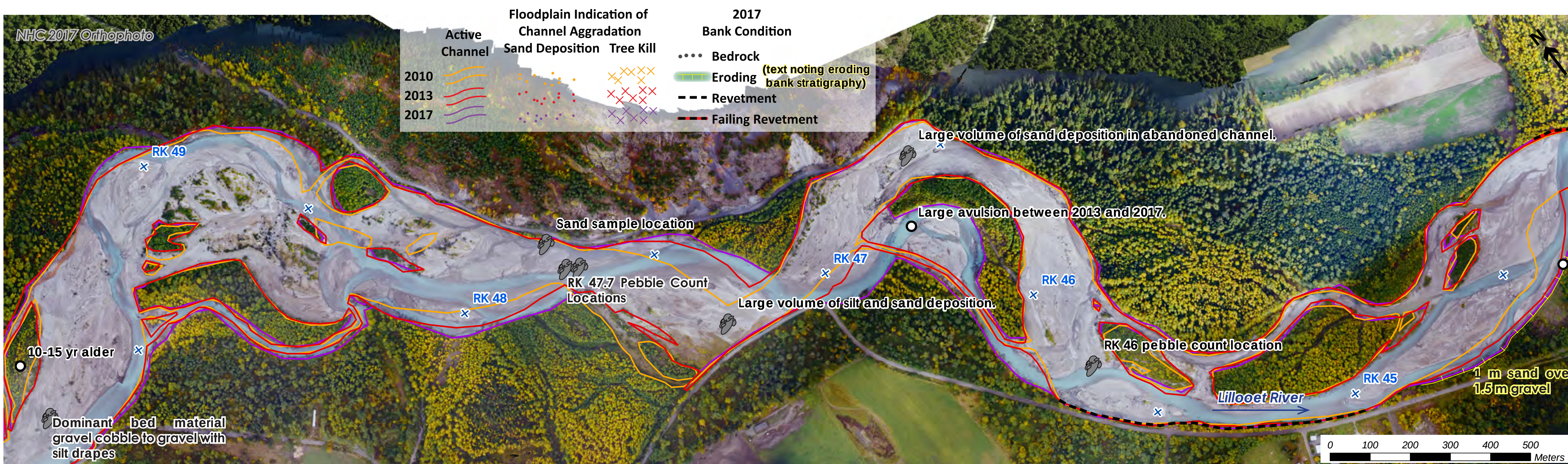
▲ Cobble gravel substrate along dominant channel at RK 54

▲ Silt and sand accumulation along margin of active channel at RK 54.

▲ Location of RK 47.7 pebble count.

▲ Panorama showing overview of sandy secondary braid channel at RK 47.75. Large sand deposits like this in an otherwise dominantly cobble-bedded river suggest very high suspended sand transport rates. In addition, the high concentration of sand on the bed is expected to substantially increase both the transport capacity and competency for the cobble-gravel bed load (e.g. Andrews 1983, Ferguson et al. 1989, Kleinhans 2002, Wilcock and Crowe 2003).

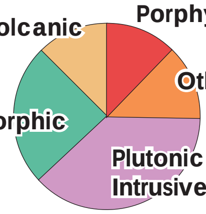
◄ Location of RK 46 pebble count. Note the locally disorganized flow pattern, a consequence of the recent avulsion just upstream



nhc

Transition from Wandering to Single-thread Morphology: RK 44-41

- The reach immediately upstream of the Lillooet Forest Service Road Bridge marks the abrupt transition from a wandering morphology upstream through a short segment of sinuous single-thread channel into a long stretch of relatively narrow, confined, and straight channel downstream.
- The presence of cut off oxbows and aggressive lateral channel migration at bends without bank protection both suggest that the reach may have historically had, and be trending towards, higher sinuosity.
- As with bulk sample locations upstream, the proportion of sand and fine gravel in the bed has increased substantially relative to pre-landslide conditions in 2001. The proportion of small gravel (<32 mm) has decreased substantially, but the proportion of coarse gravel and small cobble has increased slightly.
- Porphyritic Dacite and Andesite that is abundant in the 2010 landslide deposit is present in an appreciable quantity in the gravel in this reach. The proportion of total volcanic lithology, which can be compared directly to conditions in 2001, however, has not changed. It is therefore unclear whether this material is derived from the slide, or if it had come from previous erosion of the same source rock.

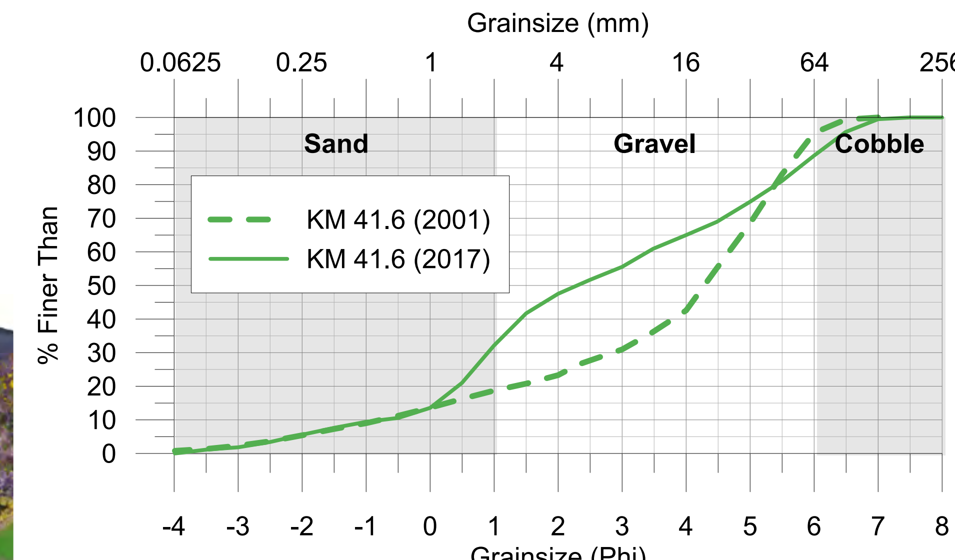


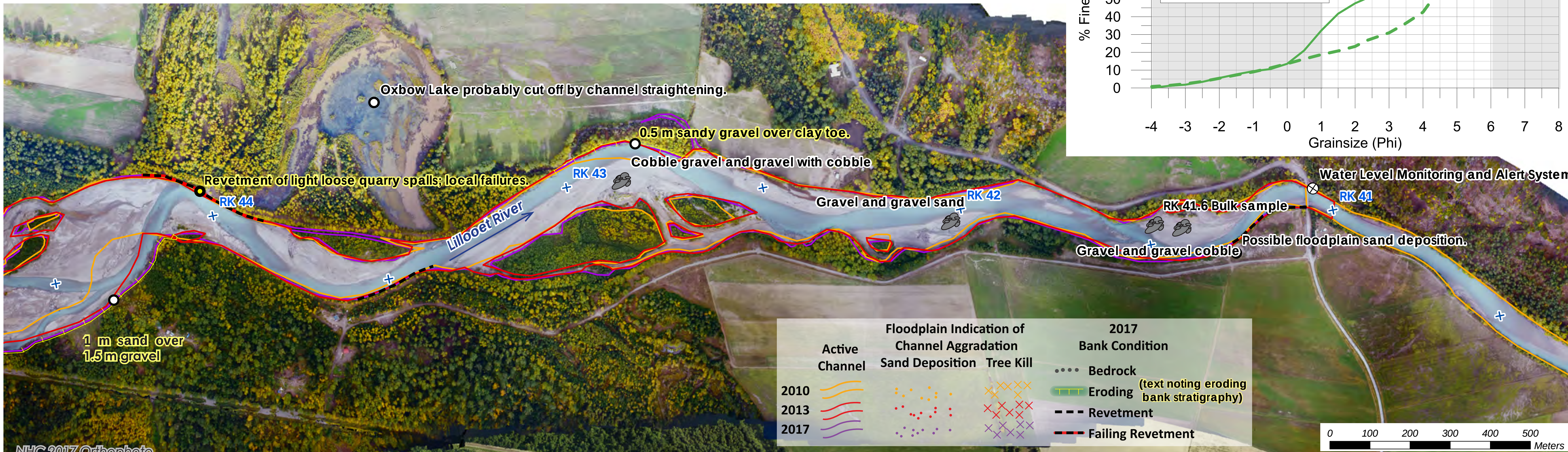
◄ Lithology of pebble count from RK 41.6 sample location.

▲ Stratigraphy of the eroding bank between RK 44 and 45 showing erosion mobilizing tan-colored sand overlying oxidized gravel deposits.

▲ Location of RK 41.6 bulk sample.

▼ Comparison of grain size distribution in 2001 and 2017 at location of RK 41.6 bulk sample showing substantial increase in the proportion of sand and fine gravel.





Single-thread gravel flume : RK 41-34

- Downstream of the location of the Lillooet Forest Service Road Bridge, the channel becomes relatively deep and narrow compared to conditions upstream. This indicates that there is relatively high bank strength. Throughout the reach, cohesive clay is observed in lower parts of banks and riprap becomes more common along the banks. Both of these (through cohesion in the case of clay and large particle sizes in the case of riprap) provide bank strength.
- The narrower and deeper channel in this reach maintains relatively high shear stress, and so the river maintains competence to move some gravel and cobble sediment even as the slope is reduced in the downstream direction.

▲ Composition of eroding bank at RK 39.5 showing crossed-bedded sand. Clay is present from just above the water line.

▲ Bank erosion at RK 37.5 cutting into high or alluvial fan that overlies clay at the bank toe.

▲ Relatively narrow and confined channel at approximately RK 37; characteristic of the reach.

nhc

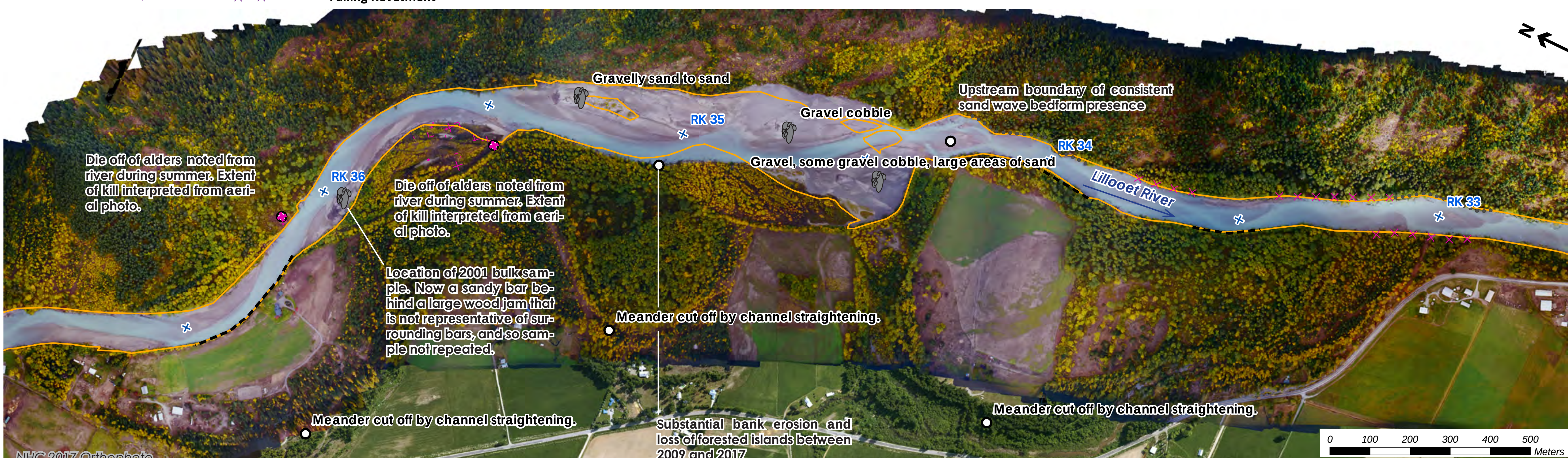
Geomorphic Conditions RK 36 to 31

- Previous channelization in this reach during the 1940s has reduced sinuosity and steepened the channel, leading to substantial river bed degradation over the past century (Weatherly and Jakob 2014).
- Most of the reach is confined, but a sedimentation zone occurs in a locally widened segment between RK 34 and 36. This appears to be an important area of cobble and gravel deposition. It is the lowest location where a substantial quantity of cobble is observed in the bed material, and occurs at a site of competence-limitation for downstream transport of this material. Tree kill upstream of the sedimentation zone suggests that bed and growing season water levels have increased.
- Although bank positions are generally extremely stable, sediment deposition around RK 35 has driven some channel expansion between 2009 and 2017.
- Below RK 34 the channel is filled with large bar-scale bedforms with locally observed superimposed dunes (see page 28). These are interpreted to be highly mobile sand waves composed of coarse sand and very fine gravel, which would indicate very high bed material transport rates. Their emergence at RK 34 is likely due to a change in the transport mechanism for sand-sized material in the channel, with more material moving as bed load or in only intermittent suspension.
- Comparison of cross-sections at RK 32.1 shows about 2 m of channel infilling between 2011 and 2017.

	Active Channel	Floodplain Indication of Channel Aggradation: Sand Deposition	Floodplain Indication of Channel Aggradation: Tree Kill	2017 Bank Condition
2009				Bedrock
2013	Not delineated			Eroding (text noting eroding bank stratigraphy)
2017				Revetment
				Failing Revetment

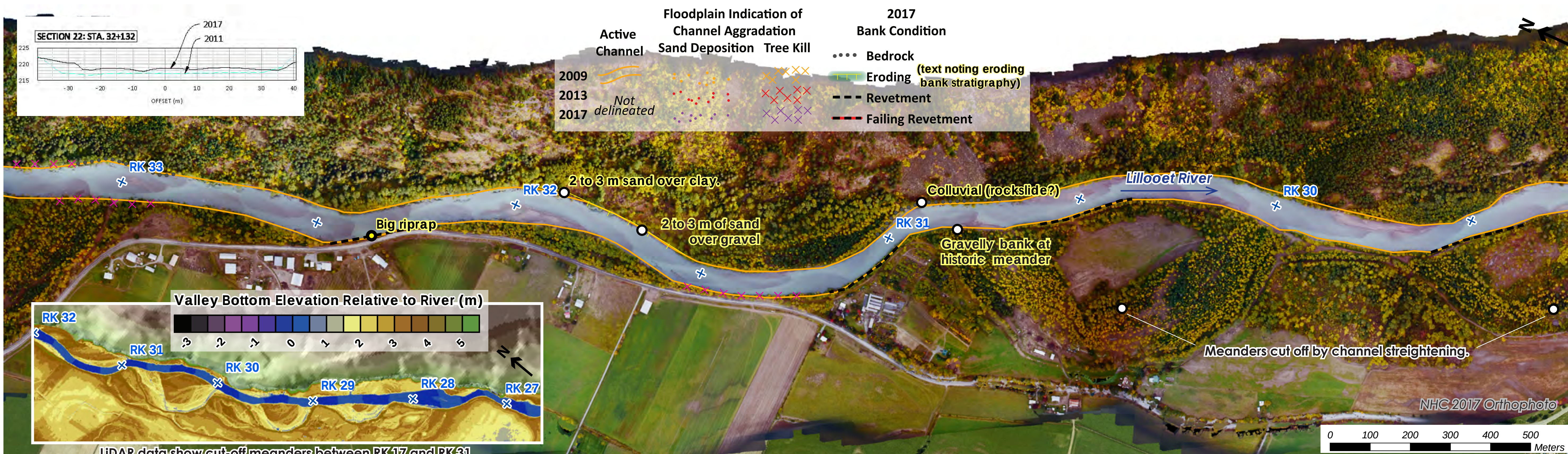
▲ Tree kill at RK 36. This is the first major tree kill noted below about RK 54.

▲ Overview of gravel cobble sedimentation zone between RK 34 and 35.5.



▲ Drowned Alder and Cedar trees on right bank at RK 33 indicate an elevated summer season water level compared to past conditions.

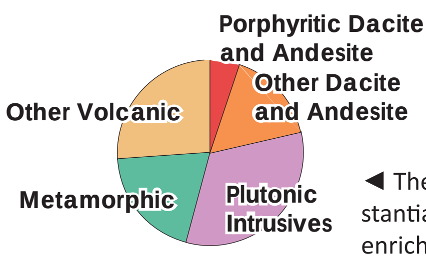
▲ Detail from near RK 33 showing large bar-scale sand wave bedforms with superimposed dunes.



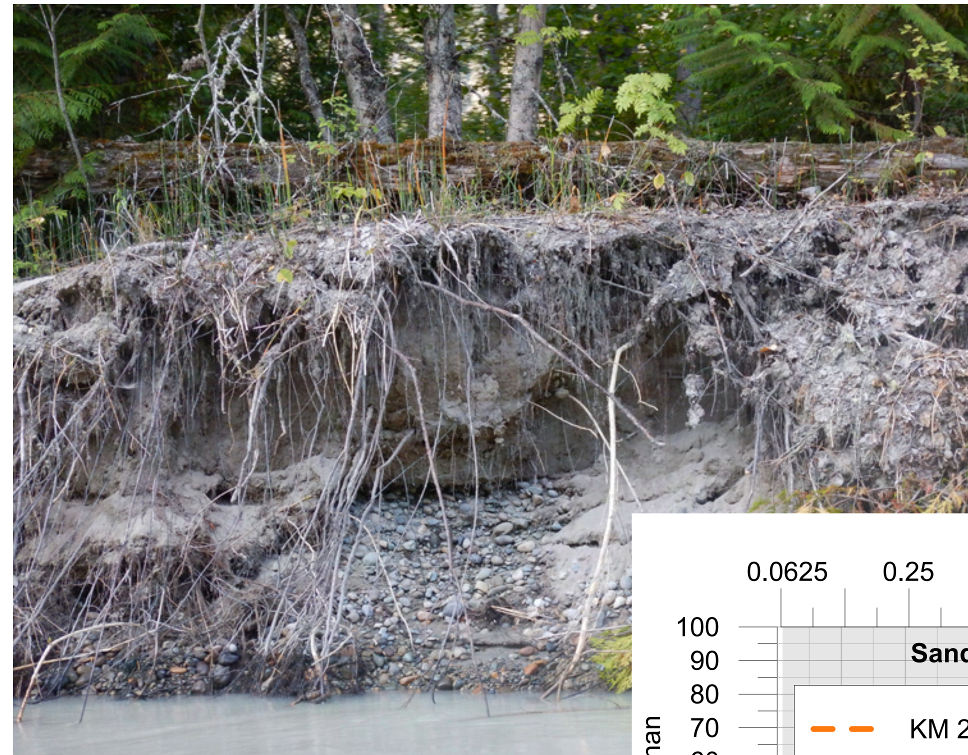
Geomorphic Conditions RK 31 to 23

- The general pattern of a confined channel filled with apparently highly mobile sand waves continues through this reach from upstream.
- A sedimentation zone occurs upstream of a strong hydraulic constriction formed by the combined influence of riprap and bedrock at RK 27.5.
- Banks are dominantly composed of sand overlying clay, except at locations where meander beds historically existed. These areas have sand over alluvial gravel. Organic peat eroded from somewhere in the banks upstream was also observed on the bar near the location of the bulk sample. Taken together these observations suggest the river is flowing through Holocene lacustrine deposits and has had very restricted lateral migration across the valley margin through the Holocene period.

▲ Washed out sand dunes over head of bar at RK 28. At the time of observation dunes were actively migrating through the back bar channel.

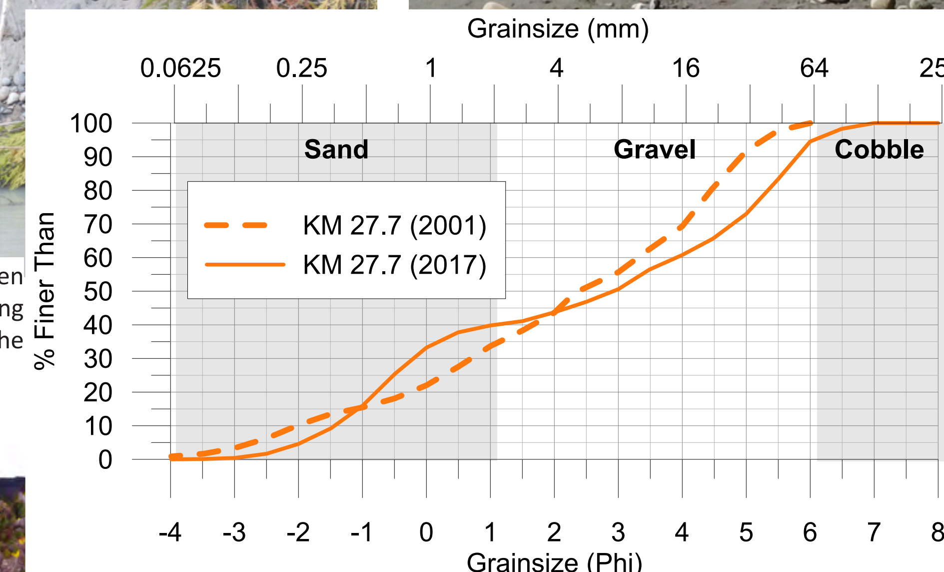


◀ The lithology of gravel at the RK 27.7 bar shows a substantial depletion in porphyritic dacite and andesite and enrichment of other volcanics compared to the sample at RK 41.6.

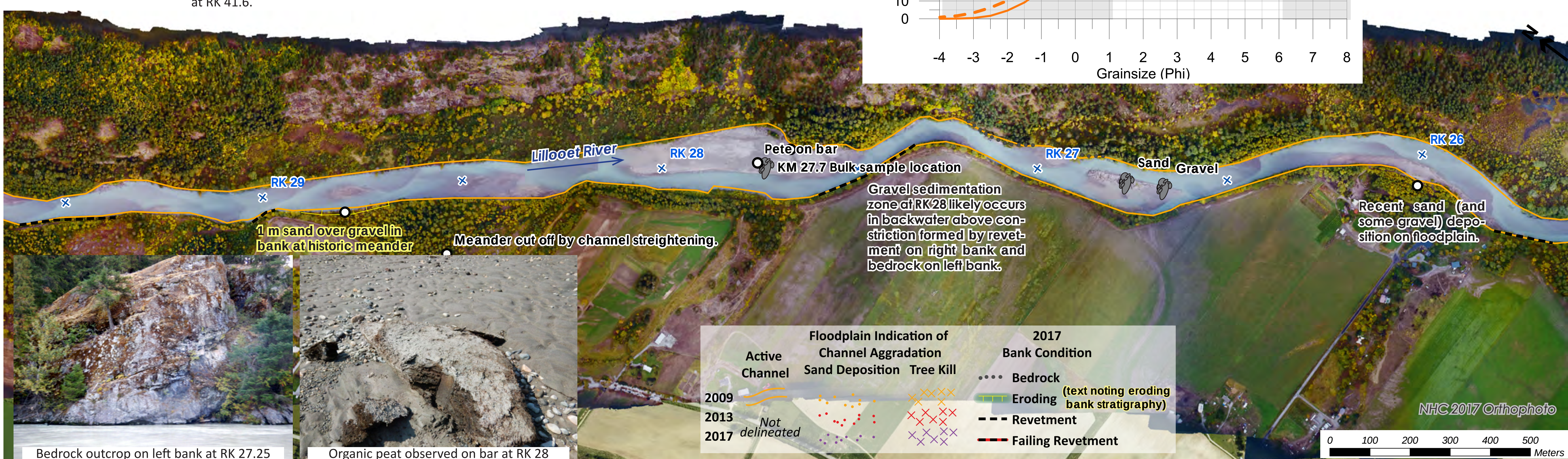


▲ Sand overlies alluvial gravel in the right bank between RK 28 and 29 where the channel margin is slowly eroding into a historic meander that was cut off to straighten the river.

▲ Location of RK 27.7 bulk sample.

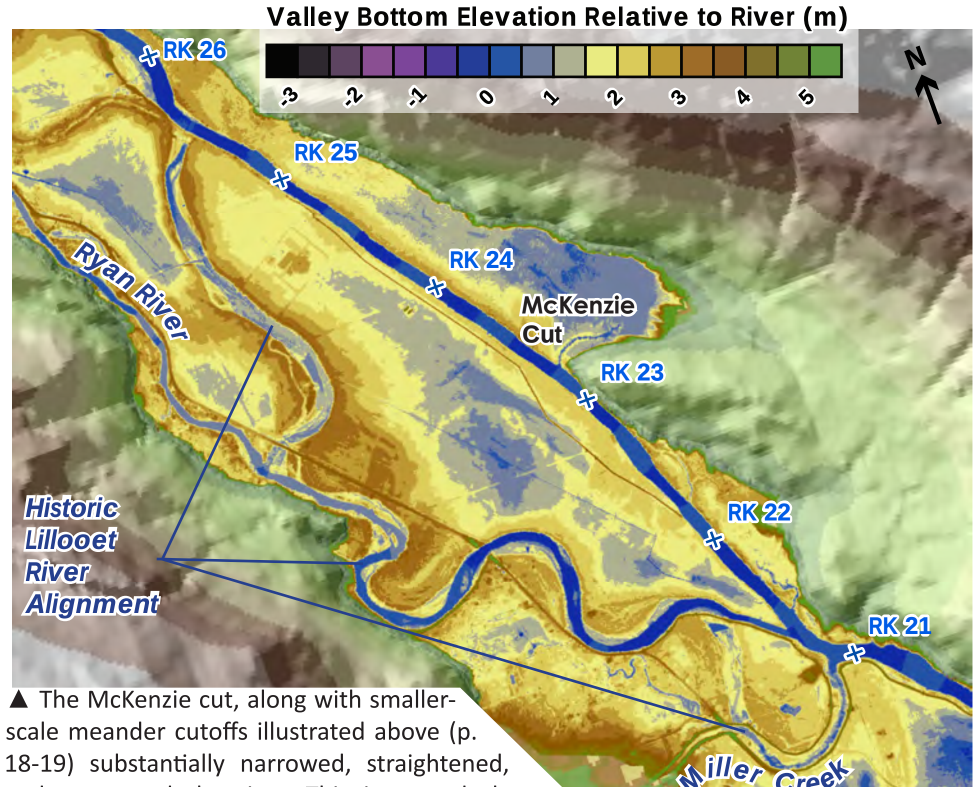


◀ Comparison of grain size distribution at location of RK 27.7 bulk sample in 2001 and 2017. The grain size is similar to that from 2001 but has become more bimodal, with a higher proportion of both sand and large gravel to small cobble.



Bedrock outcrop on left bank at RK 27.25

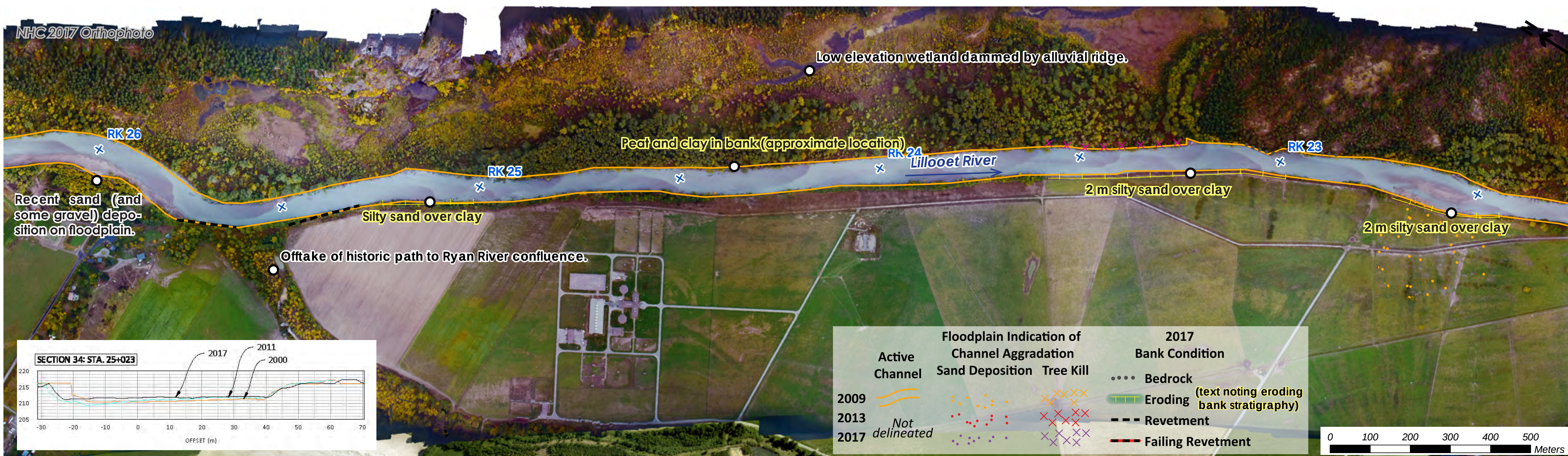
Organic peat observed on bar at RK 28



▲ The McKenzie cut, along with smaller-scale meander cutoffs illustrated above (p. 18-19) substantially narrowed, straightened, and steepened the river. This increased shear stress on the bed and led to several meters of channel degradation (Weatherly and Jakob 2014) and sent a pulse of the eroded material to the river delta, which prograded rapidly during this period (Jordan and Slaymaker 1991).

▲ Silty sand over clay observed in eroding bank at RK 23.5.

▲ Bedrock exposed along left bank at RK 23.

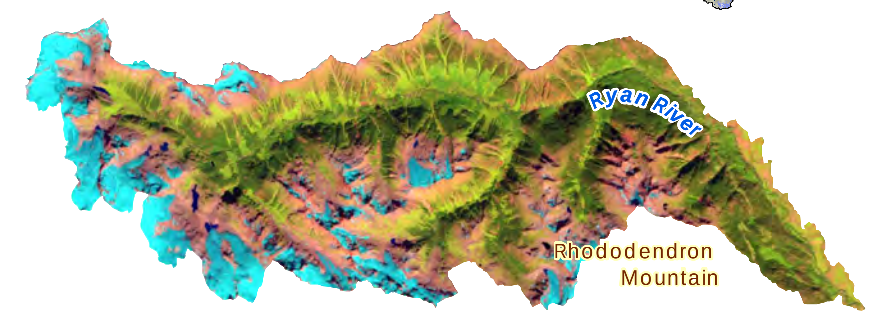


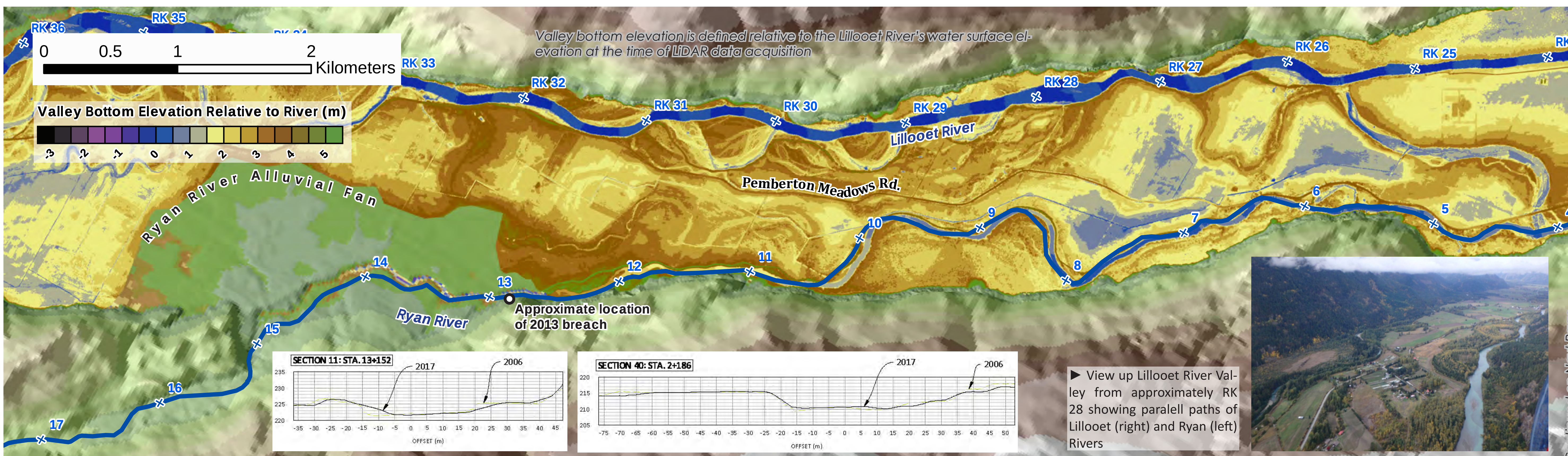
Ryan River: Tributary to RK 21.4

- Ryan River conveys flow and sediment from a 374 km² highly glaciated alpine basin and from a lower 40 km² sub-basin that includes debris-torrented slopes of Mt. Ross and most of the Lillooet River Floodplain in the reach where the two rivers flow in parallel.
- Fresh moraines throughout the river's headwaters indicate that source glaciers have retreated substantially since their Little Ice Age maxima positions. Many of the proglacial areas are dominated by bare rock and several proglacial lakes intercept sediment supply from upslope. Much of the basin's sediment yield may come from the unglaciated southern aspect slopes along the north side of the valley.
- Ryan River's profile (see next page) has a stepped pattern, characteristic of rivers flowing through glacially-sculpted landscapes. Lower gradient (0.5 to 1%) segments are punctuated by much steeper (5-10%) steps.
- At about KM 15, the river debouches into the Lillooet River Floodplain. Here its slope drops from ~5% to ~0.1% over a distance of about 5 km. Much of the river's cobble and gravel load is likely deposited in this reach. Over the Holocene geologic period, this has resulted in the formation of a large alluvial fan that has blocked about half the Lillooet River valley bottom.
- Comparison of historic cross-sections at RM 13.2 shows lateral channel instability.
- Below KM 4, Ryan River flows through a historic Lillooet River path and is underfit. Comparison of historic cross-sections at RK 2.2 shows channel infilling.
- Bed material in the lowest reach of Ryan River is dominated by highly embedded gravel finer than about 45 mm.
- Ryan River is not likely an important source of gravel to the Lillooet, but provides a substantial amount of flow.

◄ View upvalley from Pemberton Meadows Road Crossing over Ryan River at approximately RK 4.

► Cobble bar showing deposition of coarse sediment at approximatley km 12.5





► View up Lillooet River Valley from approximately RK 28 showing paralell paths of Lillooet (right) and Ryan (left) Rivers

Continued on Next Page

Miller Creek: Tributary to RK 21.2 and Lower Ryan River

- Miller Creek conveys flow and sediment from a 72 km^2 alpine basin that emerges from moraine-dammed lakes below glaciers on Rhododendron and Ipsoot Mountains.
- The creek splits into two distinct branches at about KM 4. Below their glacial sources, both branches meander at a relatively low gradient through alpine meadows and then drop precipitously into the Lillooet River Valley. The steep portion of the south branch appears more stable, while the north branch appears to be incising into unconsolidated glacial or colluvial sediment and triggering landslides along the valley walls. This is likely the dominant source of sediment to the creek. Abundant sediment supply and steep slopes in this zone may be source for potentially damaging debris flows.
- A 33 MW run-of-river hydropower facility operates on the creek. Flow is intercepted on each of the tributaries around 1200 m and conveyed through a penstock to a powerhouse at about KM 3.
- Just below the powerhouse at KM 3, the creek debouches onto an alluvial fan built into the Lillooet River Floodplain. Here it's slope drops from >10% to ~0.2 over a distance of a few kilometers.

Ryan River and Miller Creek Flood Hydrology. Flows (m^3/s^{-1}) at confluence with Lillooet River*.

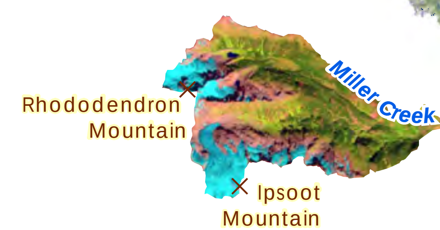
Return Period (years)	Ryan River	Miller Creek
2	106	22
5	142	30
10	169	37
20	201	43
50	246	54
100	286	63
200	330	73
500	400	89

* note: these flows are for clear water flood events as described in the Hydrology section of the main report. Localized hydrogeomorphic events may produce much higher discharges on and above fans.

- Over 90,000 m^3 of sediment was removed in the lower reach between 1980 and 1987 and approximately 11,000 m^3 was removed between 1998 and 2001.
- During a severe storm event on the week of 17 October 2003 a debris flood occurred on Miller Creek Sediment deposits extended from the apex of the fan to downstream of Pemberton Meadows Road (KWL 2004). Approximately 40,000 m^3 of sediment was removed in October 2003 to restore the channel capacity, with a further 5,000 m^3 removed in March 2004.

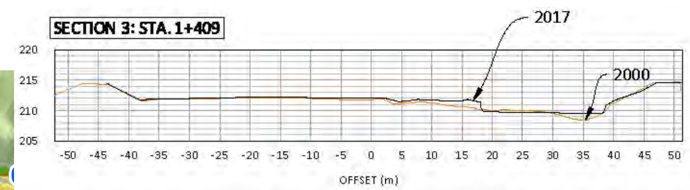
  Subsequently, a debris flow basin was constructed approximately 1.1 km upstream of Pemberton Meadows Road to contain up to 50,000 m^3 of sediment and debris. A weir was constructed in the channel at the downstream end of the basin to backwater flow and create a sediment trap to facilitate regular sediment removals. The intent of the sediment trap is to reduce the need to remove sediment in the lower reach, which could have a more substantial impact to channel habitat.
- Comparison of historical cross-sections at RK 1.409 shows a substantial amount of infilling in the reach near Pemberton Meadows Road.
- The average annual bedload of Miller Creek is estimated to be approximately 6,500 m^3/yr, based on a comparison of historical cross-sections (NHC 2018). From year to year the actual bed load varies considerably, with some years amounting to an order of magnitude more or less.

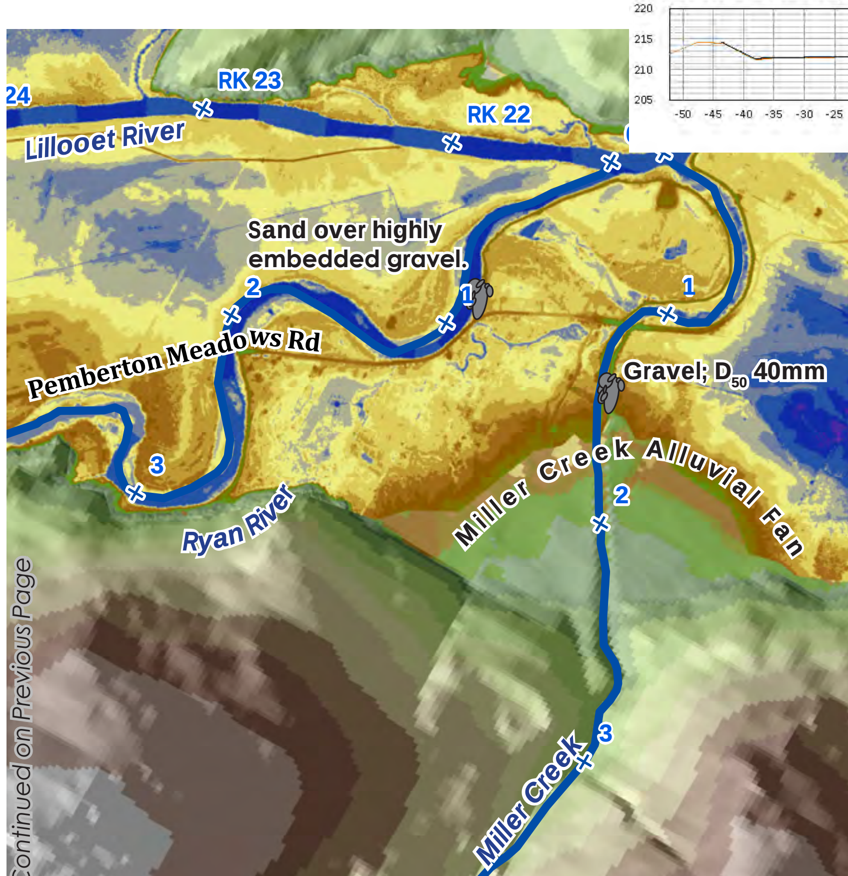
  Approximately 16,000 to 17,000 m^3 of sediment has been removed from Miller Creek since the 2004 debris flood, or less than 20% of the estimated average annual bed load. Most of the sediment removals have occurred at the trap; however, occasional sediment removals have occurred farther downstream in response to high flow events that filled in the sediment trap and carried sediment farther downstream.

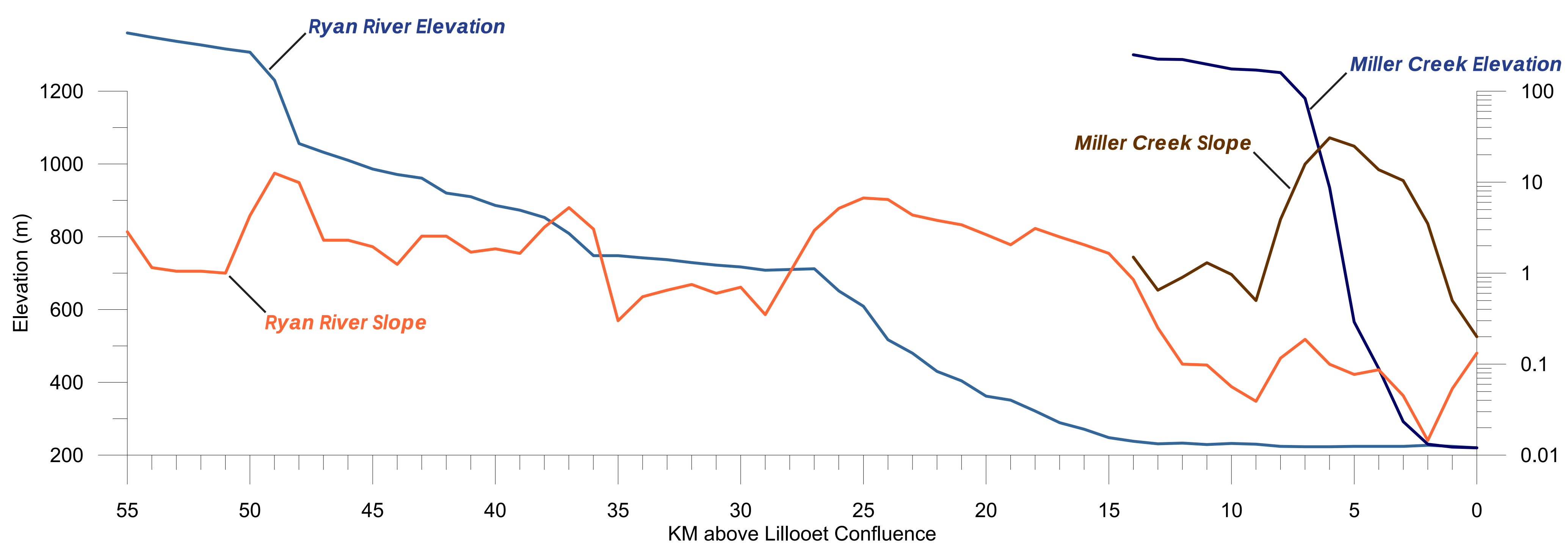


▶ Aerial photo (courtesy of PVDD) showing September 2017 sediment removal just above Pemberton Meadows Road.

▼ September 2015 view downstream towards sediment trap showing abrupt grade break as the channel crosses its alluvial fan.



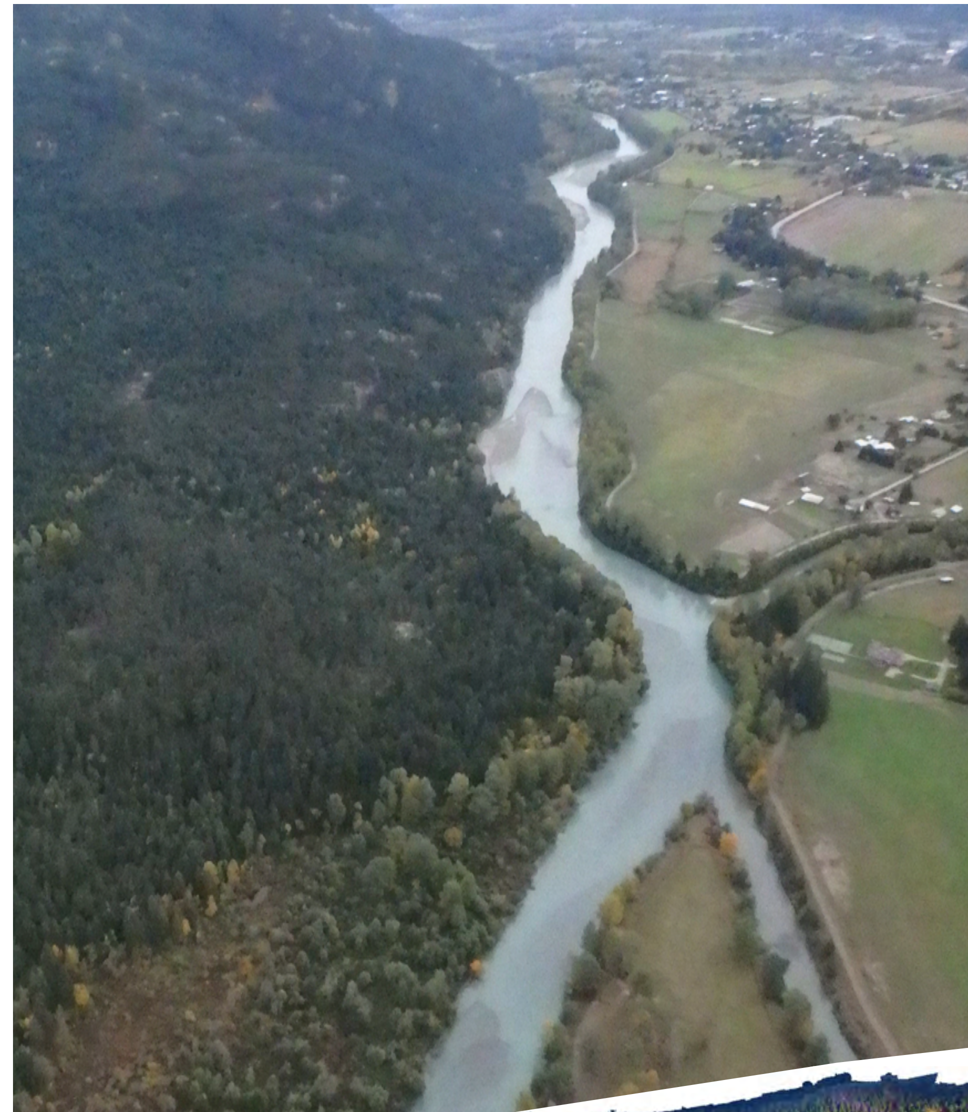




nhc

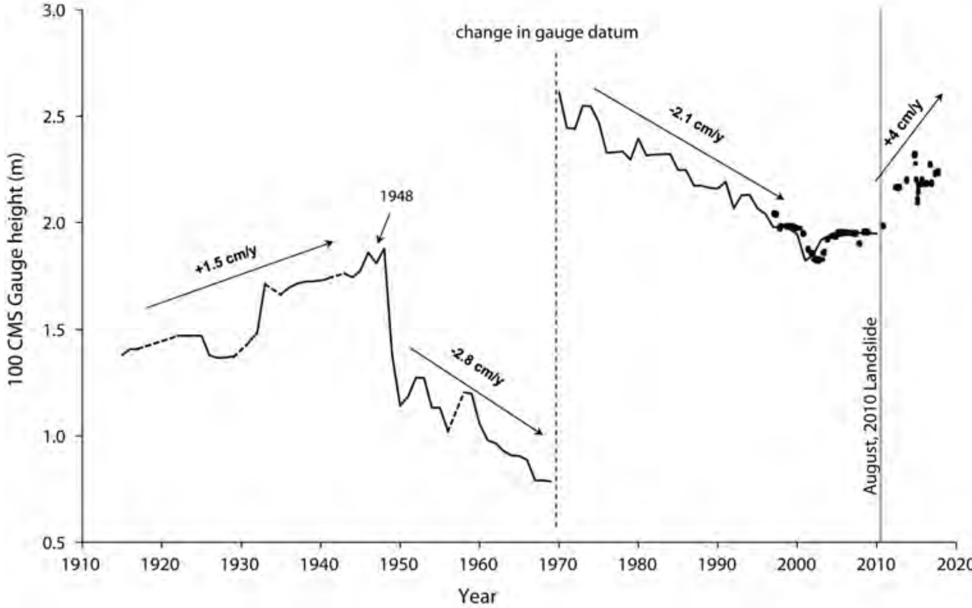
Miller Creek and Ryan River Confluence area to Pemberton: RK 23 to 15

- The combination of Miller Creek and Ryan Rivers abruptly adds about 30% to the contributing catchment area.
- As described above, Ryan River is underfit above its confluence with the Lillooet and not likely an important source of gravel. In contrast Miller creek debouches into the valley close to its confluence and crosses a steep alluvial fan. It is dominated by cobble-gravel bed material and may contribute a substantial quantity of gravel to the lower portion of the Lillooet River.
- On the Lillooet, sand waves that fill the channel from about RK 34 become notably less common and replaced by longer-wavelength gravel bars in the reach just downstream of the Miller Creek Confluence.
- The WSC gauge records the history of bed elevation variability in this reach. Prior to channelization, the river was aggrading at a rate of about 1.5 cm/yr. Following channelization the river rapidly incised by about 1 m with degradation continuing at a rate of about 2.1 cm/yr until about year 2000. A short period of stability (2000-2010) followed with a shift to rapid aggradation (~4 cm/yr) following the 2010 landslide (p. 25).
- The WSC gauge is located just upstream of a gravel-dominated riffle feature around RK 17.5. The elevation of this riffle crest probably controls the low-flow stage-discharge relation at the gauge, and so the recent increase in the stage for any given discharge probably indicates aggradation on this riffle caused by accumulation of gravel-sized sediment.
- Comparison of historic cross-sections shows channel infilling between 2000 and 2011, and more extensive infilling between 2011 and 2017.
- Since 2013 sediment management has occurred at several locations in the lower reach, with a total of about 70,000 m^3 removed. In 2013 21,600 m^3 was removed from Voyageur bar, and in 2013, 2016, and 2017 at Beem Bar (18,000 m^3 total), and Belkin Bar (~19,400 m^3 total).

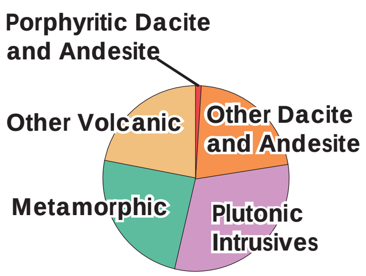


▲ View upstream towards Miller Creel confluence showing confined character of channel typical of reach.

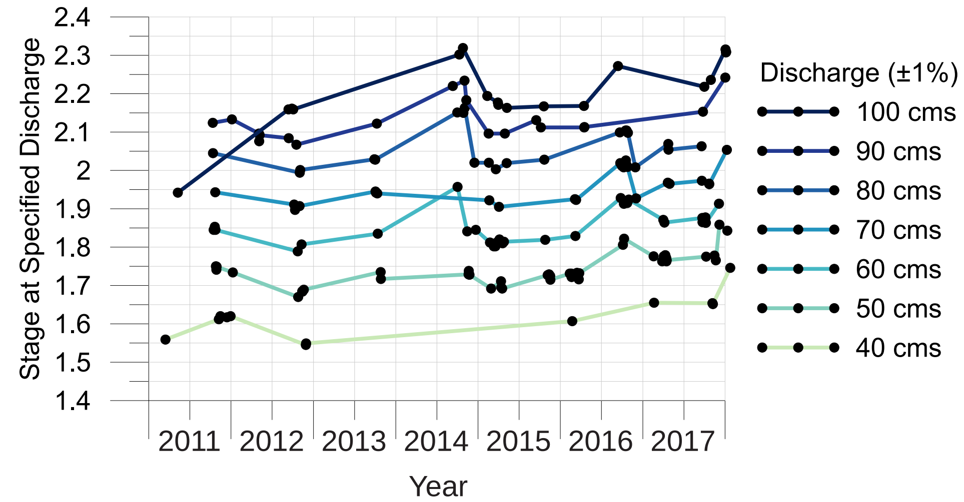
◀ View looking downstream towards Pemberton from area of Ryan River and Miller Creek confluence.



▲ Specific gauge analysis showing degradation response to channel straightening and gravel removal (1948-2000), a short period of stability (2000-2010), and shift to rapid aggradation following 2010 landslide. After Weatherly and Jakob, 2014).



◀ Lithology for RK 15.7 pebble count. Note dramatic reduction of the landslide-trace porphyritic dacite and andesite compared to the RK 27.7 sample location.



▲ Detailed specific gauge plot showing several discharge values for the period following the 2010 Landslide. Note substantial inter-annual and even seasonal variability superimposed on overall aggregational trend.

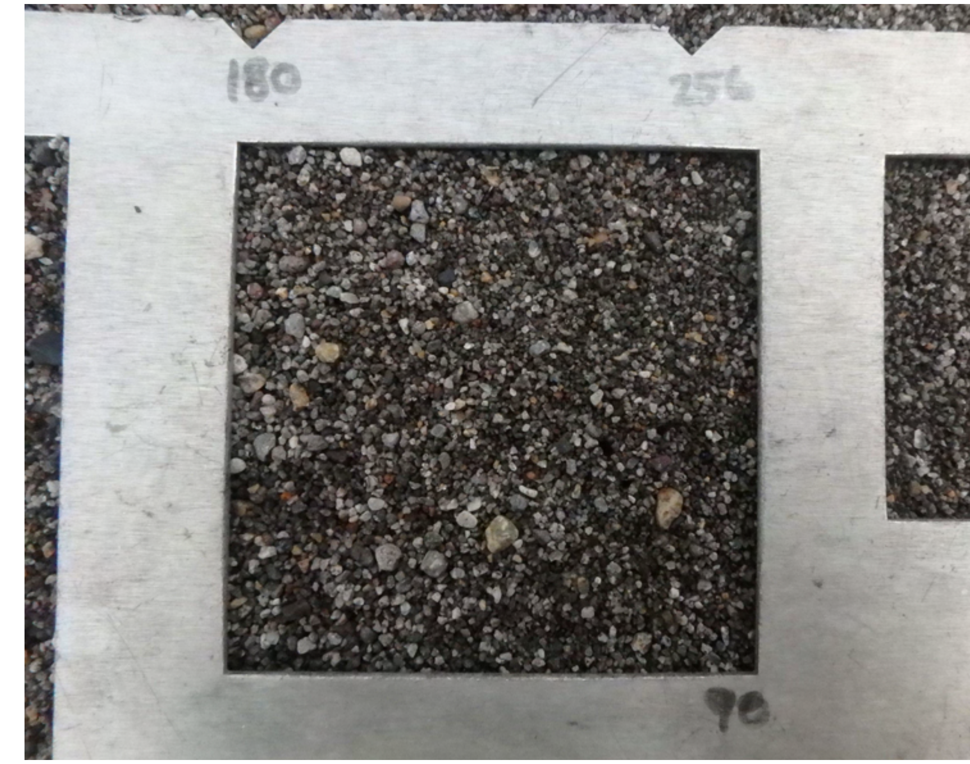
▶ Location of RK 15.7 pebble count. Anomalously large cobble-sized particles are composed of very low density (barely higher than one) vesicular volcanic rock.

▲ This gravel bar and corresponding submerged riffle at RK 17.5 form the hydraulic control for the WSC gauge. The sand sample was from a patch of sand moving over the gravel.

nhc

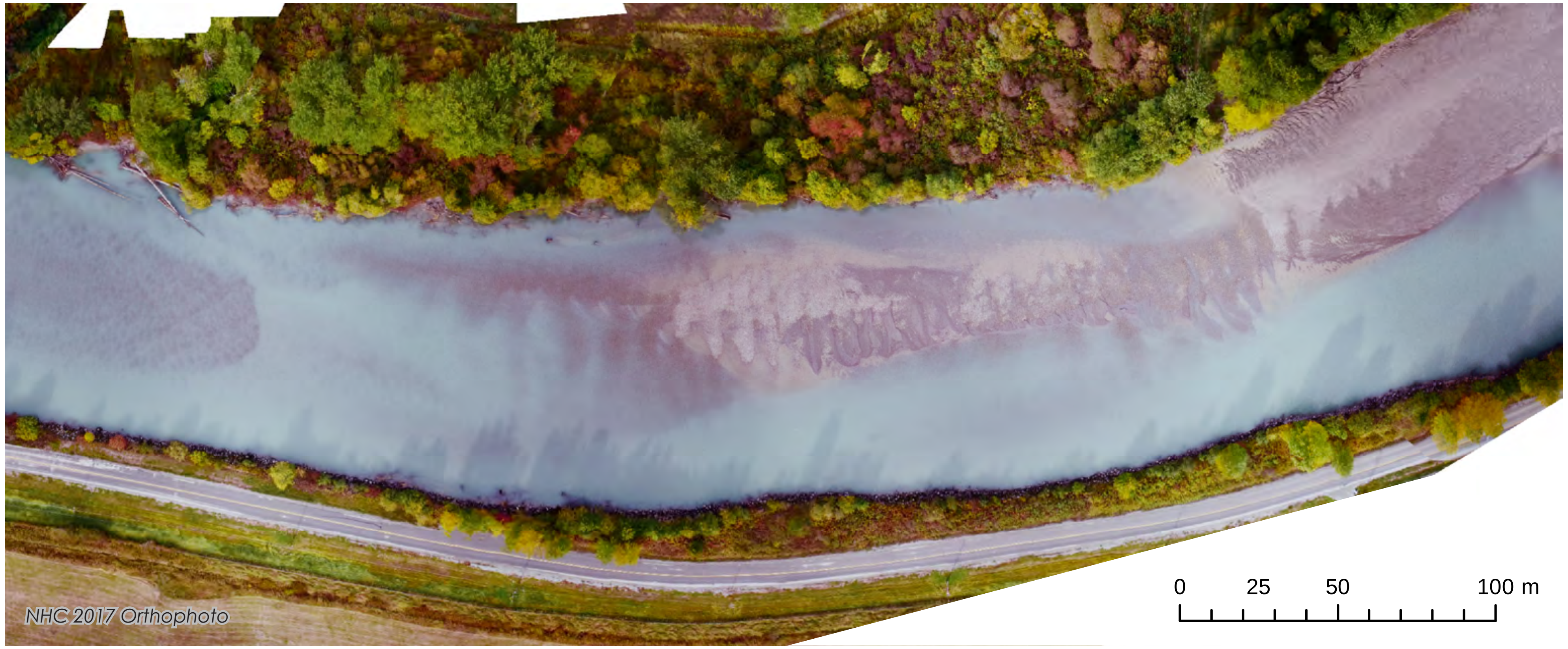
Highway 99 to Green River Confluence: RK 14 to 7

- Bed material through this reach appears to be dominated by gravel and sand. Large sand bedforms smother much of the gravel bed in deeper portions of the channel.
- Composition of the coarse sand in this reach appears to remain strongly influenced by the Meager slide source material (See Page 8).
- Comparison of historical cross-sections at RK 13.8 shows channel infilling of near 2 m at the channel thalweg between 2000 and 2011. A similar amount of infilling is shown between 2011 and 2017 which indicates nearly double the rate of sediment accumulation in the channel.
- In 2016 and 2017, approximately 7,900 m^3 and 4,100 m^3 of sediment, respectively, were removed from Big Sky Bar



▲ Views of Gravel bar at RK 13.5 with thick deposit of coarse sand covering the lower-elevation margin of the bar. Above Left: small dunes (~1m wavelength and 10 cm height) of coarse sand coat the margin of the bar; Above right: detail of coarse sand, the centred aperture in the gravitometer is 90 mm.

◀ View downstream towards the Highway 99 Bridge from the head of the bar



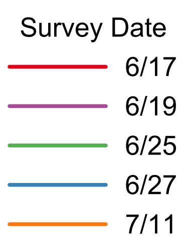
▲ Detail showing variable composition and multiple scales of bedforms in the channel between RK 10.5 and 11. Note superimposition of gravel bars (0.1 to 0.5 km wavelength), sand sheets (~100 m wavelength), and dunes (1-10 m wavelength).

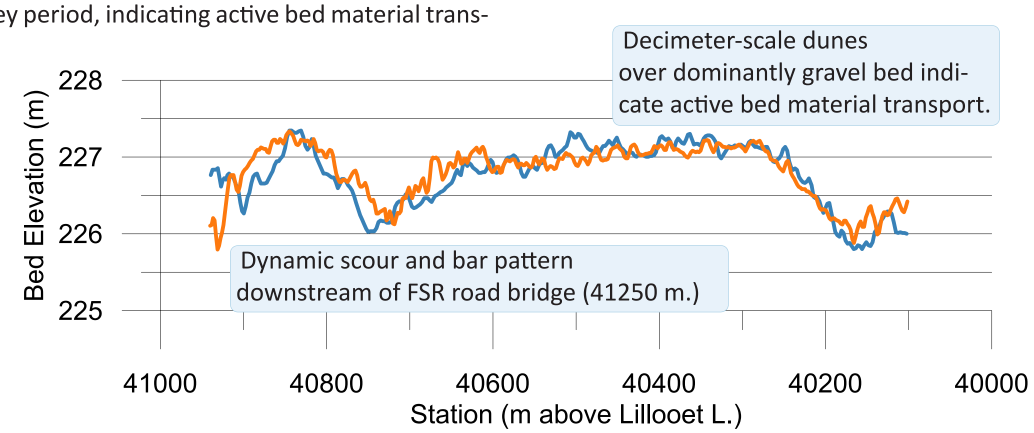
▲ Example of large island apex jam at RK 7.5.

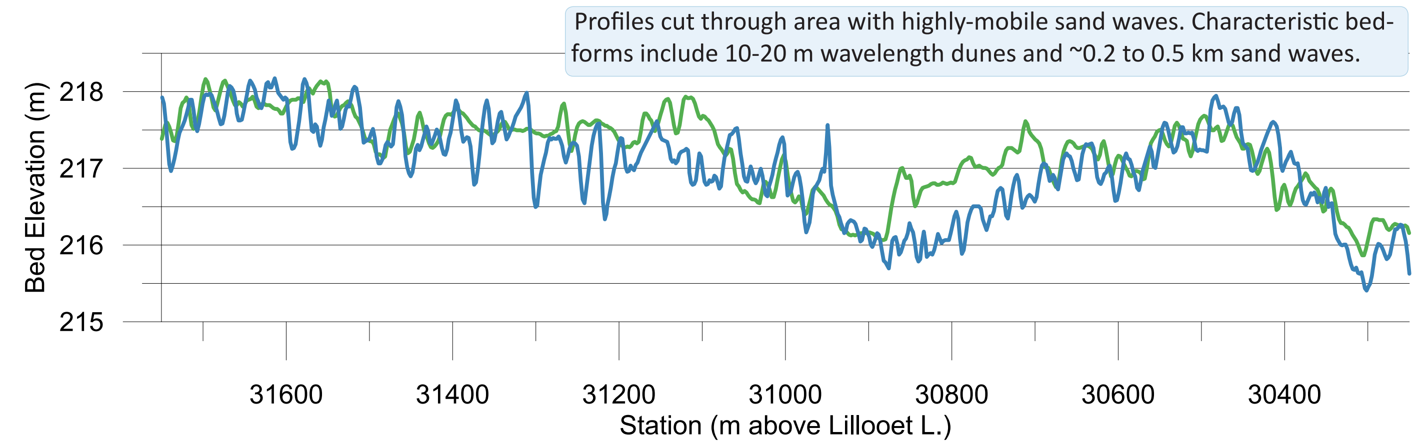
▲ Large gravel bar on inside of sharp bedrock-forced bend at RK 8.5.

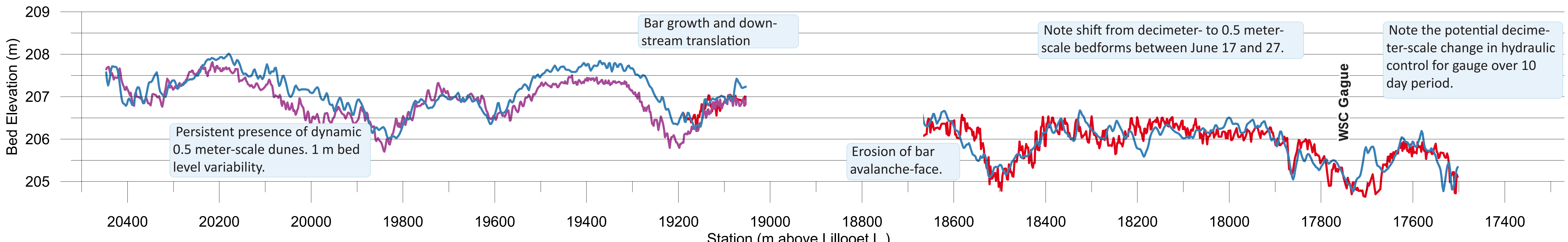
Dynamic Bedforms

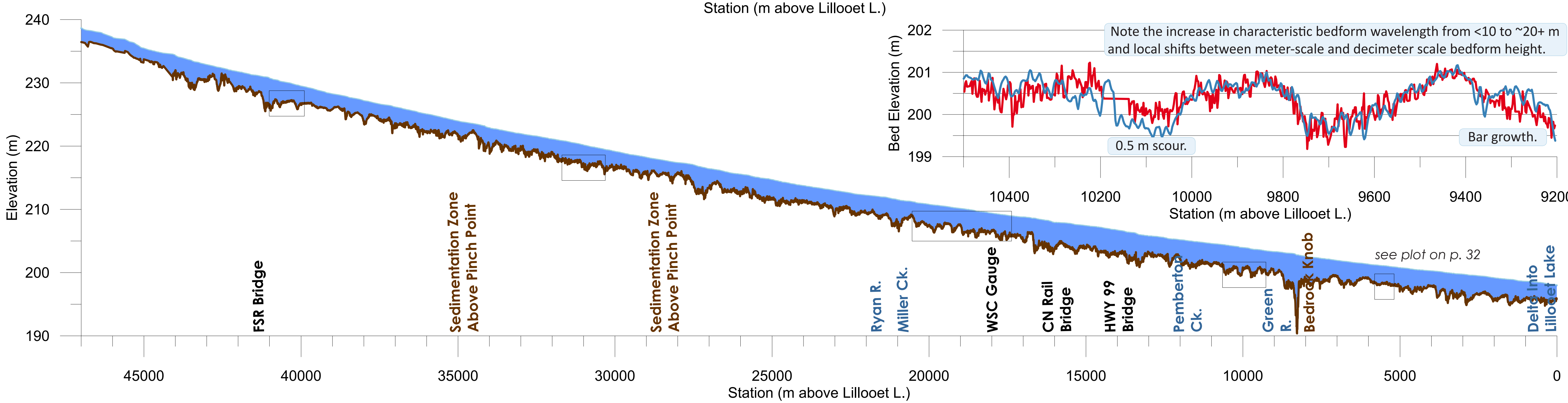
- Survey work completed during Summer 2017 included several areas where longitudinal transects were repeated.
- Longitudinal transects show the various scales of bedforms present along the river, ranging from 0.1 m by ~5 m small dunes (or megaripples) through 0.5 by 10-20 m dunes to 100+ m wavelength bars and sand waves. Repeat profiles show dynamic character and mobility of these bedforms during the survey period, indicating active bed material transport was occurring.











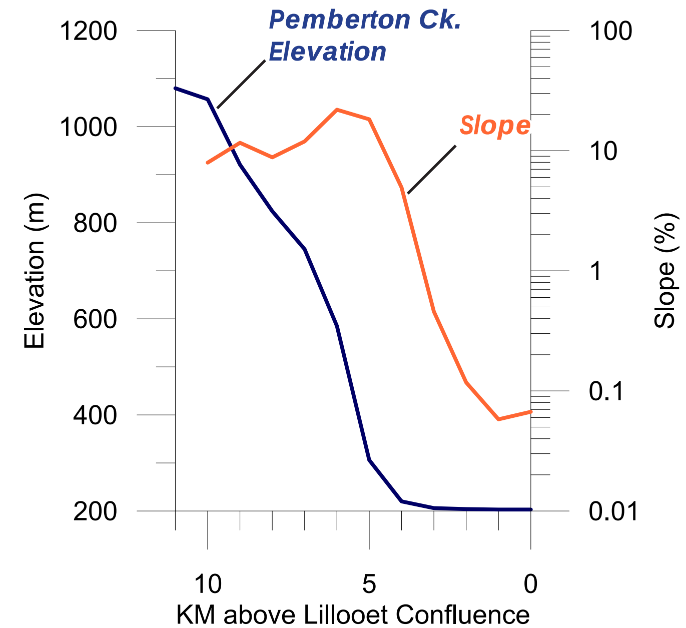
Pemberton Creek: Tributary to RK 12.5

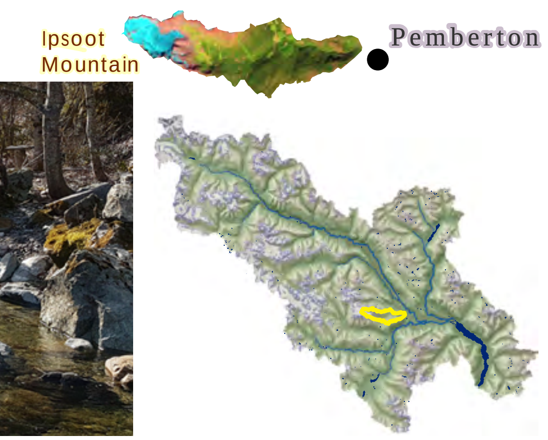
- Pemberton Creek emerges from a glacier on the east flank of Ipsoot Mountain. It conveys flow from a relatively small catchment area (30 km^2) and flows through a steep (5-10% slope) and confined valley until it emerges into the Lilloet Valley at KM 4. Interpretation of aerial photos suggests that bedrock is exposed along the creek channel in the steepest areas.
- Abundant proglacial sediment supply is available to the creek, and the walls of the upper portion of the creek valley appear to still be relaxing following glacial debutressing.
- The Village of Pemberton is constructed largely on the Pemberton Creek Alluvial Fan, and the creek is aligned to flow along the toe of the adjacent hillslope to the south across the fan. The Creek's gradient drops from 10-20% in the valley above the fan to about 0.03% at the toe of the alluvial fan. Coarse sediment starts to deposit at the fan apex, approximately 500 m upstream of the CN Rail Bridge where the gradient begins to lessen to about 3%. Natural fan processes are inhibited by a man-made flood corridor and dike system that has confined the creek and more or less fixed its position, causing the channel bed to build up over time. The grain size shifts from cobble-dominated midway across the fan at km 3.8 to gravel-dominated downstream of the fan at KM 3.
- The lowest 2 km of the creek flow at very low slope (<0.1%) across the Lillooet River floodplain. Channel aggradation is not apparent in historical cross-sections located in this area (below KM 2.2) and it is likely that Pemberton Creek is not a substantial source of gravel to the Lillooet River.

Pemberton Creek Flood Hydrology. Flows (m^3/s^{-1}) at head of Alluvial Fan*.

Return Period (years)	Pemberton Creek
2	16
5	22
10	25
20	28
50	32
100	35
200	37
500	40

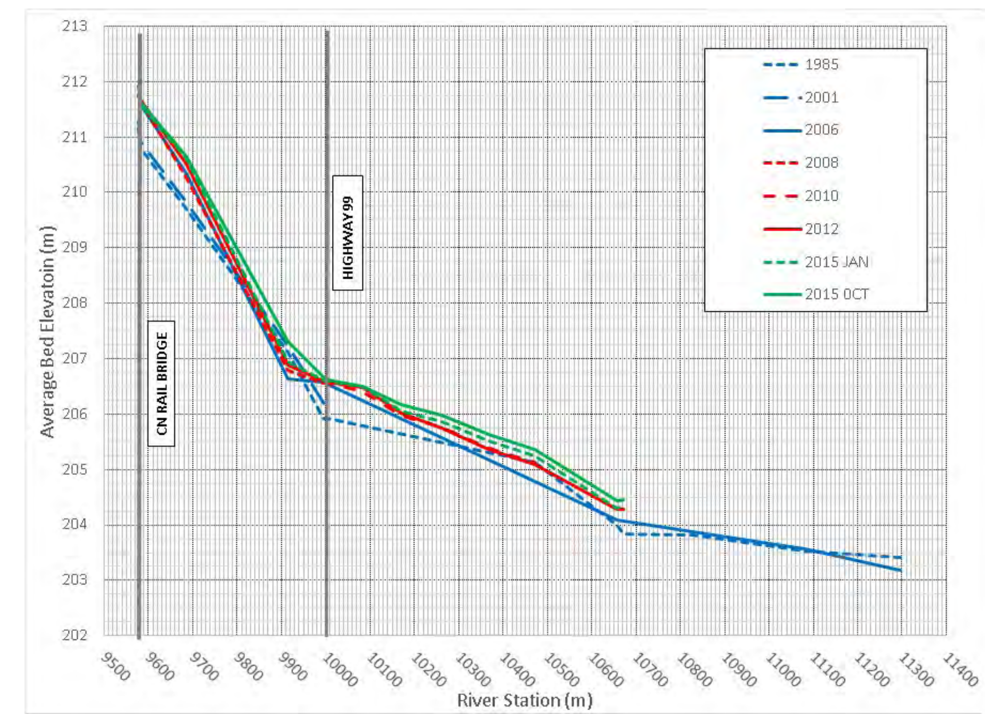
* note: these flows are for clear water flood events as described in the Hydrology section of the main report. Localized hydrogeomorphic events may produce much higher discharges on and above the fan.





▼ Characteristic conditions in channel above CN Rail Bridge

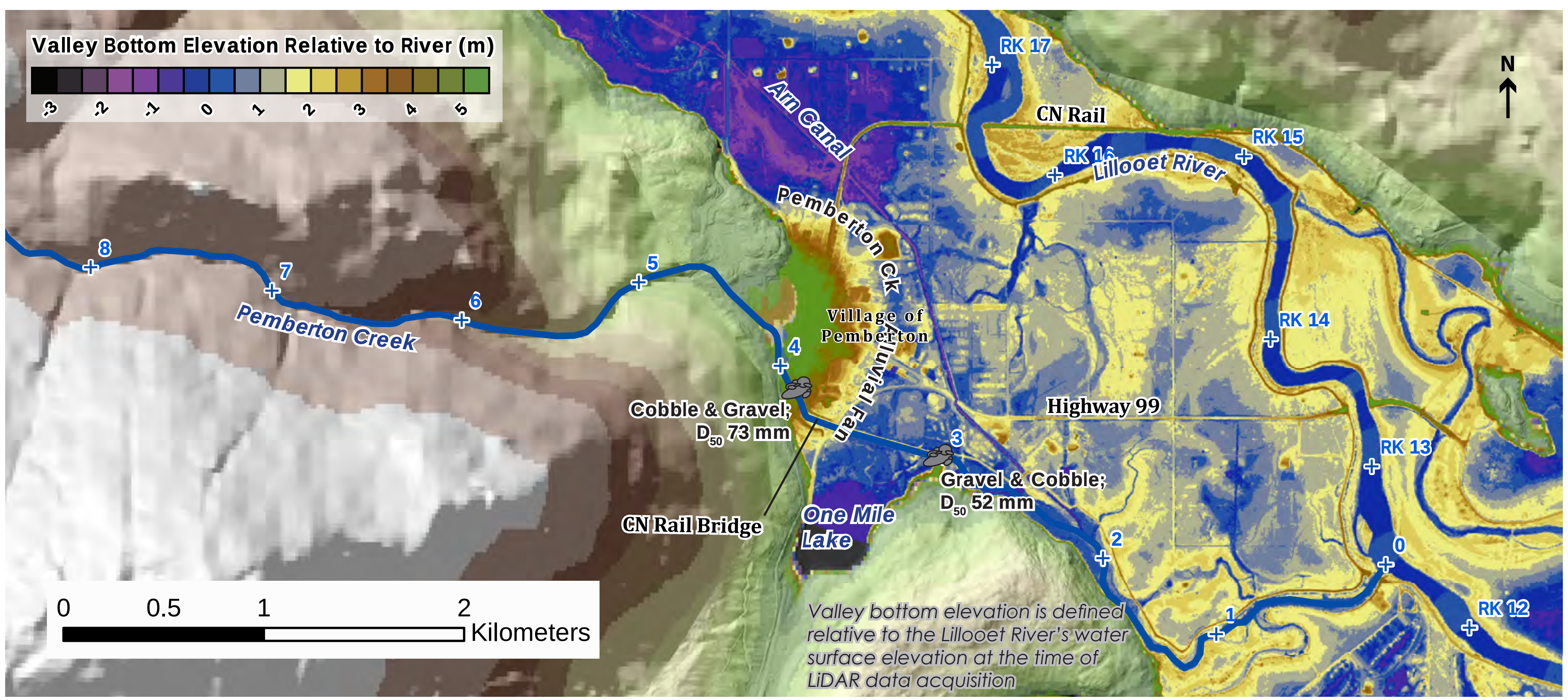
▼ Characteristic conditions in channel below CN Rail Bridge



Sedimentation rates have been estimated based on an analysis of historical cross-sections in a 1.1 km long depositional reach. The plot above shows a profile of computed average bed elevations, between 1985 and 2015. Average bed elevation is a useful measure to show the effects of sediment aggradation in a channel, and is computed by integrating the cross sectional area over the active channel width to include the deepest parts of the channel, the top of exposed gravel bars, and all other inflection points within the active channel boundary. Average bed elevation increased by about 0.4 m between Highway 99 (KM 3.3) and KM 2.2 over the 30 year period.

Accounting for sediment removals, there is an average annual gravel load of 500 m^3/yr (NHC 2015). From year to year the actual bed load varies considerably, with some years amounting to an order of magnitude more or less. A recent example of was substantial accumulation in the channel during the 20 September 2015 flood event. Channel surveys completed in January and October 2015 documented channel infilling by almost 0.5 m in a 100 m section of channel immediately upstream of Highway 99.

In an effort to manage sediment build up in the channel, an estimated 27,500 m^3 of sediment was removed between 1980 and 1987 near Highway 99 (KWL 2007. Lillooet River Gravel Management Plan. Prepared for PVDD February 2007).Between 1990 and 2017, approximately 3,900 m^3 of sediment has been removed from Pemberton Creek.



nhc

Green River: Tributary to Lillooet River at RK 8.7

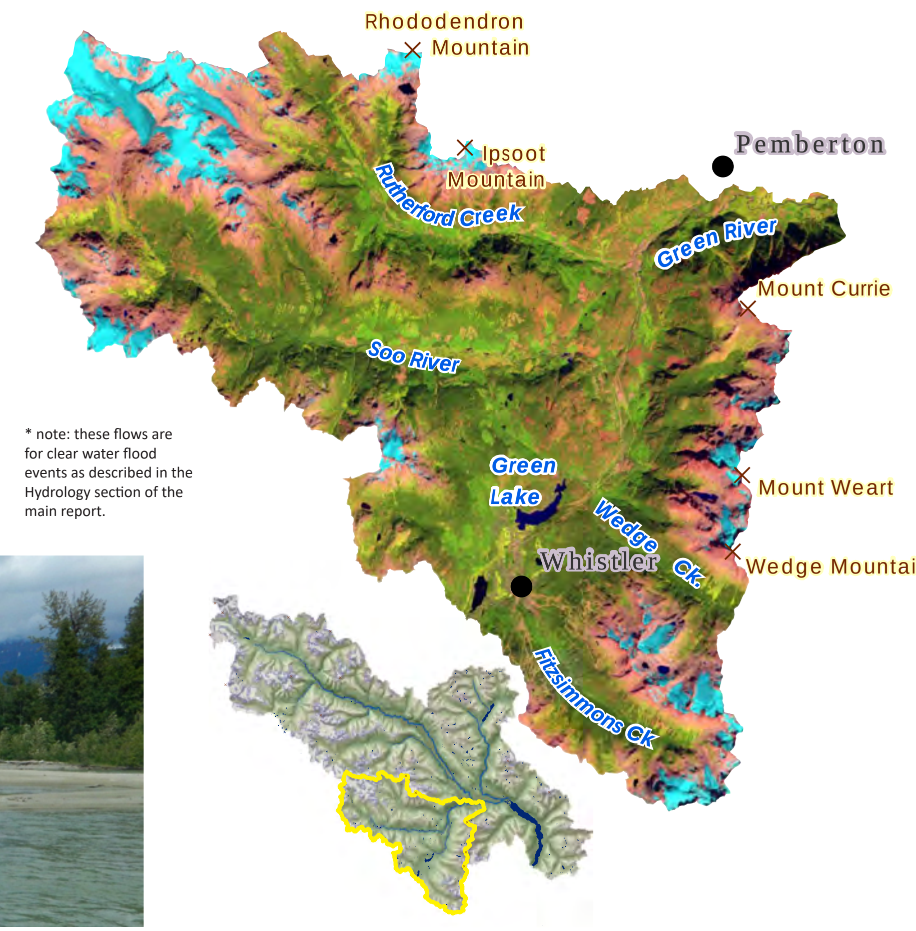
- Green River is the largest tributary to the Lillooet. It conveys flow from 874 km^2 (28% of the the basin at the confluence) that extend from Ipsoot and Rhododendron Mountains and the Pemberton Icefield in the north to the Fitzsimmons Creek Basin (surrounded by the Whistler-Blackomb Ski area), Wedge Mountain, Mt. Weart, and Mt. Currie to the south. Green Lake, at Whistler, interrupts sediment continuity from Fitzsimmons Creek.
- Green River's slope is typically 0.5 to 3% upstream of Nairn Falls, which has a drop of approximately 40 m. Below the falls the slope declines from about 0.8% to about 0.3% over a distance of about 8 km. The river deposits it's cobble and gravel load in a sedimentation zone between approximately KM 8.5 and 5, about where the river bed shifts from gravel-dominated upstream to sand-dominated downstream.
- A cross-section near KM 1.6 shows some infilling and channel erosion. However, it is likely that the Green River contributes a relatively minor amount of bed material sediment to the Lillooet River.

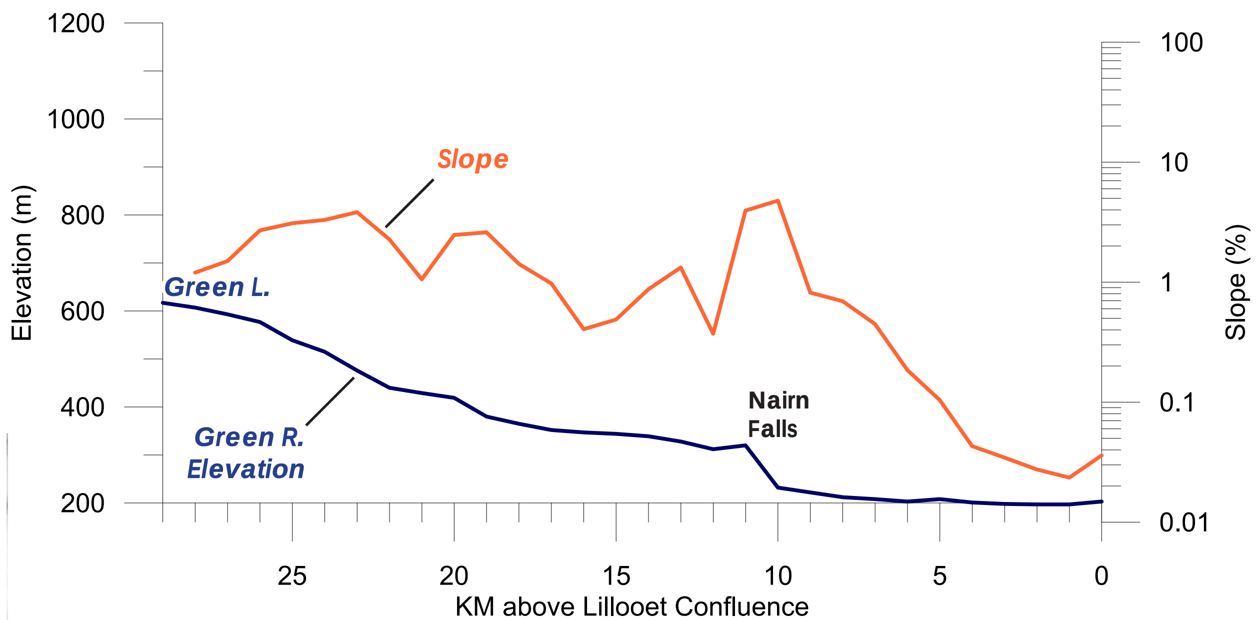
▲ View looking downstream at approximatley KM 3.5 showing large debris flow fans on flank of Mt Currie.

Green River Flood Hydrology. Flows (m^3/s^{-1}) at Lillooet Confluence.

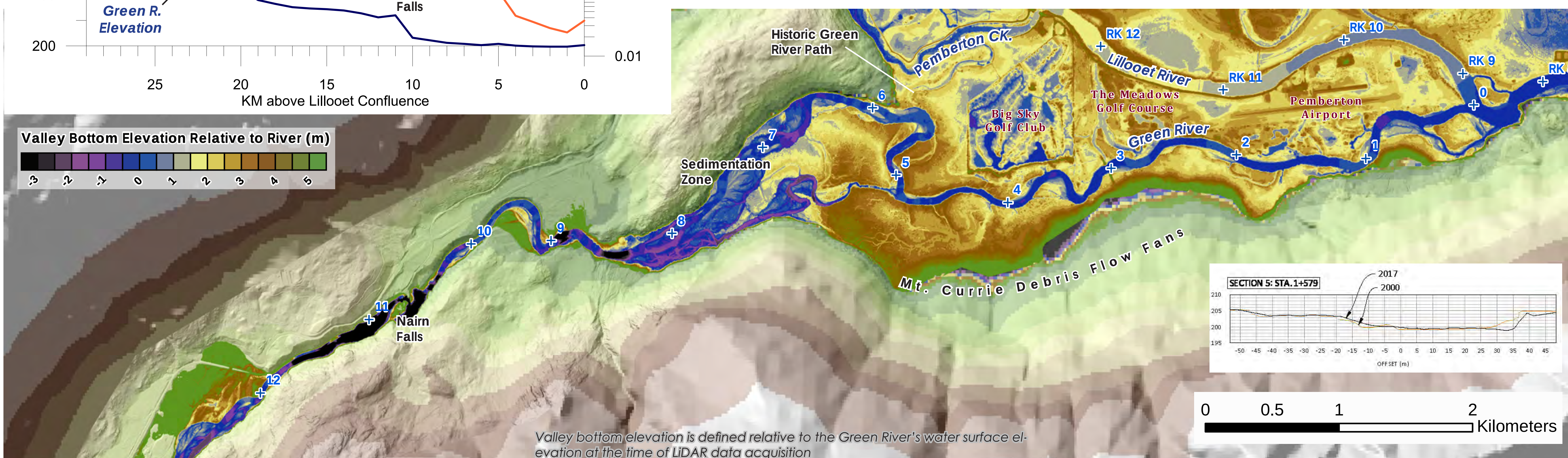
Return Period (years)	Green River
2	194
5	260
10	309
20	364
50	444
100	514
200	592
500	712

* note: these flows are for clear water flood events as described in the Hydrology section of the main report.





▼ Large sand bars at km 5.5



Valley bottom elevation is defined relative to the Green River's water surface elevation at the time of LiDAR data acquisition

Birkenhead River: Tributary to Lillooet River Delta

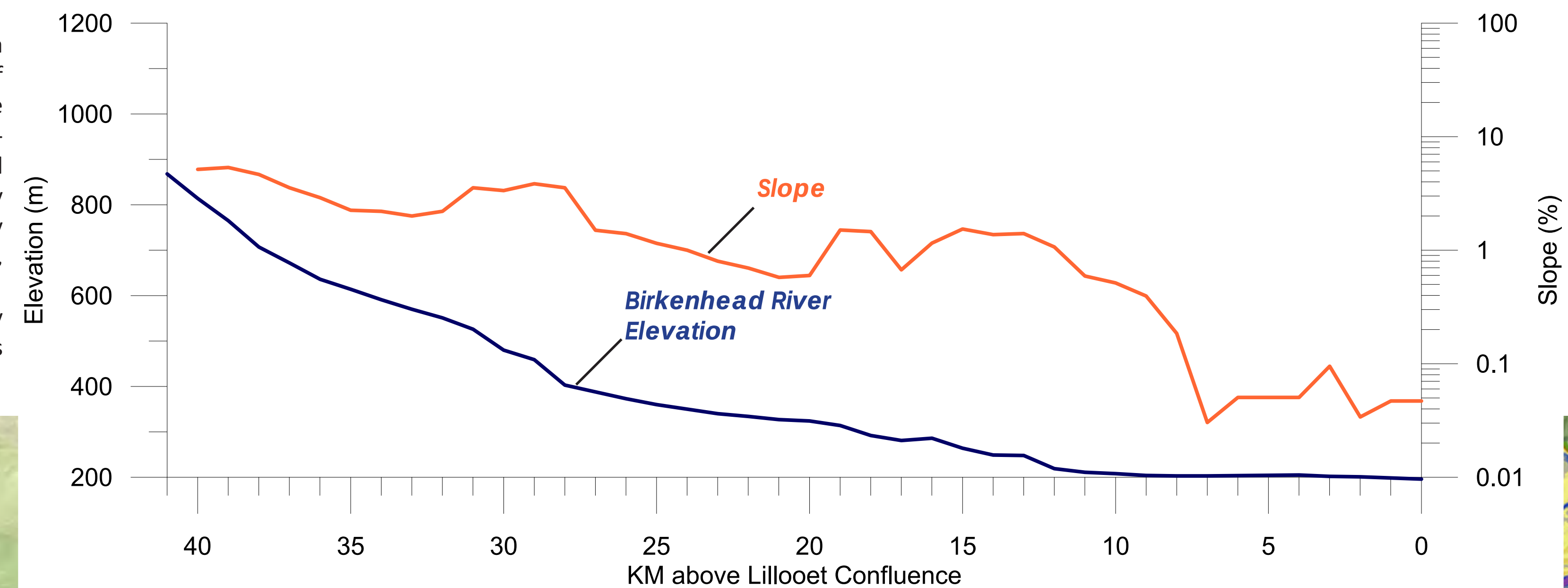
- Birkenhead River delivers flow and sediment to the Lillooet River valley and is not a direct tributary to the Lillooet River, but rather enters Lillooet Lake directly along the margin of the Lillooet River Delta. LiDAR data suggest that distributary channels of the Lillooet River have historically crossed the floodplain to connect flow from the Lillooet into the Birkenhead.
- Birkenhead River conveys flow from a 685 km² basin that is less influenced by active glaciers than other tributaries. About 44% of the watershed is located above lake bodies that act as sediment sinks. Annual peak flows generally occur between May and July during freshet, or occasionally from heavy autumn rains. It has a relatively gentle concave profile that declines from about 3% at KM 40 to 1% at about KM 25. Downstream of Birkenhead Lake, the river flows through a steep, narrow canyon into a 500 m to 1,000 m wide valley, before emerging onto a broad alluvial fan that extends into the Lillooet River Valley, downstream of KM 11. The channel gradient across the alluvial fan drops to less than 0.5% and this reach is prone to channel infilling of gravel and cobble-sized sediment and avulsions.
- In 1950, a flood channel was excavated at approximately KM 9.6 and a training berm was constructed across the fan, cutting off a portion of the original main channel and conveying flow to the north east. By the 1990s, the flood channel had substantially filled in and water was increasingly flowing across the floodplain. In 2013, the training berm breached during freshet requiring emergency upgrades. In 2014, approximately 12,000 m³ of sediment was removed to improve the channel capacity and reduce the potential for historical channels to become more active, which could threaten nearby infrastructure and properties.
- Downstream of Grandmother Slough, the main channel has been locally filled in by more than 1.3 m in places. A cross-section at KM 2.42 shows channel infilling and lateral instability extending to Lillooet Lake.

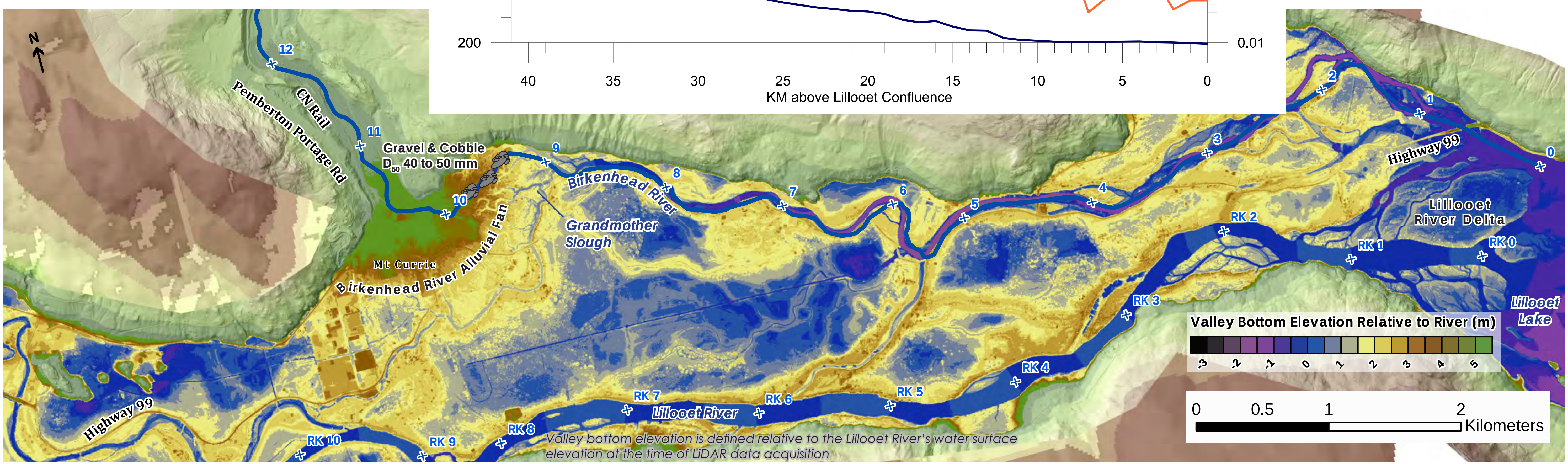
▲ Birkenhead River at Approximately KM 6.

Birkenhead River Flood Hydrology. Flows (m³/s⁻¹) at mouth into Lillooet Lake.

Return Period (years)	Green River
2	159
5	214
10	255
20	300
50	368
100	426
200	491
500	592

* note: these flows are for clear water flood events as described in the Hydrology section of the main report.

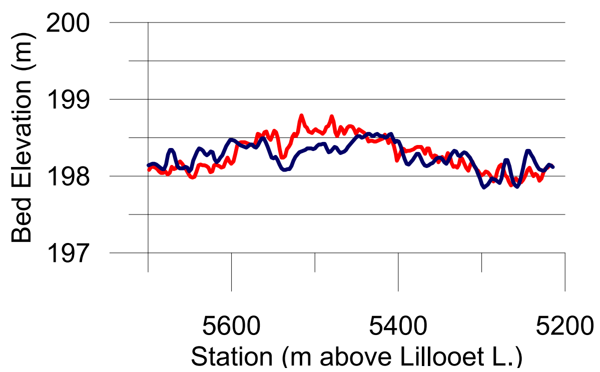




nhc

Below Green River to Lillooet Lake Delta: RK 7 to 0

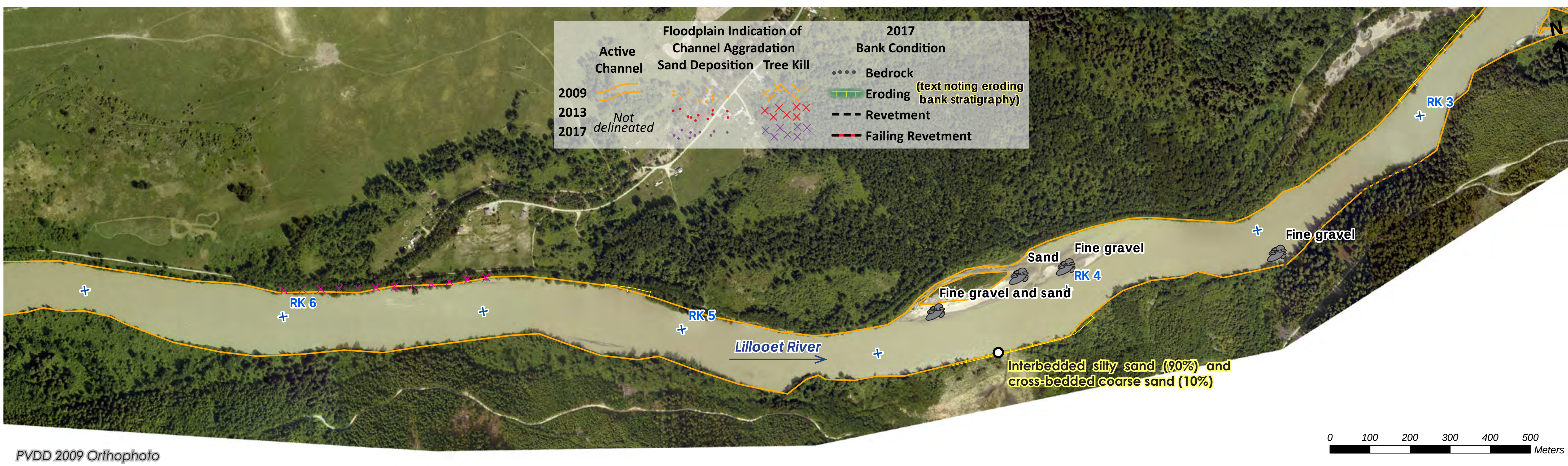
- Bed material through this reach appears to be dominated by sand, but gravel is present all the way onto the distal portion of the delta.
- 2017 aerial photos were not collected over this reach, and so it is not possible to determine how much the channel has shifted laterally, but bank erosion appears to be generally minor and localized.
- Since 2012, the delta has been prograding at a rate of about 19 m per year; this slightly faster than the long-term historical average (1885-2018) rate of 13 m per year (data from this study and Jordan and Slaymaker 1991) but within the range of historical variability, which has included periods with rates as fast as 28 m per year (Jordan and Slaymaker 1991).
- No porphyritic dacite (abundant in the 2010 Meager Landslide) was observed in gravel at the RK 1.04 sample location. This suggests that it is unlikely gravel-sized sediment from the slide has reached this far downstream.



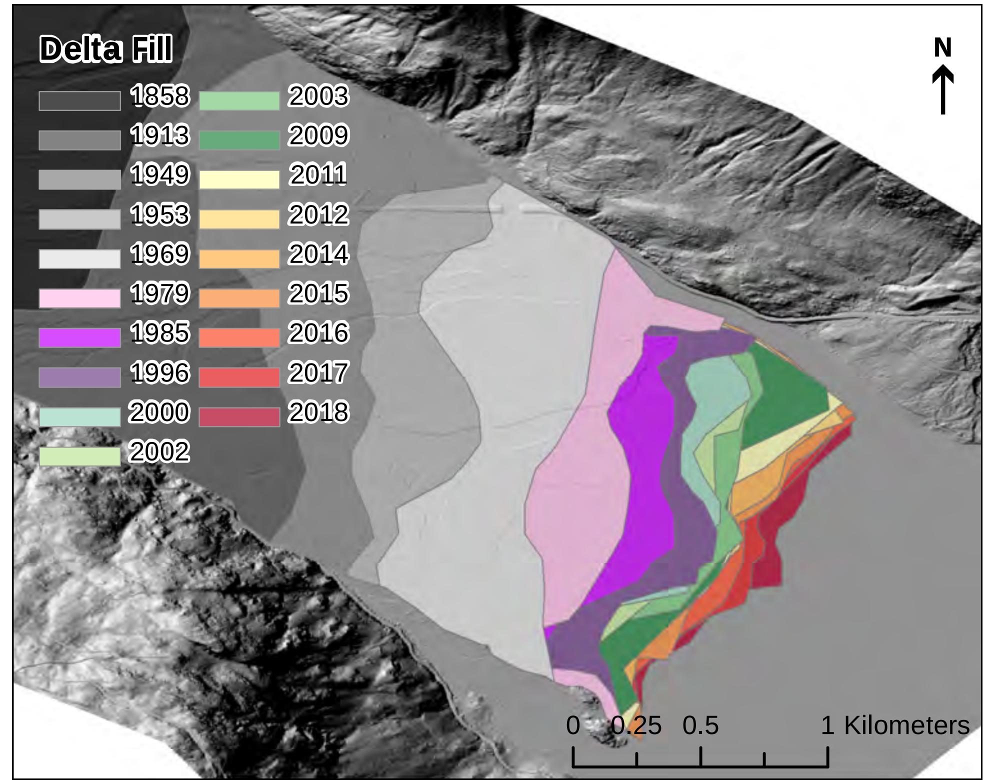
◀ Comparison of June 17 (red) and July 27 (blue), 2017 longitudinal profiles show dynamic dune-scale bedforms, indicating active bed material transport was occuring.

▲ Minor left bank erosion at RK 5.25.

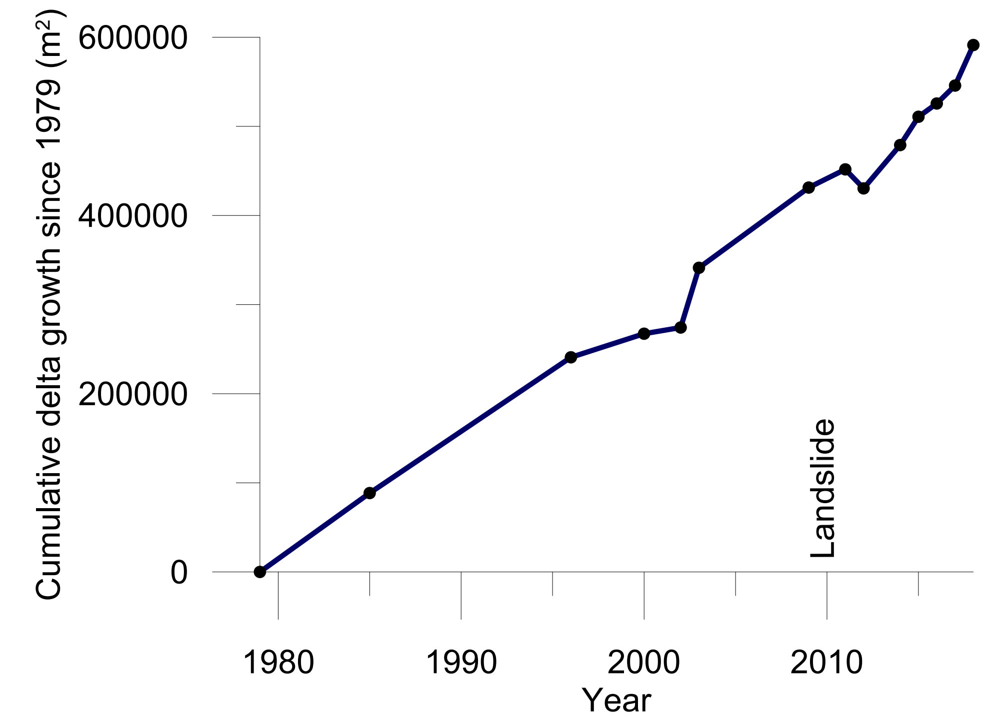
▲ View Upstream at RK 2.25.



▲ Location of RK 1.04 Bulk Sample. Some gravel is transported all the way into the river's delta into Lillooet Lake, but sand dominated bed material through the delta.



▲ The position of the edge of the Lillooet River Delta was mapped from Landsat Satellite imagery during wintertime (December through March) low-lake level conditions (post 1973) and by Gilbert (1973) for 1858-1969 positions.



▲ Analysis of delta growth through time indicates that the rate of delta growth may have not systematically changed following the 2010 Landslide. The mean delta growth rate between 2000 and 2009 was about 14,000 m^2 yr^{-1}, while between 2011 and 2018 it has been about 25,000 m^2 yr^{-1} , high interannual variability, however, precludes statistical discernment of a difference between the two rates (df=1, F=0.27, P=0.61).

◀ The lithology of gravel at the location of the RK 1.04 Bulk Sample shows a conspicuous absence of the porphyritic dacite abundant in the 2010 Meager Landslide. Although gravel is transported all the way into the river's delta into Lillooet Lake, it appears no gravel from the slide has yet reached the lowest part of the river.

Assessment of Observations

The previous section presented detailed observations of local conditions along the Lillooet River. In this section, these observations are summarized, integrated, and plotted at the scale of the whole river to aid understanding of the processes connecting sediment supplied from the landslide to geomorphic changes extending from the slide deposit to Lillooet Lake.

The patterns of downstream geomorphic change suggest that fluvially-remobilized sediment from the landslide should be divided into four conceptual bodies based on grainsize and sediment transport mechanism:

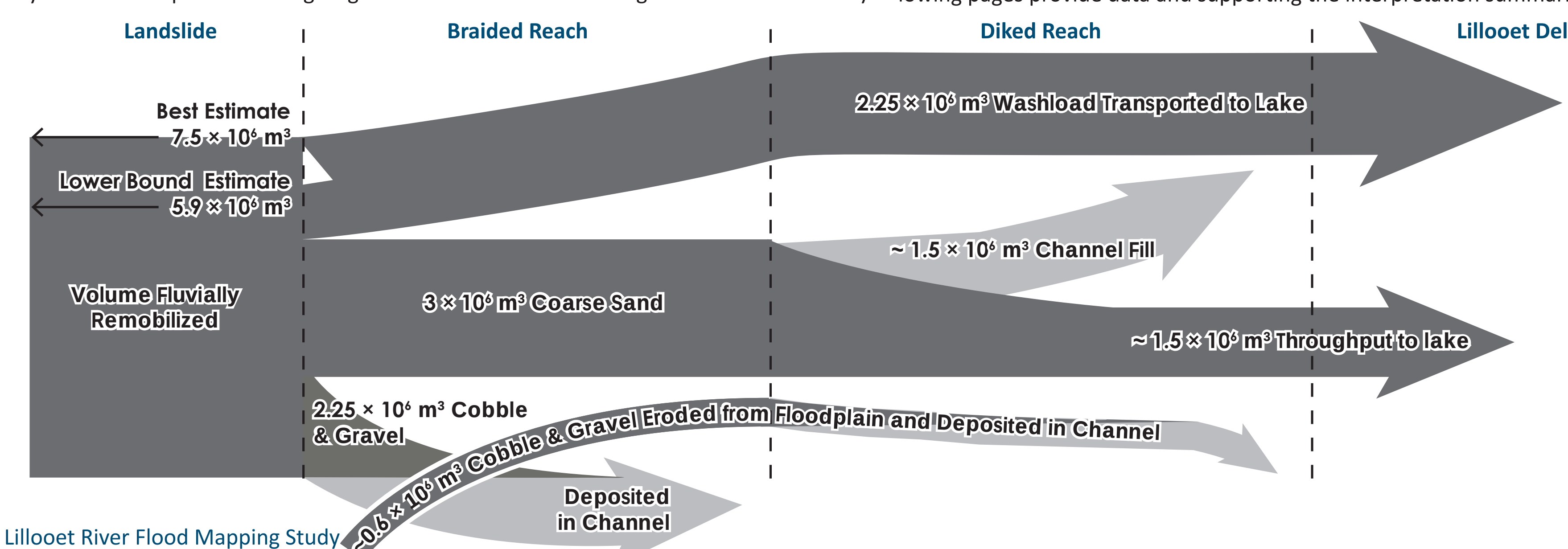
1) Sediment smaller than medium sand (0.25 mm), accounting for about 30% of the slide mass (p. 5), has been transported as wash load to the rivers delta and deep portions of Lillooet Lake, exerting little geomorphic affect on the river.
2) Coarse sand and granules (0.25-8 mm), accounting for about 40% of the slide mass (p. 5), have interacted with the bed material through the braided (above about RK 49) and wandering (RK 41-49) reaches, dramatically reducing the subsurface grainsize distribution, flushed rapidly (on the timescale of a flood event and likely largely in suspension) through the steep braided reach. When this rapidly flushed material enters the lower gradient channel downstream where shear stress and the channels sediment transport capacity are reduced, it becomes bed material load (probably transported both in suspension and as bed load). Downstream sediment transport capacity limitation has resulted in substantial bed aggradation through the confined, lower gradient reach downstream of about RK 40.
3) Cobble and gravel material (8-256 mm) represents about 25-30% of the slide mass (p. 5), and about 30% of the remobilized material. This has formed a sediment slug that is slowly dispersing downstream, with the largest impacts close to the landslide deposit and leading edge of impacts interpreted to be about 25 km downstream of the landslide around RK 55. Geomorphic changes associated with the coarse sediment slug include substantial bed aggradation (probably on the order of 1 to 2 meters), aggressive lateral channel migration and active channel expansion, and formation of new avulsion channels.
4) Boulder sized sediment (>256 mm), accounting for less than 5% of the slide mass, is not present in the remobilized sediment and has remained at and in the vicinity of the landslide. Accumulation of this coarse material as a lag deposit along the channel boundary is slowly reducing the rate of fluvial remobilization of the landslide deposit.

Impacts of the sand fraction are particularly complex. Increased sand supply has resulted in much finer grainsize distribution of the bed material throughout the braided reach, even beyond the interpreted leading edge of the coarse material slug. This has dramatically (by greater than a factor of 10) increased the mobility of the bed material, which in turn has increased lateral channel migration rate and channel width. Channel widening has recruited a substantial volume of coarse material from the floodplain, which supplies gravel sized sediment into the channelized reach (downstream of RK 41), even though cobble and gravel from the landslide are not interpreted to have yet reached that far downstream. Through the diked reach, accumulation of sand and gravel on the bed has had an immediate hydraulic impact. It has aggraded the bed by on the order of 0.5 to 1.5 m, reducing the channels hydraulic capacity and raising water levels across a broad range of flows. The following pages provide data and supporting the interpretation summarized above.

◄ View of the Lillooet River Looking upstream from about RK 49 showing transition from braided towards wandering morphology and area where aggradation from the coarse sediment slug may soon begin.

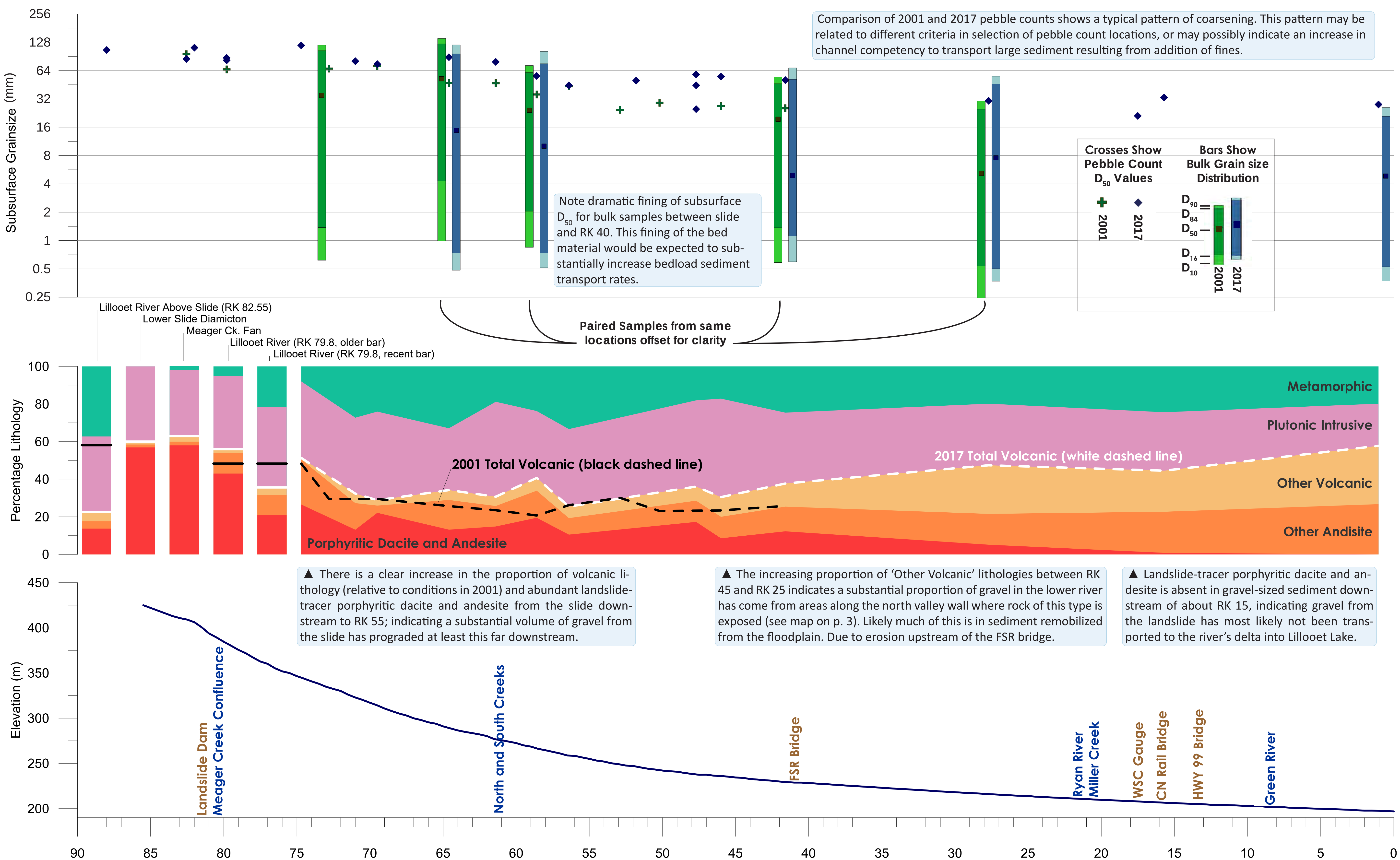
▼ View of the Lillooet River Looking upstream from about RK 40 with a clear view of the channel to about RK 49 showing transition from wandering morphology into the channelized reach downstream of the FSR Bridge.

► View of sediment filled channel looking downstream towards Highway 99 Bridge at RK 13.5.



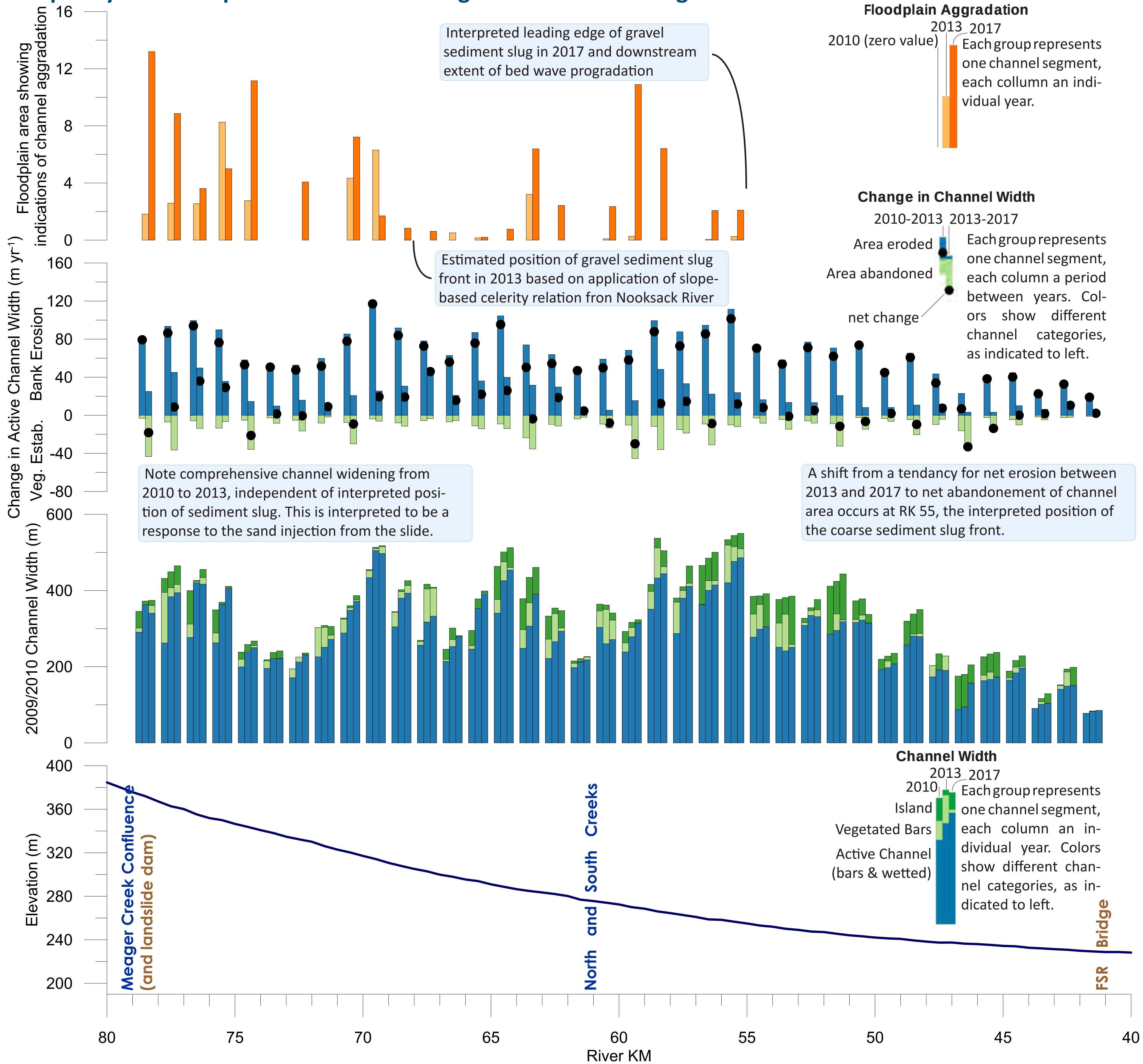
◄ This conceptual sediment budget for the period between the landslide in 2010 and summer 2017 illustrates key sediment exchanges interpreted from available evidence. Volume estimates are subject to substantial uncertainty, ranging from ± 20% for the best constrained to order-of-magnitude for the least constrained. The best estimate for the total volume of fluvially remobilized sediment is based on the estimated exponential decay in the slide volume, while the lower bound estimate is based on the 2010-2015 LiDAR comparison and estimated bank erosion volumes between 2015 and 2017, which does not account for any vertical adjustment in the channel during the later period (p. 4).

Change in Grain size and Lithologic Composition of Bed Material between 2001 and 2017



nhc

Morphodynamic Response to Sediment Slug Above the FSR Bridge



Some Key Definitions

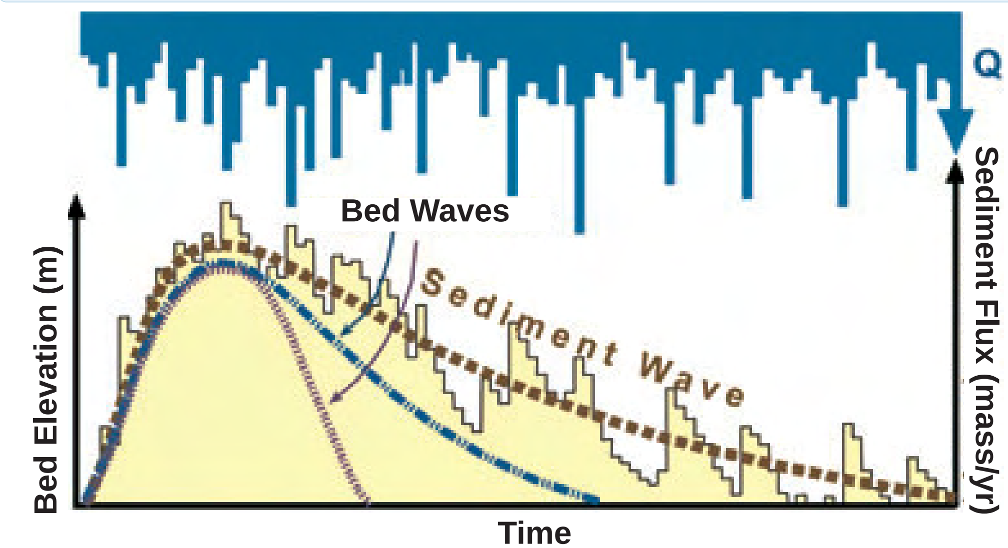
Sediment Slug: A coherent body of sediment that may evolve through various geometric transformations including end member responses of translation and dispersion.

Channel Bed Wave: Rise and fall of the mean channel bed elevation in response to sedimentation.

Sediment Wave: A transient sediment flux elevated above background levels.

Gilbert Wave: A prototypical model of river response to large scale injection of sediment where the both bed and sediment waves are right-skewed with respect to time and where the sediment wave lags behind the bed wave in response to slow evacuation of sediment from lateral storage reservoirs.

See Nicholas et al. (1995), Lisle et al. (2001), and (James 2010).



The plot above shows James' (2010) conceptual model of a right-skewed Gilbert wave showing lag of sediment wave behind the bed wave. James (2010) and Lisle et al. (2001) both describe that when an introduced sediment load is relatively fine, and channel confined, sediment slug translation may occur and the bed may aggrade and degrade fairly rapidly, resulting in symmetrical sediment and bed wave passage. In the more common case, however, lateral channel instability results in substantial storage of bed material across the floodplain; slower release from this reservoir results in a strongly right-skewed and protracted sediment wave. James' model includes modulation of the sediment wave in response to stochastic flood events.

In order to put the front of the slug at its interpreted location of RK 55, the average progradation rate for the leading edge of the bed wave has been about 3.5 km/yr. This compares well to established rates of bed wave propagation. Beechie (2001) describes how sediment slug movement may be expected to relate to channel width and found that slugs typically move at a rate of about 20 times the bankfull width annually. The typical bankfull width through the braided reach is between 200 and 300 m, which would yield an estimated rate of movement of 4 to 6 km/yr.

Anderson and Konrad (2016) and USGS (2018), in an ongoing study, are finding that sediment wave velocity on the Nooksack River in NW Washington state is proportional to the channel slope with a relation of Velocity (km/yr) = 49.1 X Slope$^{0.51}$. The exact relation is expected to vary between different rivers, but the form may be generally similar. The Nooksack River has a similar size and physiographic setting to the Lillooet River, and so the analogy provides a useful tool for evaluating expected future progradation rates as the channel slope declines downstream. In the case of the Lillooet River, it matches the single empirical data closely and the proportional relationship predicts the sediment wave to be at about RK 56 at the time of observation in 2017. Applying the relation would predict that the leading edge of the wave may reach the Forest Service Bridge sometime around 2023 and would be expected to reach the WSC gauge in two decades.

Grain size, Morphodynamic Change, and Sediment Transport Rate

Bedload sediment transport depends, fundamentally, on the relationship between the grain size distribution of the bed material and hydraulic force applied by the flow. Above the Forest Service Road (FSR) bridge, the Lillooet River has adjusted both its bed material grain size distribution—which has become much finer and more easily moved—and channel width—which has increased, reducing the depth and therefore the strength of the flow at any given point on the bed.

Sediment transport rates increase exponentially with an increasing T/T_c ratio, and so moderate shifts in grain size distribution can have a very large impact on bed material sediment transport rate. This is particularly true due to the influence of increasing sand concentration, which reduces the critical shear stress required to move larger grains, compounding the effect. See the box to right for definitions of terms.

Sediment transport calculations were completed to illustrate the magnitude of change in sediment transport rate expected given to the substantial fining of bed material observed at repeat bulk sample locations. Results of these are shown below. All calculations were completed utilizing the Parker and Klingman (1982) subsurface grain size distribution-based sediment transport function as implemented in BAGS (Pitlick et al., 2009). Input parameters used are specified in each plot. In the case of the RK 64.6 and 58.5 sample locations, channel width has changed appreciably following the 2010 slide (see page 11 and 12, respectively), and width used was the average width for 2 km near the sample location for both pre-and post slide conditions (2010 and 2017, respectively). For the FSR Bridge sample location, the actual cross section from 2017 was utilized, here the channel width has not appreciably changed since the slide occurred (See page 16).

Results of this analysis show that the increase in sediment transport rate due to fining of the bed material far outweigh the reduction in shear stress due to channel widening. Assuming the same hydraulic conditions are associated with the 2001 and 2017 grain size distributions, the calculated bedload transport rate for >8mm material is orders of magnitude higher for the 2017 grain size distribution than for the 2001 grain size distribution. In contrast the reduction in transport rate associated with channel widening is about an order of magnitude or less.

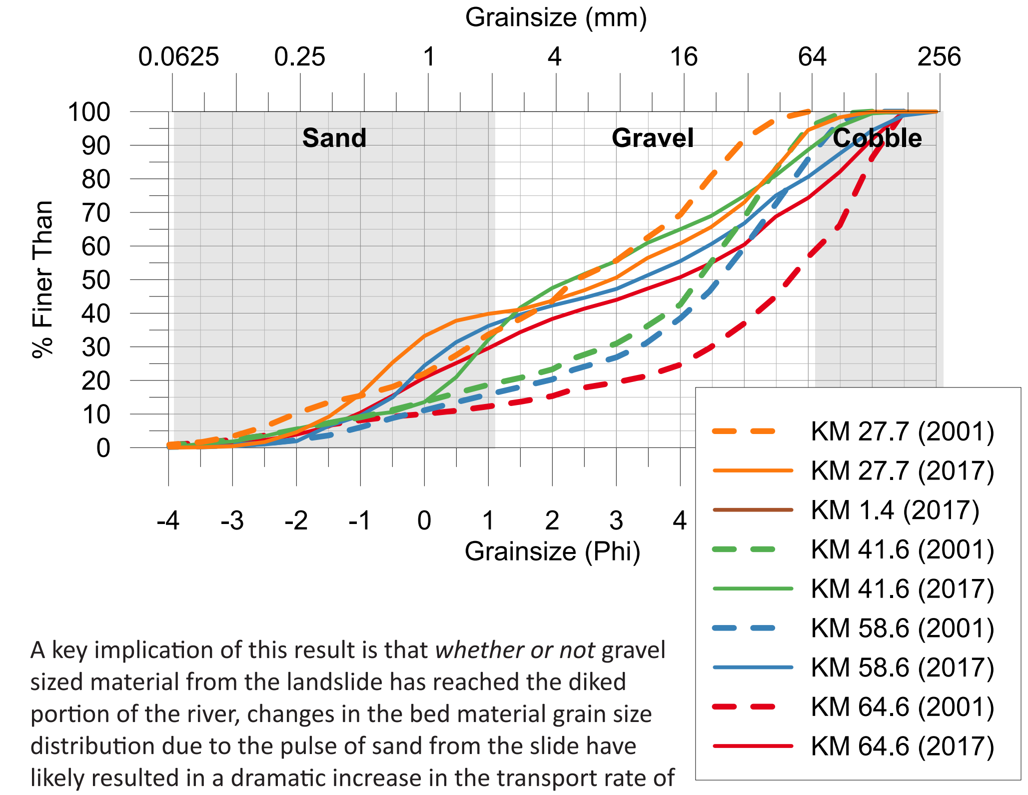
Sediment Transport Parameters

Shear Stress (T): The strength of flow available to move sediment, proportional to flow depth times flow slope.

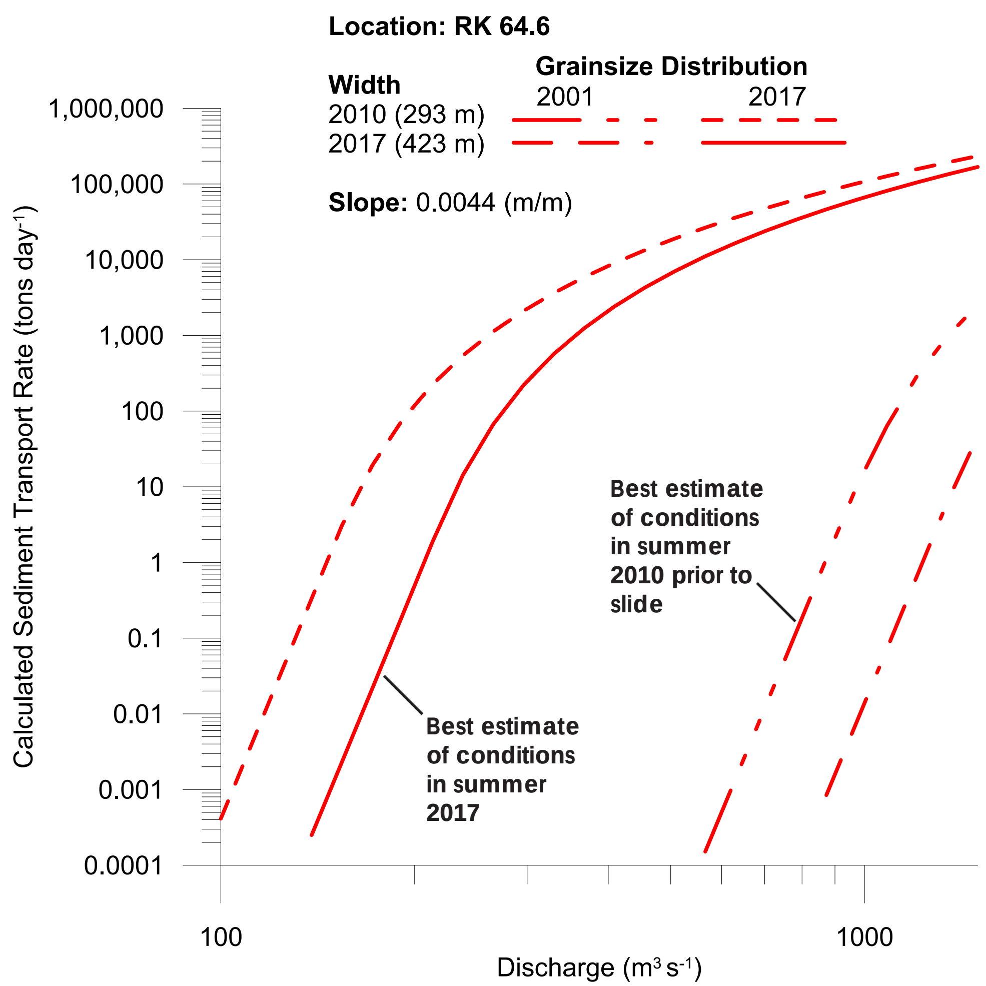
Critical Shear Stress (T_c): The shear stress required to move a given size of sediment as bedload.

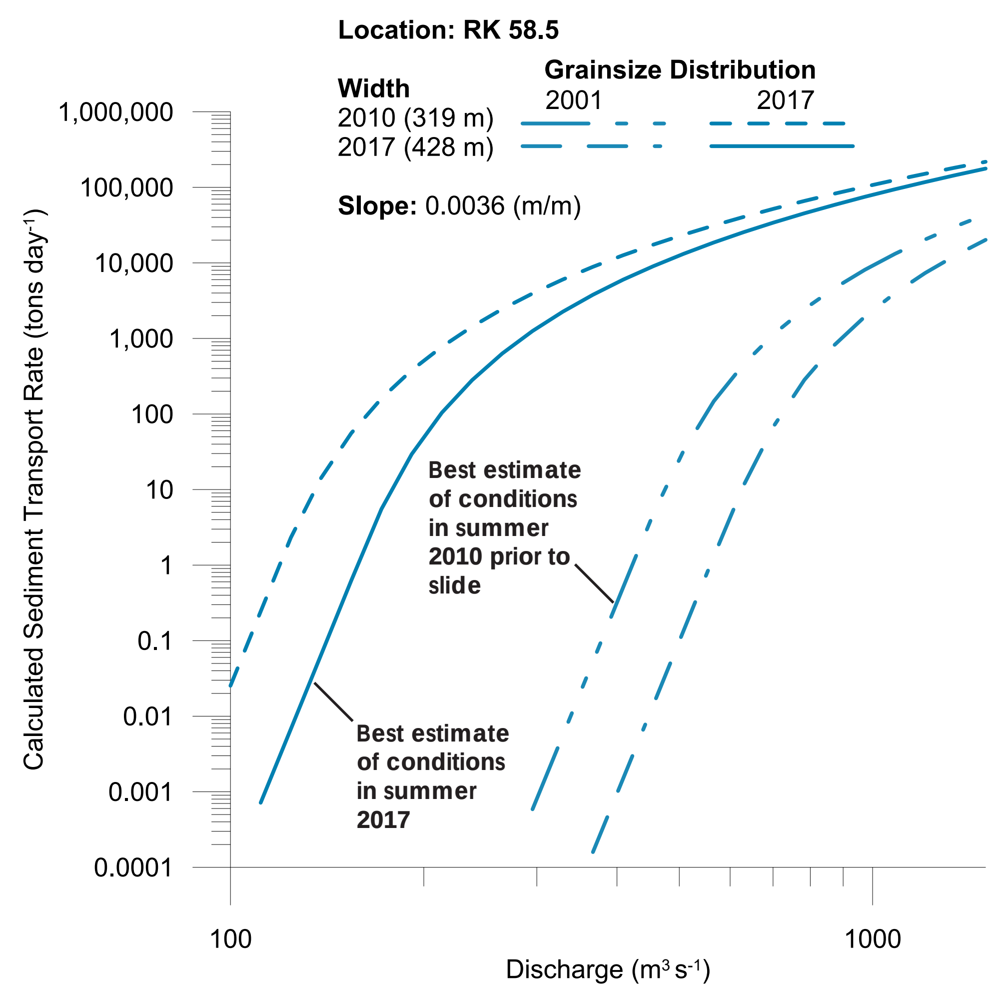
Sheilds Paramiter (T^*_c): The ratio of fluid forces tending to initiate particle motion to the gravity force tending to keep the particle at rest. It depends on the size of the individual particle, but also the arrangement, shape, and size distribution of the surrounding material. A value of 0.045 is typically used, but values from 0.02 to 0.25 are possible. Larger amounts of sand and finer subsurface material promote lower values of T*c.

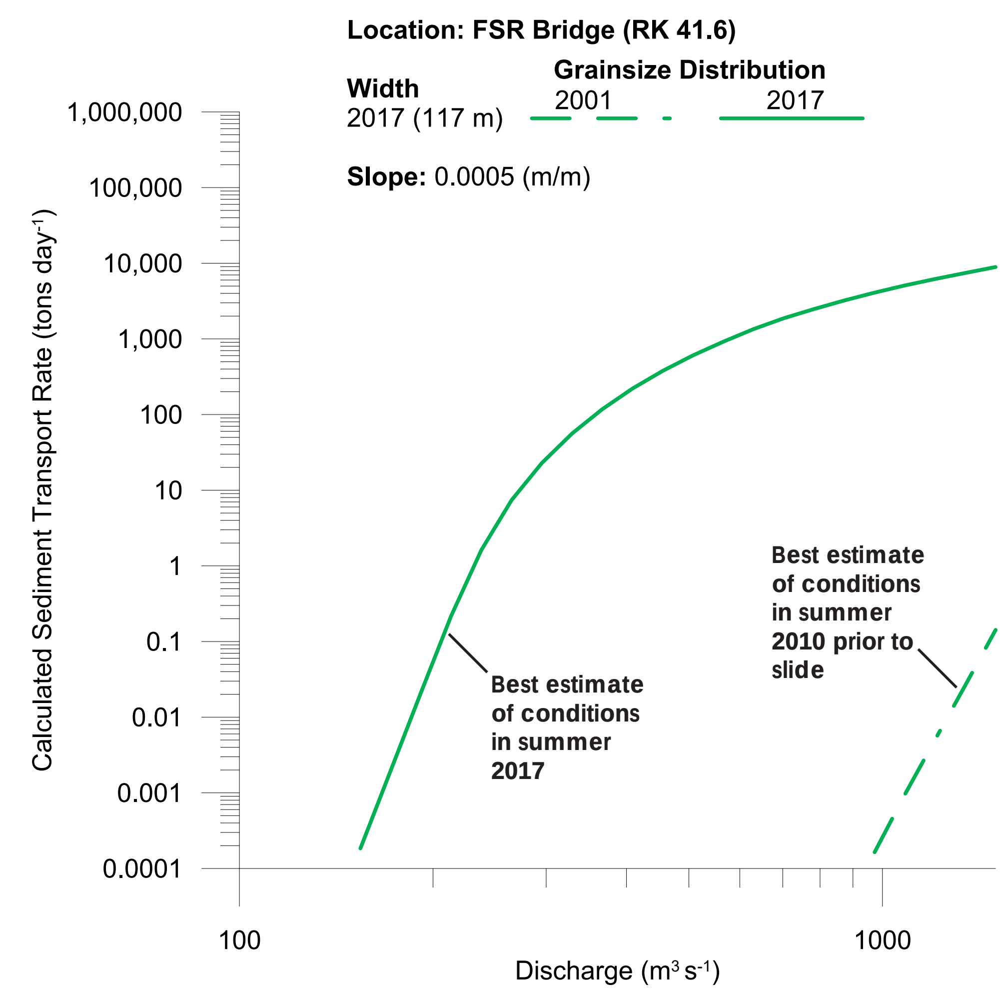
Rouse Number (P): A non-dimensional number that determines the concentration profile and transport mode of suspended sediment. It is the ratio between the sediment fall velocity and upward velocity of the flow, computed as the product of the shear velocity (an expression of T in terms of velocity rather than force) and von Kármán constant (K). Lower values of P inciate higher degree of suspension.



A key implication of this result is that *whether or not* gravel sized material from the landslide has reached the diked portion of the river, changes in the bed material grain size distribution due to the pulse of sand from the slide have likely resulted in a dramatic increase in the transport rate of gravel-sized sediment into the managed reach of the river.



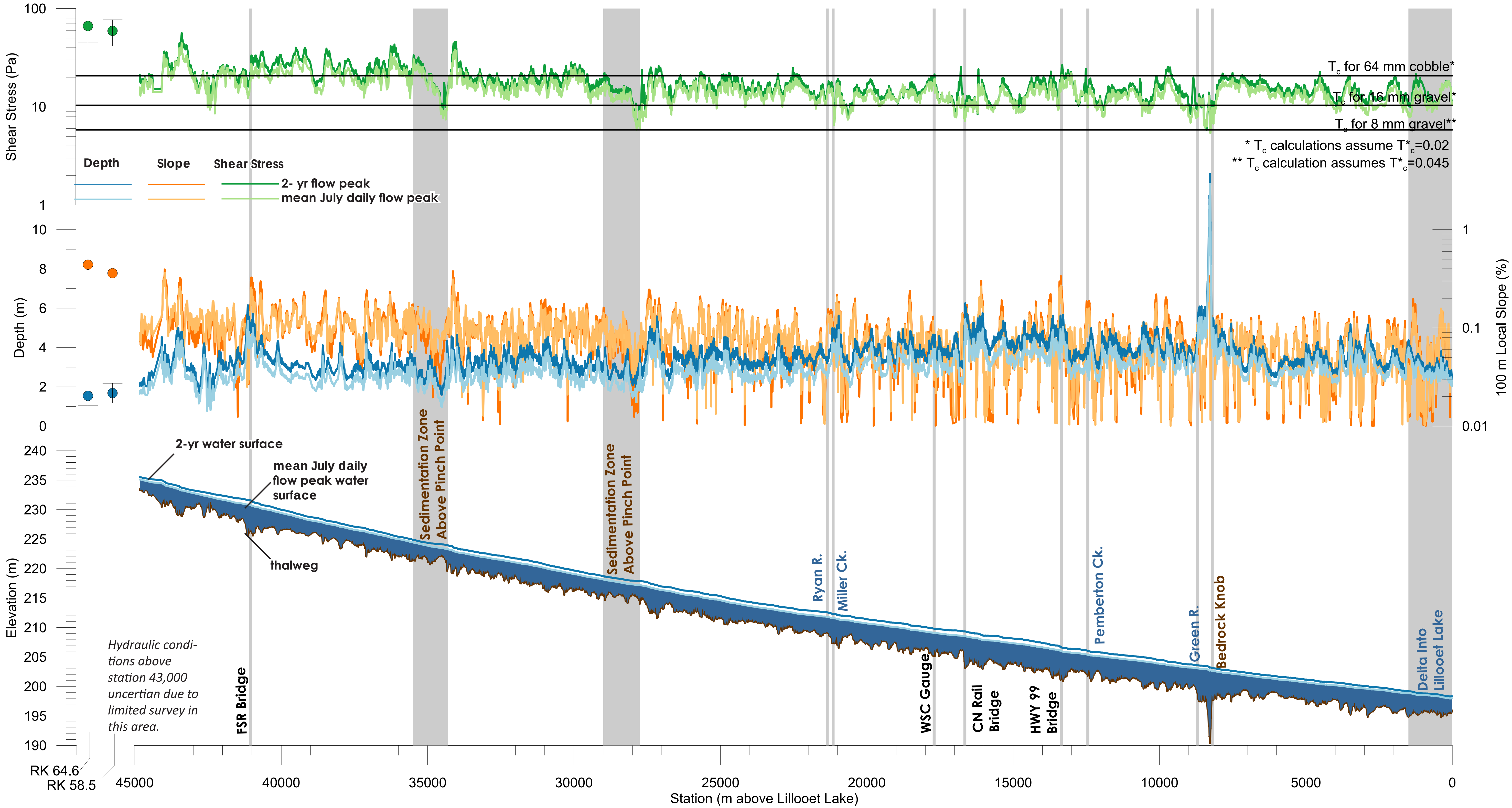




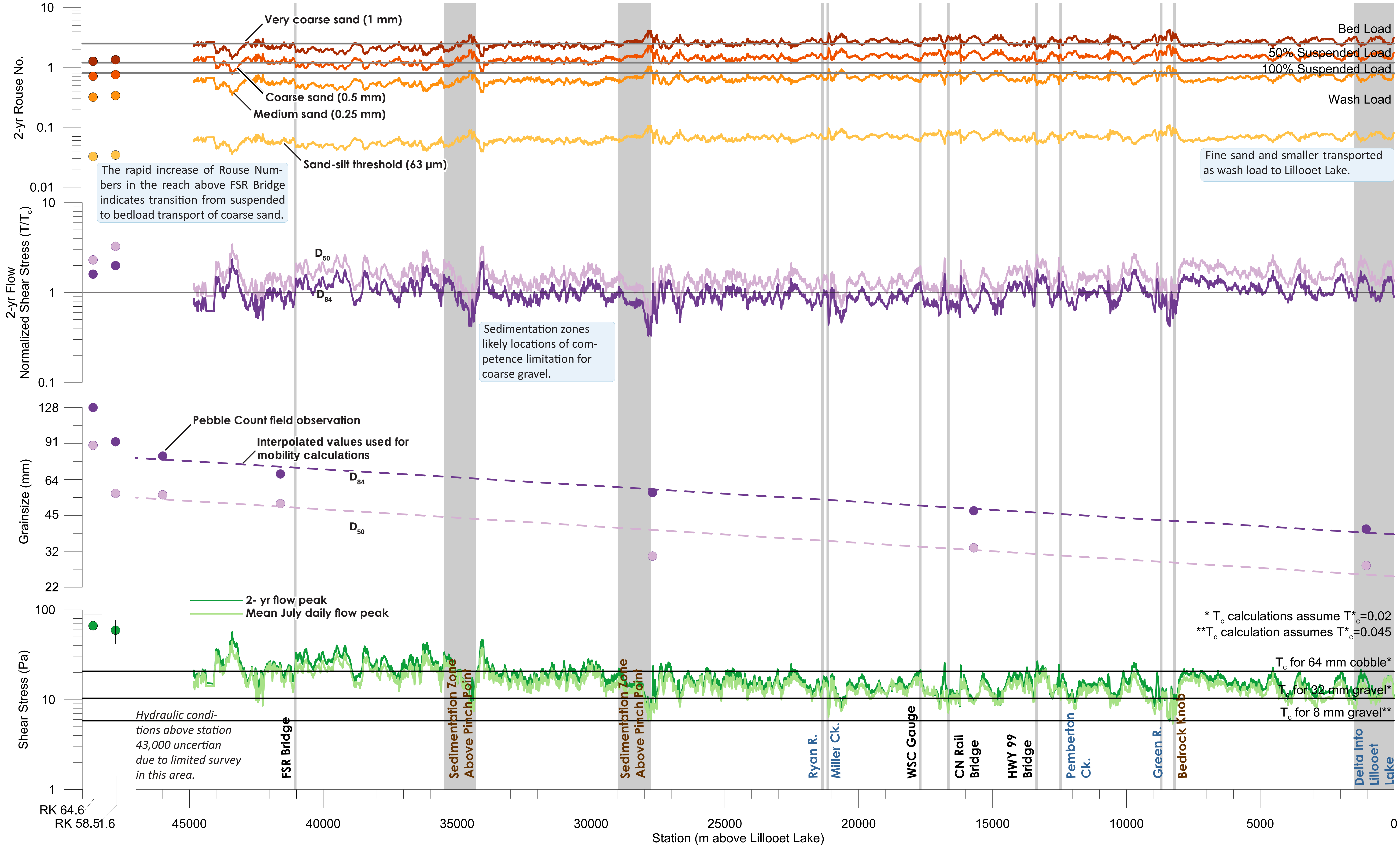
nhc

Channel Hydraulics and Sediment Mobility Downstream of RK 47

- These plots shows hydraulic and sediment mobility parameters (see box on page 37 for definitions) extracted from NHC's 2D HEC-RAS model of the river; rough estimates of conditions at locations of bulk sediment samples upstream of the model domain are also shown. See accompanying report for details of hydraulic model development.
- Values are plotted for two discharges: the 2-year recurrence interval flood, which shows the maximum value for each parameter over the course of an unsteady hydraulic model run, and the mean daily peak in July, which was run as a steady discharge.
- Reach-scale hydraulic patterns are the same for the two discharges.
- Shear stress for the 2-year flood peak is typically about 14 ± 7% higher (± 1σ) than for the mean daily peak in July, and so sediment mobility calculations (Normalized Shear Stress and Rouse Number) are only shown for the 2-year flood.



Sediment Mobility



nhc

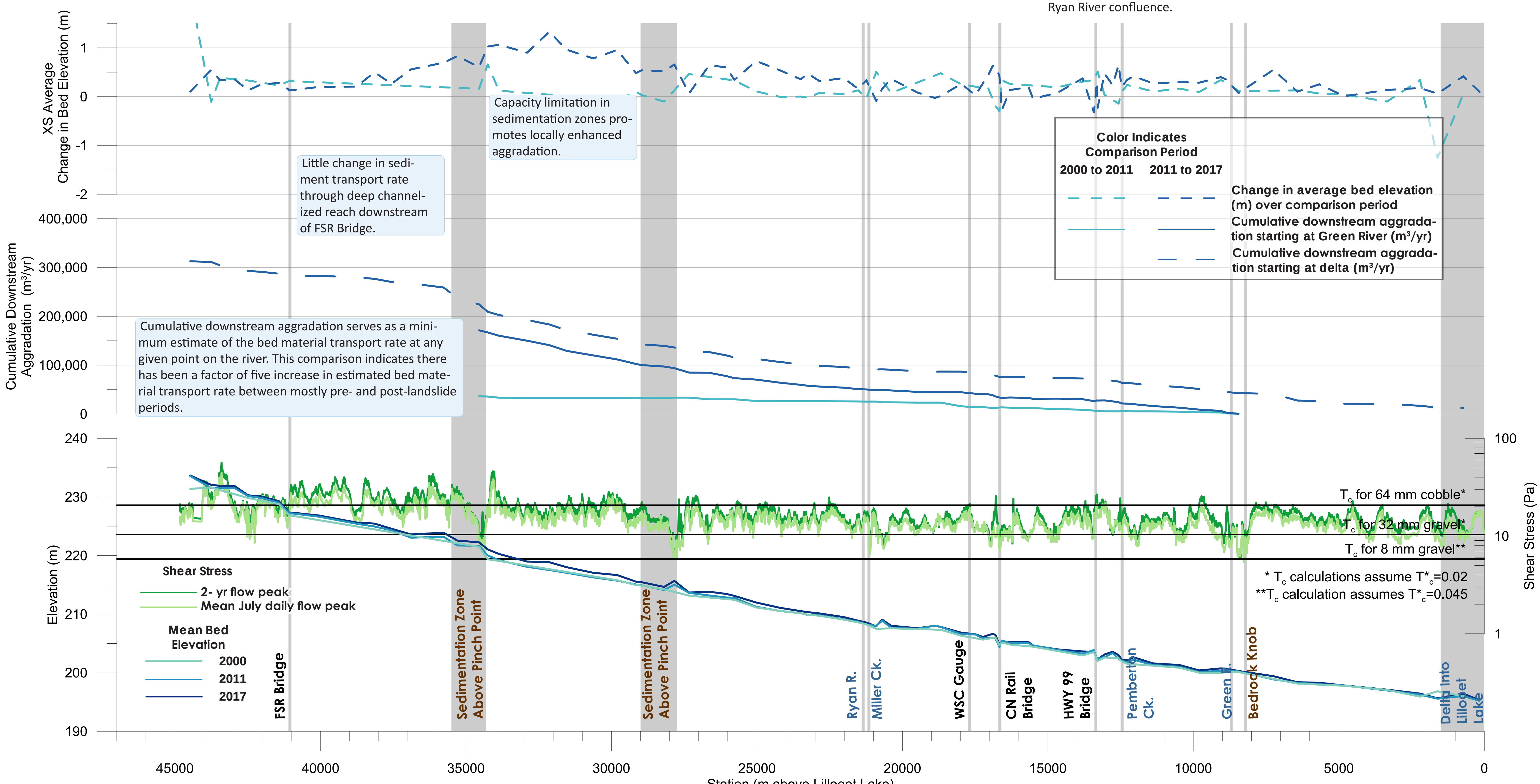
Sediment Accumulation

Methods

- Repeat survey of cross-sections in 2000, 2011, and 2017 allows evaluation of sediment accumulation in the Lillooet River Channel, for mostly pre-landslide (2000 to 2011) and post landslide (2011 to 2017) periods.
- Change in cross-section area was computed by evaluating the cross sectional area below the modeled 2017 2-yr flow water surface at each location. Volumetric change at each location was then estimated based on the distance between each cross section.
- A minimum estimate of the bed material transport rate was next determined by integrating the deposition volume at all cross-sections downstream and normalizing to the period between surveys.

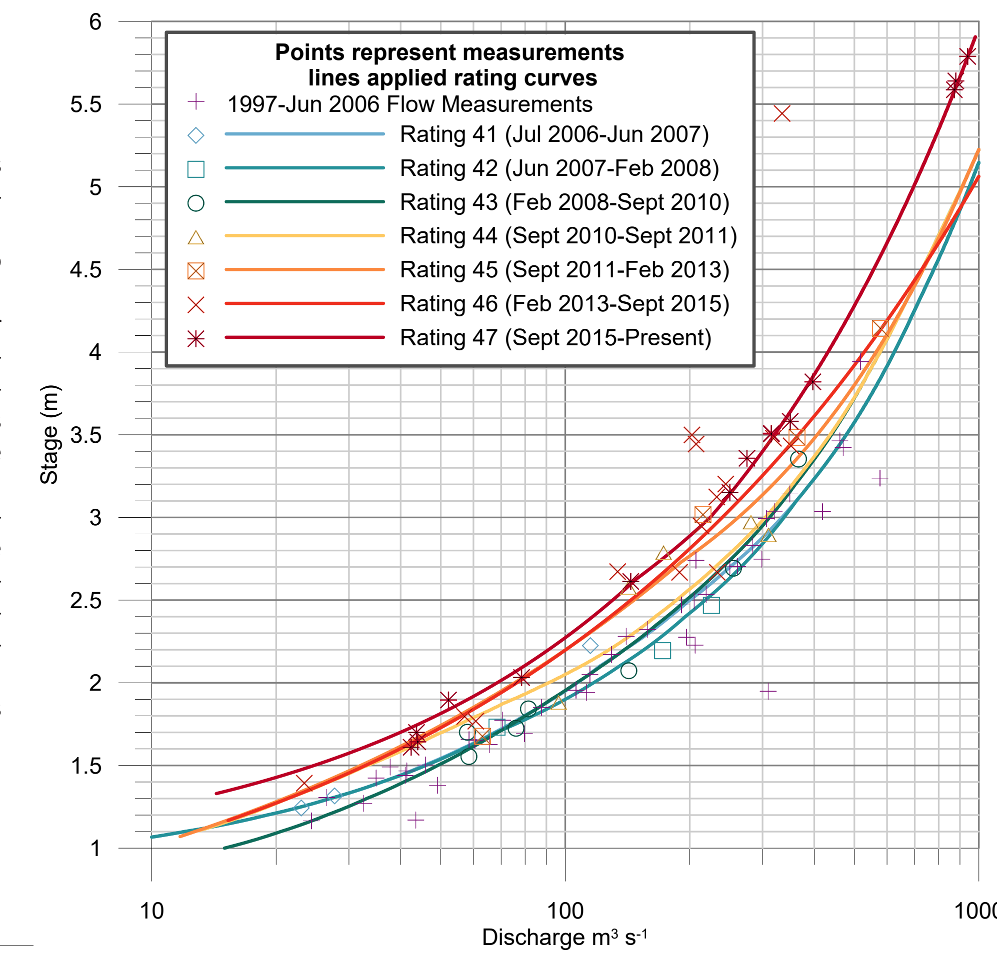
Results

- The estimated bed material transport rate at approximately RK 35 has increased from about 40,000 m³/yr over the mostly pre-landslide period to about 180,000 m³/yr in the post-landslide period. At RK 44, it is about 300,000 m³/yr for the 2011 to 2017 period.
- Deposition is concentrated in sedimentation zones upstream of hydraulic pinch points and–somewhat less intensely–along the reach between RK 35 and Ryan River Confluence where sand wave bedforms are abundant.
- Since 2011, the average bed elevation has increased an average of about 0.4 m over the entire cross-section comparison reach, with more substantial increases in the reach upstream of RK 25.
- Averaged over the comparison period, the average bed elevation is increasing in the order of 0.07 m/yr in the reach between the CN Rail Bridge and WSC Gage, with more substantial increases at localized accumulation zones in the reach upstream of the sediment management zone, a rate that is generally greater than computed using cross section data from 2000 and 2011. This amounts to an increase in average bed elevation of about 0.5 m by 2025. Bed level changes of up to 1.2 m have occurred in the reach upstream of Ryan River confluence.

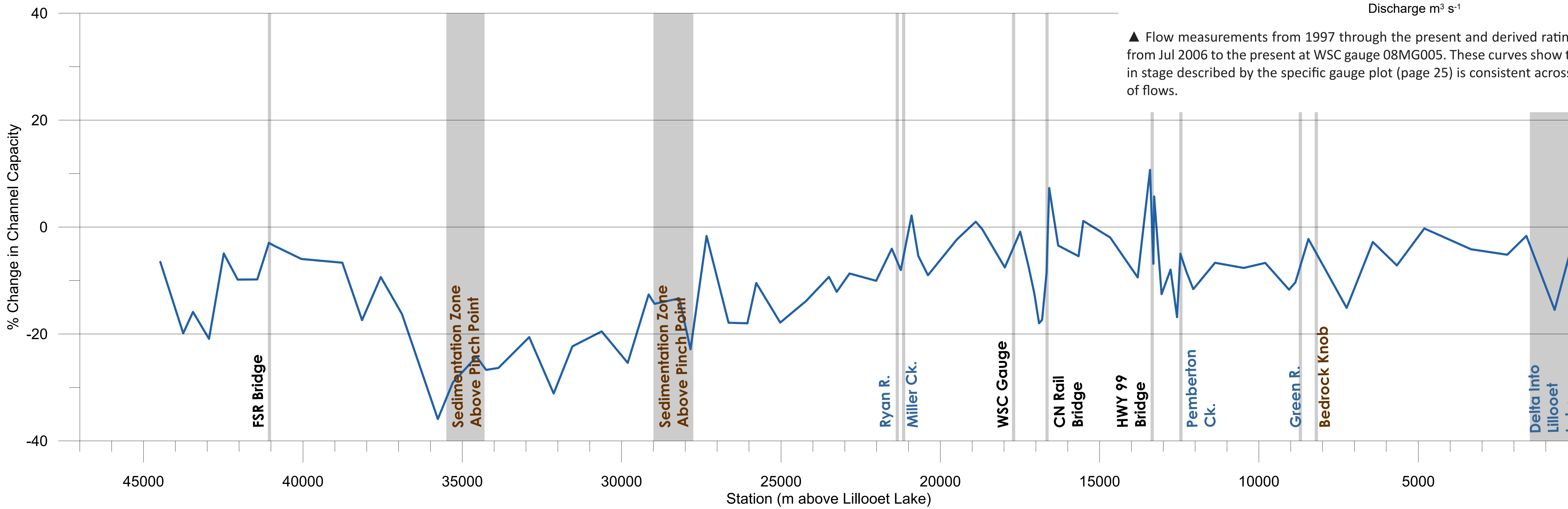


Hydraulic and Flood Management Implications of Geomorphic Change

- Sediment supply from the 2010 Meager Creek landslide will remain high for several decades. Sediment supply is expected to decay exponentially over time. Based on the comparison of surveys in 2010 and 2017, the estimated “half-life” of the disturbance is approximately 30 years.
- The landslide has introduced a slug of sediment that has moved as a sediment wave down the Lillooet River. The leading edge of the coarse cobble and gravel fraction of the material has moved downstream at a rate of approximately 3.5 km/year to approximately RK 55 (14 km upstream of the Forest Service Bridge). The speed of the sediment wave is likely affected by the channel slope and is expected to slow in the downstream direction as the slope flattens out. It is expected that the leading edge of the wave will reach the Forest Service Bridge around 2023 and will reach the WSC gauge at RK 17.5 in the next two decades.
- The sand and fine gravel component from the landslide event has been transported partially in suspension and has moved downstream at a faster rate than the coarse gravel and cobble sediment, which moves in contact with the bed as bedload. The sand and fine gravel component has reached the lower depositional zone, downstream of the Ryan River confluence, and the substantial increase in the concentration of sand in the channel bed has reduced the amount of hydraulic force necessary to move the larger sediment fraction of the bed. This sediment is accumulating in the depositional zone and has likely decreased the stability of the bed in this reach.
- The estimated bed material transport rate at RK 35 has increased from approximately 40,000 m^3/yr (pre-landslide) to 160,000 m^3/yr for the period 2011 to 2017. There is substantial uncertainty in the approach used to estimate bed material transport rates (+/-50%), however, the comparison clearly indicates a substantial relative increase in transport rate since 2011.
- Deposition is concentrated in sedimentation zones upstream of hydraulic constrictions (pinch points) and along the reach between River Kilometre 35 and the Ryan River confluence confluence. The average bed level has increased 0.4 m (0.07 m/yr) in the reach between the CN Rail Bridgeand WSC Gauge. The average bed level has increased up to 1.2 m in the reach upstream of the Ryan River confluence.
- Analysis of the WSC gauge rating curves (specific gauge analysis), indicates the water levels at the gauge have varied in a complex manner over the last several decades in response to previous engineering works. However, it appears that a relatively stable stage-discharge relation existed during the period 2000-2010, suggesting the channel was approaching equilibrium. Since the 2010 landslide event, the specific gauge values are trending upwards, with water levels being elevated by approximately 0.4 m since 2010.
- The effects observed to-date in the diked reach (below RK 30), represent the initial response of the channel due to the arrival of the fine gravel and sand component of the sediment slug. The impacts from the coarse fraction of the load will be increasingly apparent over the next two decades. It is expected this will include enhanced lateral channel instability, channel widening, and bed aggradation. Over this time period, accumulation of sediment in the diked reach will continue to increase water levels. Localized increases in channel velocity and scour potential are also anticipated as material builds up at gravel bars and other depositional zones. These changes will increase the potential for dike overtopping and failure of dike armour.



▲ Flow measurements from 1997 through the present and derived rating curves in use from Jul 2006 to the present at WSC gauge 08MG005. These curves show that the change in stage described by the specific gauge plot (page 25) is consistent across a broad range of flows.



References

Adams, J. (1980). Contemporary uplift and erosion of the Southern Alps, New Zealand. Geological Society of America Bulletin, 91(1 Part II), 1–114.

Andreson, S., and Konrad, C. (2016). Observations of regionally-coherent sediment waves in glaciated basins of Washington State. AGU Annual Meeting Poster.

Beechie, T. J. (2001). Empirical predictors of annual bed load travel distance, and implications for salmonid habitat restoration and protection. Earth Surface Processes and Landforms, 26(9), 1025–1034. doi:10.1002/esp.251.

Croissant, T., Lague, D., Steer, P., and Davy, P. (2017). Rapid post-seismic landslide evacuation boosted by dynamic river width. Nature Geoscience, 10, 680–684. doi:10.1038/ngeo3005.

Dadson, S. J., Hovius, N., Chen, H., Dade, W. B., Lin, J.-C., Hsu, M.-L., Lin, C.-W., Horng, M.-J., Chen, T.-C., Milliman, J., and others (2004). Earthquake-triggered increase in sediment delivery from an active mountain belt. Geology, 32(8), 733–736.

Friele, P. A., Clague, J. J., Simpson, K., and Stasiuk, M. (2005). Impact of a Quaternary volcano on Holocene sedimentation in Lillooet River valley, British Columbia. Sedimentary Geology, 176(3–4), 305–322. doi:10.1016/j.sedgeo.2005.01.011.

Gilbert, R. (1973). Observations of lacustrine sedimentation at Lillooet Lake, British Columbia. University of British Columbia. [online] Available from: https://open.library.ubc.ca/cIRcle/collections/ubctheses/831/items/1.0093262 (Accessed 31 January 2018).

Guthrie, R. H., Friele, P., Allstadt, K., Roberts, N., Evans, S. G., Delaney, K. B., Roche, D., Clague, J. J., and Jakob, M. (2012). The 6 August 2010 Mount Meager rock slide-debris flow, Coast Mountains, British Columbia: characteristics, dynamics, and implications for hazard and risk assessment. Natural Hazards and Earth System Science, 12(5), 1277–1294. doi:10.5194/nhess-12-1277-2012.

Hovius, N., Meunier, P., Lin, C.-W., Chen, H., Chen, Y.-G., Dadson, S., Horng, M.-J., and Lines, M. (2011). Prolonged seismically induced erosion and the mass balance of a large earthquake. Earth and Planetary Science Letters, 304(3), 347–355.

Huang, M. Y.-F., and Montgomery, D. R. (2012). Fluvial response to rapid episodic erosion by earthquake and typhoons, Tachia River, central Taiwan. Geomorphology, 175–176, 126–138. doi:10.1016/j.geomorph.2012.07.004.

James, A. (2010). Secular Sediment Waves, Channel Bed Waves, and Legacy Sediment: Secular sediment waves and legacy sediment. Geography Compass, 4(6), 576–598. doi:10.1111/j.1749-8198.2010.00324.x.

Jordan, P., and Slaymaker, O. (1991). Holocene Sediment Production in Lillooet River Basin, British Colombia: A Sediment Budget Approach. Géographie physique et Quaternaire, 45(1), 45. doi:10.7202/032844ar.

Koi, T., Hotta, N., Ishigaki, I., Matuzaki, N., Uchiyama, Y., and Suzuki, M. (2008). Prolonged impact of earthquake-induced landslides on sediment yield in a mountain watershed: The Tanzawa region, Japan. Geomorphology, 101(4), 692–702. doi:10.1016/j.geomorph.2008.03.007.

KWL (2002). Engineering Study for the Lillooet River Corridor- Final Report. Report Prepared by KWL for the Mount currie Band, Pemberton Valley Dyking District, B.C. Ministry of Water, Land and Air Protection, Public Works and Government Services Canada, and Indian and Northern Affairs Canada.

KWL (2004) Memorandum RE: Pemberton Valley Dyking District 2004 Miller Creek Excavation. File No. 713.010. Prepared for Fisheries and Oceans Canada, Pemberton Valley Dyking District, and Cascade Environmental Resource Group. 31 May 2004.

Lisle, T. E., Cui, Y., Parker, G., Pizzuto, J. E., and Dodd, A. M. (2001). The dominance of dispersion in the evolution of bed material waves in gravel-bed rivers. Earth Surface Processes and Landforms, 26(13), 1409–1420. doi:10.1002/esp.300.

Major, J. J., Pierson, T. C., Dinehart, R. L., and Costa, J. E. (2000). Sediment yield following severe volcanic disturbance—a two-decade perspective from Mount St. Helens. Geology, 28(9), 819–822.

Nelson, A., and Dubé, K. (2016). Channel response to an extreme flood and sediment pulse in a mixed bedrock and gravel-bed river. Earth Surface Processes and Landforms, 41(2), 178–195. doi:10.1002/esp.3843.

NHC 2018. Miller Creek Sediment Trap Excavation 2018 Design Brief. Prepared for PVDD, 15 March 2018

Nicholas, A. P., Ashworth, P. J., Kirkby, M. J., Macklin, M. G., and Murray, T. (1995). Sediment slugs: large-scale fluctuations in fluvial sediment transport rates and storage volumes. Progress in Physical Geography, 19(4), 500–519. doi:10.1177/030913339501900404.

Parker, G., and Klingeman, P. C. (1982). On why gravel bed streams are paved. Water Resources Research, 18(5), 1409–1423. doi:10.1029/WR018i005p01409.

Pearce, A. J., and Watson, A. J. (1986). Effects of earthquake-induced landslides on sediment budget and transport over a 50-yr period. Geology, 14(1), 52–55.

Pitlick, J., Wilcock, P., and Cui, Y. (2009). BAGS: Bedload Assessment in Gravel-bedded Streams. United States Forest Service Stream Systems Technology Center. [online] Available from: http://www.stream.fs.fed.us/publications/bags.html.

Rice, S. P., and Haschenburger, J. K. (2004). A hybrid method for size characterization of coarse subsurface fluvial sediments. Earth Surface Processes and Landforms, 29(3), 373–389. doi:10.1002/esp.1043.

Roberti, G., Friele, P., van Wyk de Vries, B., Ward, B., Clague, J. J., Perotti, L., and Giardino, M. (2017). Rheological evolution of the Mount Meager 2010 debris avalanche, southwestern British Columbia. Geosphere, 13(2), 369–390. doi:10.1130/GES01389.1.

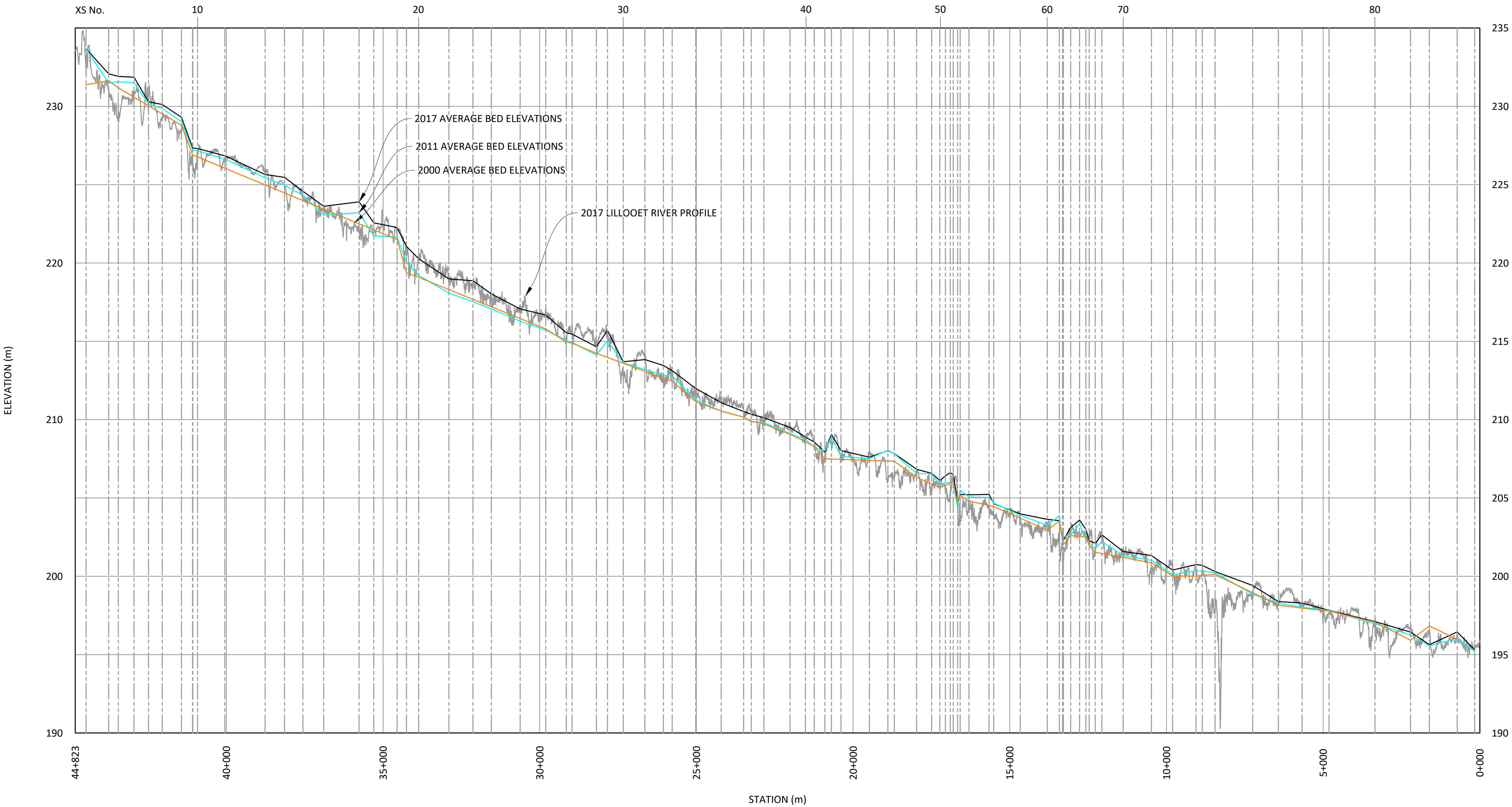
USGS (2018). Sediment storage and transport in the Nooksack River basin from 2006-2015 (Preliminary Draft).

Vogt, N. (2013). Geochemical Analysis of Source and Sink Sediments, Lillooet River Watershed, British Columbia, Canada. The University of Northern British Columbia.

Weatherly, H., and Jakob, M. (2014). Geomorphic response of Lillooet River, British Columbia, to meander cutoffs and base level lowering. Geomorphology, 217, 48–60. doi:10.1016/j.geomorph.2014.04.002.

Appendix C: Profile and Cross Section Comparison

LILLOOET RIVER PROFILE, SCALE 1H:500V



PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

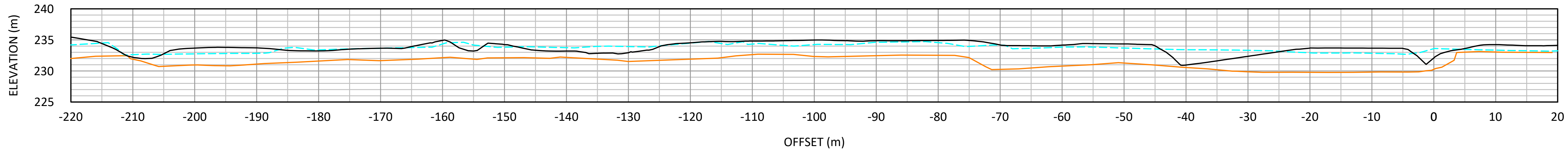
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

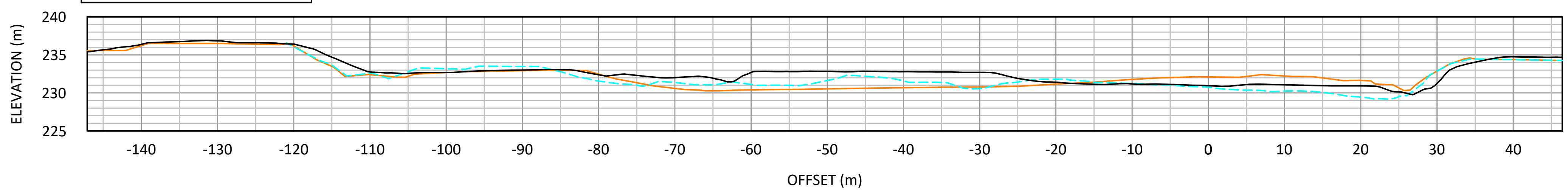
LILLOOET RIVER
HISTORICAL PROFILE COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-001
SHEET NUMBER	1 of 16
REVISION	0

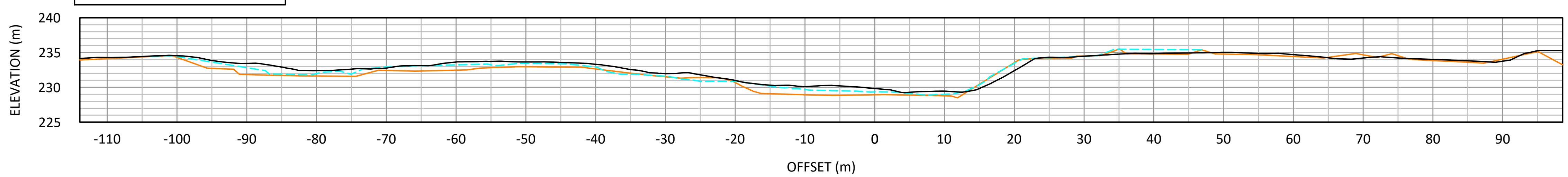
SECTION 1: STA. 44+475



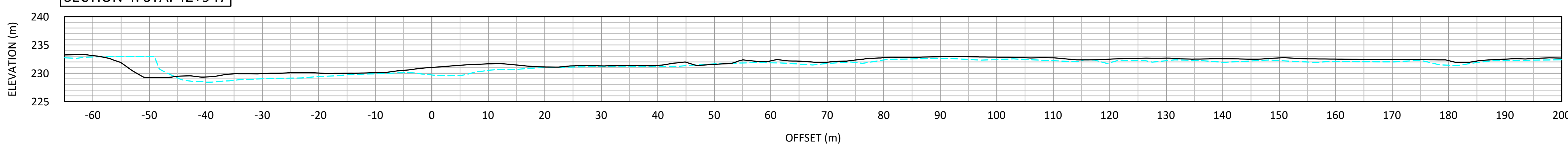
SECTION 2: STA. 43+757



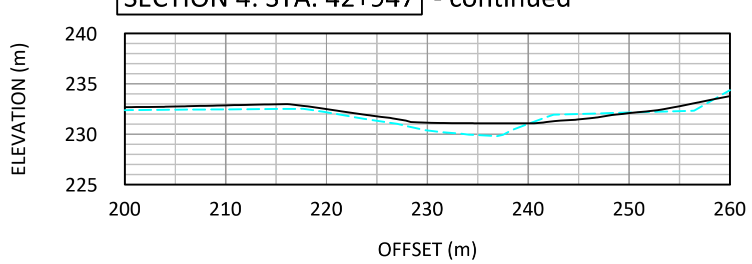
SECTION 3: STA. 43+450



SECTION 4: STA. 42+947



SECTION 4: STA. 42+947 - continued



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
- 2000
- 2011
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

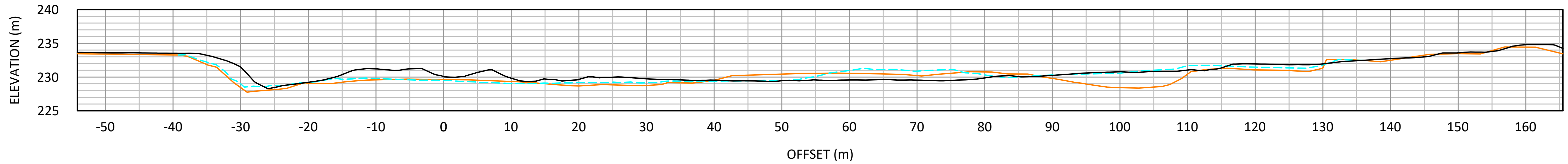
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

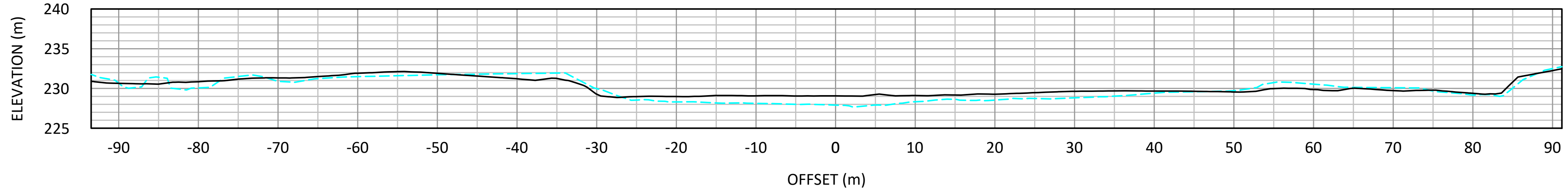
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-002
SHEET NUMBER	2 of 16
REVISION	0

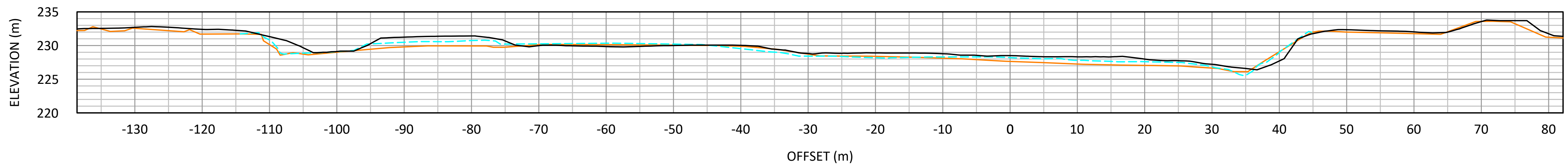
SECTION 5: STA. 42+484



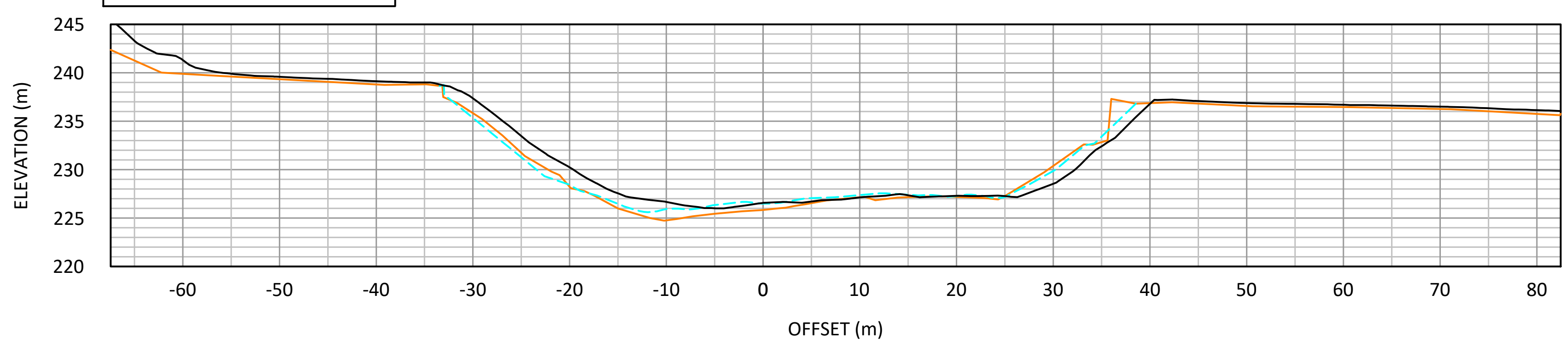
SECTION 6: STA. 42+048



SECTION 7: STA. 41+432



SECTION 8: STA. 41+079



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

- 2000
- 2011
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

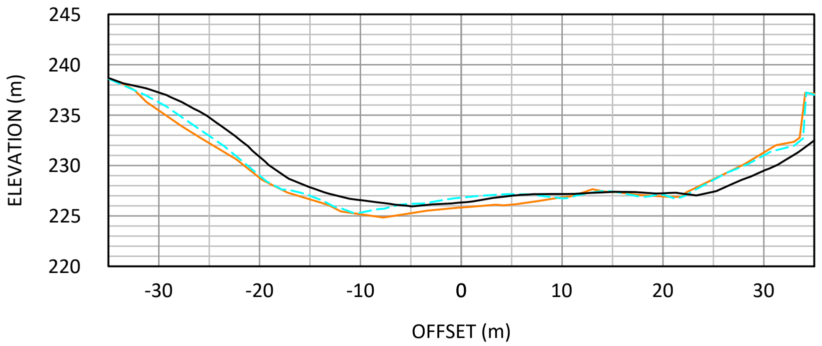
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

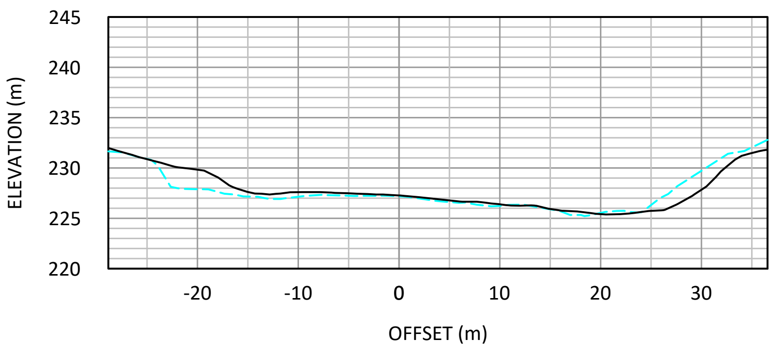
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-003
SHEET NUMBER	3 of 16
REVISION	0

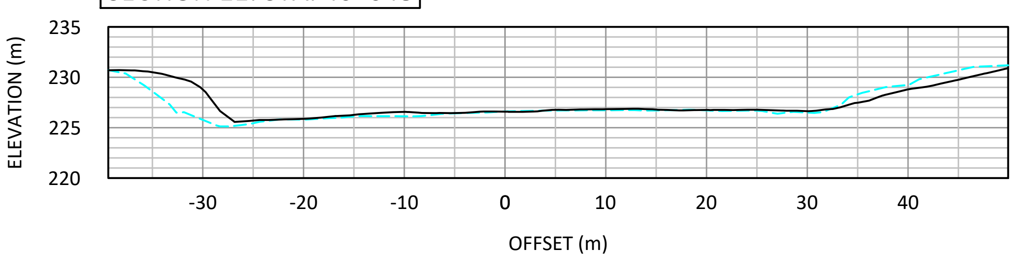
SECTION 9: STA. 41+071



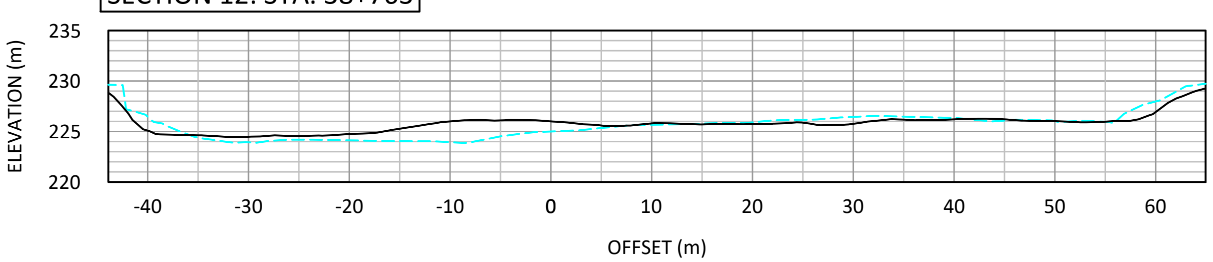
SECTION 10: STA. 40+920



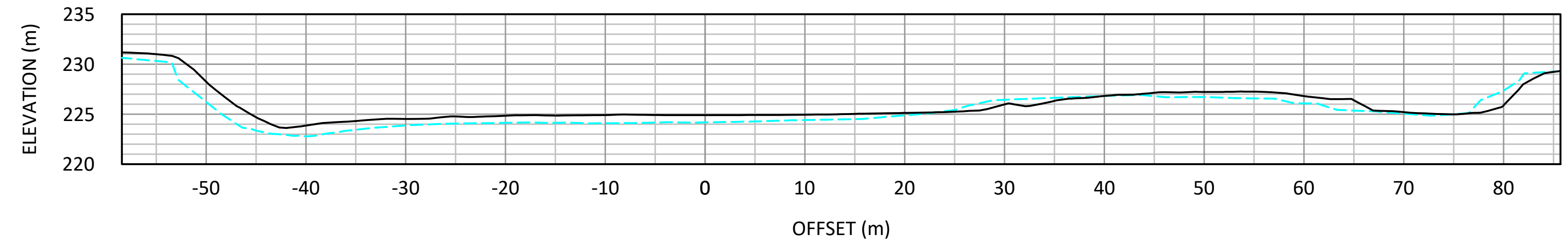
SECTION 11: STA. 40+048



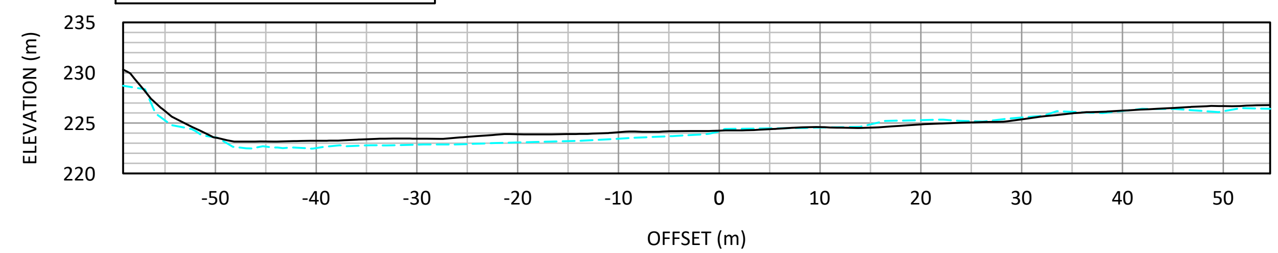
SECTION 12: STA. 38+763



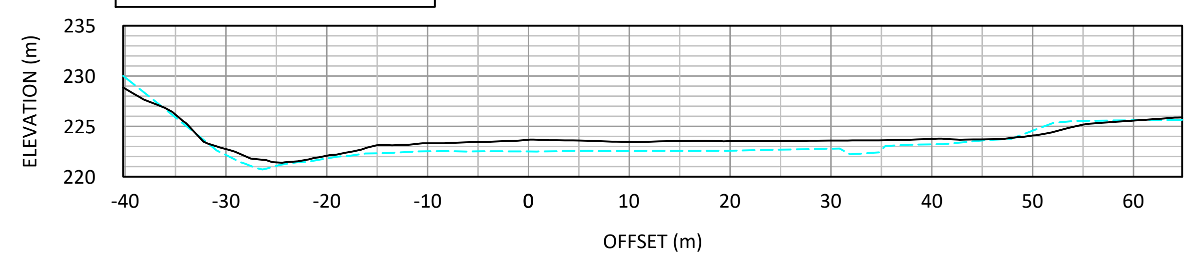
SECTION 13: STA. 38+144



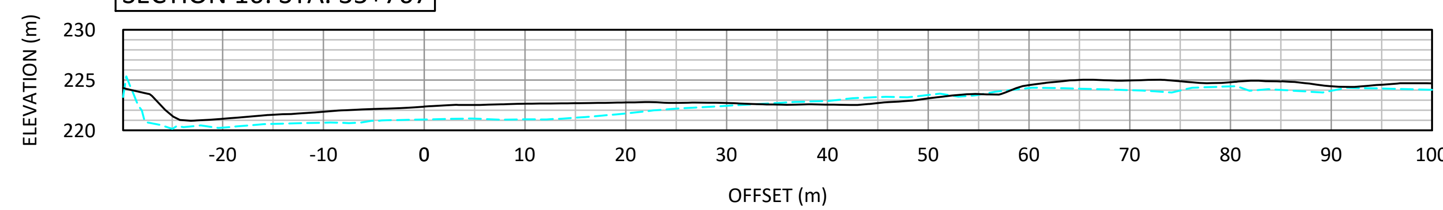
SECTION 14: STA. 37+557



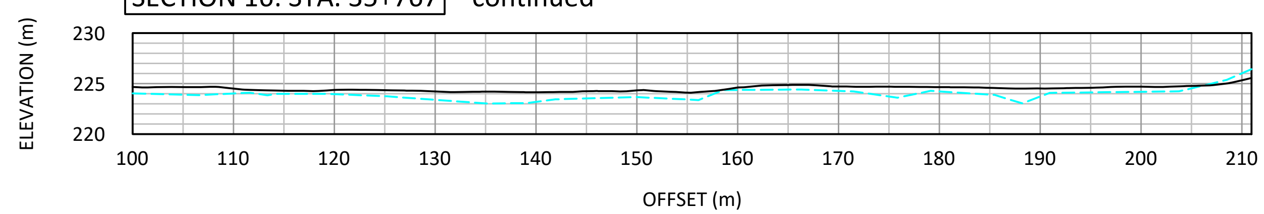
SECTION 15: STA. 36+892



SECTION 16: STA. 35+767



SECTION 16: STA. 35+767 - continued



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

- 2000
- 2011
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

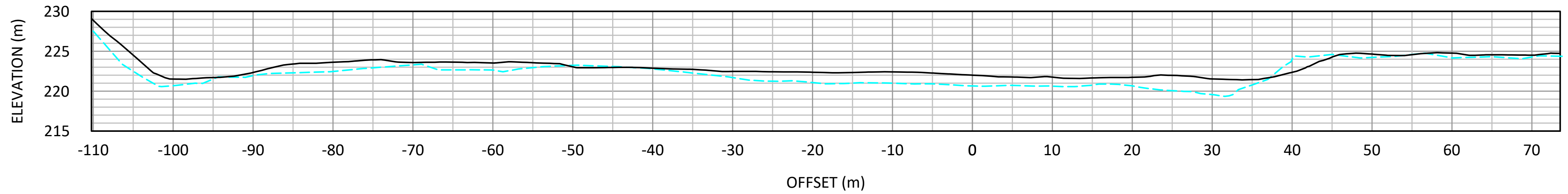
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

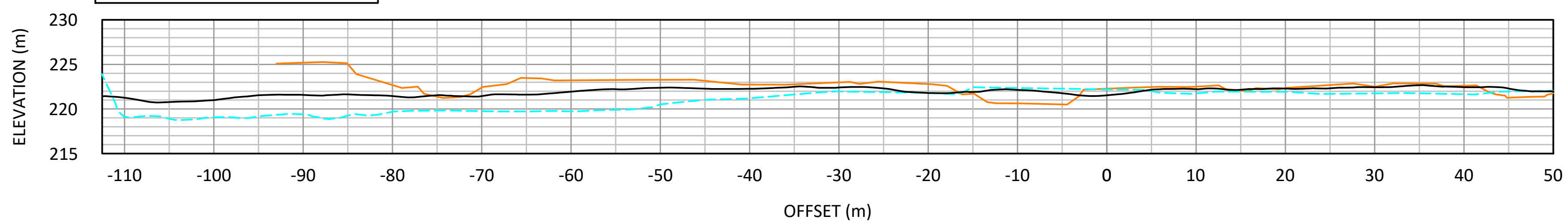
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-004
SHEET NUMBER	4 of 16
REVISION	0

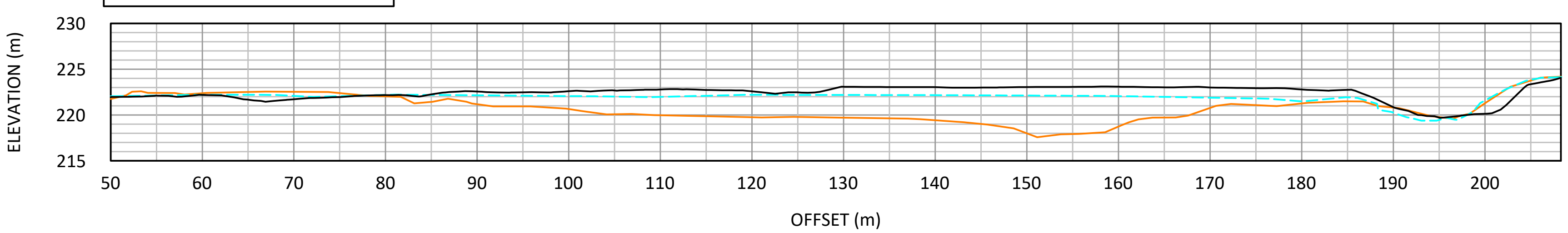
SECTION 17: STA. 35+294



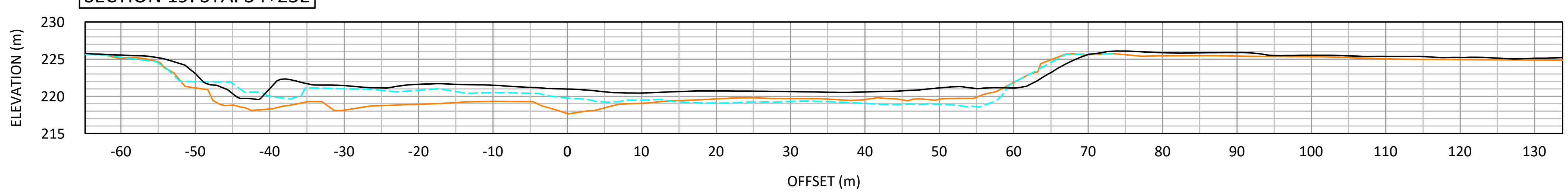
SECTION 18: STA. 34+552



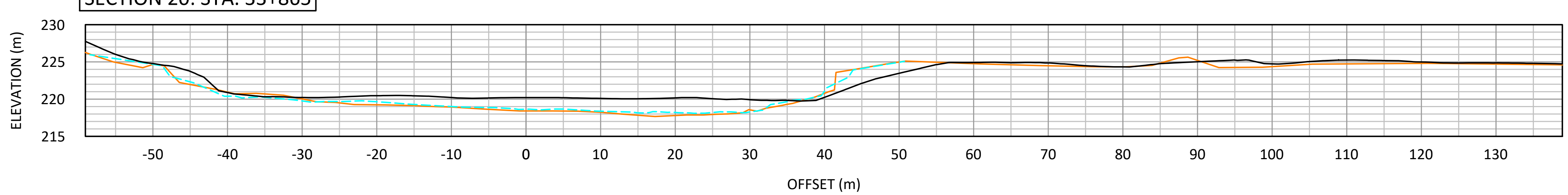
SECTION 18: STA. 34+552 - continued



SECTION 19: STA. 34+252



SECTION 20: STA. 33+865



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
2000
2011
2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

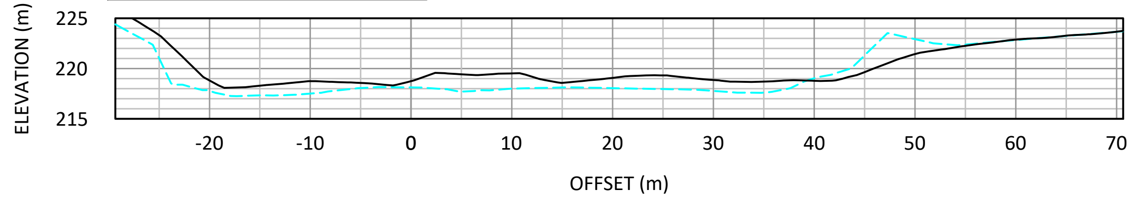
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

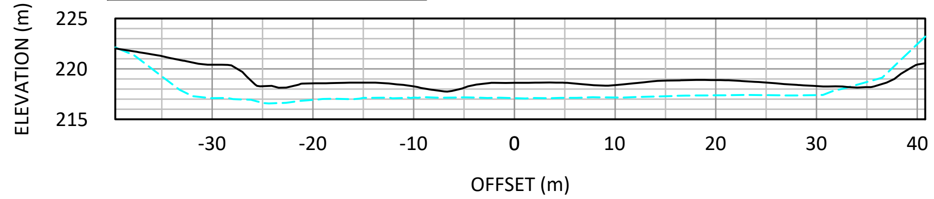
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-005
SHEET NUMBER	5 of 16
REVISION	0

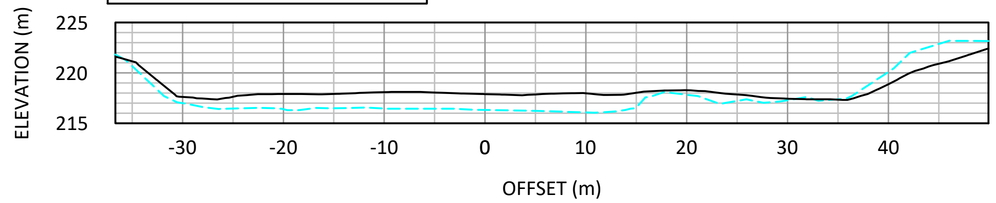
SECTION 21: STA. 32+899



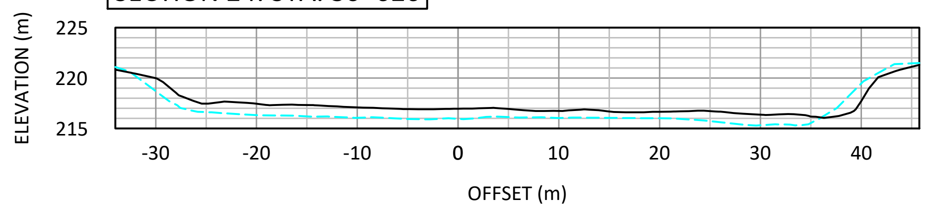
SECTION 22: STA. 32+132



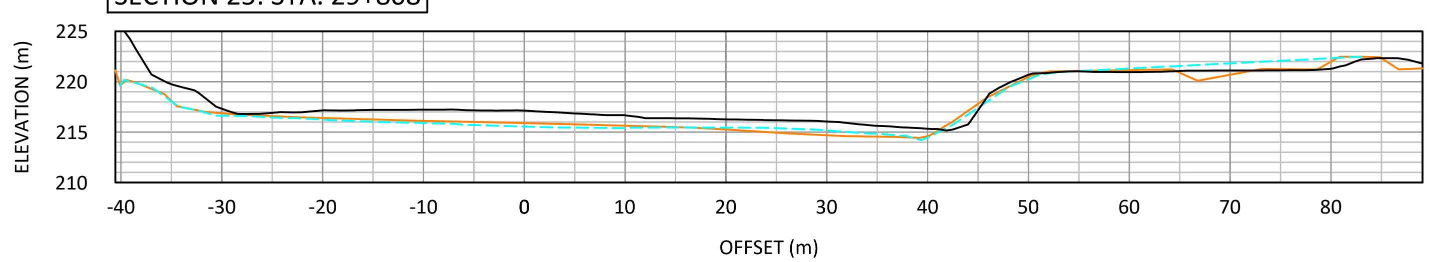
SECTION 23: STA. 31+545



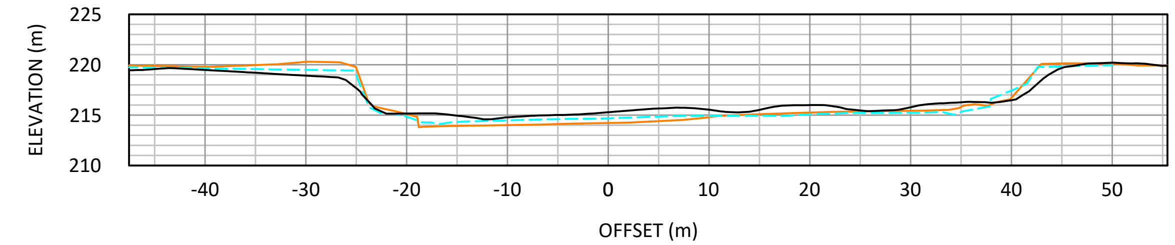
SECTION 24: STA. 30+626



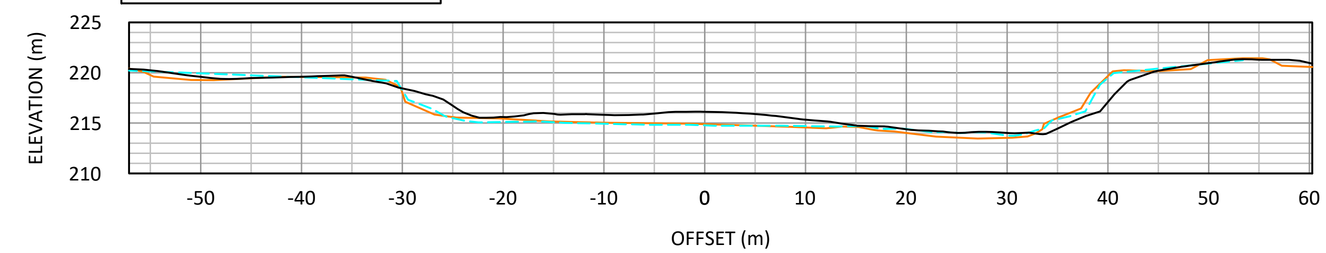
SECTION 25: STA. 29+808



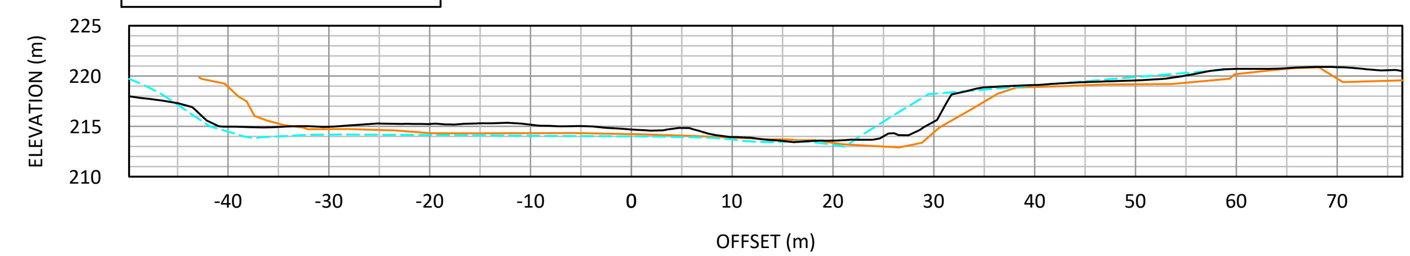
SECTION 26: STA. 29+151



SECTION 27: STA. 28+967



SECTION 28: STA. 28+191



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2011

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

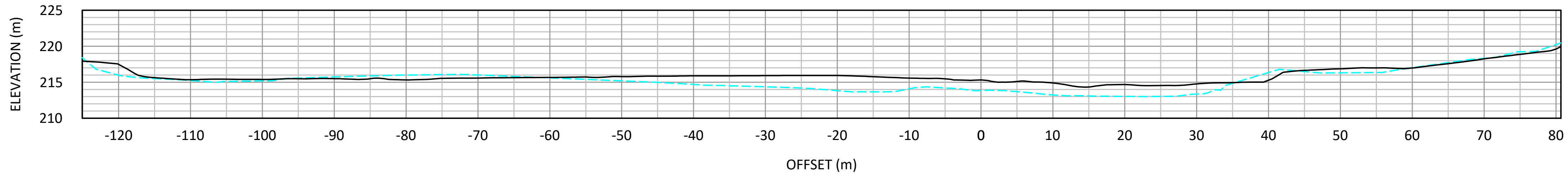
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

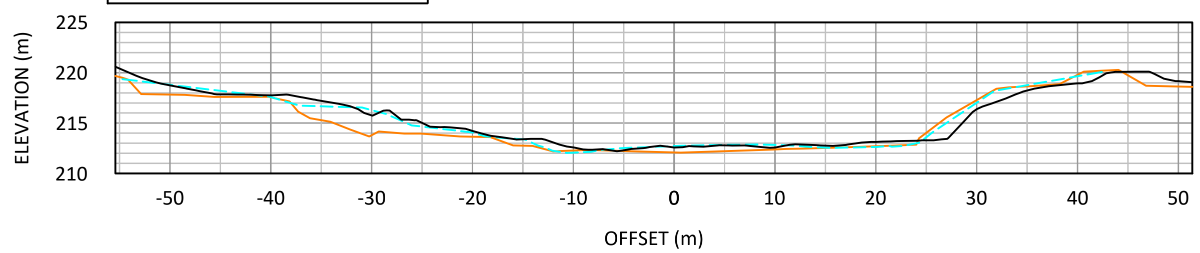
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-006
SHEET NUMBER	6 of 16
REVISION	0

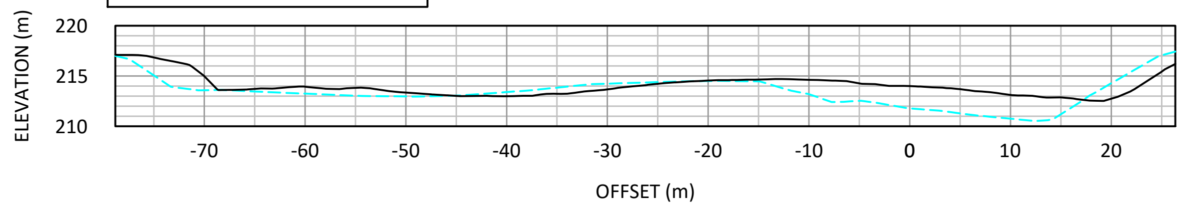
SECTION 29: STA. 27+837



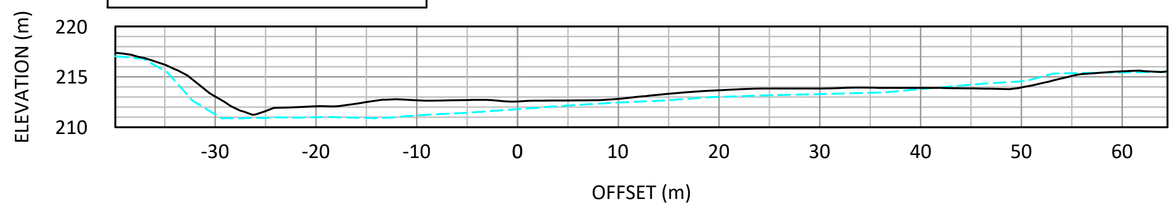
SECTION 30: STA. 27+334



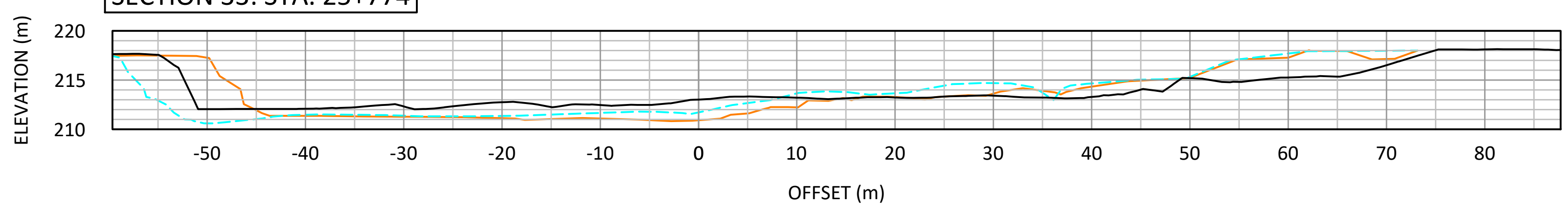
SECTION 31: STA. 26+644



SECTION 32: STA. 26+053



SECTION 33: STA. 25+774



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
- 2000
- 2011
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

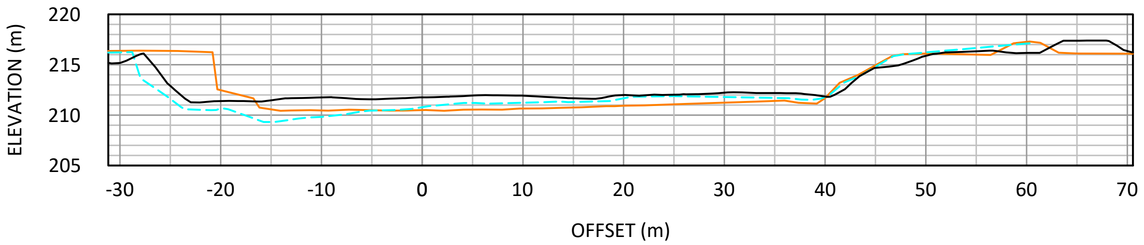
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

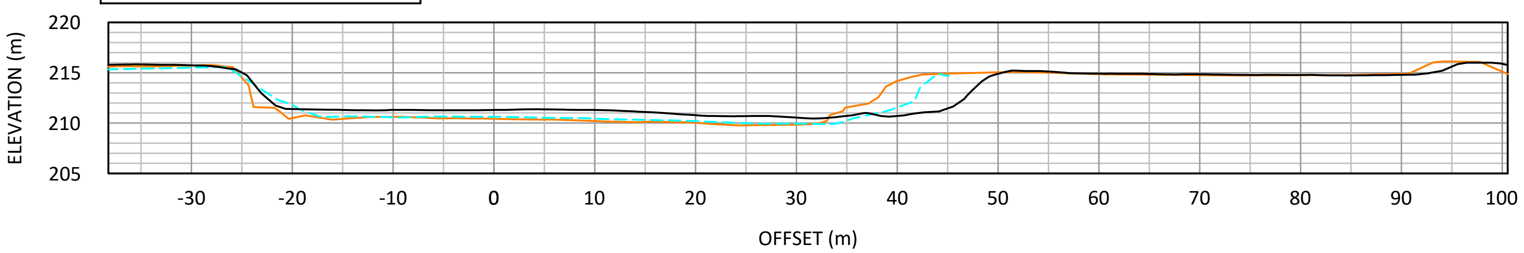
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-007
SHEET NUMBER	7 of 16
REVISION	0

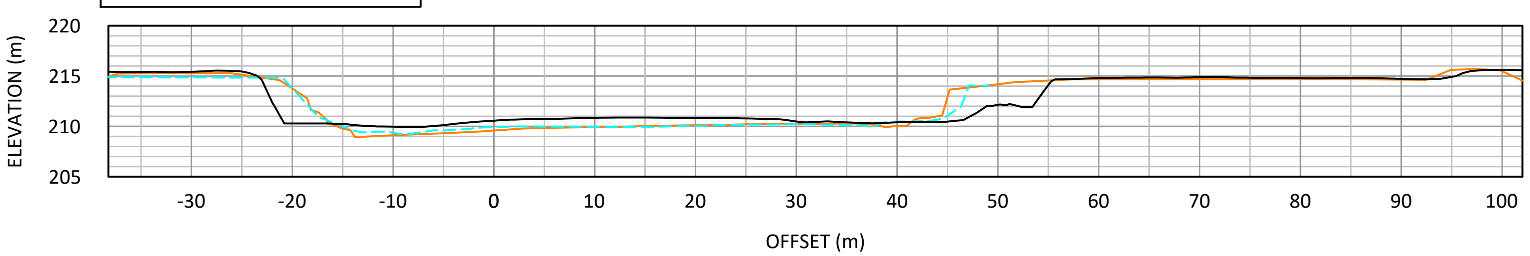
SECTION 34: STA. 25+023



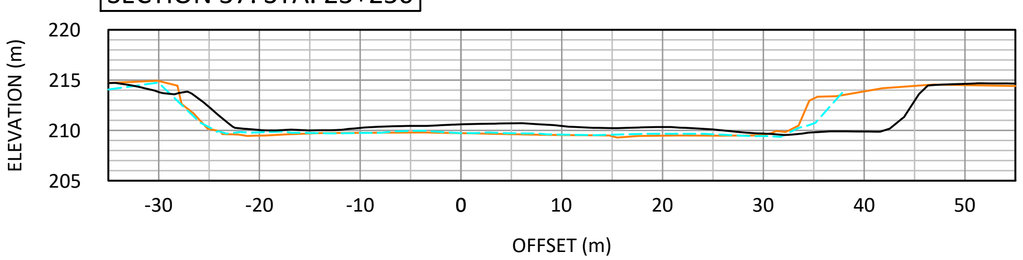
SECTION 35: STA. 24+210



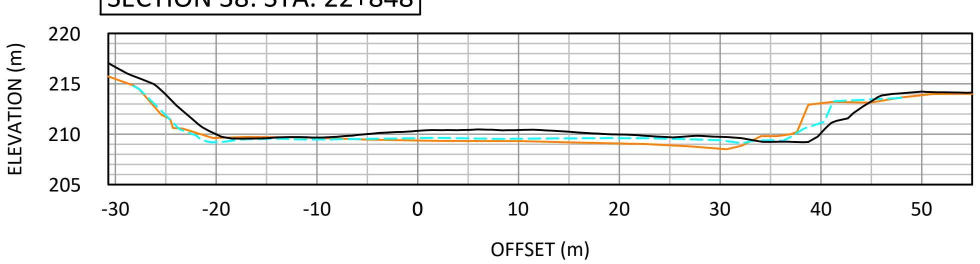
SECTION 36: STA. 23+494



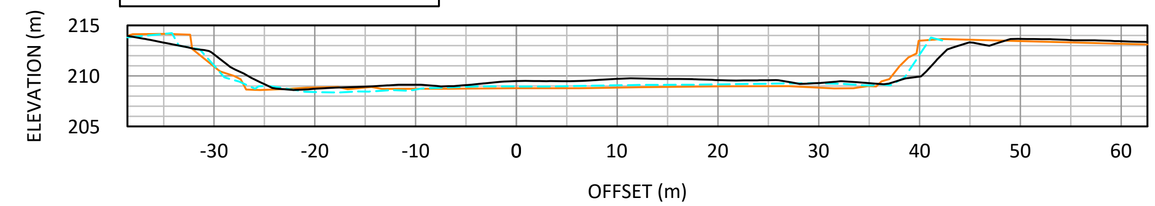
SECTION 37: STA. 23+250



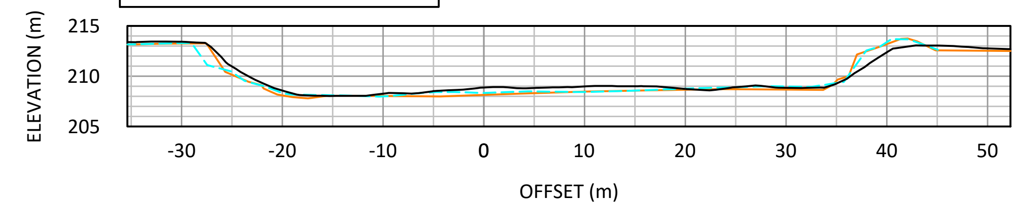
SECTION 38: STA. 22+848



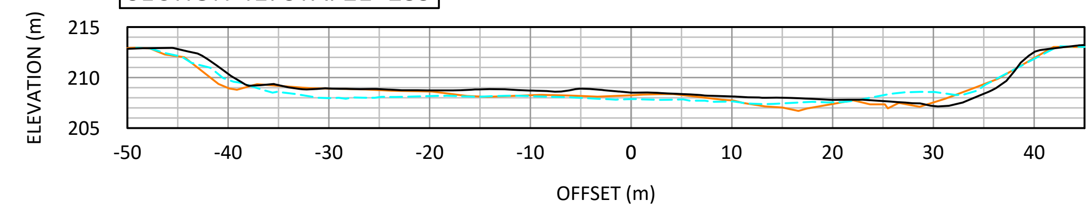
SECTION 39: STA. 22+012



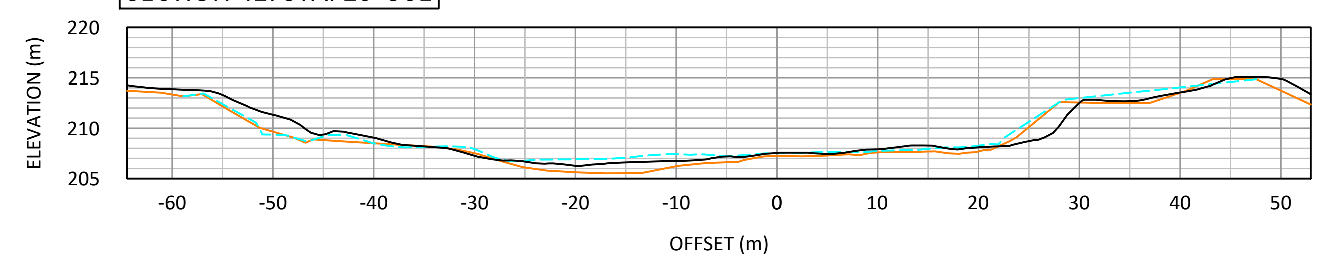
SECTION 40: STA. 21+522



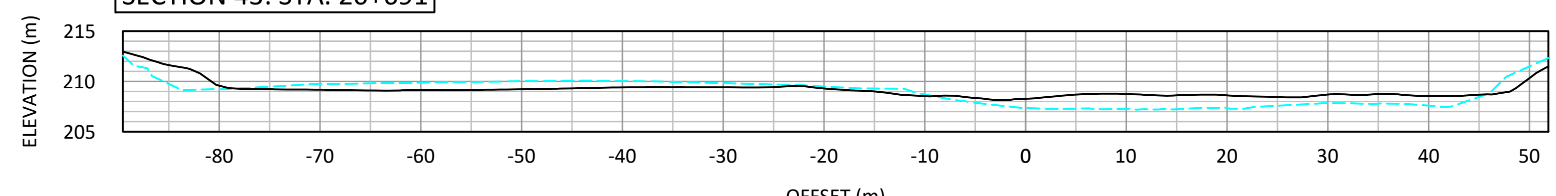
SECTION 41: STA. 21+239



SECTION 42: STA. 20+901



SECTION 43: STA. 20+691



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
2000
2011
2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

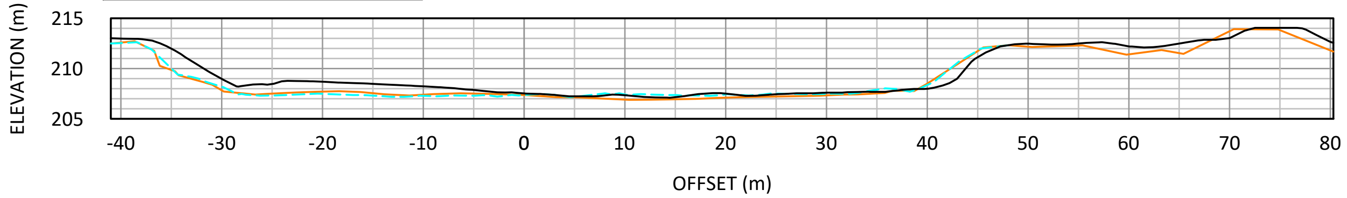
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

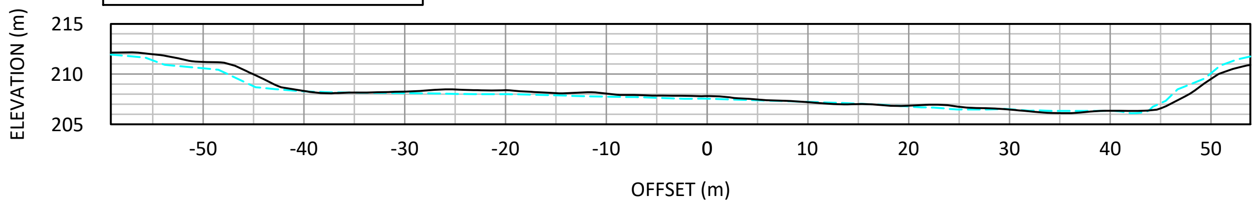
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-008
SHEET NUMBER	8 of 16
REVISION	0

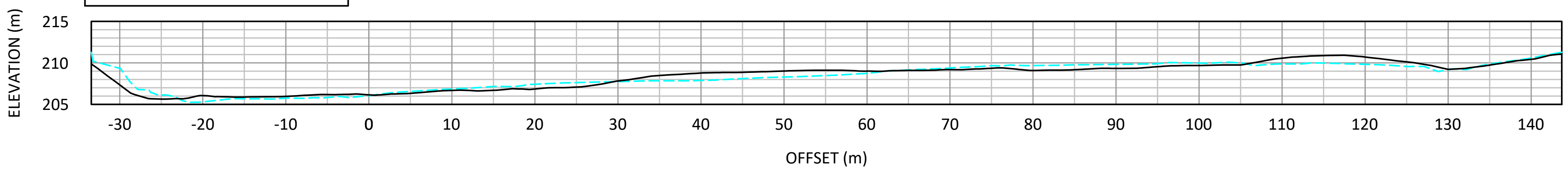
SECTION 44: STA. 20+387



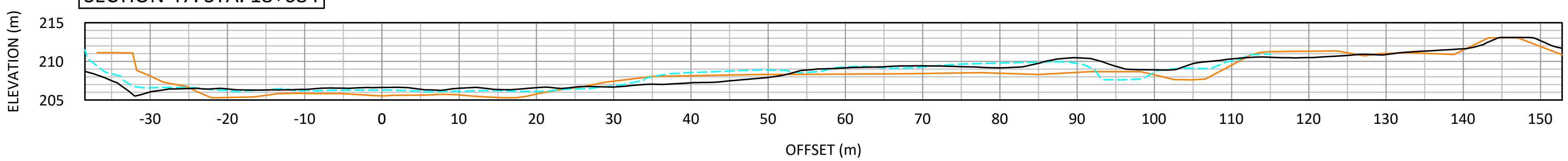
SECTION 45: STA. 19+480



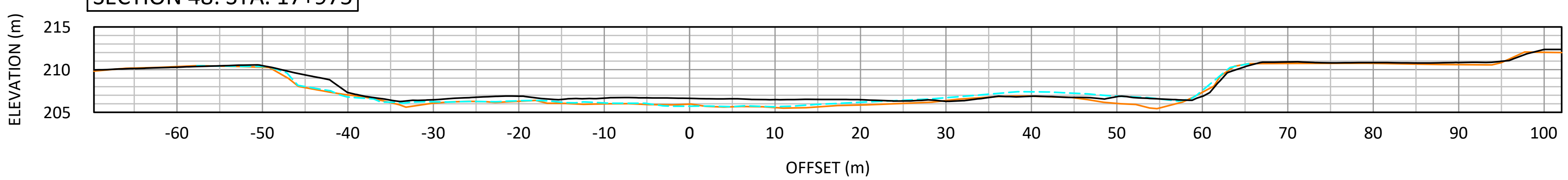
SECTION 46: STA. 18+888



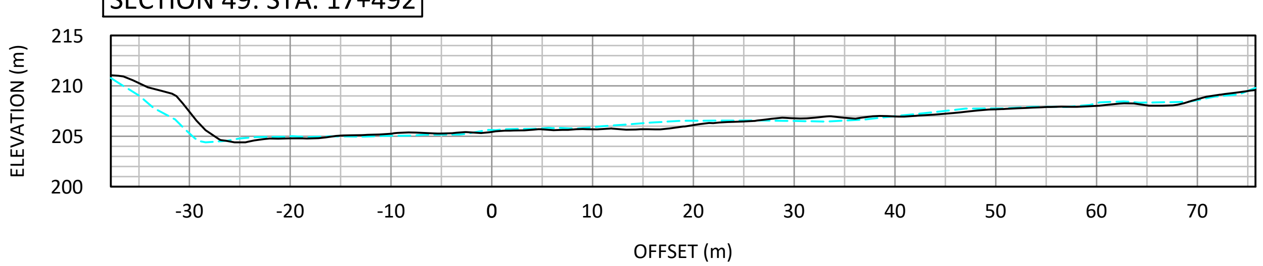
SECTION 47: STA. 18+684



SECTION 48: STA. 17+975



SECTION 49: STA. 17+492



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
- 2000
- 2011
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

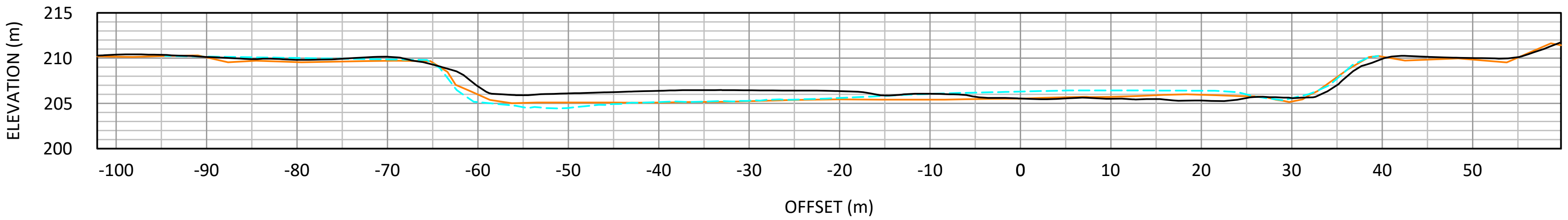
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

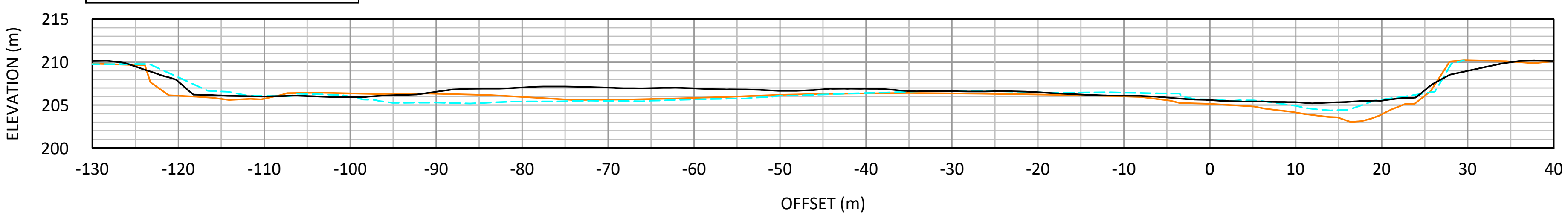
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-009
SHEET NUMBER	9 of 16
REVISION	0

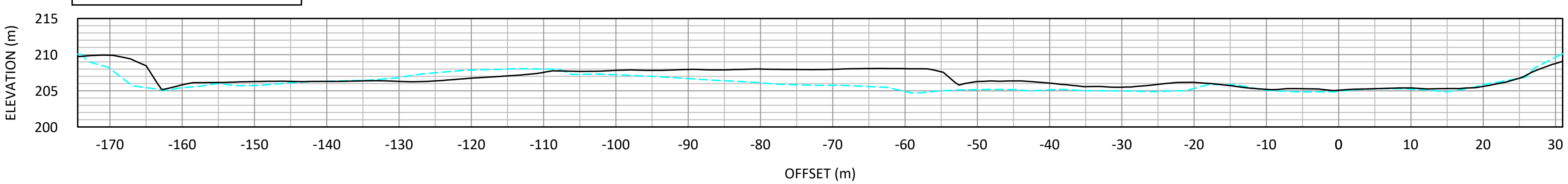
SECTION 50: STA. 17+232



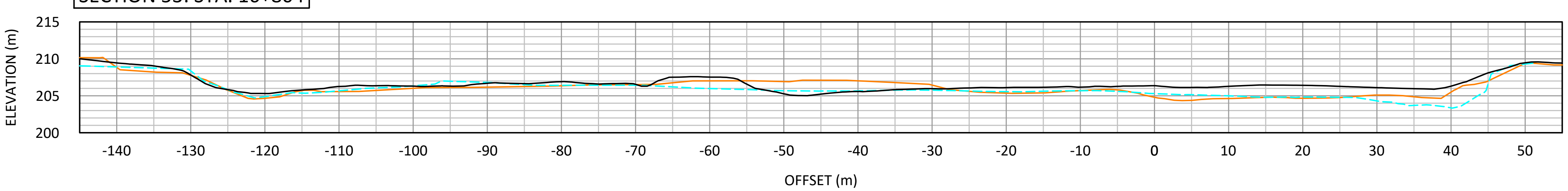
SECTION 51: STA. 17+054



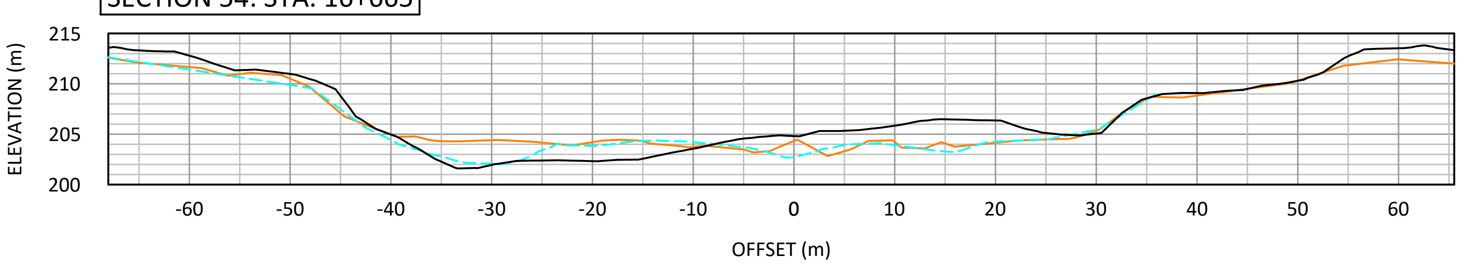
SECTION 52: STA. 16+900



SECTION 53: STA. 16+804



SECTION 54: STA. 16+665



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
2000
2011
2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

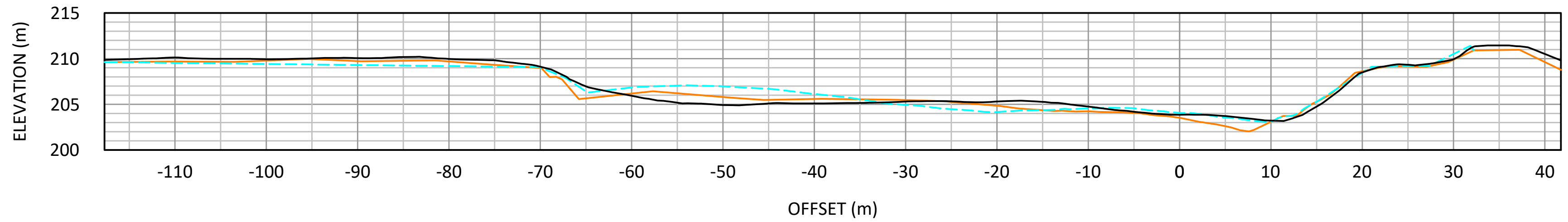
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

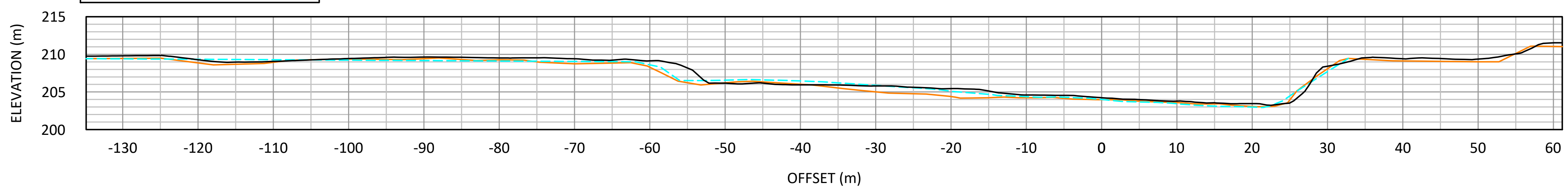
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-010
SHEET NUMBER	10 of 16
REVISION	0

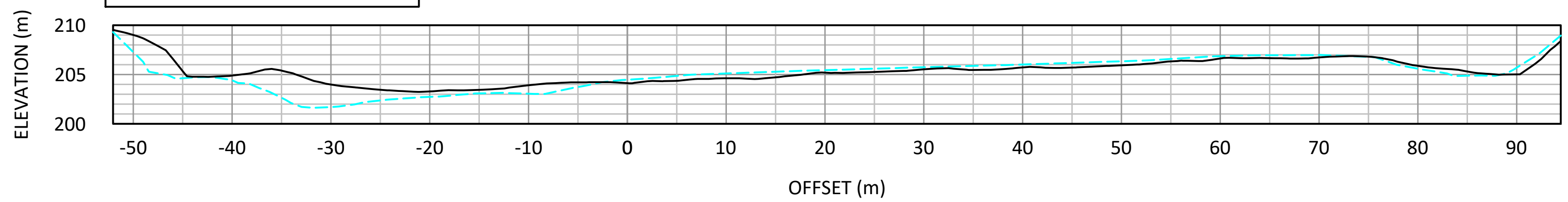
SECTION 55: STA. 16+583



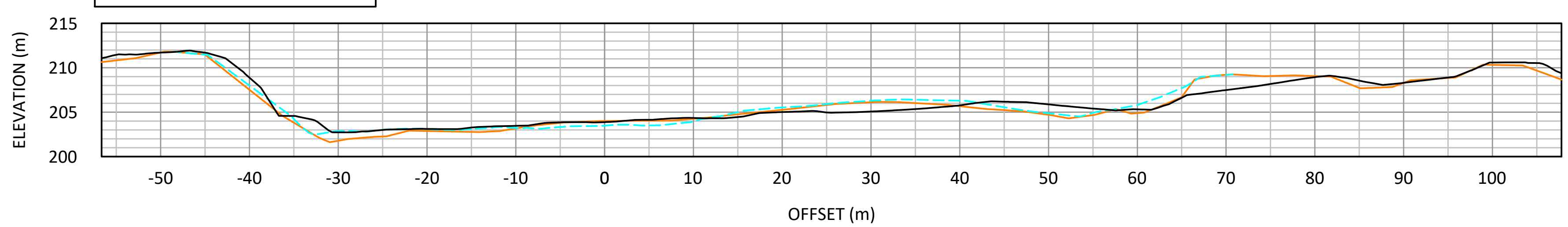
SECTION 56: STA. 16+300



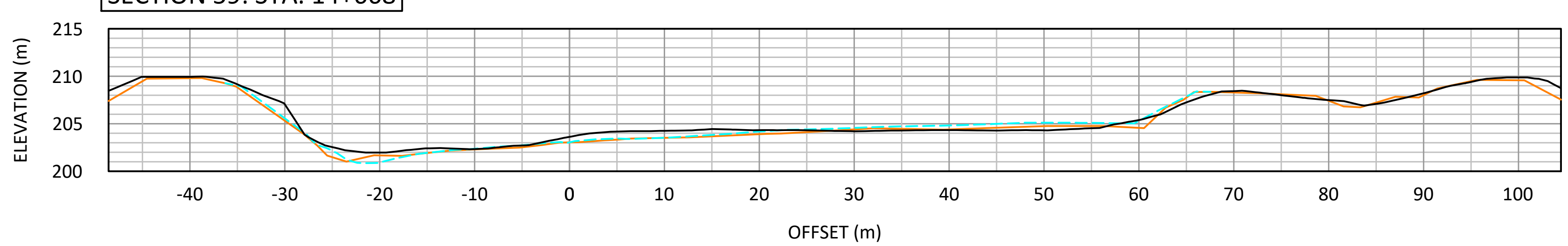
SECTION 57: STA. 15+660



SECTION 58: STA. 15+513



SECTION 59: STA. 14+668



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
- 2000
- 2011
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

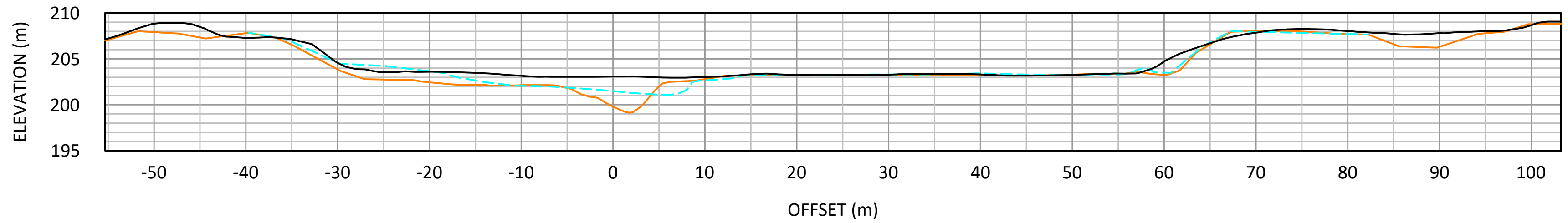
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

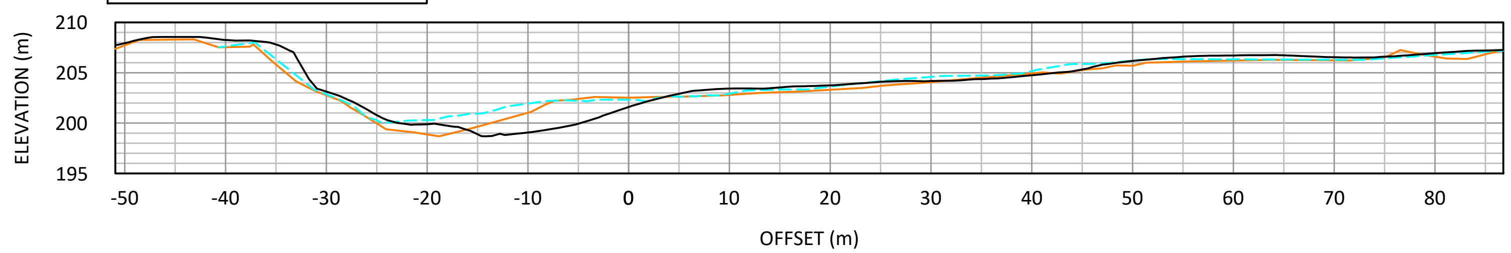
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-011
SHEET NUMBER	11 of 16
REVISION	0

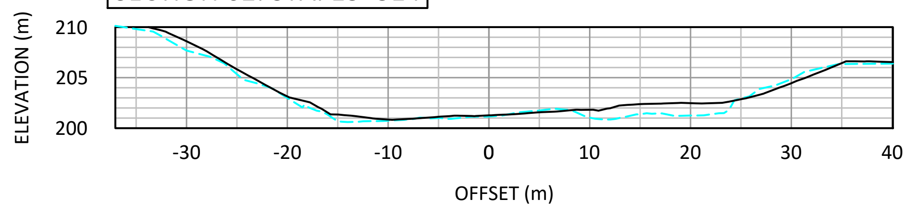
SECTION 60: STA. 13+805



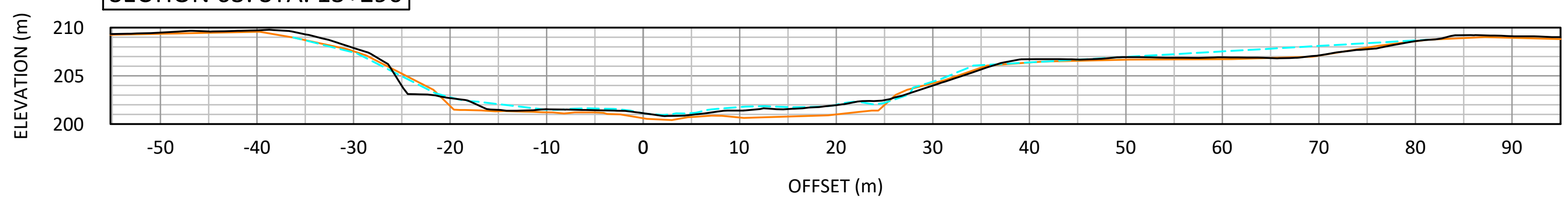
SECTION 61: STA. 13+419



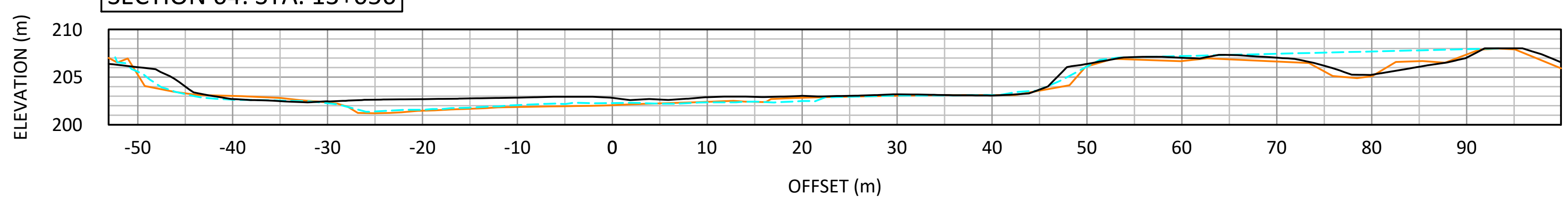
SECTION 62: STA. 13+314



SECTION 63: STA. 13+290



SECTION 64: STA. 13+056



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2011

2017

PEMBERTON VALLEY DYKING DISTRICT

1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants

405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

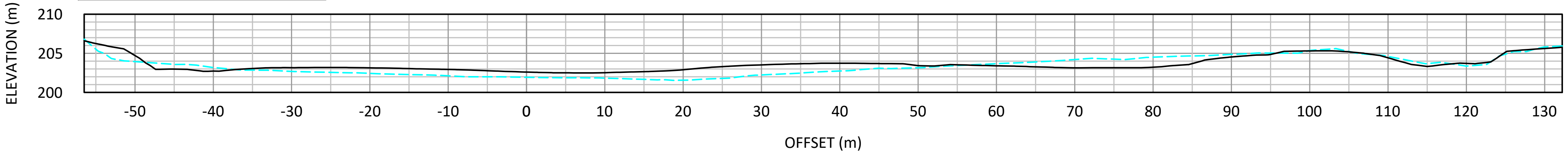
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

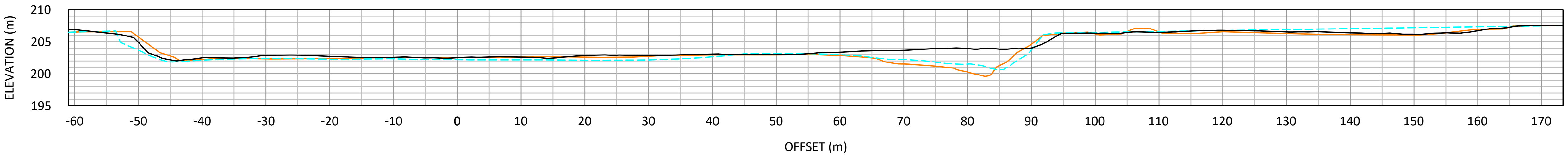
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-012
SHEET NUMBER	12 of 16
REVISION	0

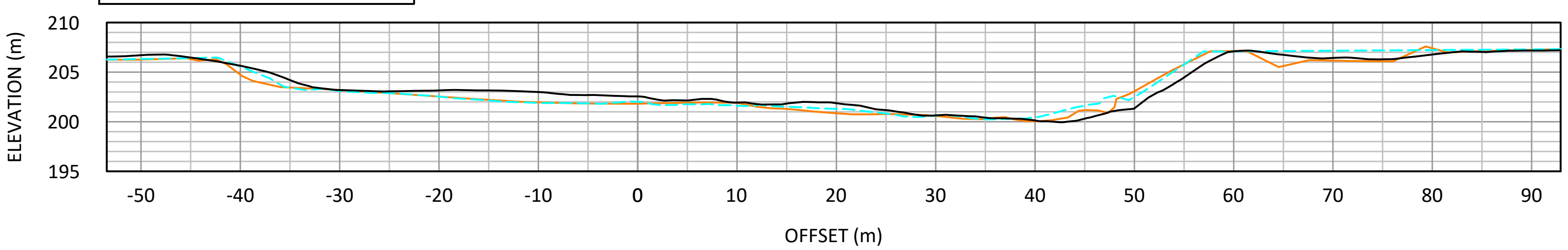
SECTION 65: STA. 12+773



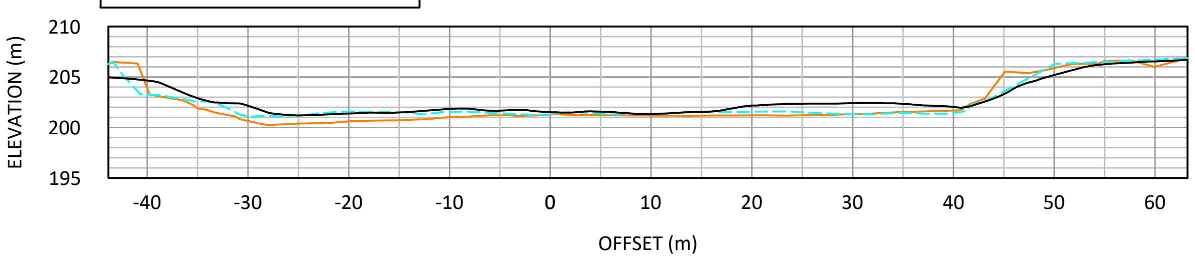
SECTION 66: STA. 12+570



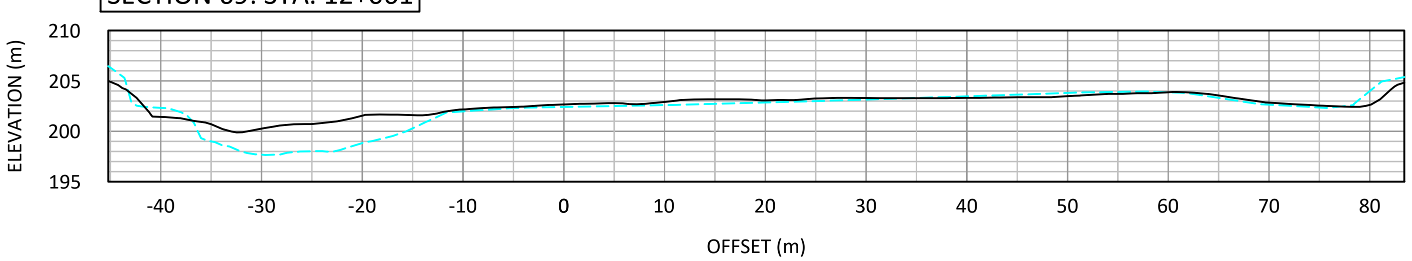
SECTION 67: STA. 12+466



SECTION 68: STA. 12+273



SECTION 69: STA. 12+061



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:
- 2000
- 2011
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

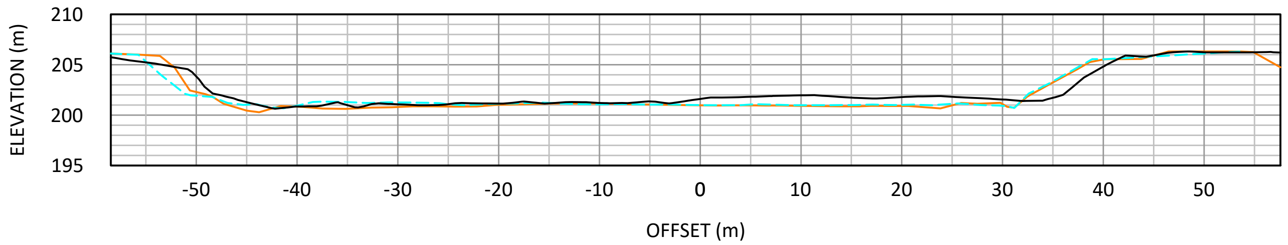
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

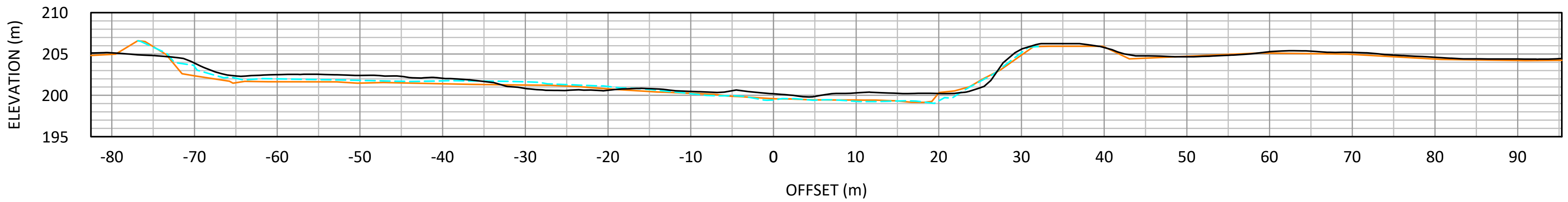
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-013
SHEET NUMBER	13 of 16
REVISION	0

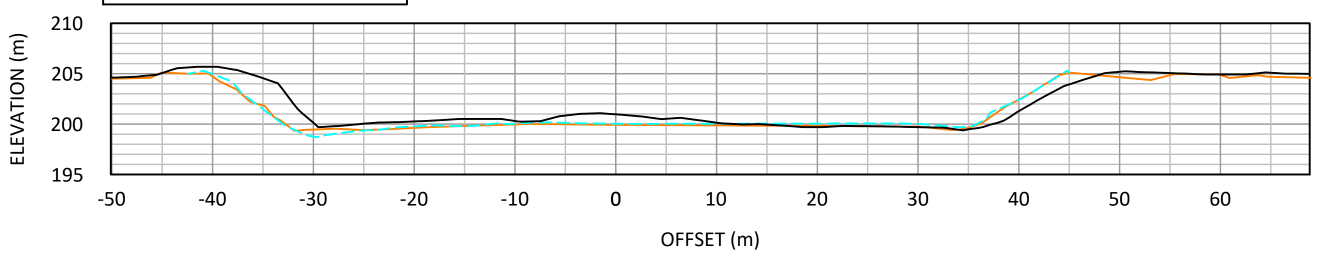
SECTION 70: STA. 11+379



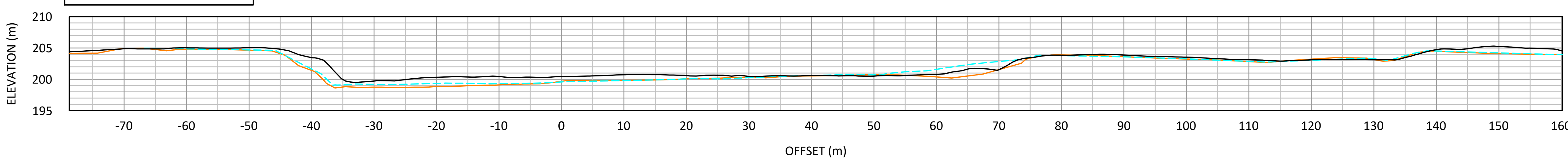
SECTION 71: STA. 10+478



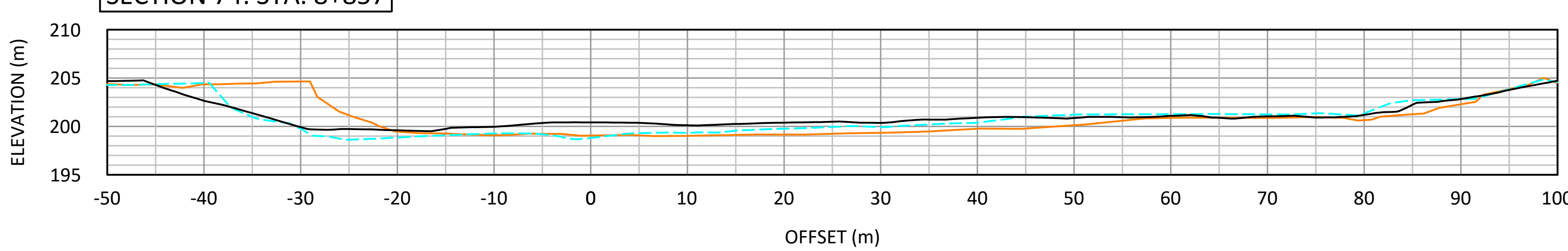
SECTION 72: STA. 9+803



SECTION 73: STA. 9+057



SECTION 74: STA. 8+857



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2011

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

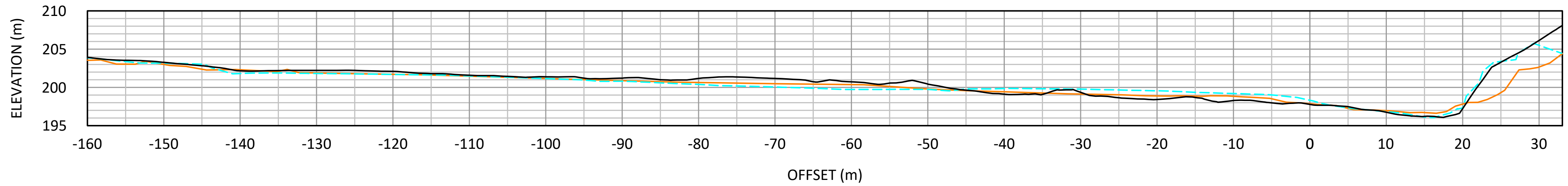
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

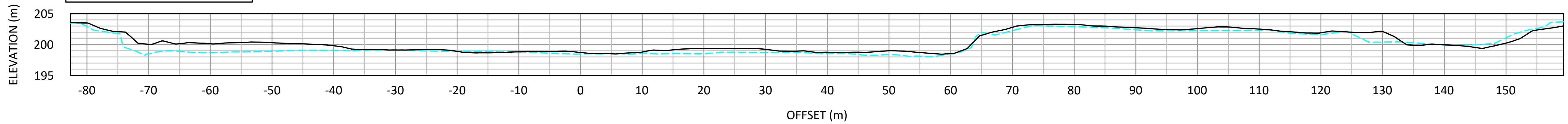
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-014
SHEET NUMBER	14 of 16
REVISION	0

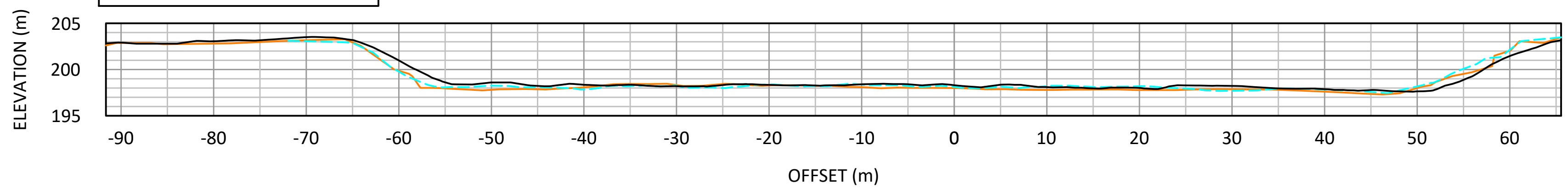
SECTION 75: STA. 8+448



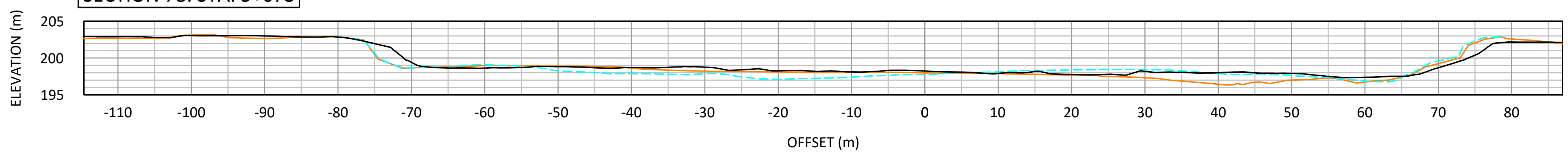
SECTION 76: STA. 7+248



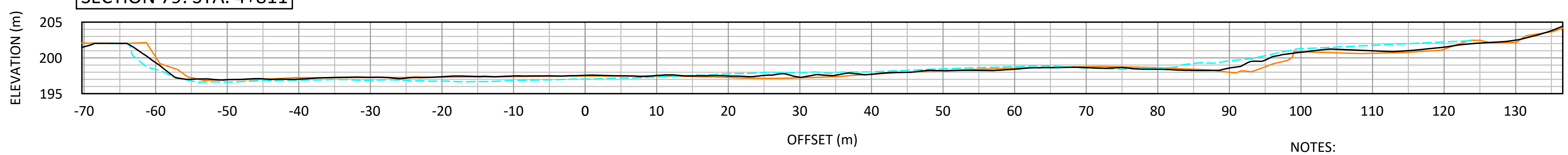
SECTION 77: STA. 6+427



SECTION 78: STA. 5+673



SECTION 79: STA. 4+811



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2011

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

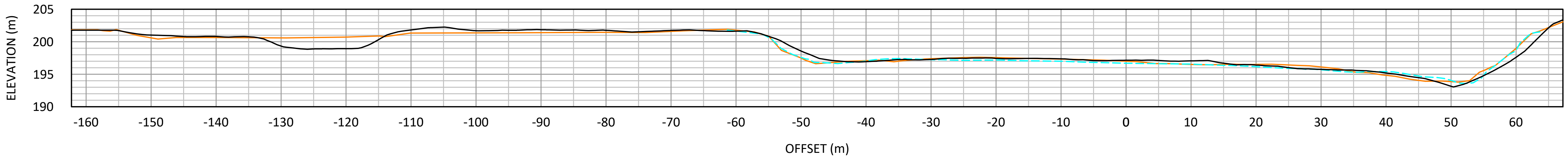
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

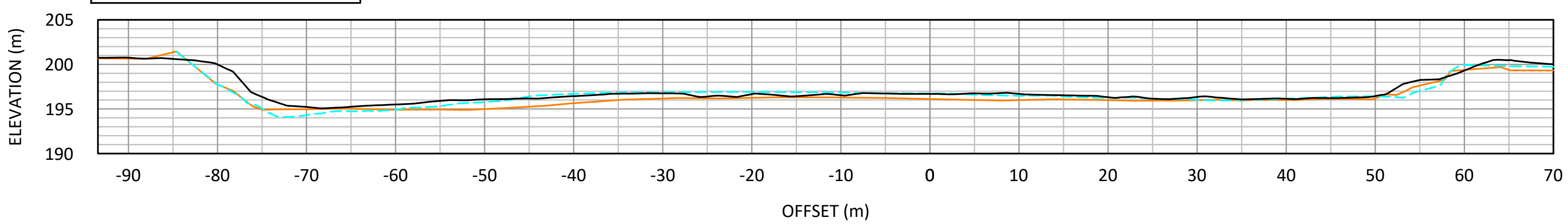
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-015
SHEET NUMBER	15 of 16
REVISION	0

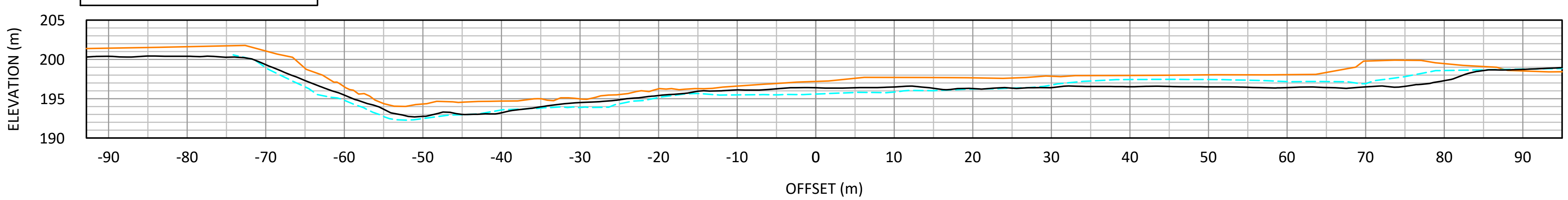
SECTION 80: STA. 3+345



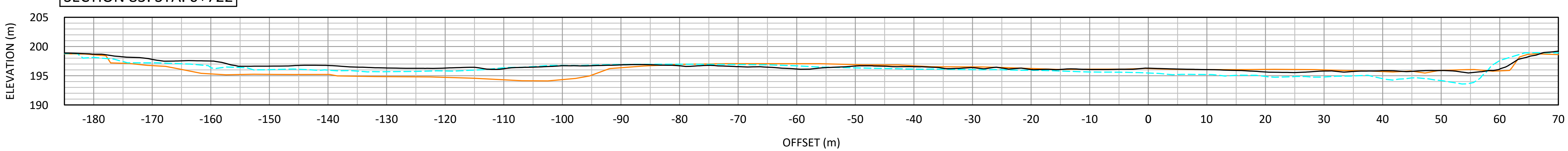
SECTION 81: STA. 2+210



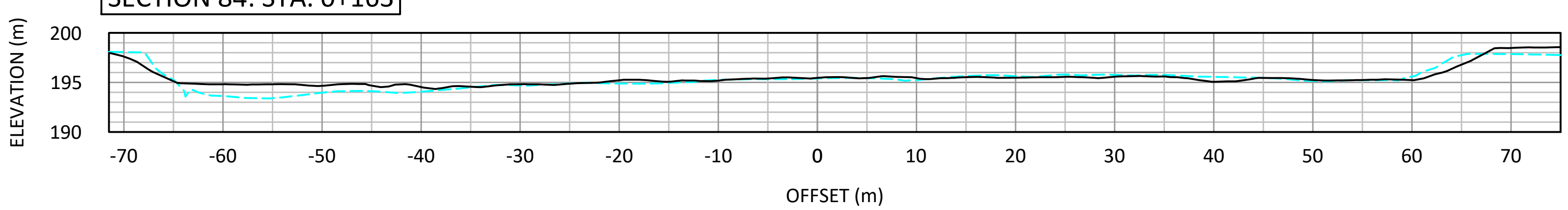
SECTION 82: STA. 1+609



SECTION 83: STA. 0+722



SECTION 84: STA. 0+163



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2011

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

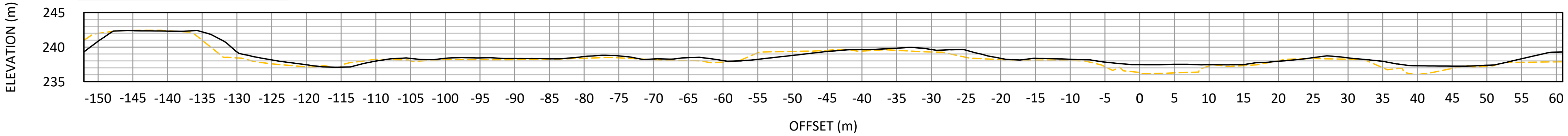
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

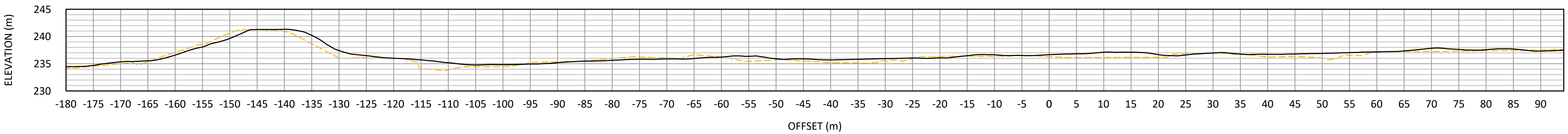
LILLOOET RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-016
SHEET NUMBER	16 of 16
REVISION	0

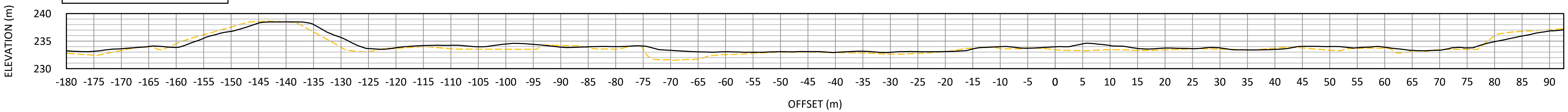
SECTION 1: STA. 15+546



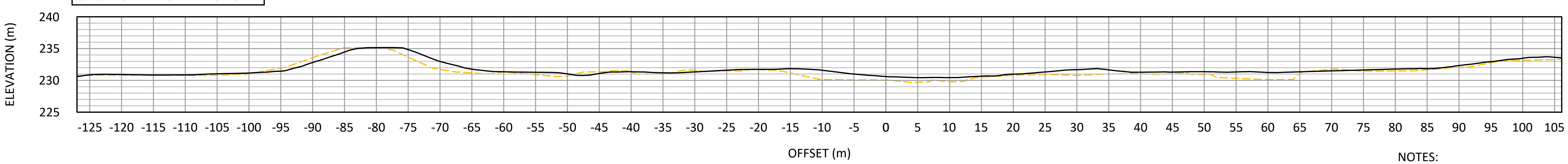
SECTION 2: STA. 15+462



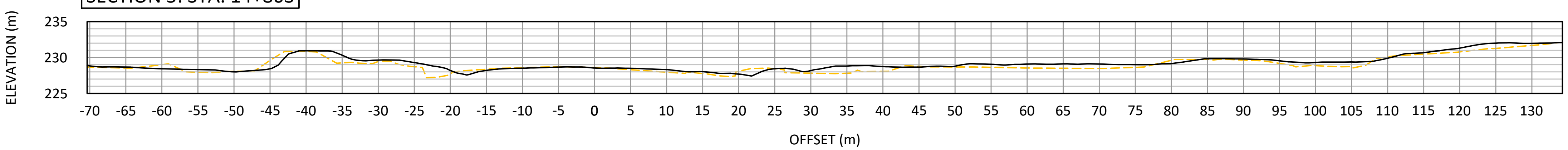
SECTION 3: STA. 15+279



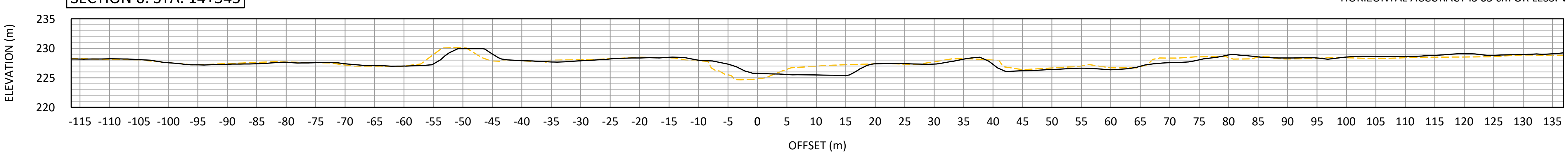
SECTION 4: STA. 15+072



SECTION 5: STA. 14+803



SECTION 6: STA. 14+545



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

- - - - 2006

——— 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

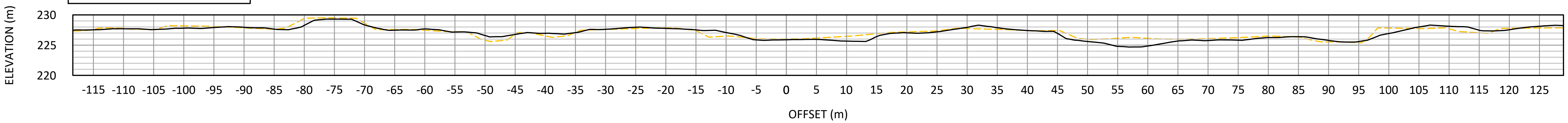
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

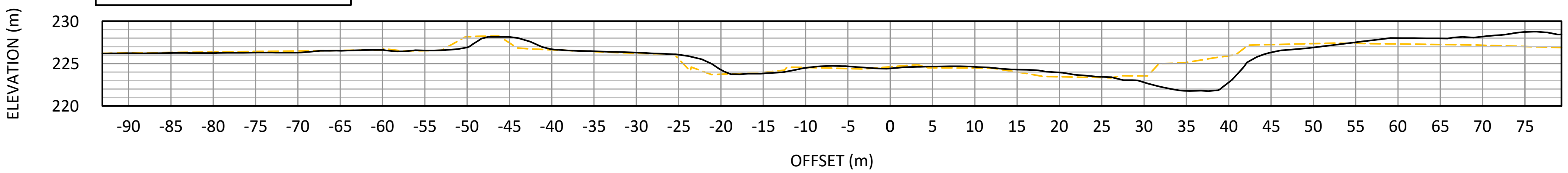
RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-017
SHEET NUMBER	1 of 8
REVISION	0

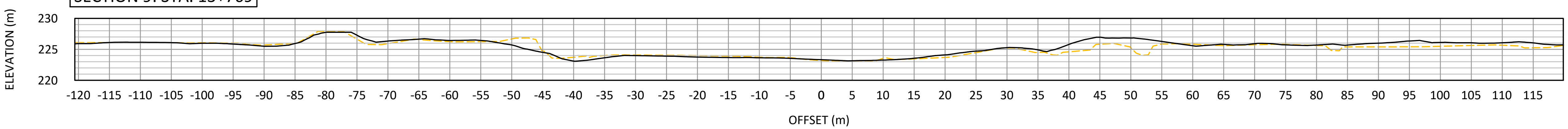
SECTION 7: STA. 14+416



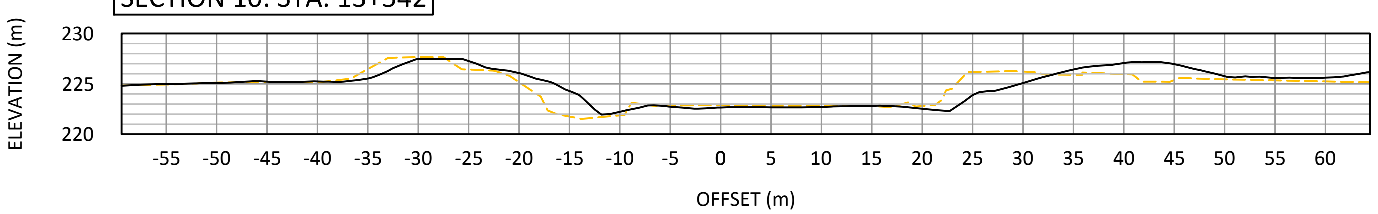
SECTION 8: STA. 14+095



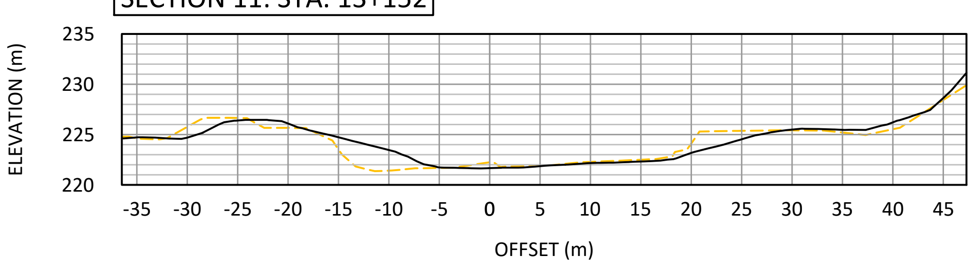
SECTION 9: STA. 13+769



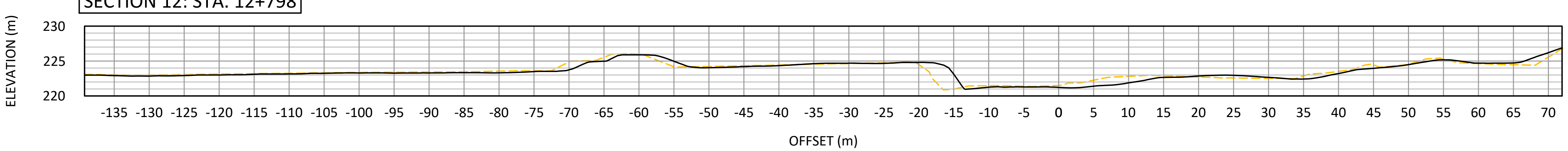
SECTION 10: STA. 13+542



SECTION 11: STA. 13+152



SECTION 12: STA. 12+798



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

- - - - 2006
—— 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

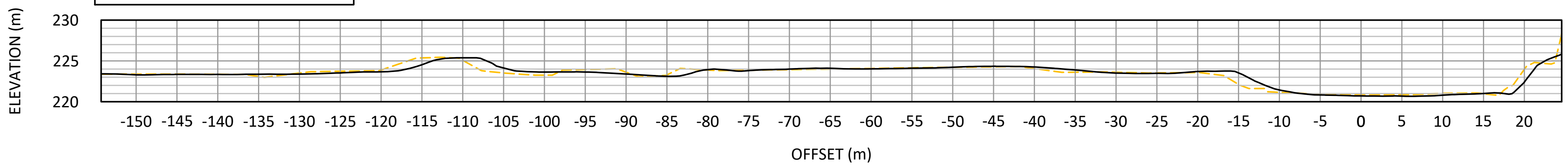
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

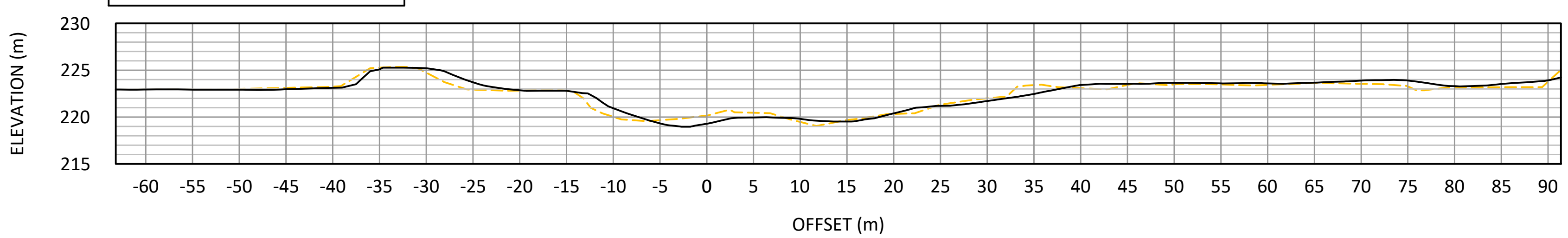
RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-018
SHEET NUMBER	2 of 8
REVISION	0

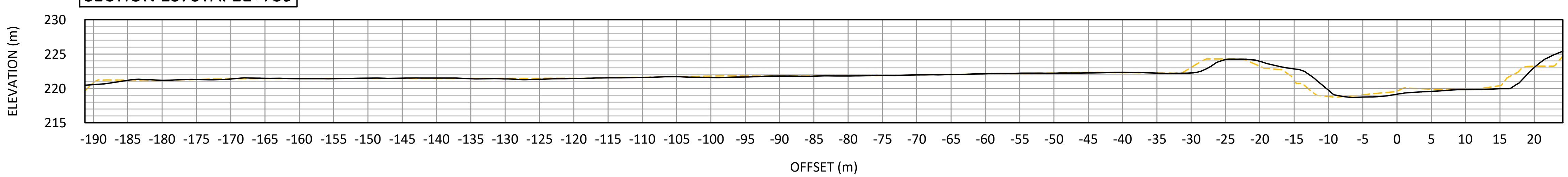
SECTION 13: STA. 12+466



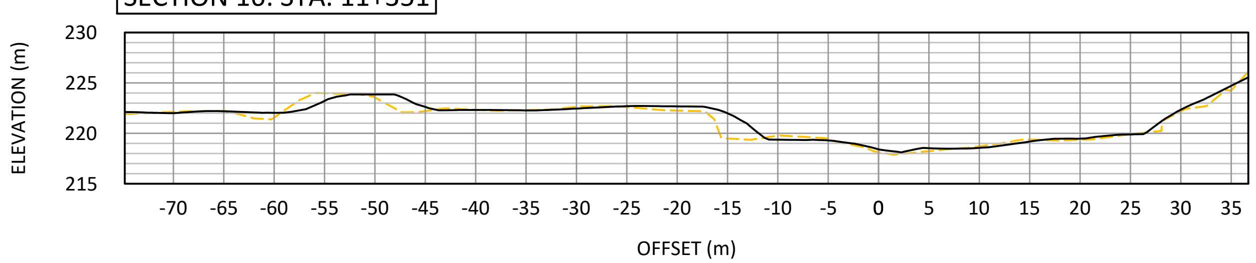
SECTION 14: STA. 12+193



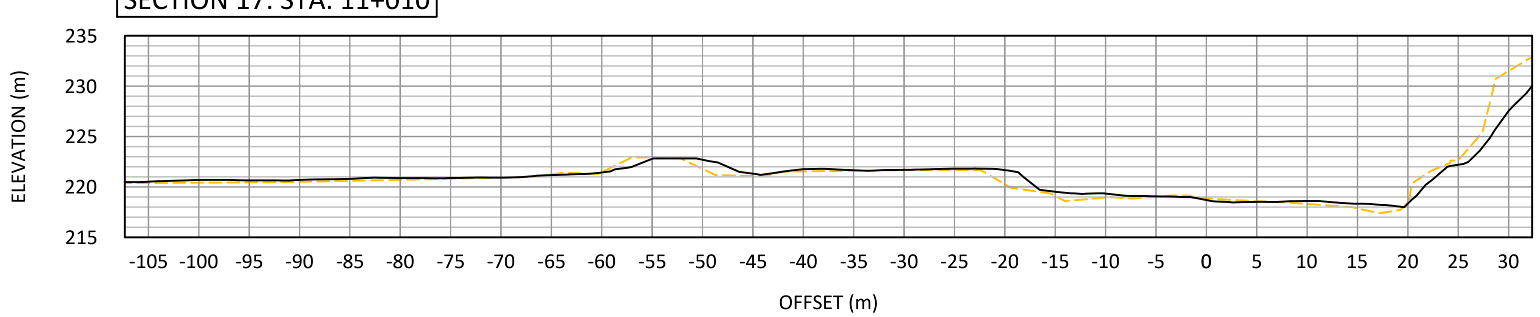
SECTION 15: STA. 11+739



SECTION 16: STA. 11+351



SECTION 17: STA. 11+010



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

- - - - 2006

——— 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

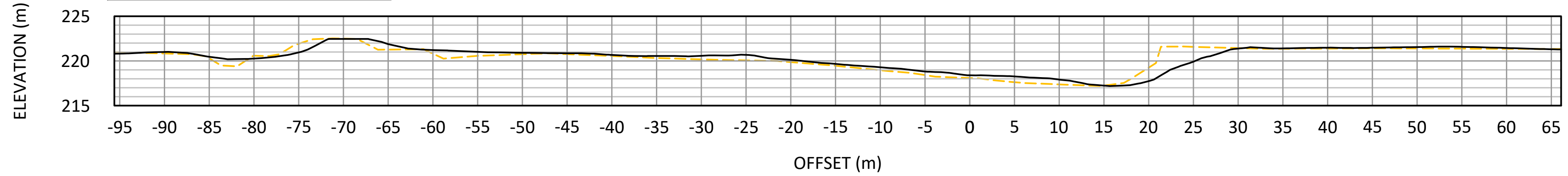
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

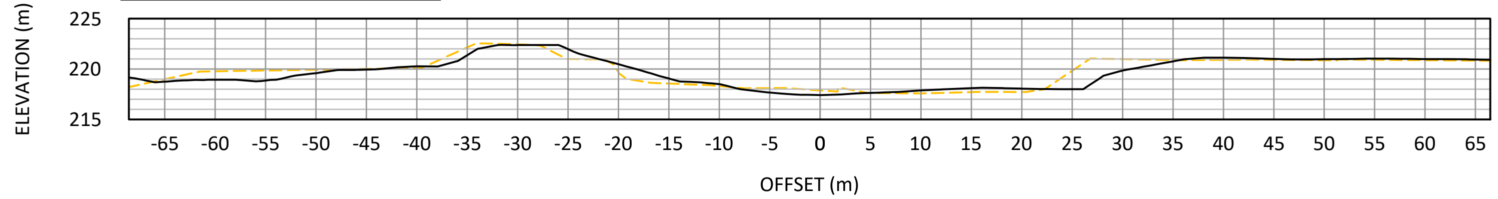
RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-019
SHEET NUMBER	3 of 8
REVISION	0

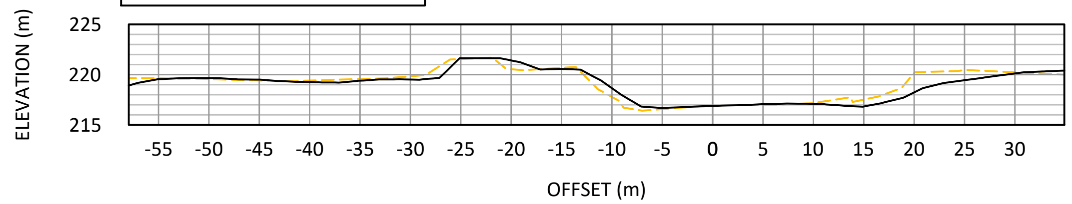
SECTION 18: STA. 10+616



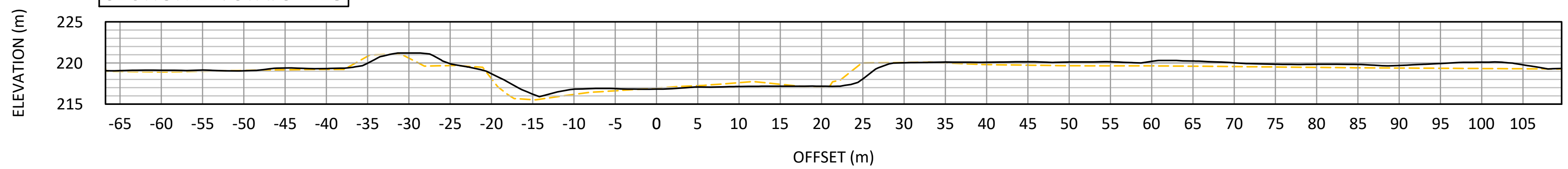
SECTION 19: STA. 10+142



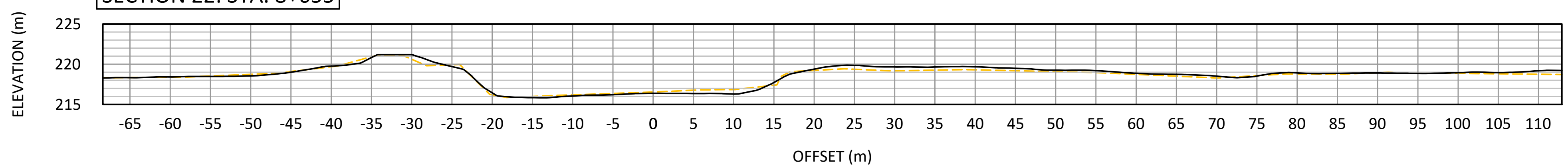
SECTION 20: STA. 9+661



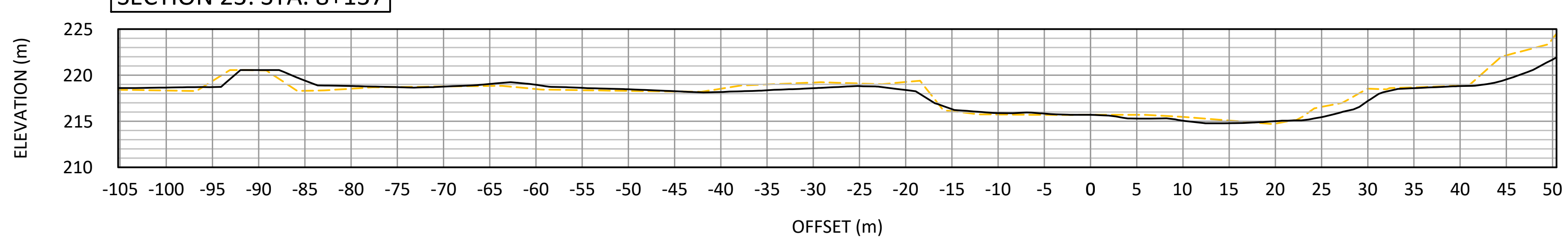
SECTION 21: STA. 9+118



SECTION 22: STA. 8+655



SECTION 23: STA. 8+137



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2006 (dashed)

2017 (solid)

PEMBERTON VALLEY DYKING DISTRICT

1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

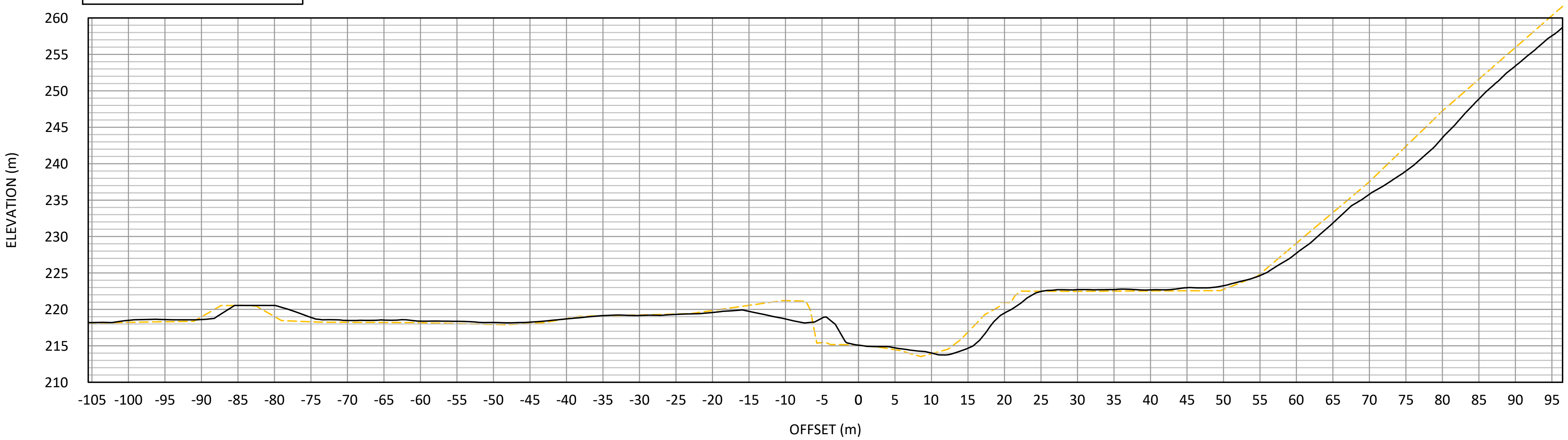
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

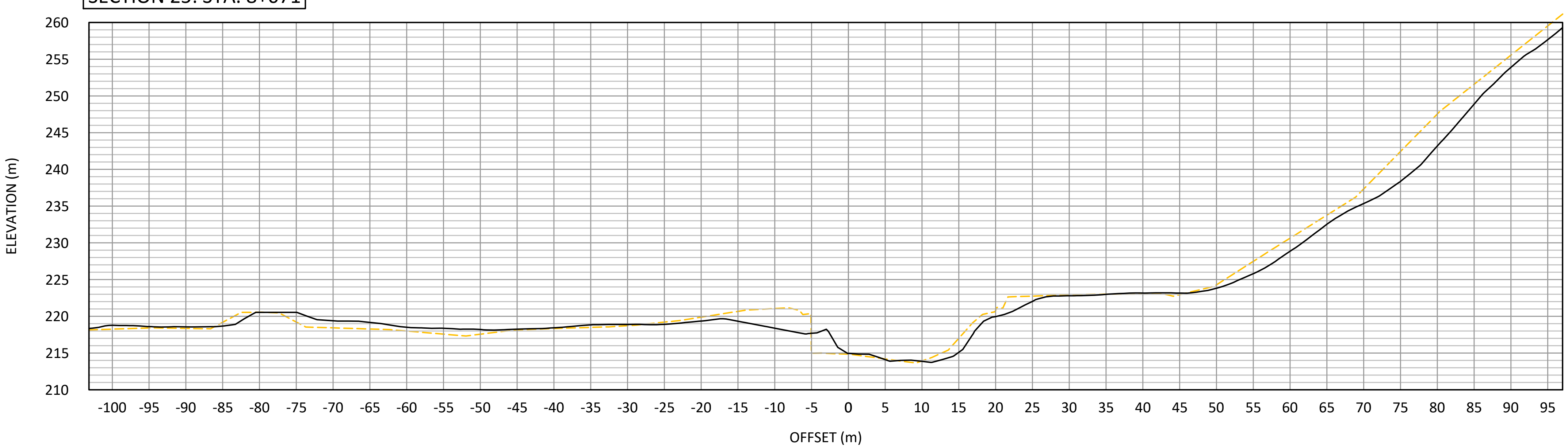
RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-020
SHEET NUMBER	4 of 8
REVISION	0

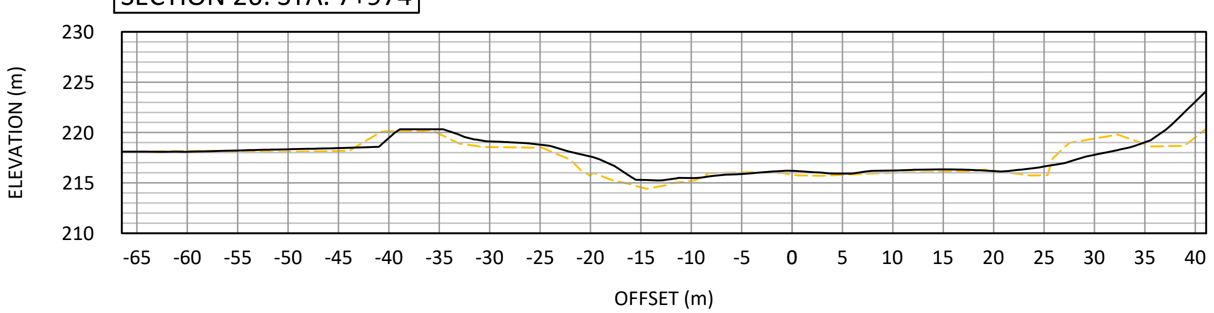
SECTION 24: STA. 8+075



SECTION 25: STA. 8+071



SECTION 26: STA. 7+974



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2006

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

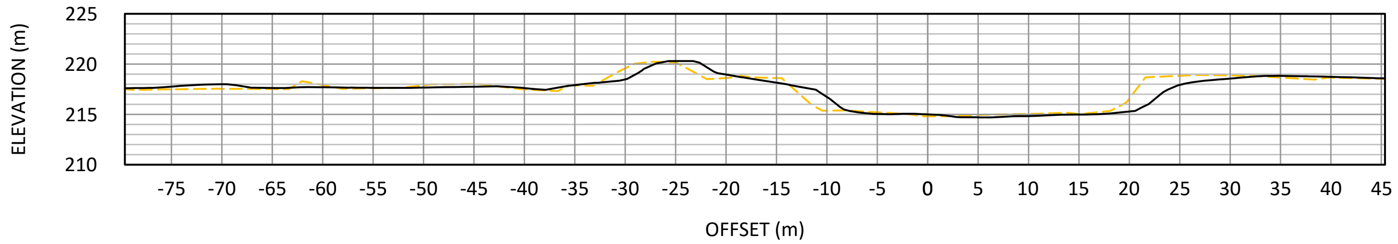
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

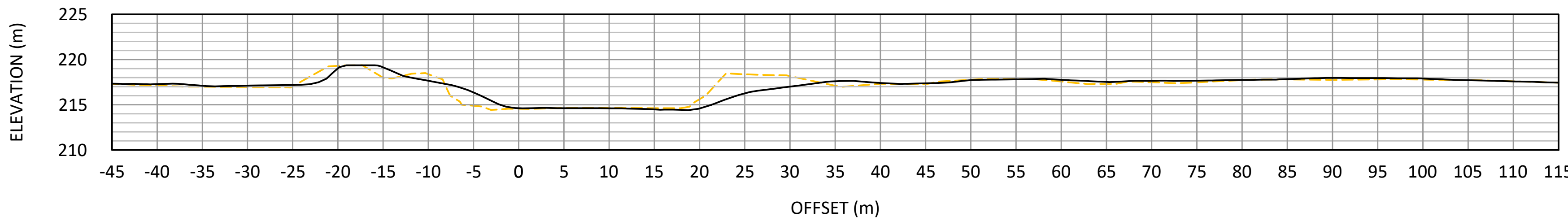
PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-021
SHEET NUMBER	5 of 8
REVISION	0

SECTION 27: STA. 7+686

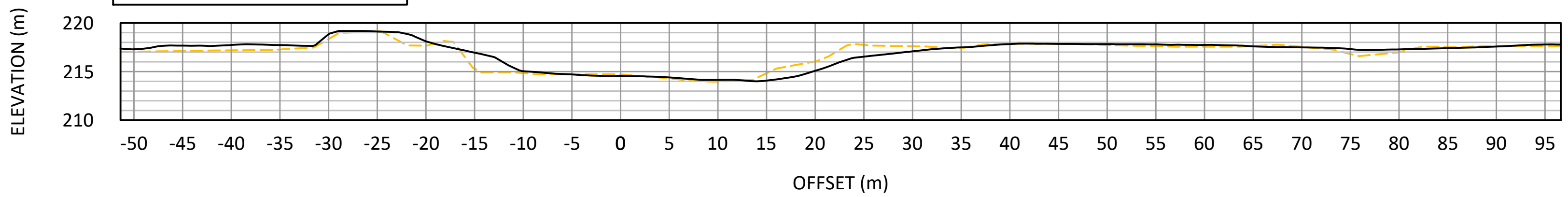


NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

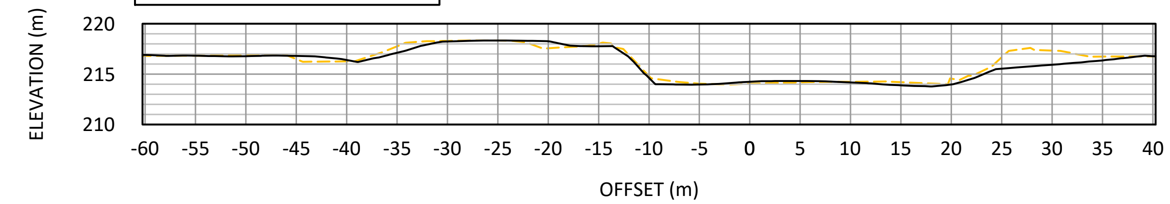
SECTION 28: STA. 7+192



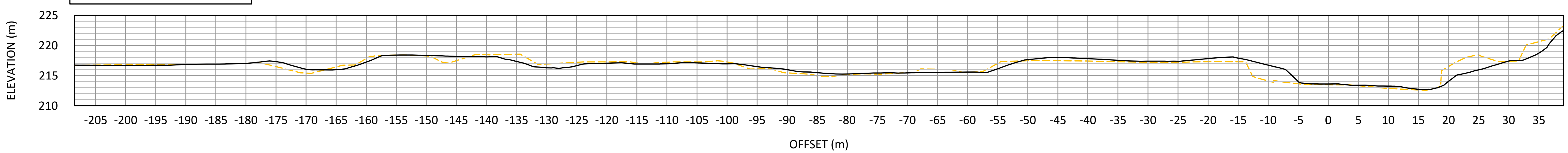
SECTION 29: STA. 6+866



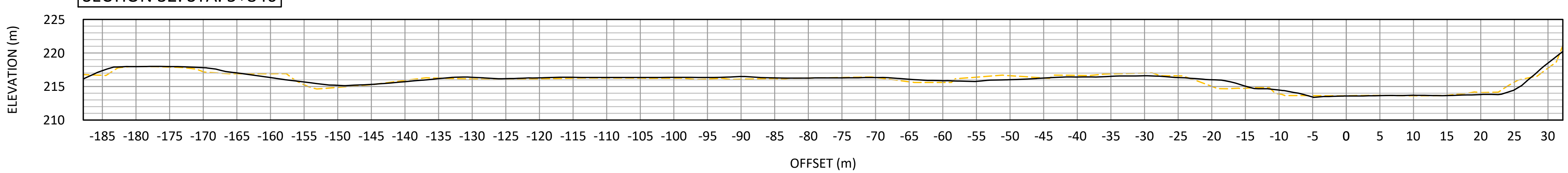
SECTION 30: STA. 6+360



SECTION 31: STA. 6+078



SECTION 32: STA. 5+846



LEGEND:

- - - - 2006

——— 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

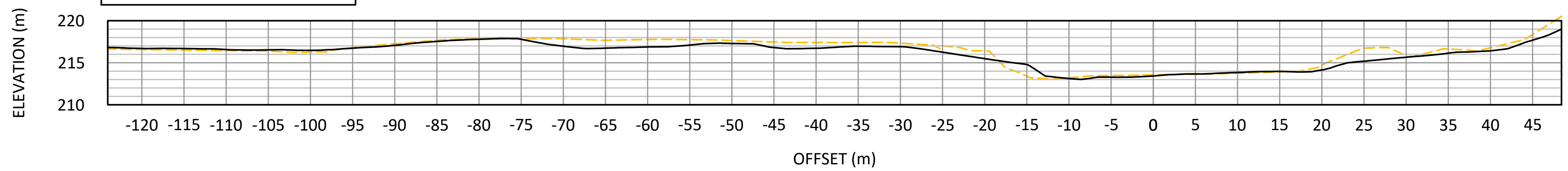
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

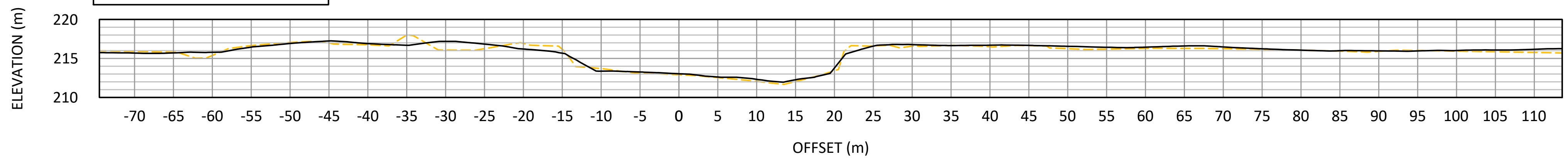
RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-022
SHEET NUMBER	6 of 8
REVISION	0

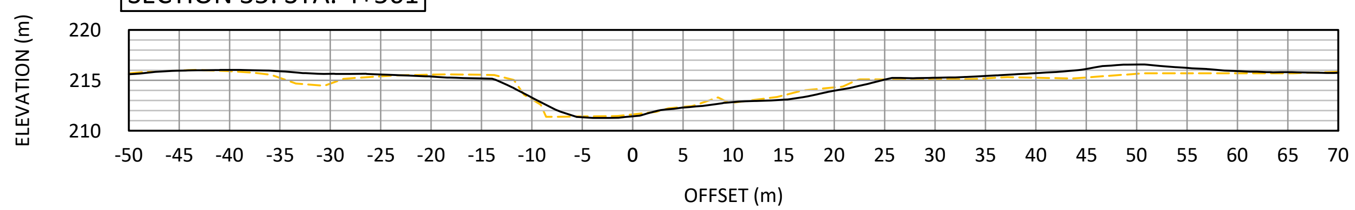
SECTION 33: STA. 5+681



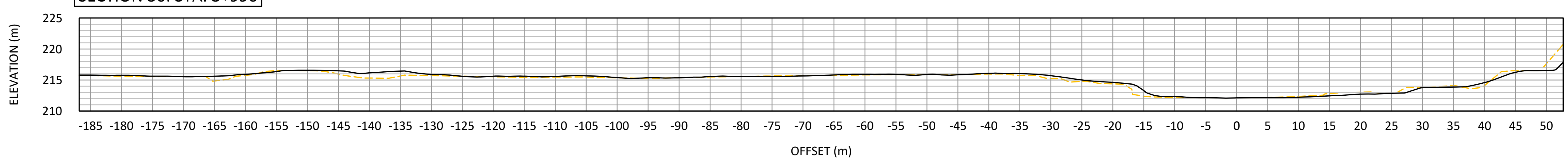
SECTION 34: STA. 5+070



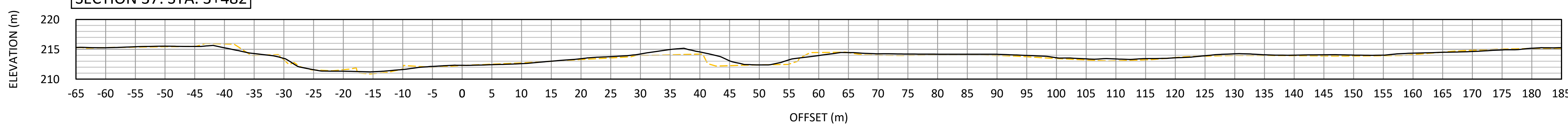
SECTION 35: STA. 4+561



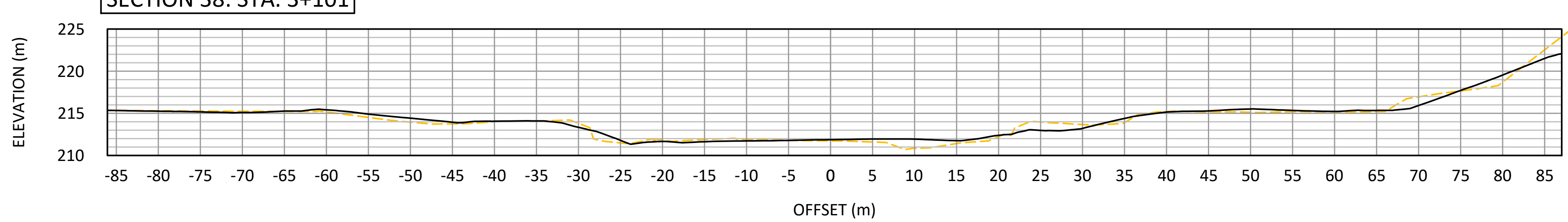
SECTION 36: STA. 3+996



SECTION 37: STA. 3+482



SECTION 38: STA. 3+101



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2006

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

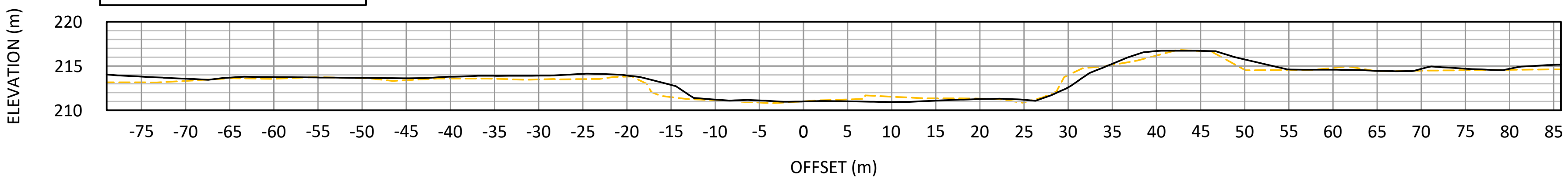
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

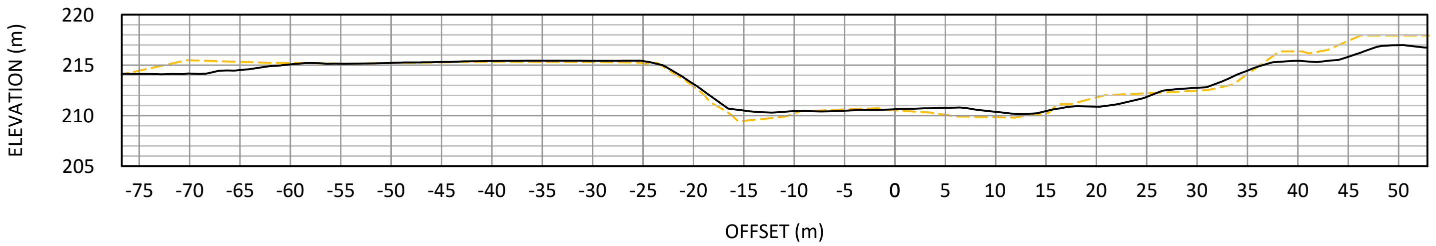
RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-023
SHEET NUMBER	7 of 8
REVISION	0

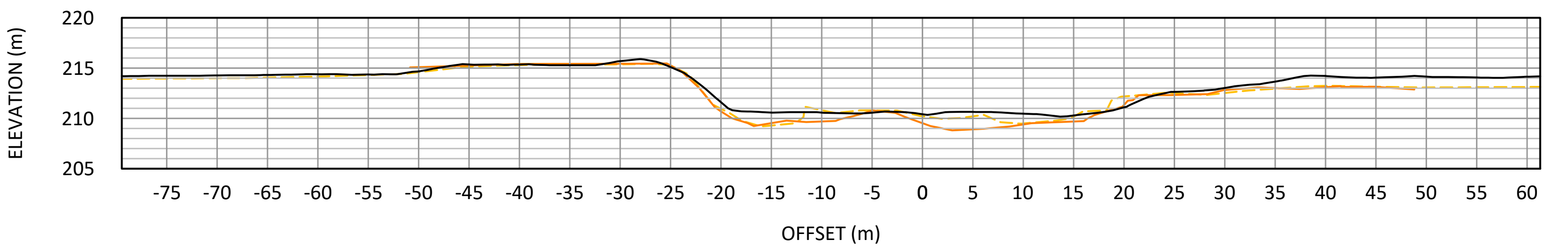
SECTION 39: STA. 2+683



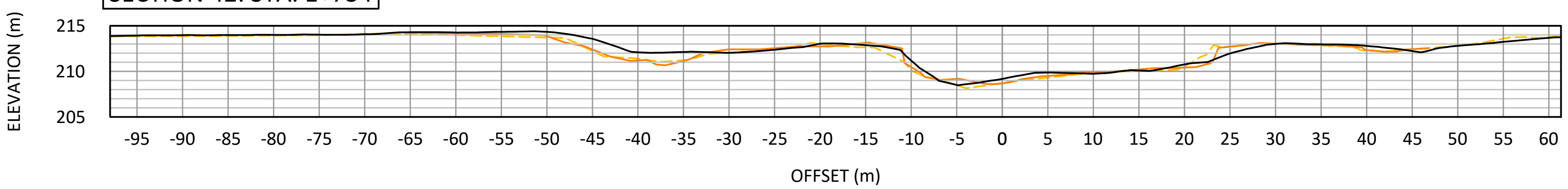
SECTION 40: STA. 2+186



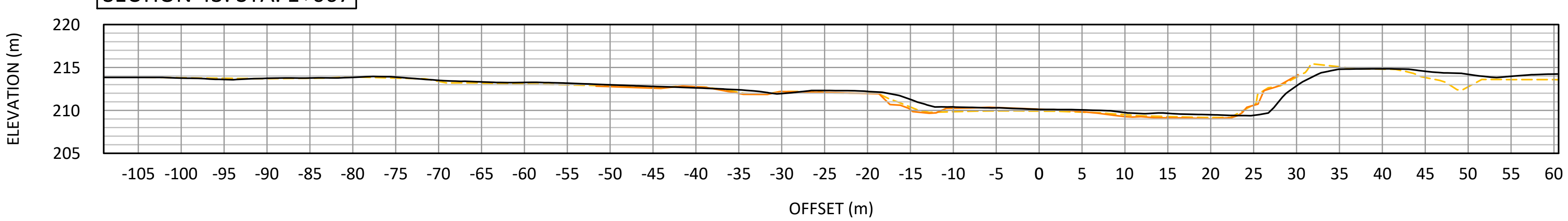
SECTION 41: STA. 2+176



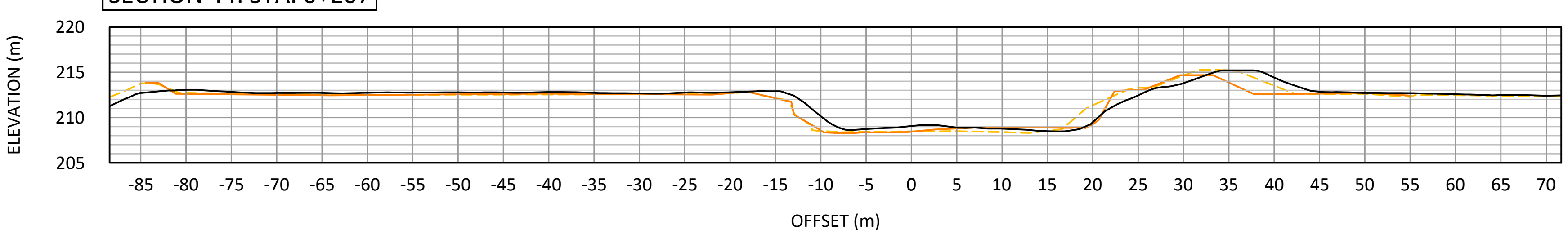
SECTION 42: STA. 1+734



SECTION 43: STA. 1+067



SECTION 44: STA. 0+207



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2006

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

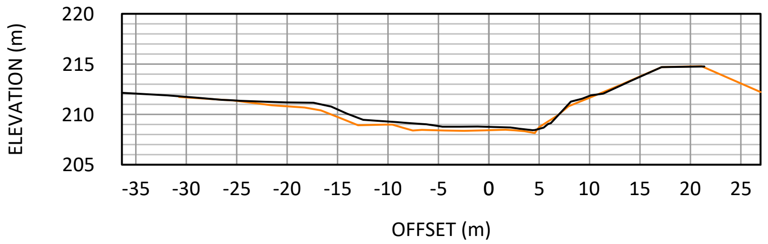
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

RYAN RIVER
HISTORICAL CROSS SECTION COMPARISON

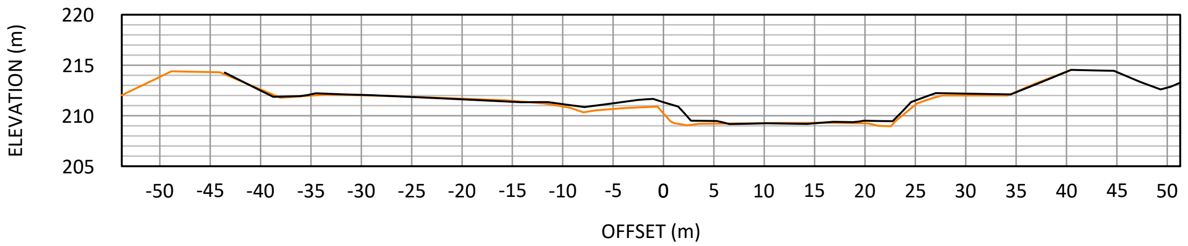
PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-024
SHEET NUMBER	8 of 8
REVISION	0

SECTION 1: STA. 2+084

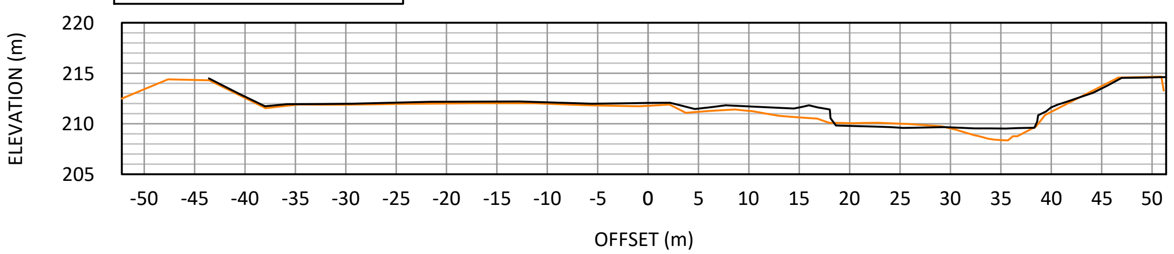


NOTES:
1. 2000/2001, 2003 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
2. 2017 TOPOGRAPHY SURVEYED 11 APRIL 2017 BY HIGHMARK SURVEY AND ENGINEERING.

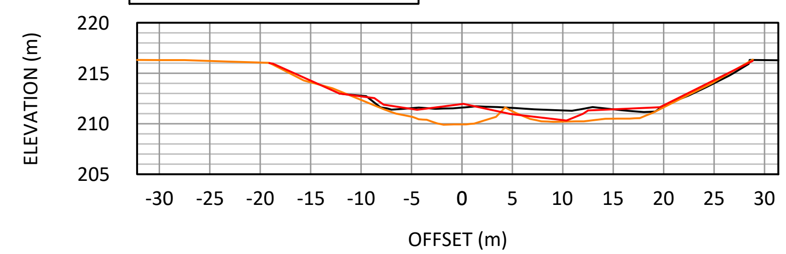
SECTION 2: STA. 1+845



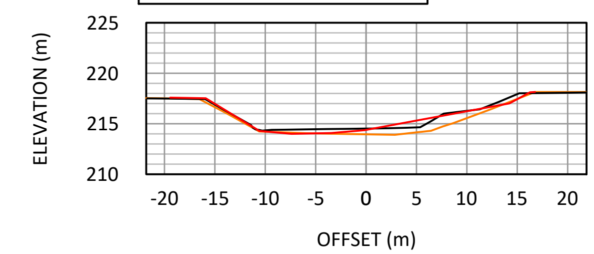
SECTION 3: STA. 1+409



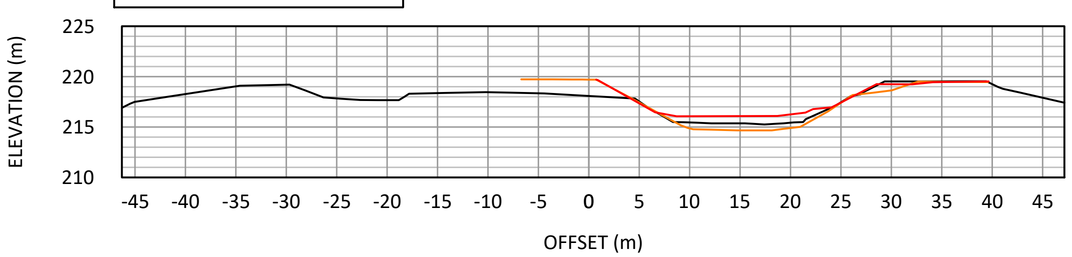
SECTION 4: STA. 1+171



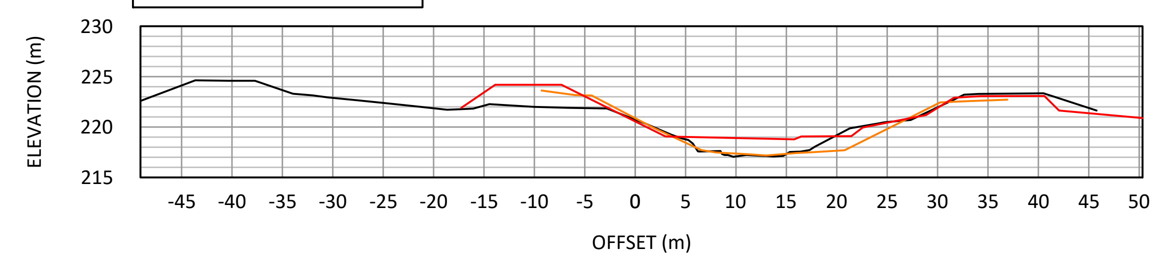
SECTION 5: STA. 0+755



SECTION 6: STA. 0+535



SECTION 7: STA. 0+204



LEGEND:

2000

2003

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc
northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

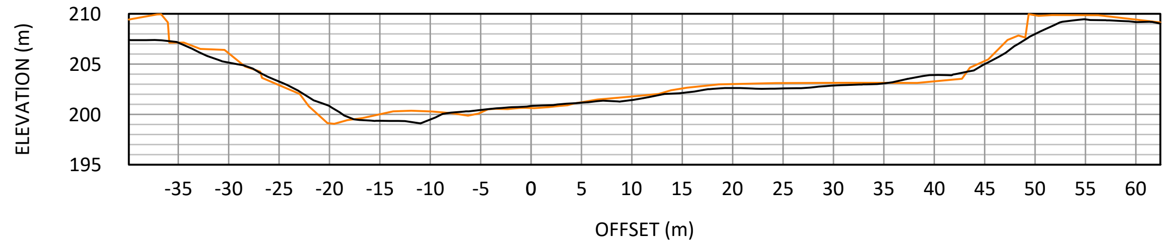
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

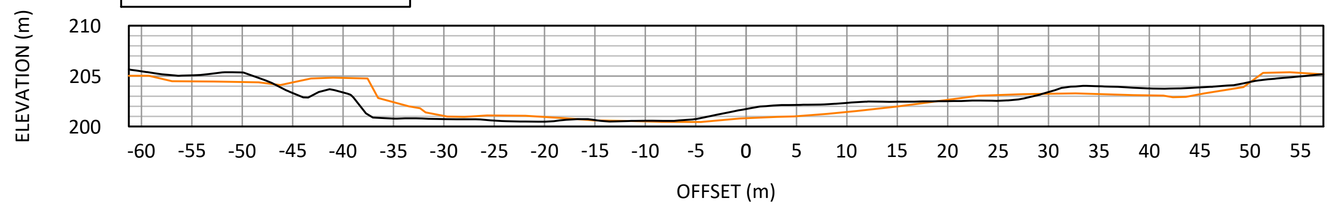
MILLER CREEK
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-025
SHEET NUMBER	1 of 1
REVISION	0

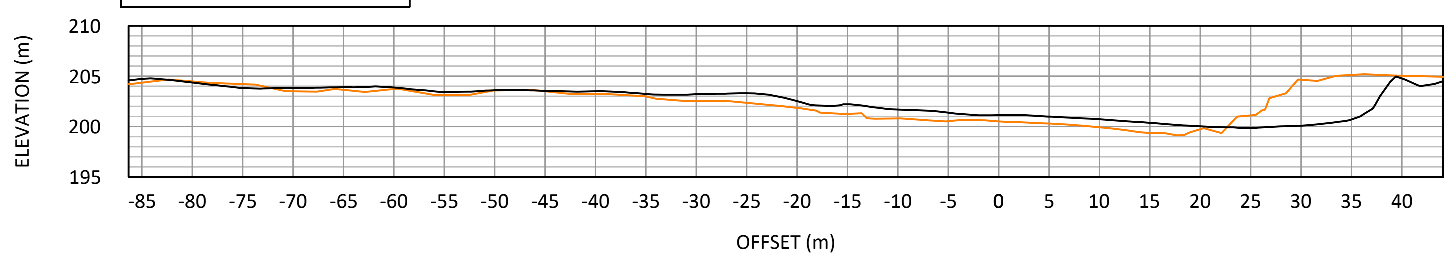
SECTION 1: STA. 3+126



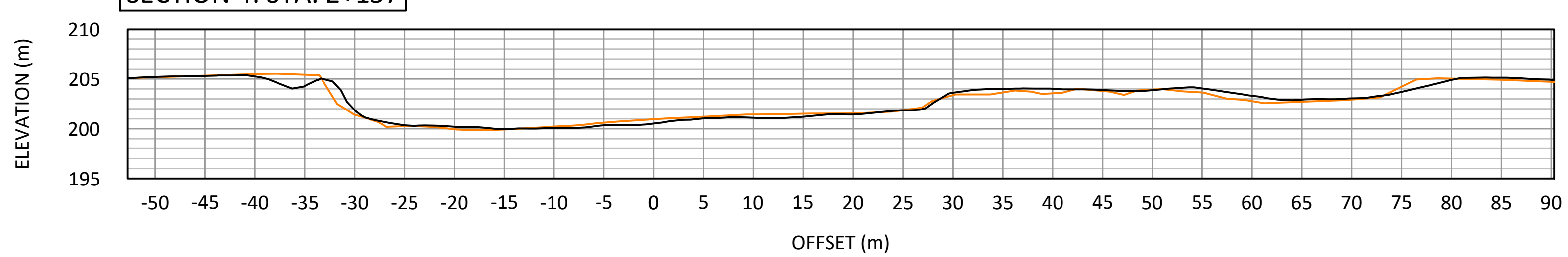
SECTION 2: STA. 3+079



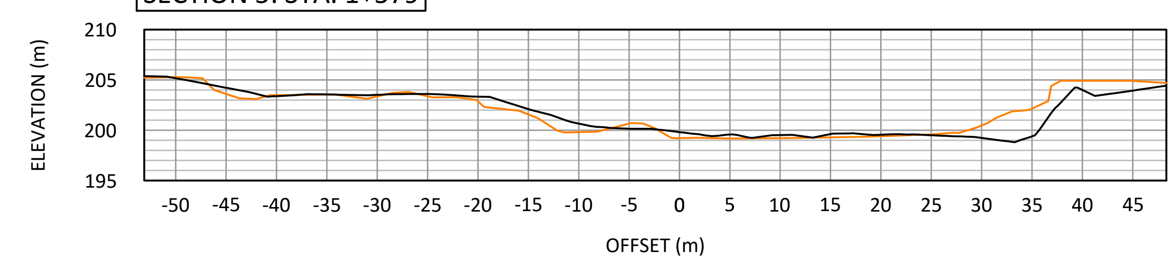
SECTION 3: STA. 2+732



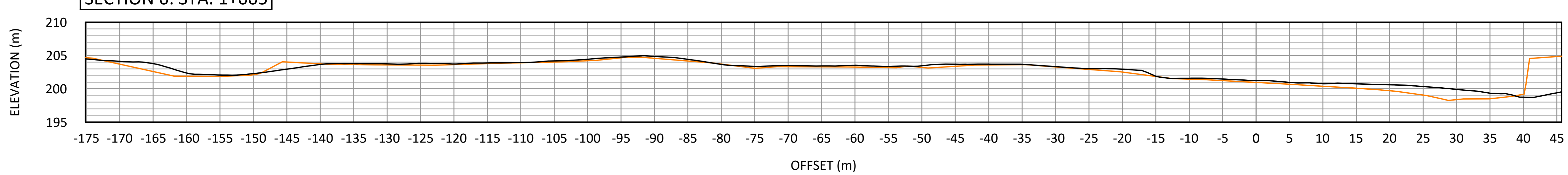
SECTION 4: STA. 2+157



SECTION 5: STA. 1+579



SECTION 6: STA. 1+005



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

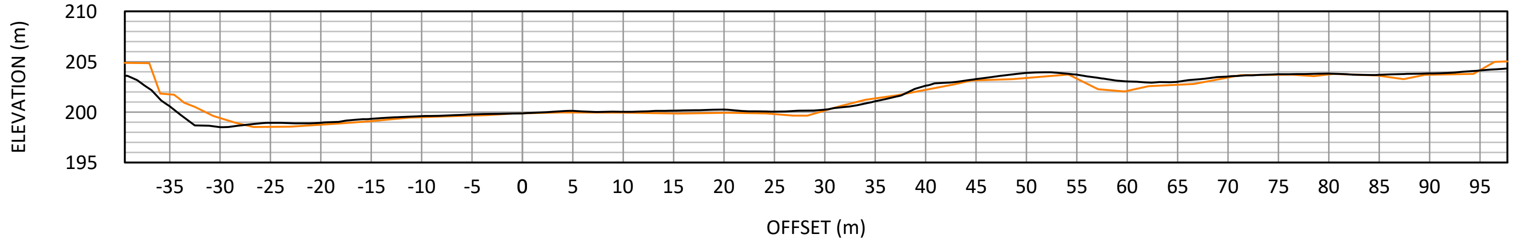
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

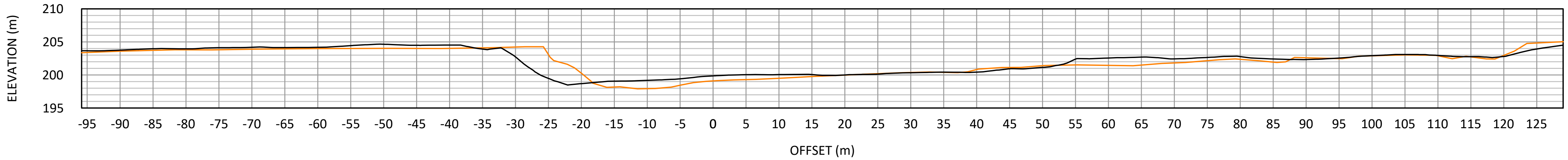
GREEN RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-026
SHEET NUMBER	1 of 2
REVISION	0

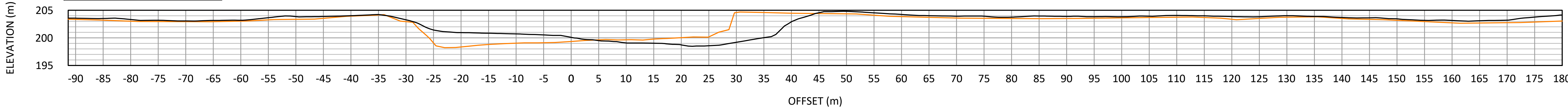
SECTION 7: STA. 0+822



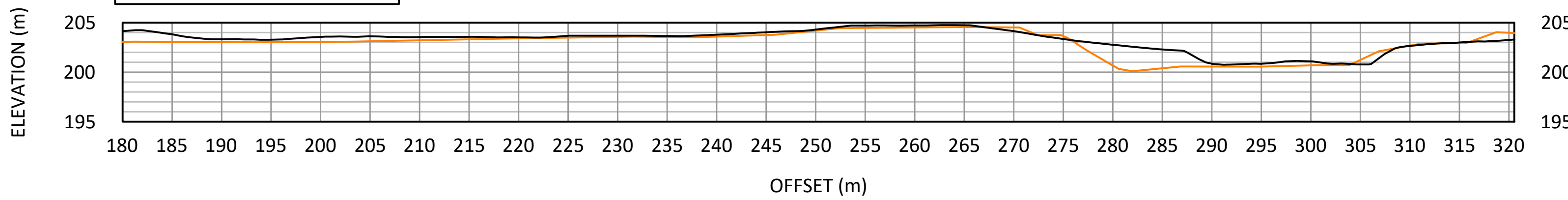
SECTION 8: STA. 0+480



SECTION 9: STA. 0+201



SECTION 9: STA. 0+201 - continued



NOTES:

1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

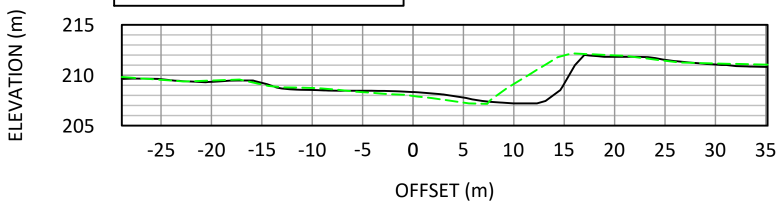
LILLOOET RIVER
FLOOD MAPPING STUDY

GREEN RIVER
HISTORICAL CROSS SECTION COMPARISON

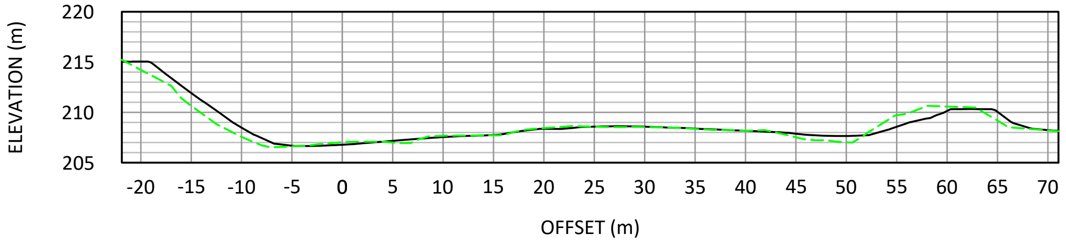
PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-027
SHEET NUMBER	2 of 2
REVISION	0

NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

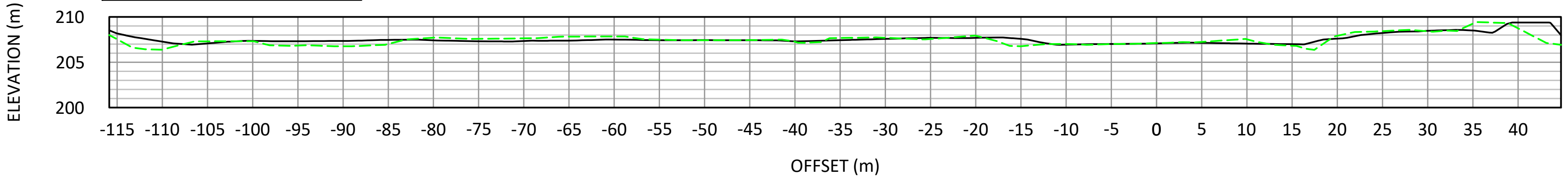
SECTION 1: STA. 9+930



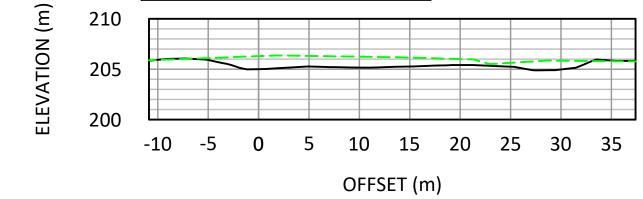
SECTION 2: STA. 9+754



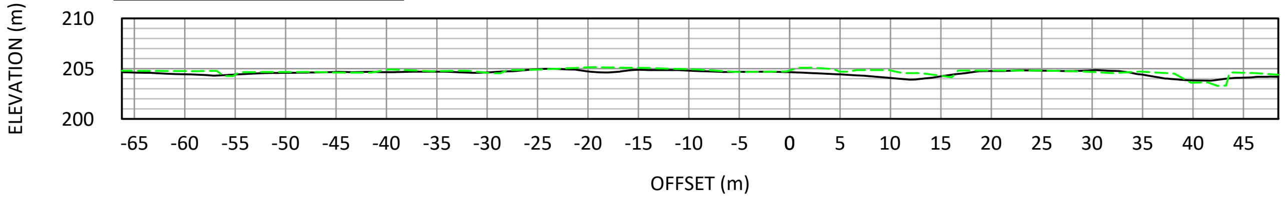
SECTION 3: STA. 9+579



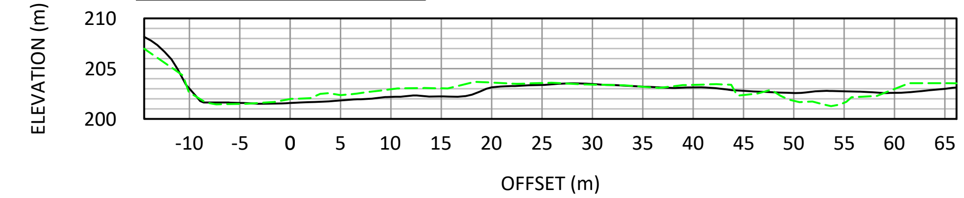
SECTION 4: STA. 9+186



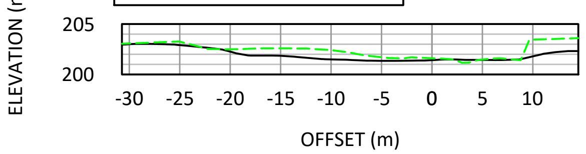
SECTION 5: STA. 8+996



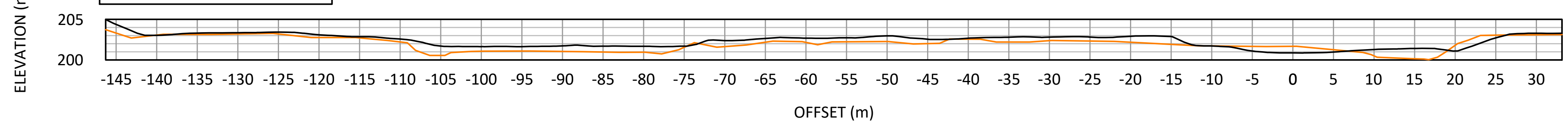
SECTION 6: STA. 8+602



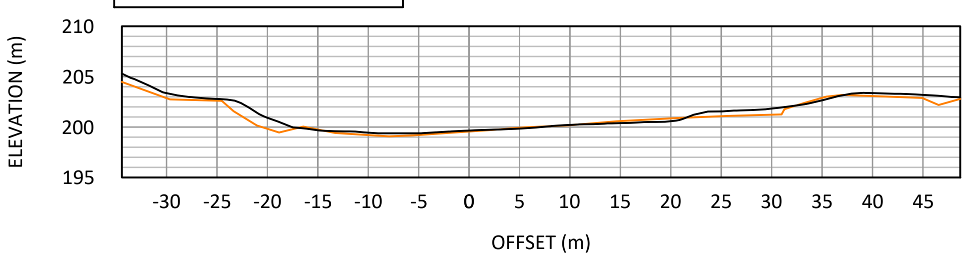
SECTION 7: STA. 8+433



SECTION 8: STA. 8+303



SECTION 9: STA. 7+705



LEGEND:

- 2000
- 2014
- 2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

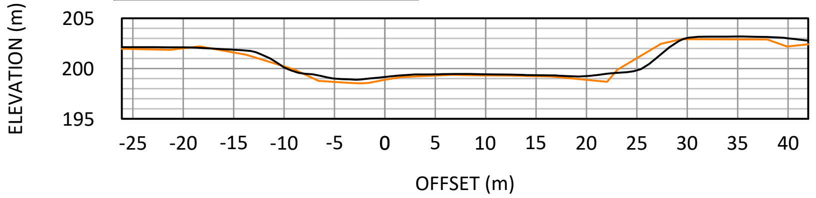
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

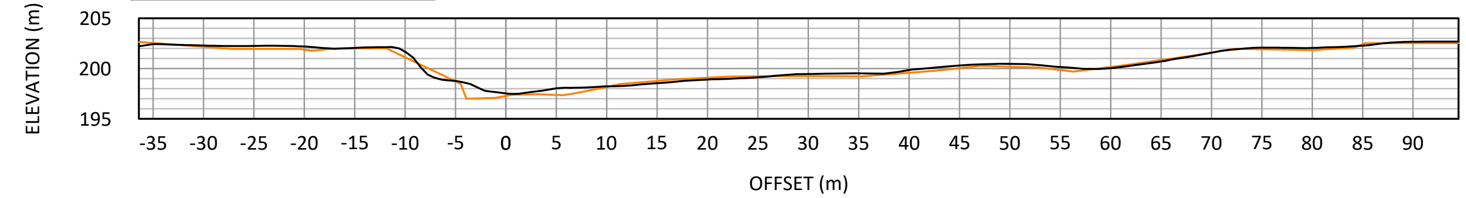
BIRKENHEAD RIVER
HISTORICAL CROSS SECTION COMPARISON

PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-028
SHEET NUMBER	1 of 3
REVISION	0

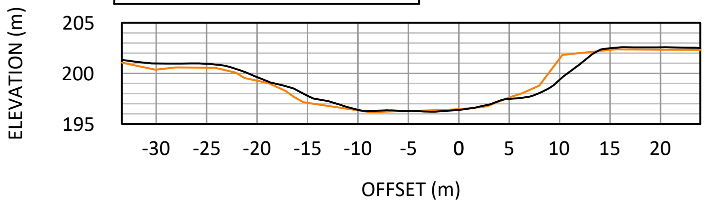
SECTION 10: STA. 7+348



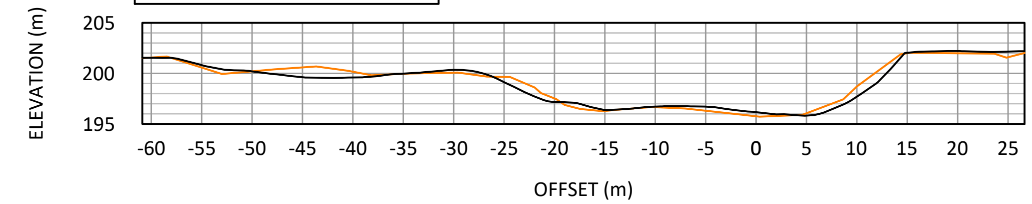
SECTION 11: STA. 6+555



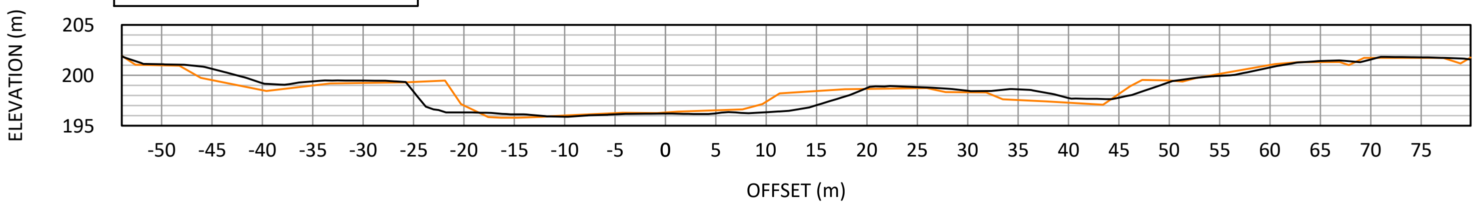
SECTION 12: STA. 5+794



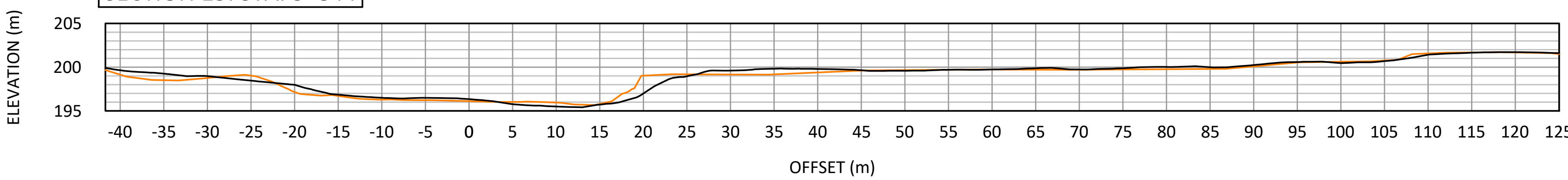
SECTION 13: STA. 4+763



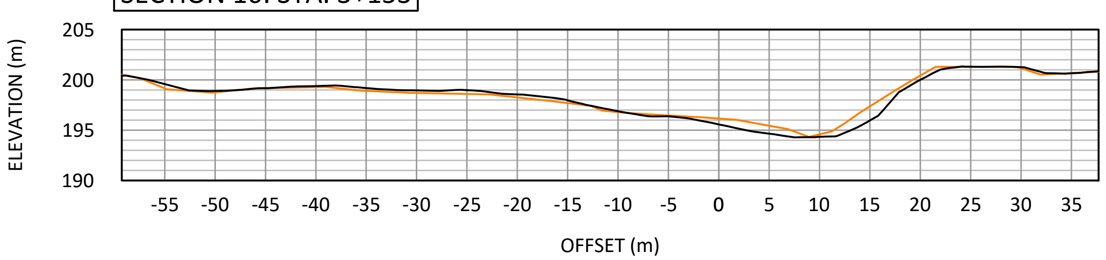
SECTION 14: STA. 4+005



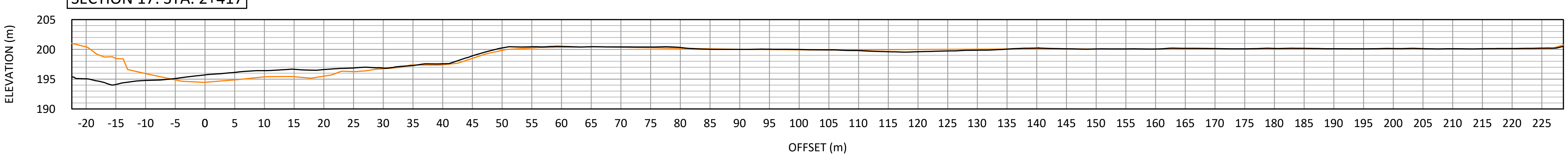
SECTION 15: STA. 3+844



SECTION 16: STA. 3+153



SECTION 17: STA. 2+417



NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

LEGEND:

2000

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

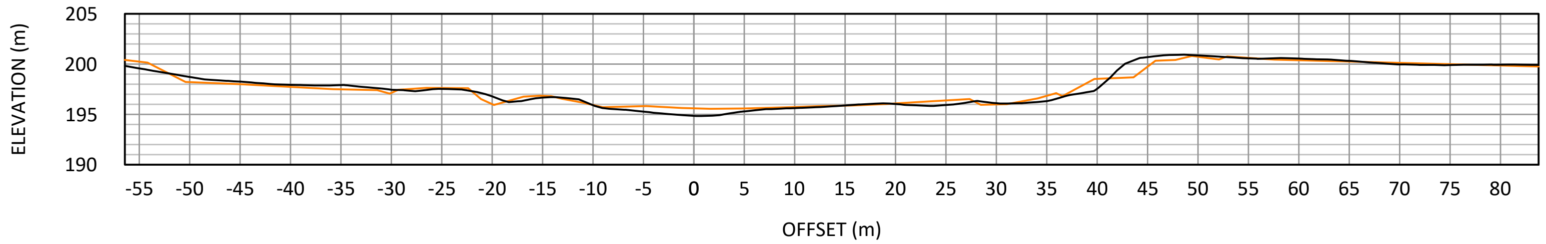
DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

LILLOOET RIVER
FLOOD MAPPING STUDY

BIRKENHEAD RIVER
HISTORICAL CROSS SECTION COMPARISON

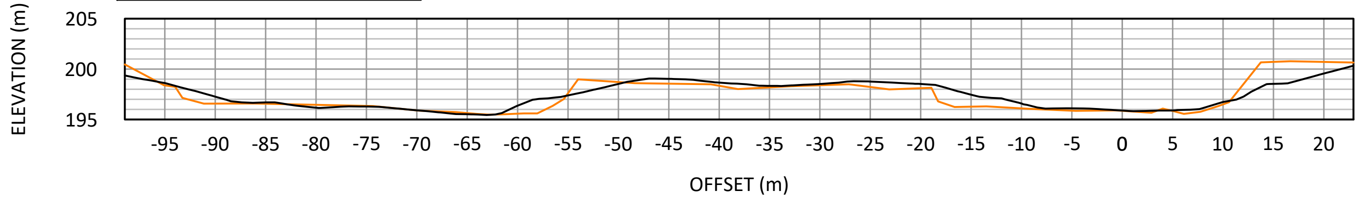
PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-029
SHEET NUMBER	2 of 3
REVISION	0

SECTION 18: STA. 1+805

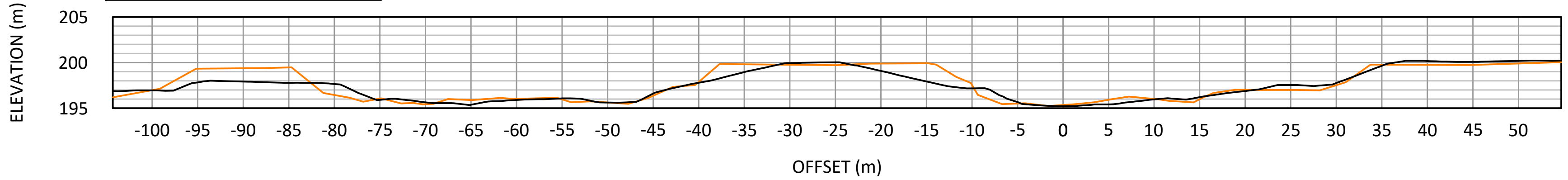


NOTES:
1. ALL DATA IS RELATIVE TO CGVD2013.
2. 2000, 2006, 2011 TOPOGRAPHY SURVEYED BY KERR WOOD LEIDAL.
3. BATHYMETRY SURVEYED BY NHC 2017. UPLAND AREAS BASED ON LIDAR DATA PROVIDED BY X, Y, AND Z.
4. DIGITAL ELEVATION MODEL (DEM) DERIVED FROM LIDAR DATA:
   - LIDAR DATA SUPPLIED BY PEMBERTON VALLEY DYKING DISTRICT (PVDD), AND NATIONAL DISASTER MITIGATION PROGRAM – LOWER MAINLAND (NDMP) AND GEO BC (MFLNRO).
   - 2009 LIDAR BY MCELHANNEY (PROVIDED BY PVDD).
   - MID-JUNE 2016 TO MID-SEPTEMBER 2016 LIDAR (PROVIDED BY NDMP AND MFLNRO). AVERAGE POINT DENSITY IS TWELVE POINTS PER SQUARE METRE. HORIZONTAL ACCURACY IS 65 cm OR LESS. VERTICAL ACCURACY IS 15 cm OR LESS.

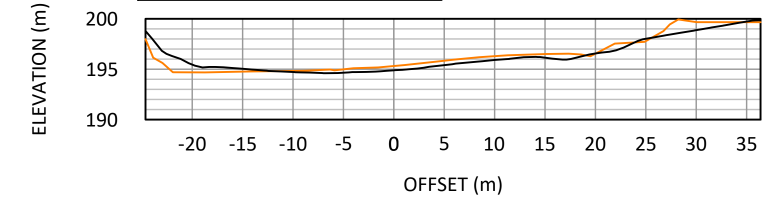
SECTION 19: STA. 1+555



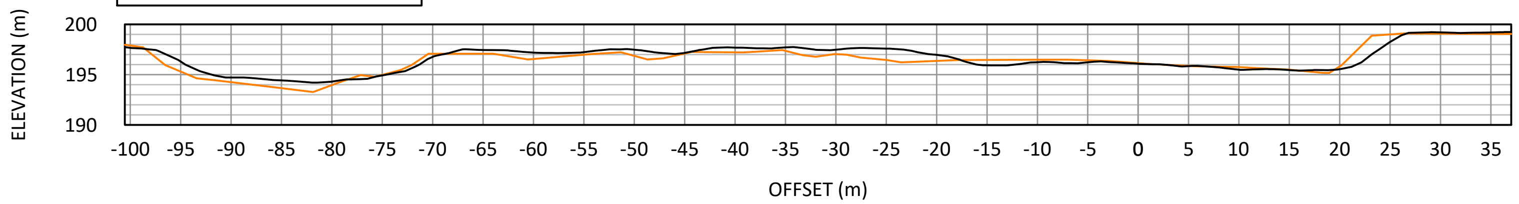
SECTION 20: STA. 1+030



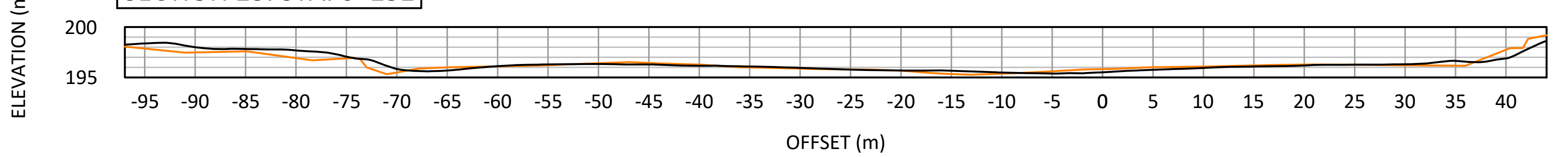
SECTION 21: STA. 0+883



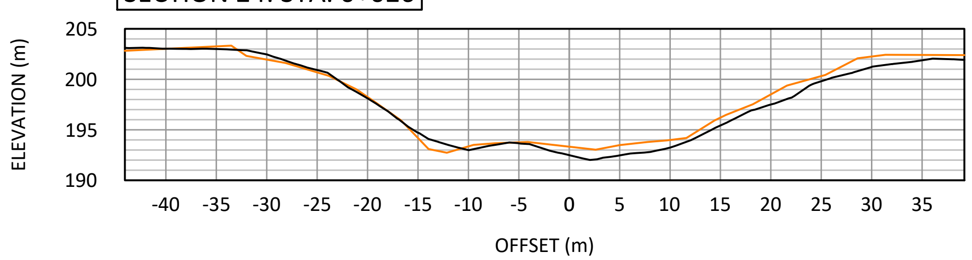
SECTION 22: STA. 0+336



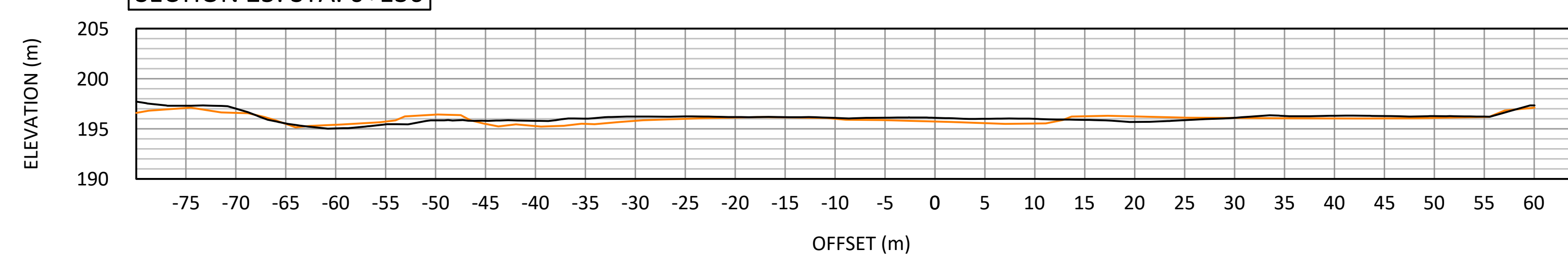
SECTION 23: STA. 0+252



SECTION 24: STA. 0+026



SECTION 25: STA. 0+136



LEGEND:

2000

2017

PEMBERTON VALLEY DYKING DISTRICT
1381 ASTER STREET
PEMBERTON BC V0N 2L0

nhc northwest hydraulic consultants
405 - 495 Dunsmuir St.
Nanaimo, BC
Canada V9R 6B9
Office: 250.754.6425
Fax: 250.754.9264
www.nhcweb.com

REVISIONS		
0	6 Jun 2018	ISSUED FOR REVIEW

DRAWING INFORMATION	
DATE	6 Jun 2018
DESIGNED BY	
DRAWN BY	CSM
CHECKED BY	
SHEET SIZE	B (11" x 17")

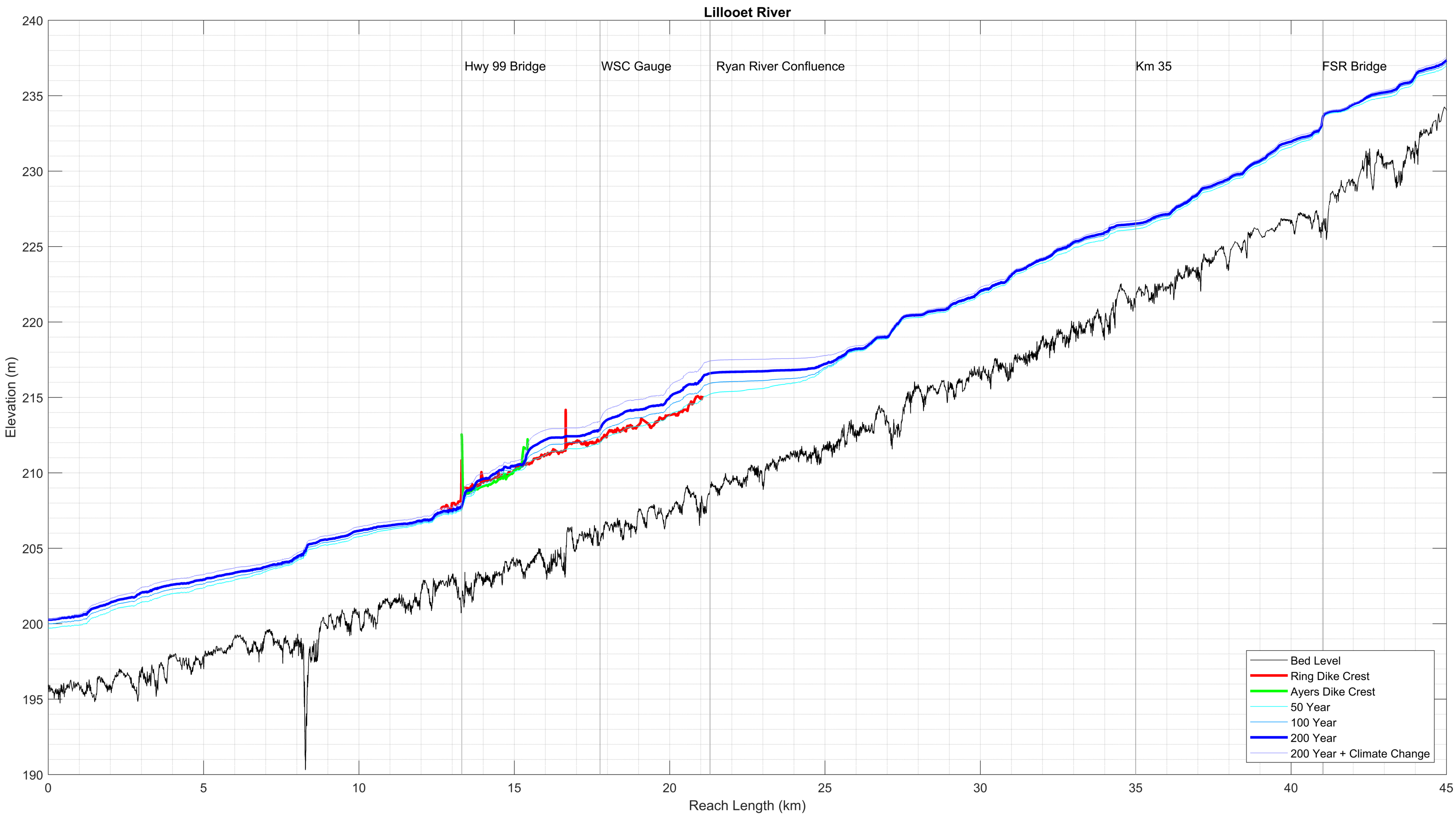
LILLOOET RIVER
FLOOD MAPPING STUDY

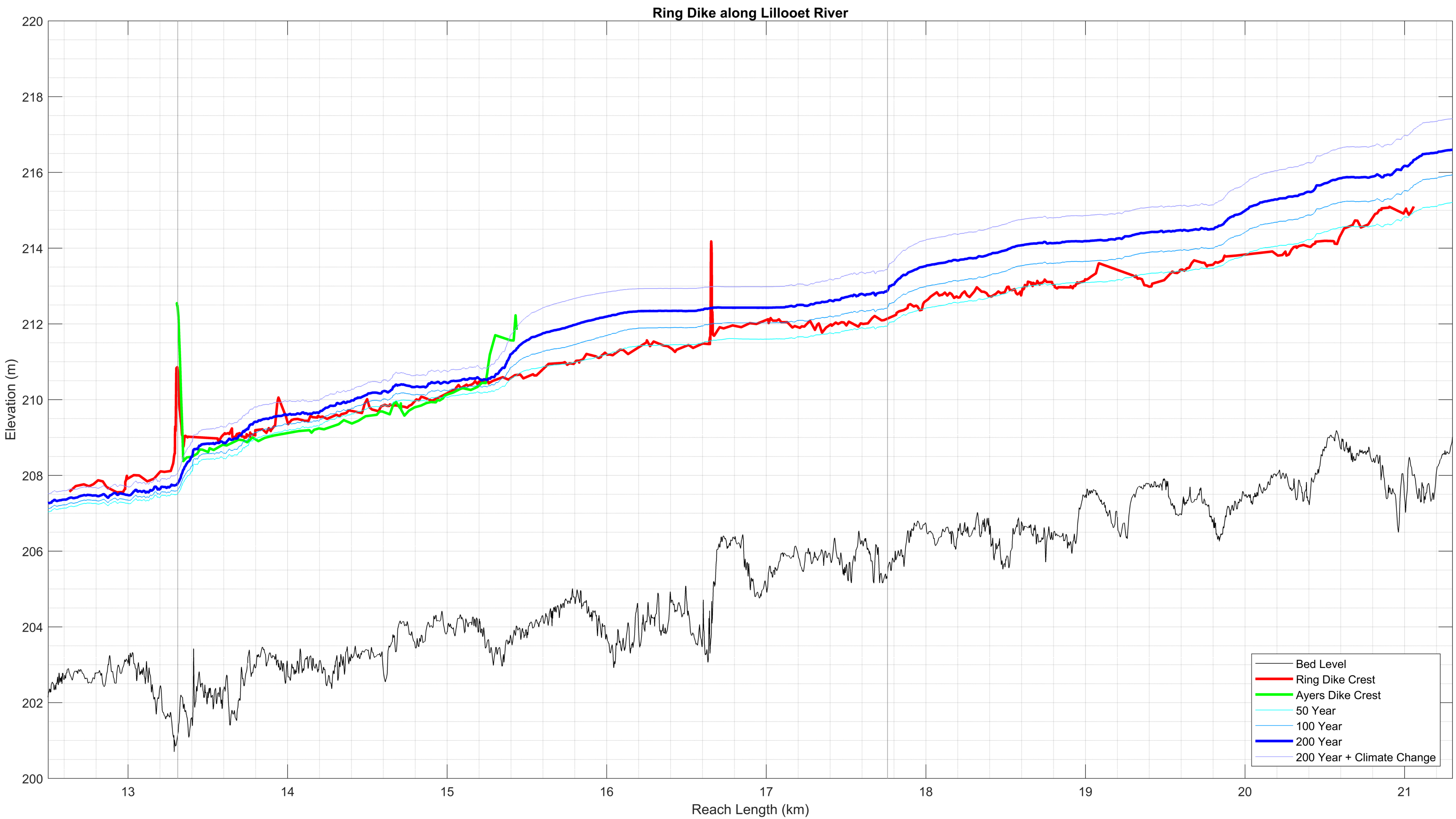
BIRKENHEAD RIVER
HISTORICAL CROSS SECTION COMPARISON

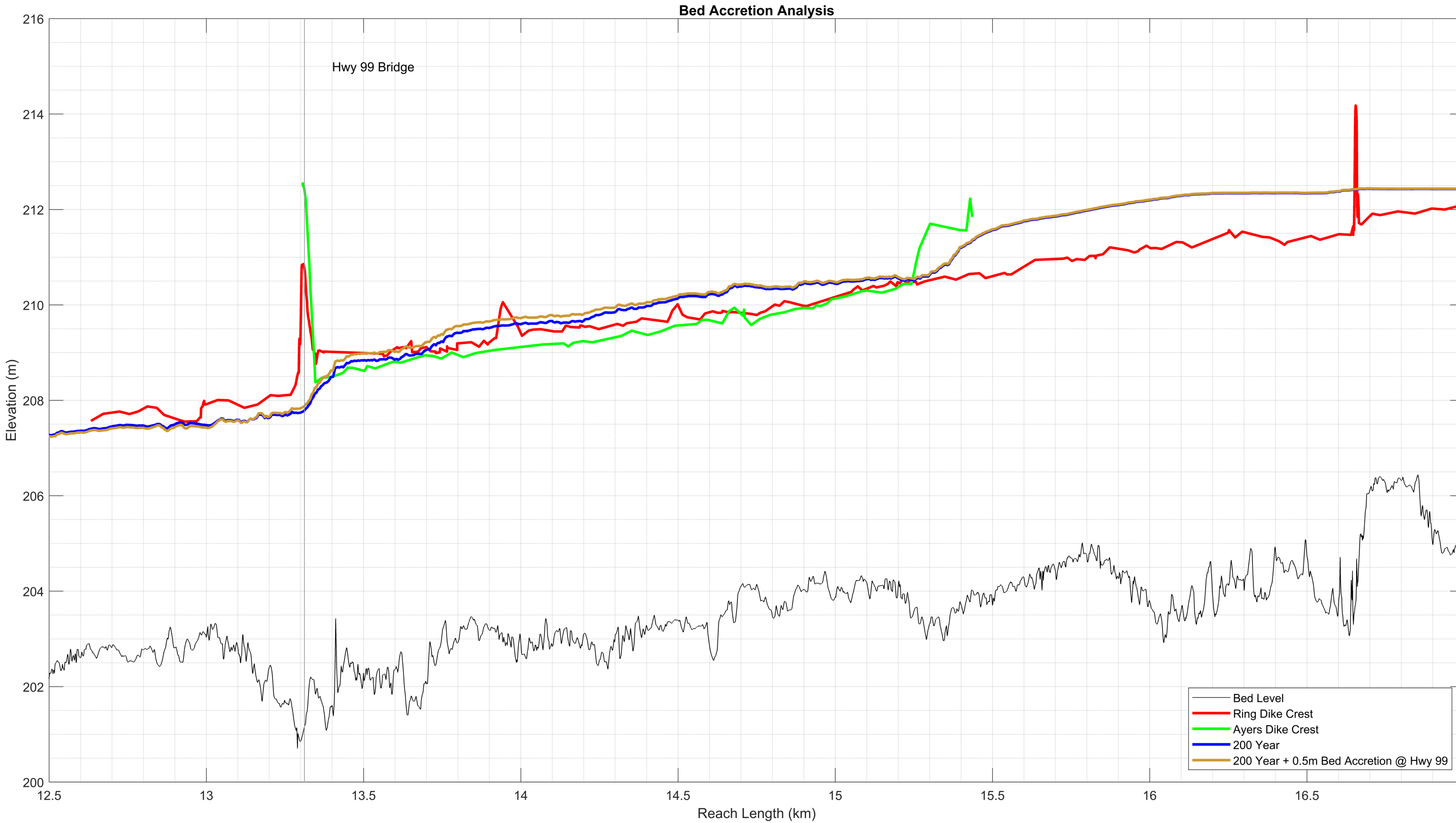
PROJECT NUMBER	3002903
DRAWING NUMBER	3002903-030
SHEET NUMBER	3 of 3
REVISION	0

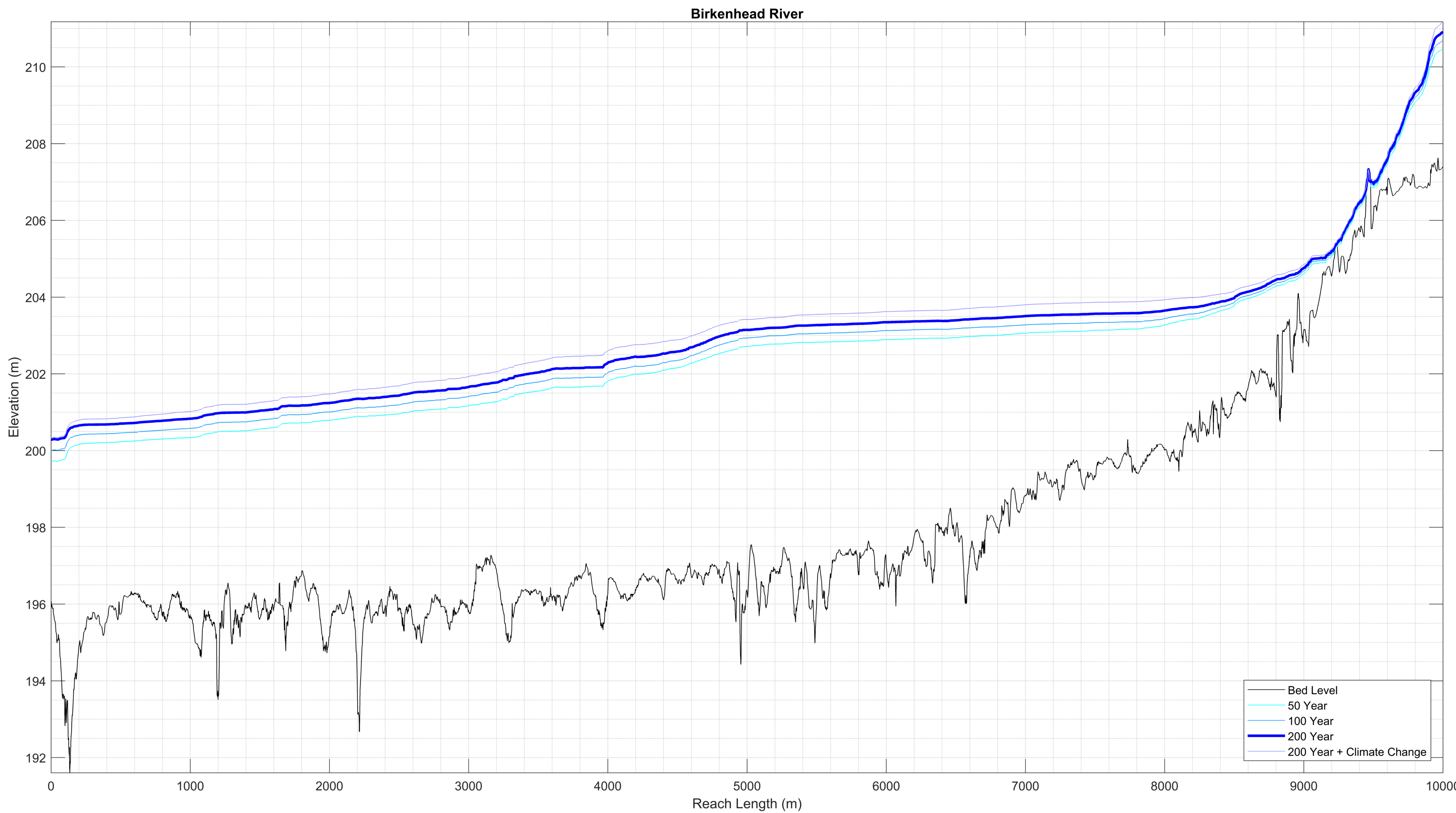
Appendix D: Hydraulic Data

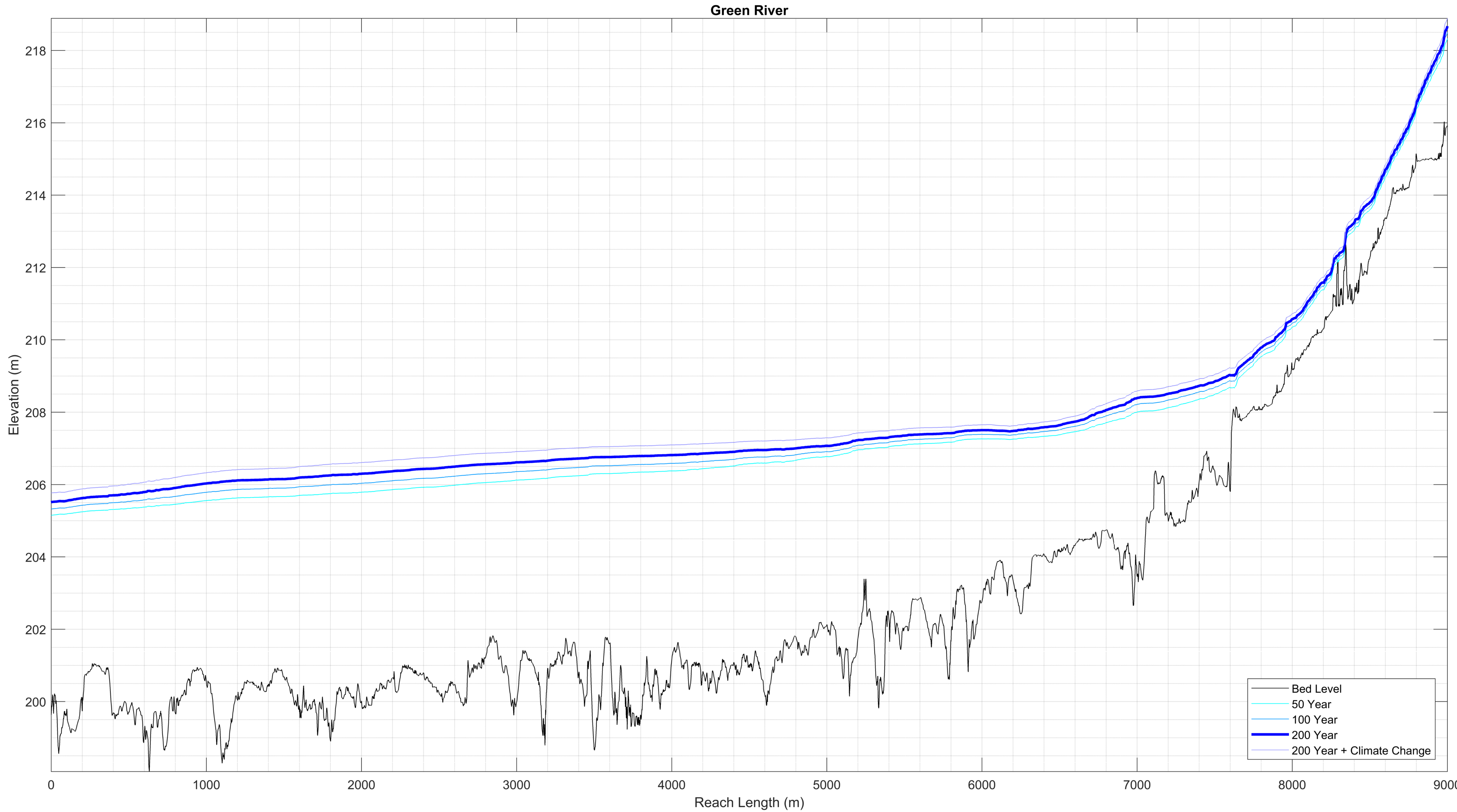
D.1 Design Profiles for Lillooet River and Tributaries
D.2 Mesh Sensitivity Plots


Lillooet River
Hwy 99 Bridge
WSC Gauge
Ryan River Confluence
Km 35
FSR Bridge
Elevation (m)
Reach Length (km)
240
235
230
225
220
215
210
205
200
195
190
0
5
10
15
20
25
30
35
40
45
Bed Level
Ring Dike Crest
Ayers Dike Crest
50 Year
100 Year
200 Year
200 Year + Climate Change

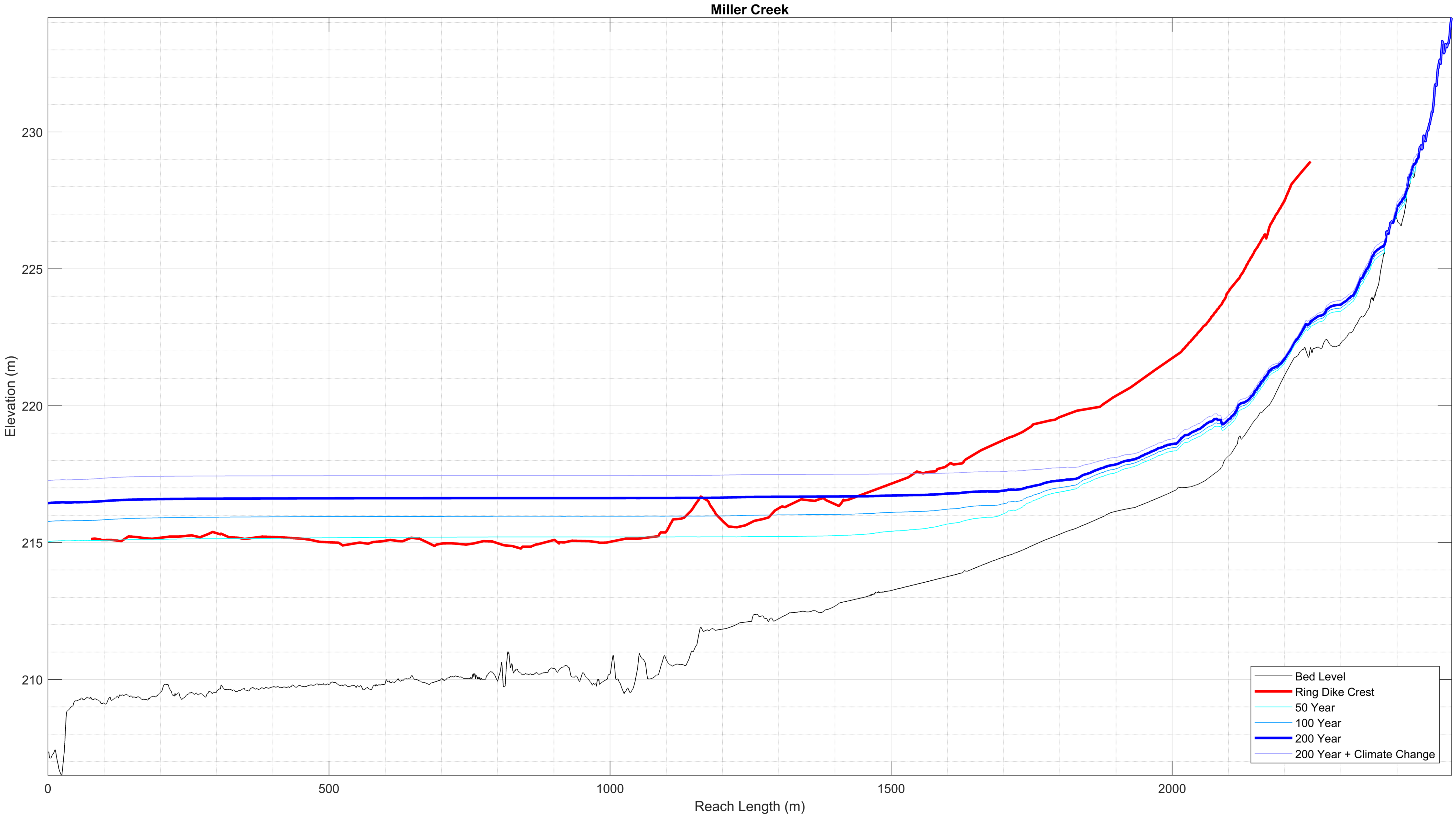

Ring Dike along Lillooet River
Elevation (m)
Reach Length (km)
220
218
216
214
212
210
208
206
204
202
200
13
14
15
16
17
18
19
20
21
Bed Level
Ring Dike Crest
Ayers Dike Crest
50 Year
100 Year
200 Year
200 Year + Climate Change

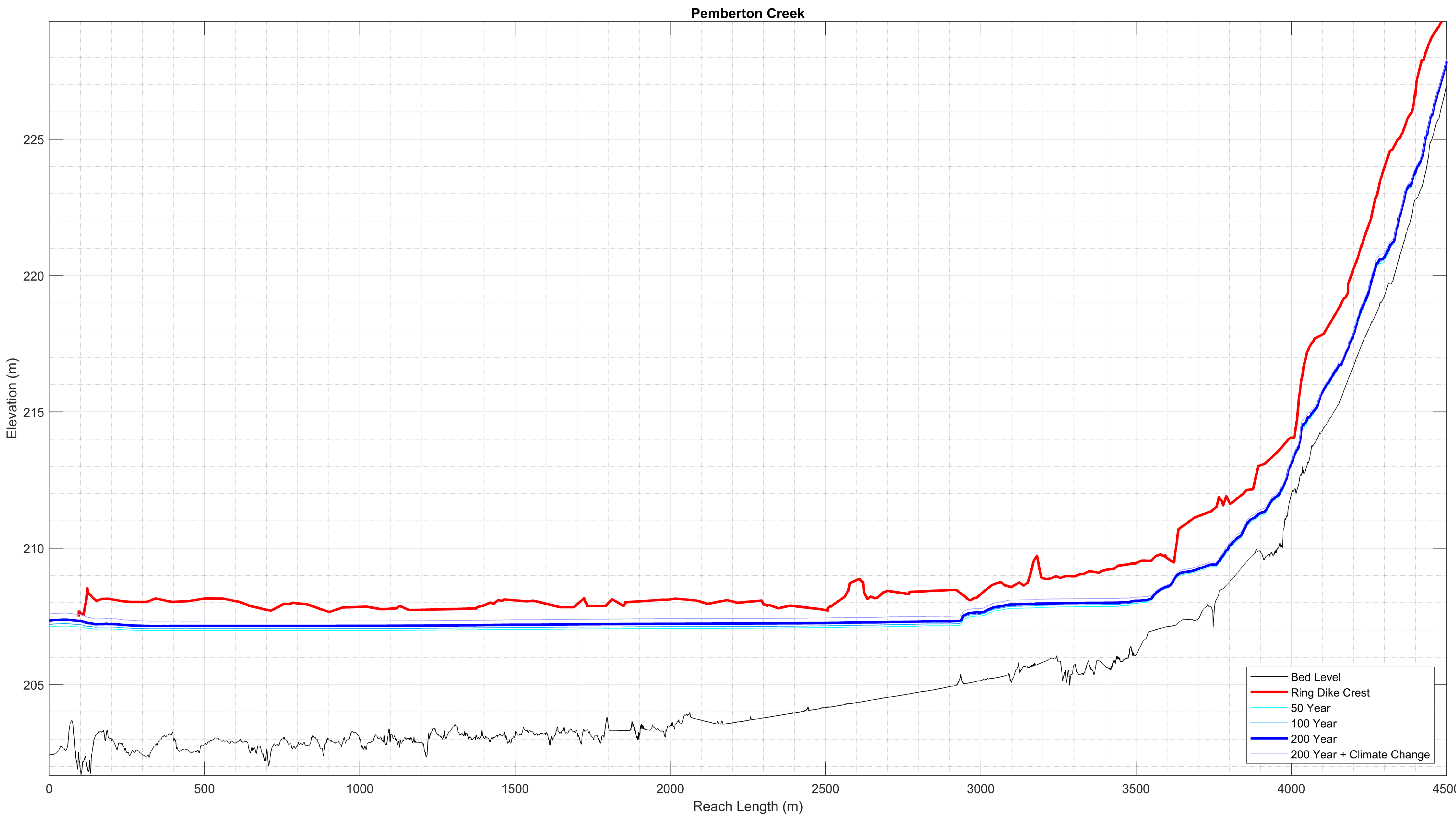

Bed Accretion Analysis
Hwy 99 Bridge
Elevation (m)
Reach Length (km)
216
214
212
210
208
206
204
202
200
12.5
13
13.5
14
14.5
15
15.5
16
16.5
17
Bed Level
Ring Dike Crest
Ayers Dike Crest
200 Year
200 Year + 0.5m Bed Accretion @ Hwy 99


Birkenhead River
Elevation (m)
Reach Length (m)
210
208
206
204
202
200
198
196
194
192
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Bed Level
50 Year
100 Year
200 Year
200 Year + Climate Change

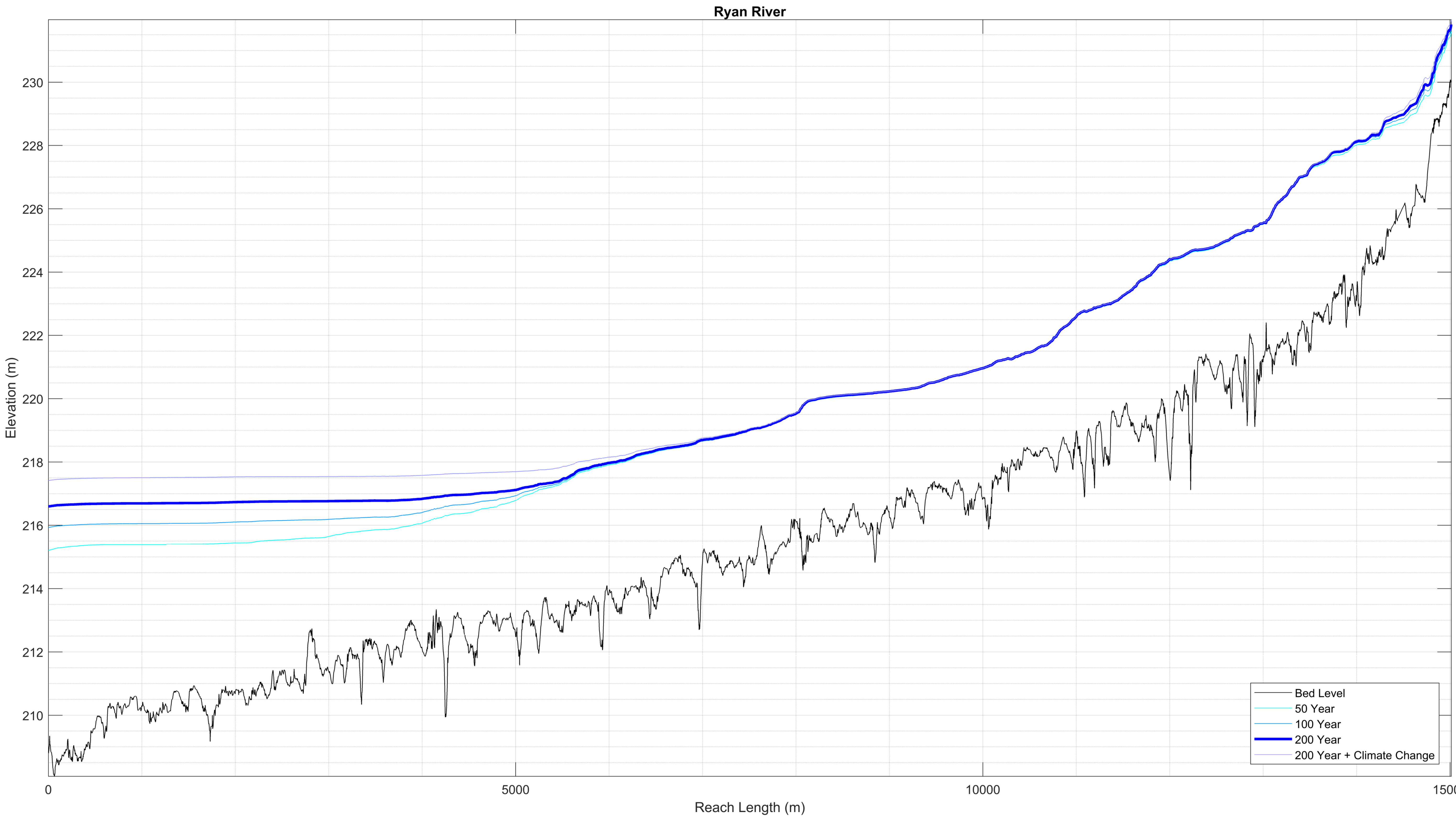


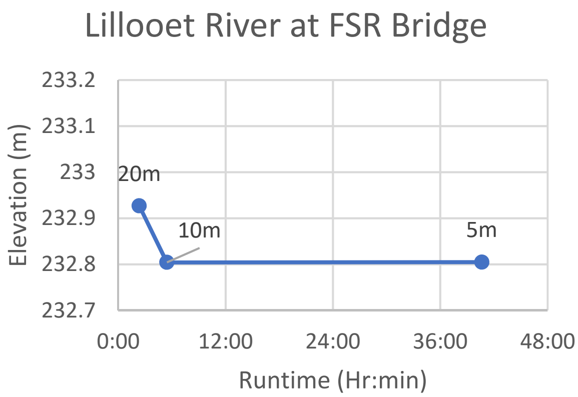
Green River
Elevation (m)
Reach Length (m)
218
216
214
212
210
208
206
204
202
200
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Bed Level
50 Year
100 Year
200 Year
200 Year + Climate Change

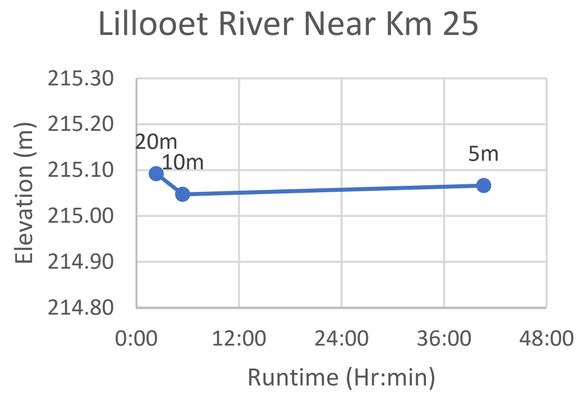

Miller Creek
Elevation (m)
230
225
220
215
210
0
500
1000
1500
2000
Reach Length (m)
Bed Level
Ring Dike Crest
50 Year
100 Year
200 Year
200 Year + Climate Change

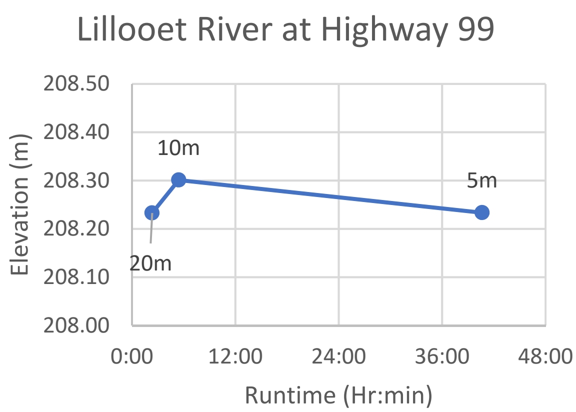


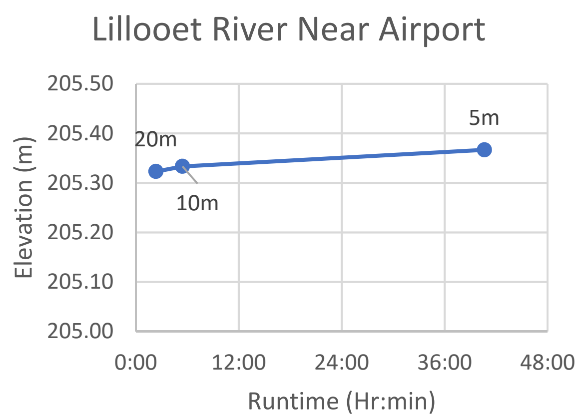
Pemberton Creek
Elevation (m)
Reach Length (m)
225
220
215
210
205
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Bed Level
Ring Dike Crest
50 Year
100 Year
200 Year
200 Year + Climate Change

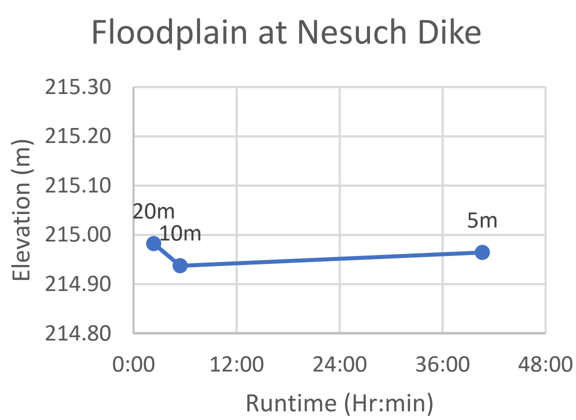

Ryan River
Elevation (m)
Reach Length (m)
230
228
226
224
222
220
218
216
214
212
210
0
5000
10000
15000
Bed Level
50 Year
100 Year
200 Year
200 Year + Climate Change

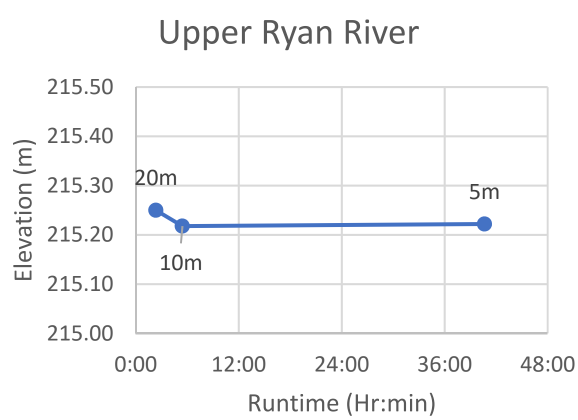

Lillooet River at FSR Bridge
Elevation (m)
Runtime (Hr:min)
20m
10m
5m


Lillooet River Near Km 25
Elevation (m)
Runtime (Hr:min)
20m
10m
5m

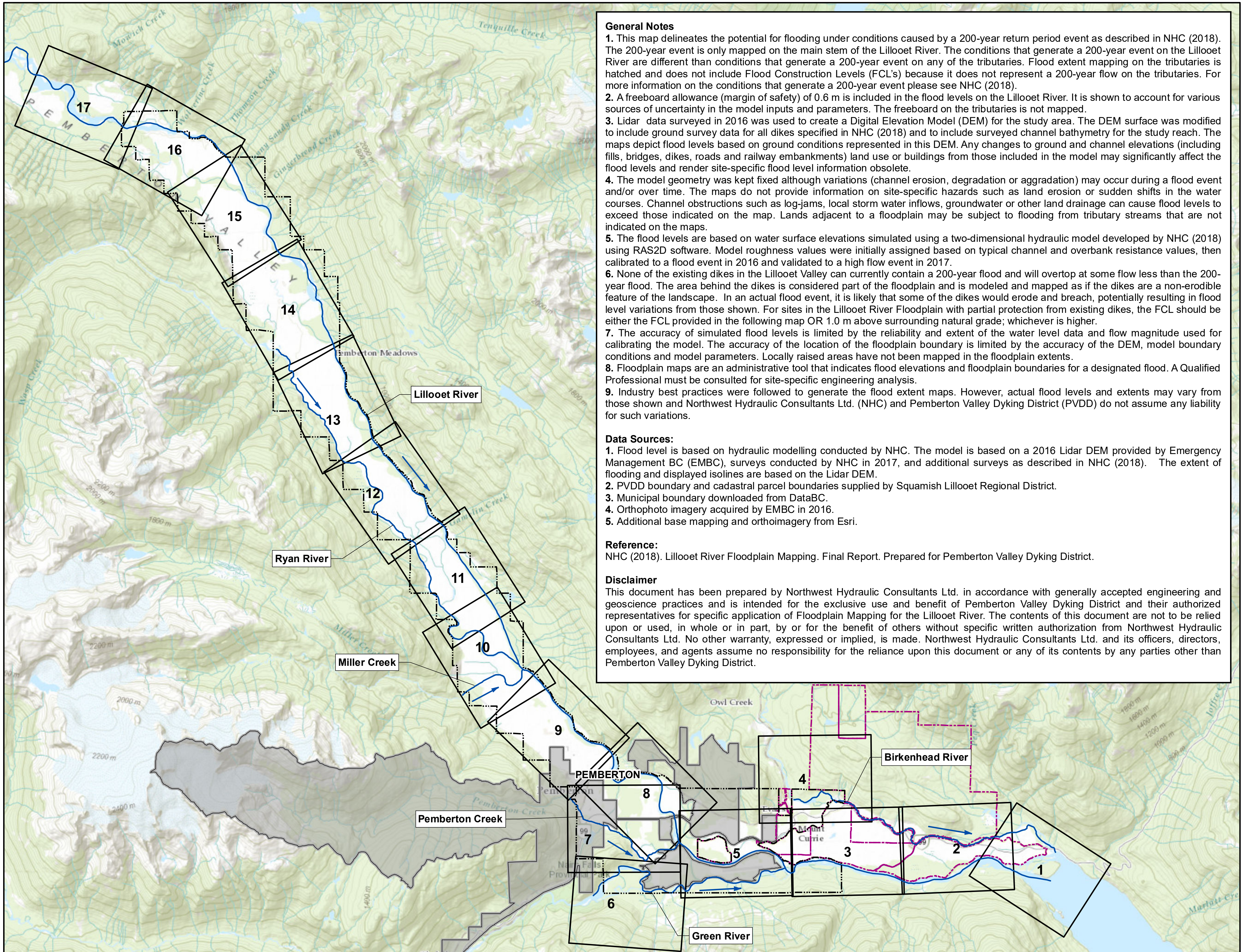

Lillooet River at Highway 99
Elevation (m)
Runtime (Hr:min)
10m
5m
20m


Lillooet River Near Airport
Elevation (m)
Runtime (Hr:min)
20m
10m
5m


Floodplain at Nesuch Dike
Elevation (m)
Runtime (Hr:min)
20m
10m
5m


Upper Ryan River
Elevation (m)
Runtime (Hr:min)
20m
10m
5m

Designated Flood Maps



General Notes

1. This map delineates the potential for flooding under conditions caused by a 200-year return period event as described in NHC (2018). The 200-year event is only mapped on the main stem of the Lillooet River. The conditions that generate a 200-year event on the Lillooet River are different than conditions that generate a 200-year event on any of the tributaries. Flood extent mapping on the tributaries is hatched and does not include Flood Construction Levels (FCL's) because it does not represent a 200-year flow on the tributaries. For more information on the conditions that generate a 200-year event please see NHC (2018).
2. A freeboard allowance (margin of safety) of 0.6 m is included in the flood levels on the Lillooet River. It is shown to account for various sources of uncertainty in the model inputs and parameters. The freeboard on the tributaries is not mapped.
3. Lidar data surveyed in 2016 was used to create a Digital Elevation Model (DEM) for the study area. The DEM surface was modified to include ground survey data for all dikes specified in NHC (2018) and to include surveyed channel bathymetry for the study reach. The maps depict flood levels based on ground conditions represented in this DEM. Any changes to ground and channel elevations (including fills, bridges, dikes, roads and railway embankments) land use or buildings from those included in the model may significantly affect the flood levels and render site-specific flood level information obsolete.
4. The model geometry was kept fixed although variations (channel erosion, degradation or aggradation) may occur during a flood event and/or over time. The maps do not provide information on site-specific hazards such as land erosion or sudden shifts in the water courses. Channel obstructions such as log-jams, local storm water inflows, groundwater or other land drainage can cause flood levels to exceed those indicated on the map. Lands adjacent to a floodplain may be subject to flooding from tributary streams that are not indicated on the maps.
5. The flood levels are based on water surface elevations simulated using a two-dimensional hydraulic model developed by NHC (2018) using RAS2D software. Model roughness values were initially assigned based on typical channel and overbank resistance values, then calibrated to a flood event in 2016 and validated to a high flow event in 2017.
6. None of the existing dikes in the Lillooet Valley can currently contain a 200-year flood and will overtop at some flow less than the 200-year flood. The area behind the dikes is considered part of the floodplain and is modeled and mapped as if the dikes are a non-erodible feature of the landscape. In an actual flood event, it is likely that some of the dikes would erode and breach, potentially resulting in flood level variations from those shown. For sites in the Lillooet River Floodplain with partial protection from existing dikes, the FCL should be either the FCL provided in the following map OR 1.0 m above surrounding natural grade; whichever is higher.
7. The accuracy of simulated flood levels is limited by the reliability and extent of the water level data and flow magnitude used for calibrating the model. The accuracy of the location of the floodplain boundary is limited by the accuracy of the DEM, model boundary conditions and model parameters. Locally raised areas have not been mapped in the floodplain extents.
8. Floodplain maps are an administrative tool that indicates flood elevations and floodplain boundaries for a designated flood. A Qualified Professional must be consulted for site-specific engineering analysis.
9. Industry best practices were followed to generate the flood extent maps. However, actual flood levels and extents may vary from those shown and Northwest Hydraulic Consultants Ltd. (NHC) and Pemberton Valley Dyking District (PVDD) do not assume any liability for such variations.

Data Sources:

1. Flood level is based on hydraulic modelling conducted by NHC. The model is based on a 2016 Lidar DEM provided by Emergency Management BC (EMBC), surveys conducted by NHC in 2017, and additional surveys as described in NHC (2018). The extent of flooding and displayed isolines are based on the Lidar DEM.
2. PVDD boundary and cadastral parcel boundaries supplied by Squamish Lillooet Regional District.
3. Municipal boundary downloaded from DataBC.
4. Orthophoto imagery acquired by EMBC in 2016.
5. Additional base mapping and orthoimagery from Esri.

Reference:

NHC (2018). Lillooet River Floodplain Mapping. Final Report. Prepared for Pemberton Valley Dyking District.

Disclaimer

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants

- Stream Network Modelled
- Pemberton Valley Dyking District
- Map View Outline
- Village of Pemberton Boundaries (2017)
- First Nation Reserve

SCALE - 1:110,000

0 1,100 2,200 4,400 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN - KEY PLAN

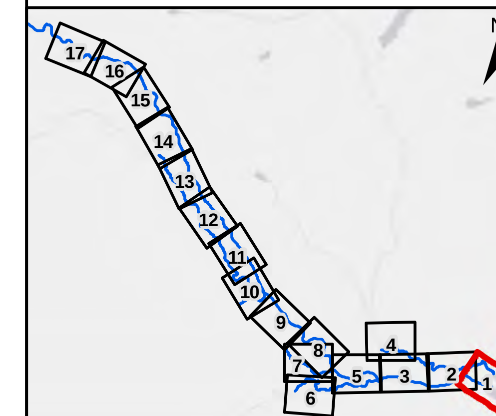
INDEX SHEET

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplain_Index.mxd

SHEET 2 ↑

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

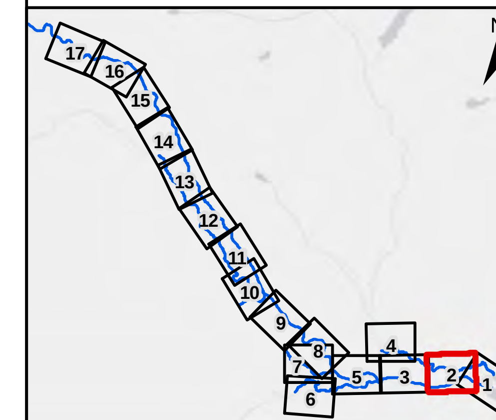
200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 1 OF 17

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

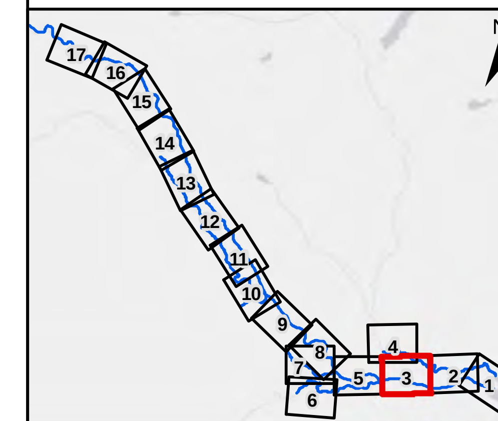
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 2 OF 17

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd



Flow Direction
Dike
FCL Isoline
Railway
Major Road
Local Road
Pemberton Valley Dyking District
Flood Extents Including 0.6m Freeboard
Flood Extents
Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

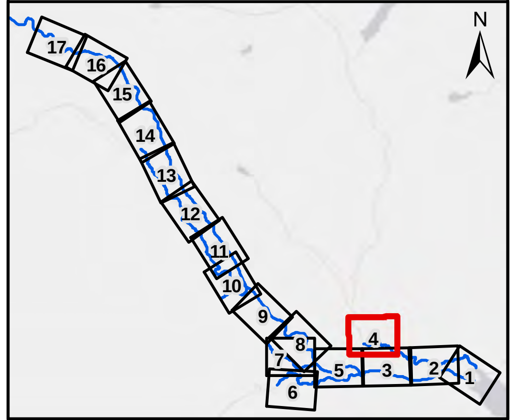
200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 3 OF 17

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

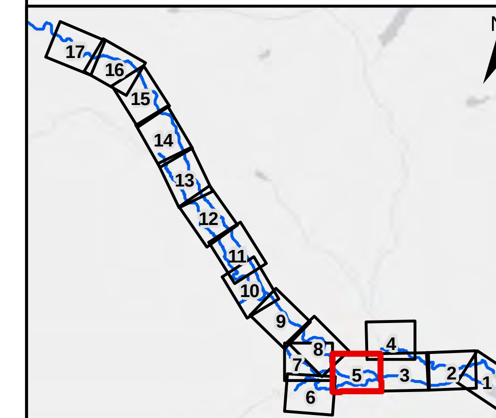
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
FCL Isoline
Railway
Major Road
Local Road
Pemberton Valley Dyking District
Flood Extents Including 0.6m Freeboard
Flood Extents
Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

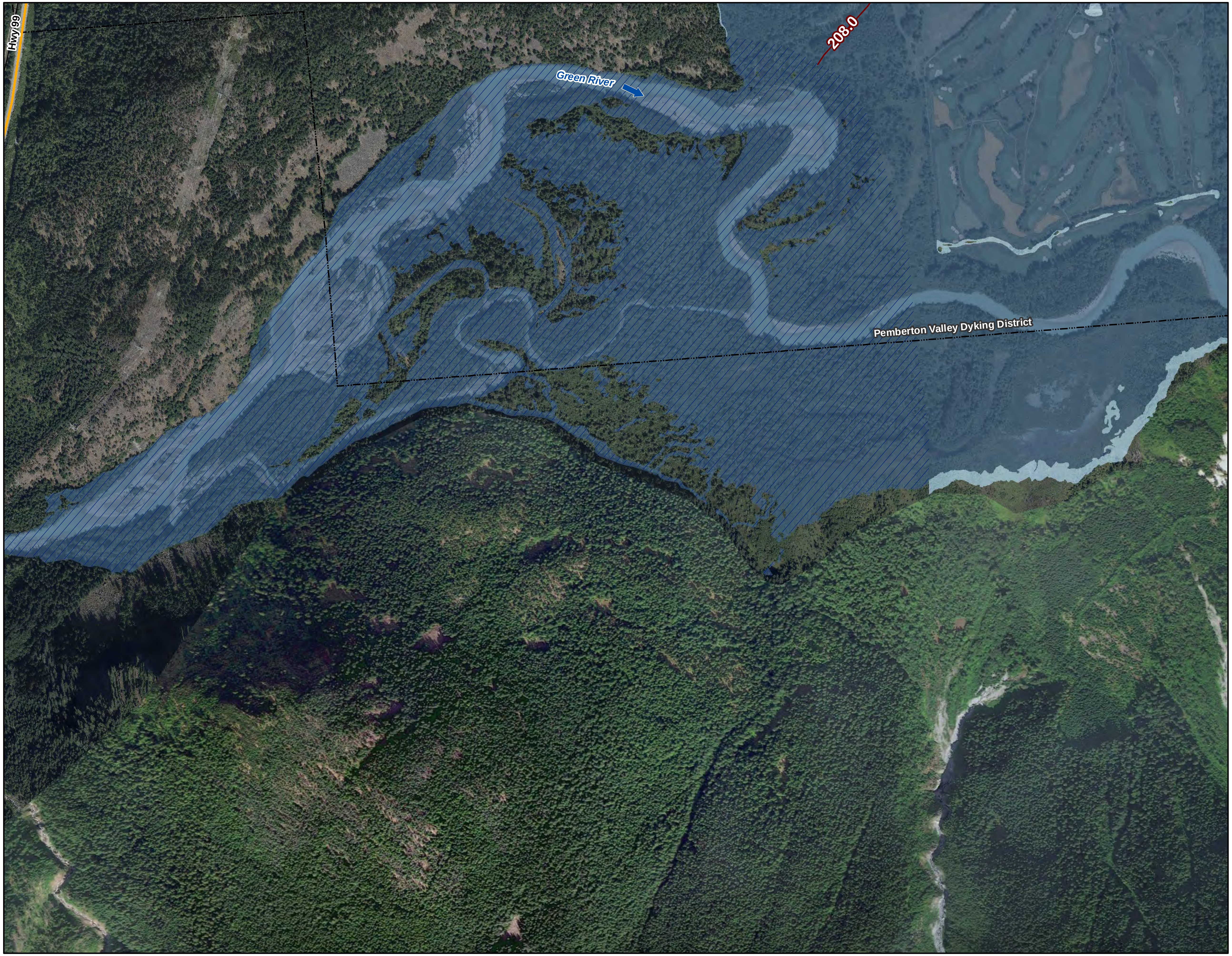
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

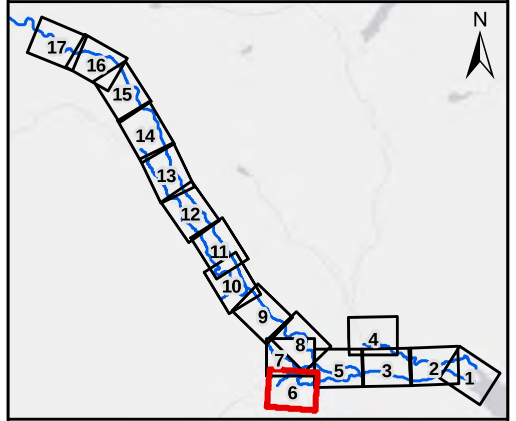
SHEET 5 OF 17

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 *Metres*

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES *Vertical Datum: CGVD(2013)*

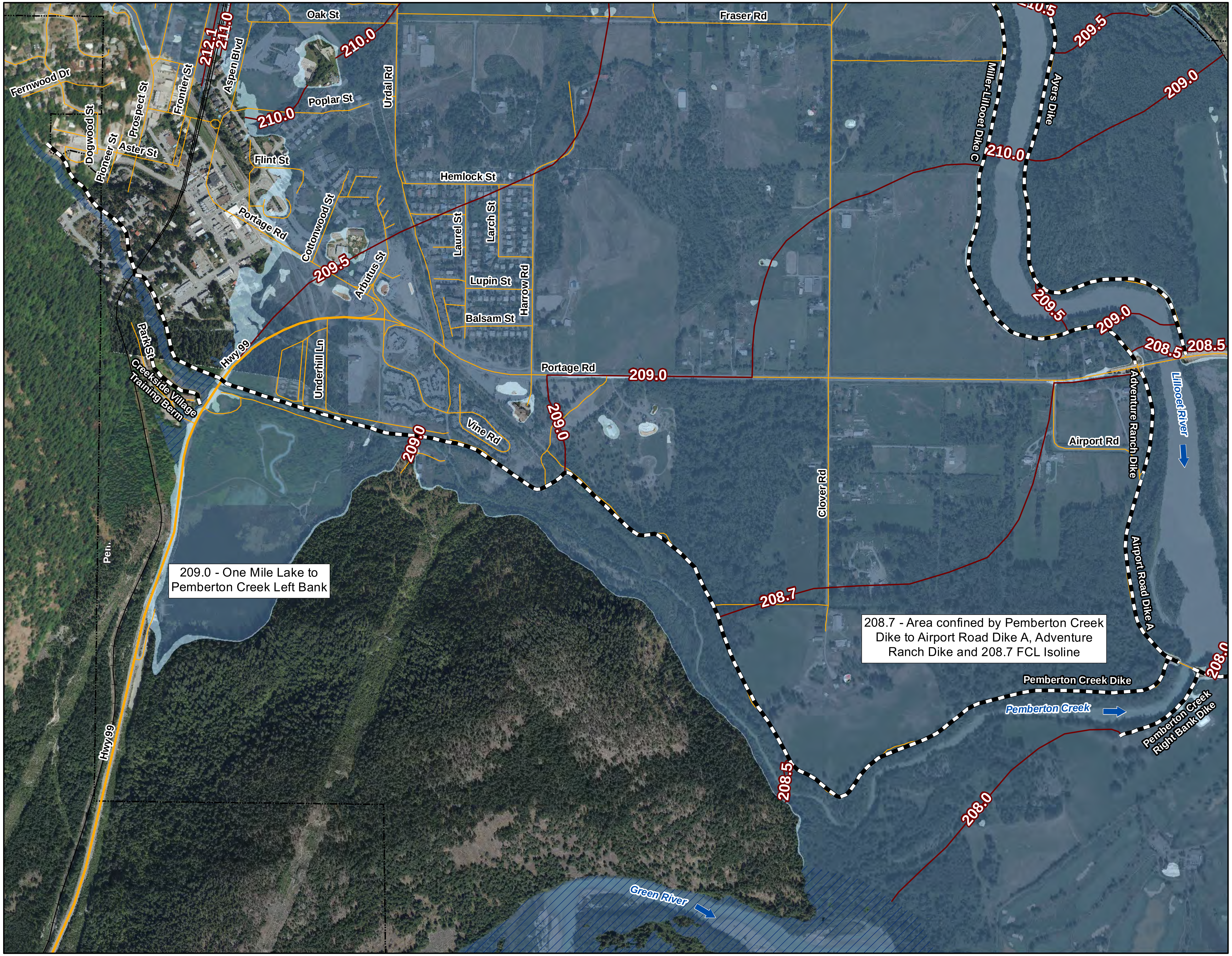
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

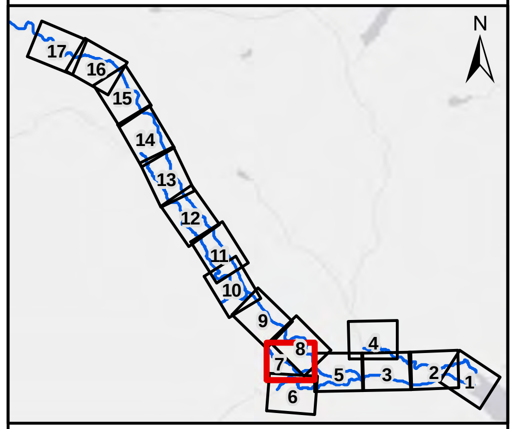
200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 6 OF 17



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
FCL Isoline
Railway
Major Road
Local Road
Pemberton Valley Dyking District
Flood Extents Including 0.6m Freeboard
Flood Extents
Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

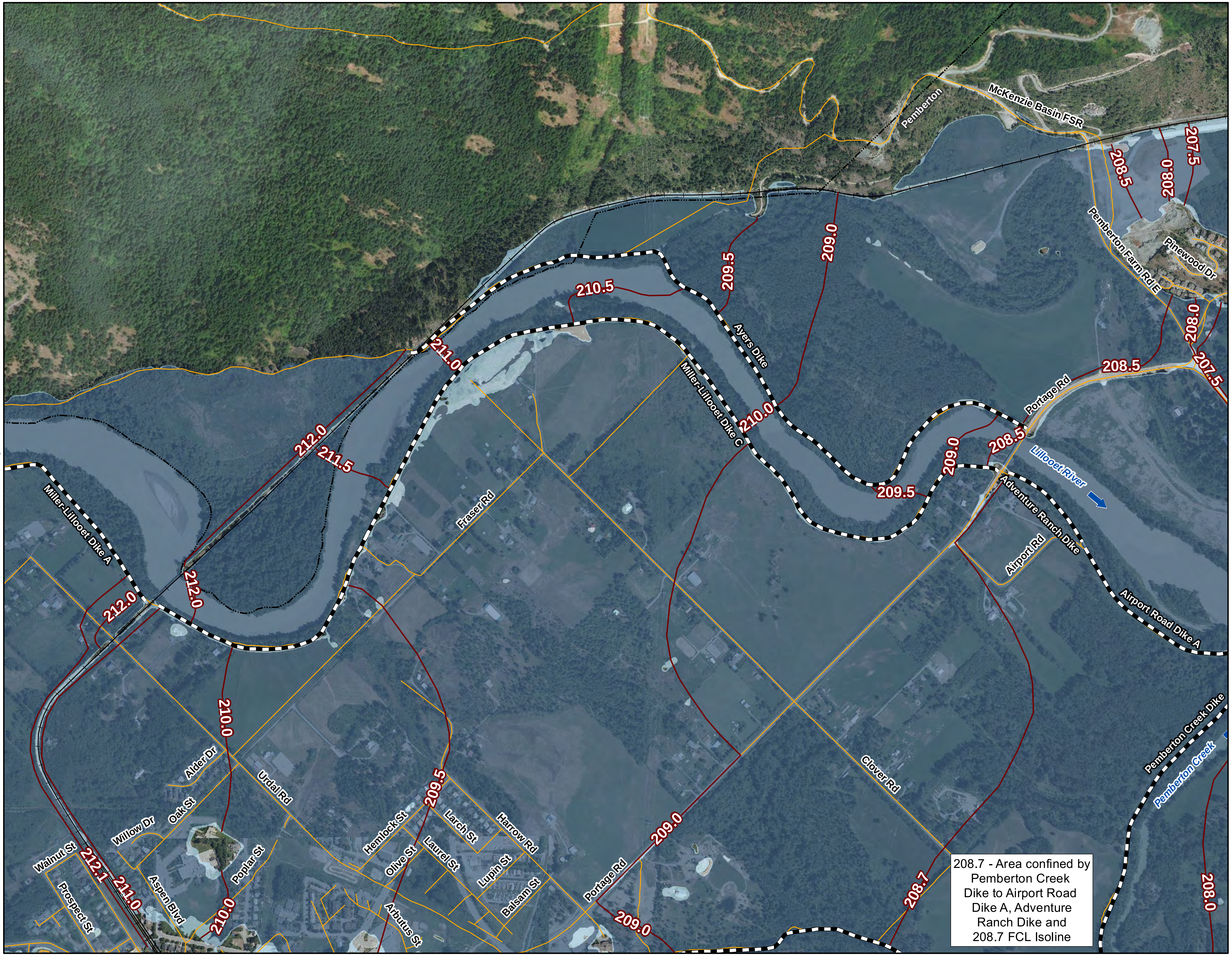
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

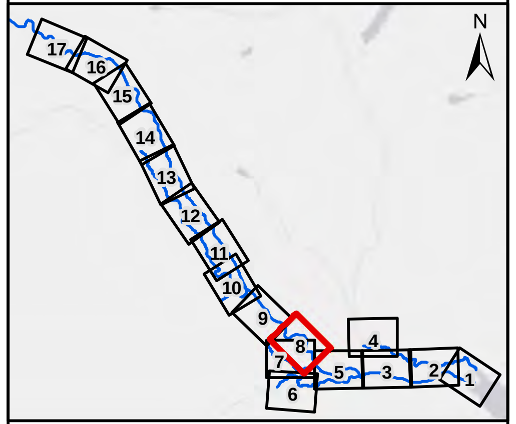
LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

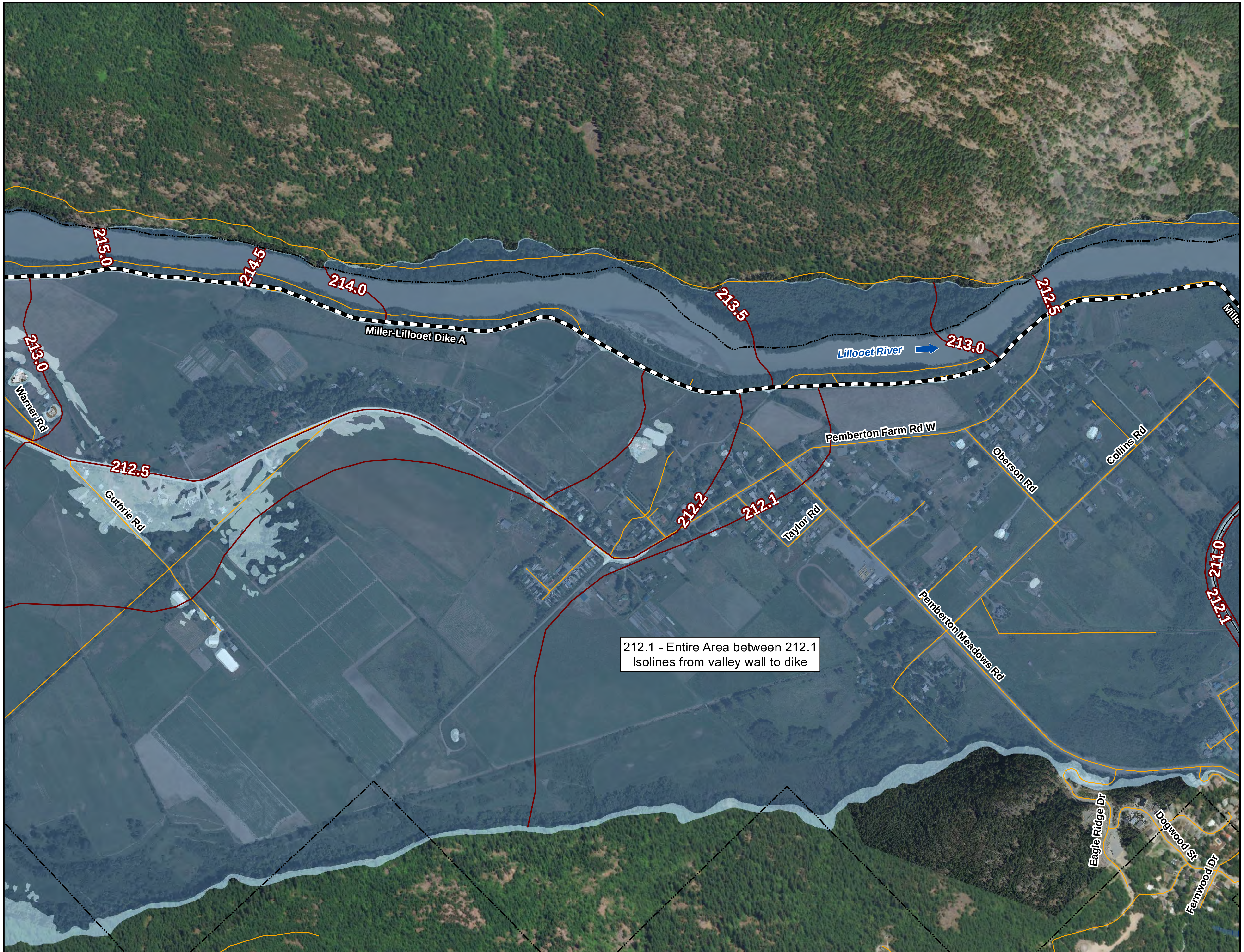
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

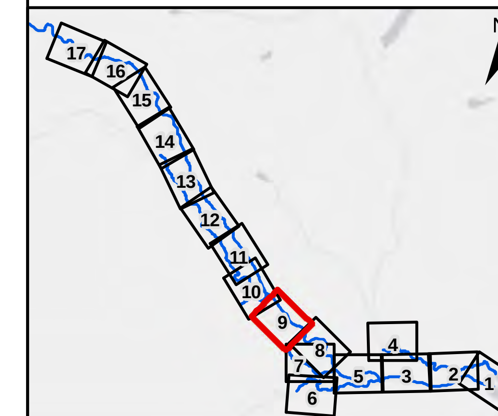
LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

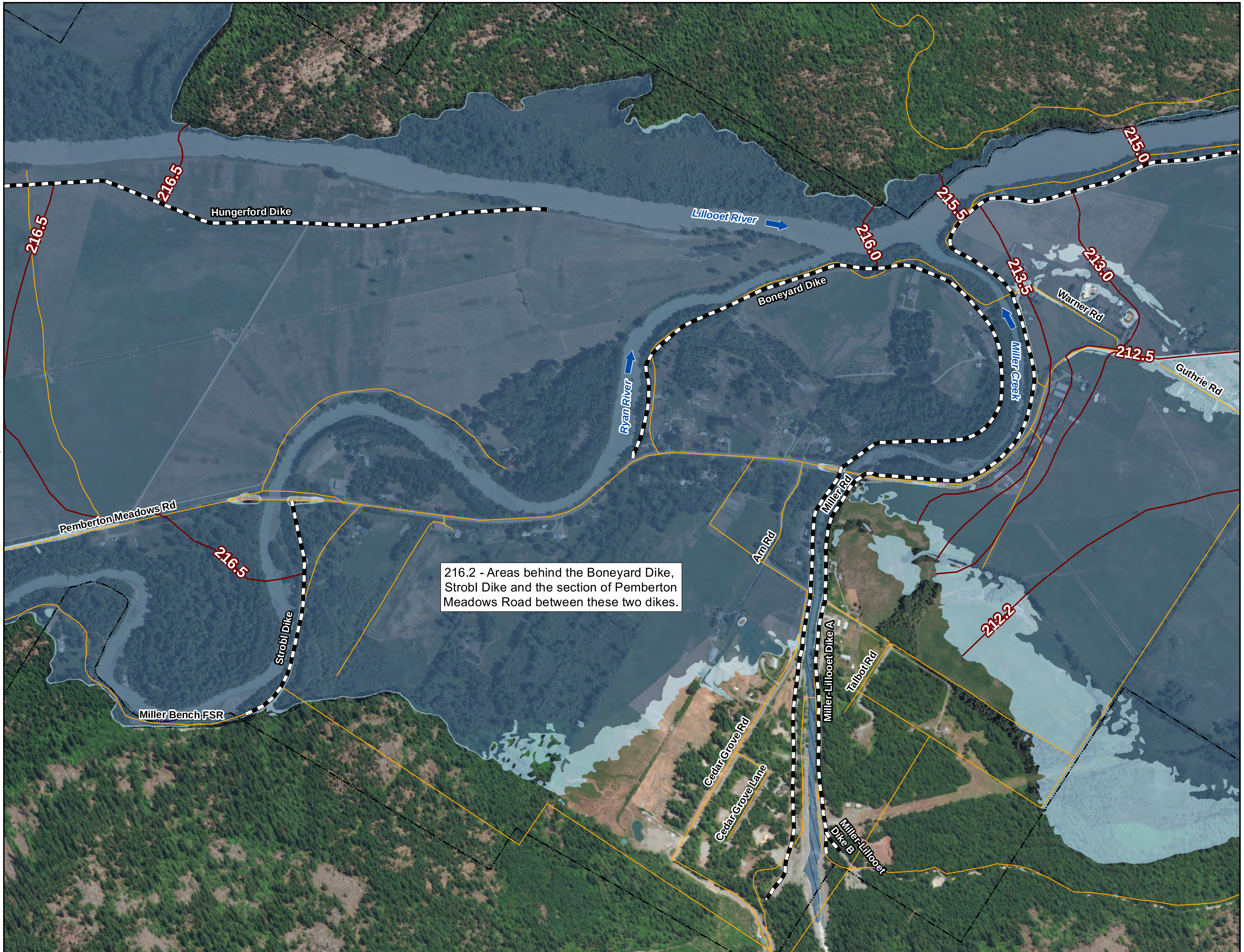
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

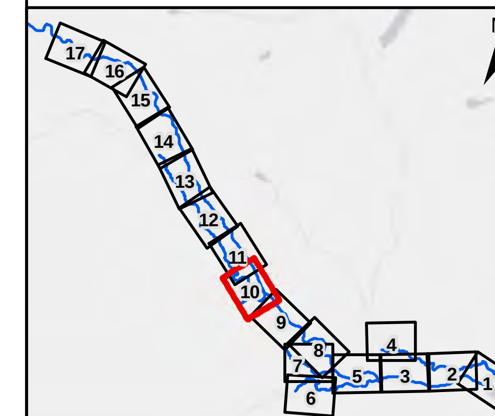
LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

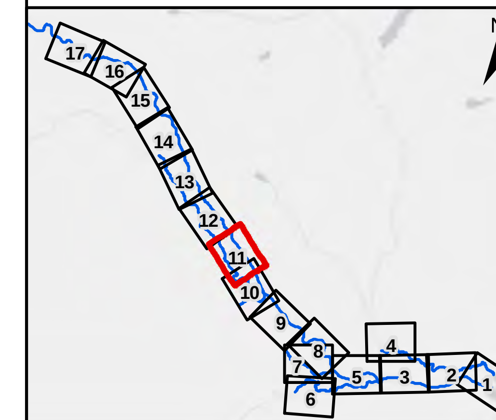
200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 10 OF 17

MAO Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

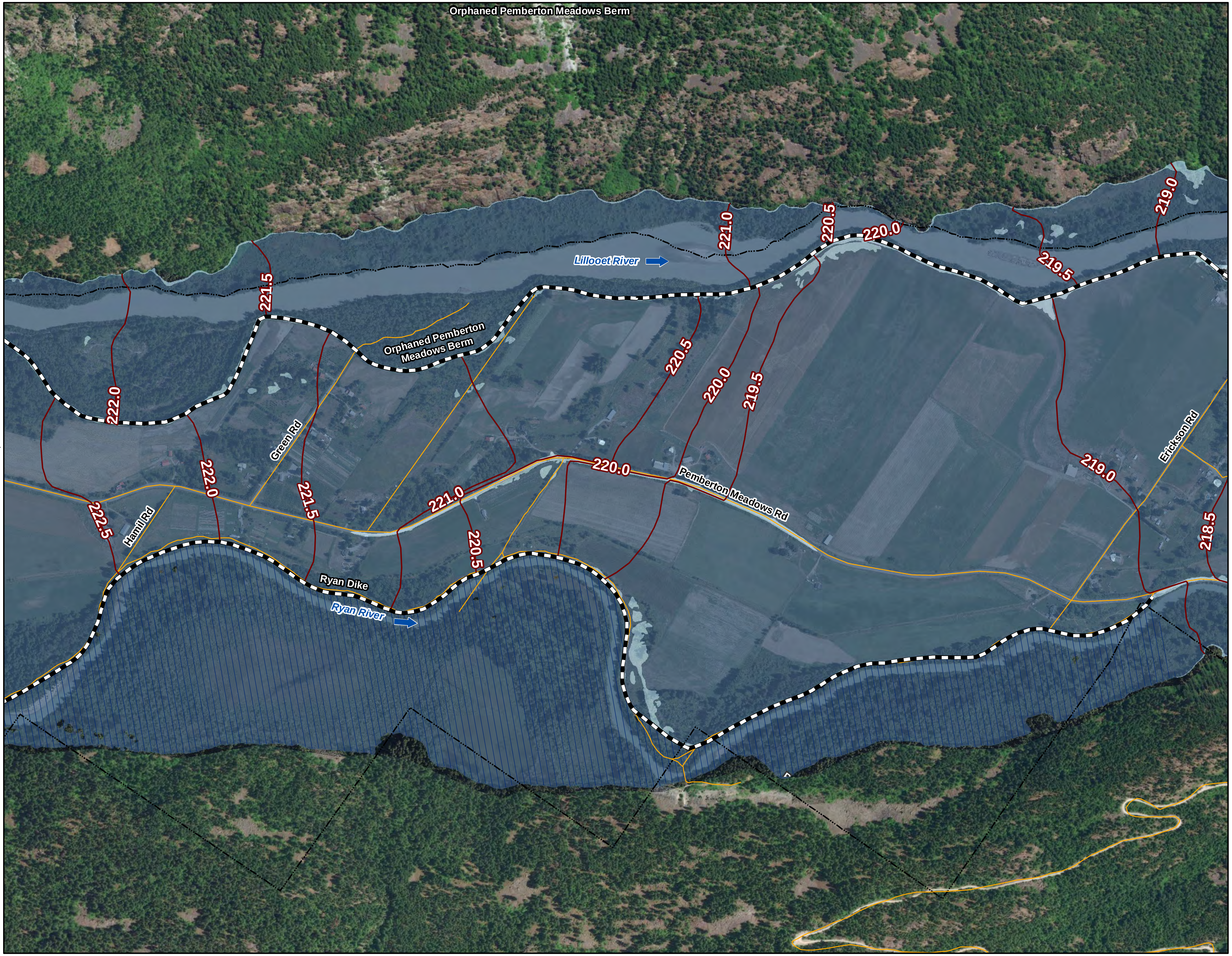
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

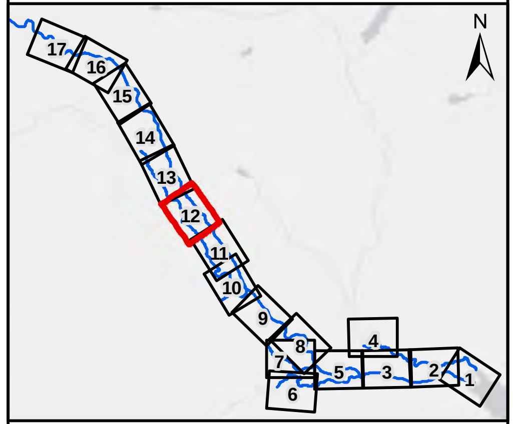
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD





PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants

- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

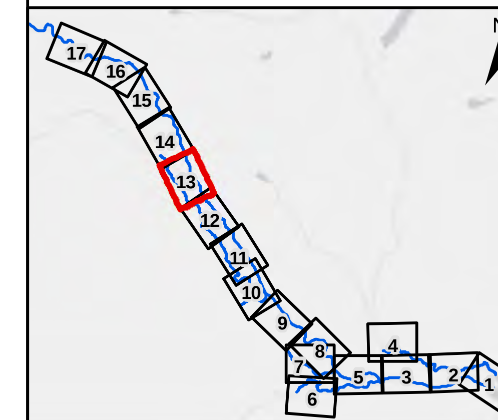
LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

MAO_Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
FCL Isoline
Railway
Major Road
Local Road
Pemberton Valley Dyking District
Flood Extents Including 0.6m Freeboard
Flood Extents
Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

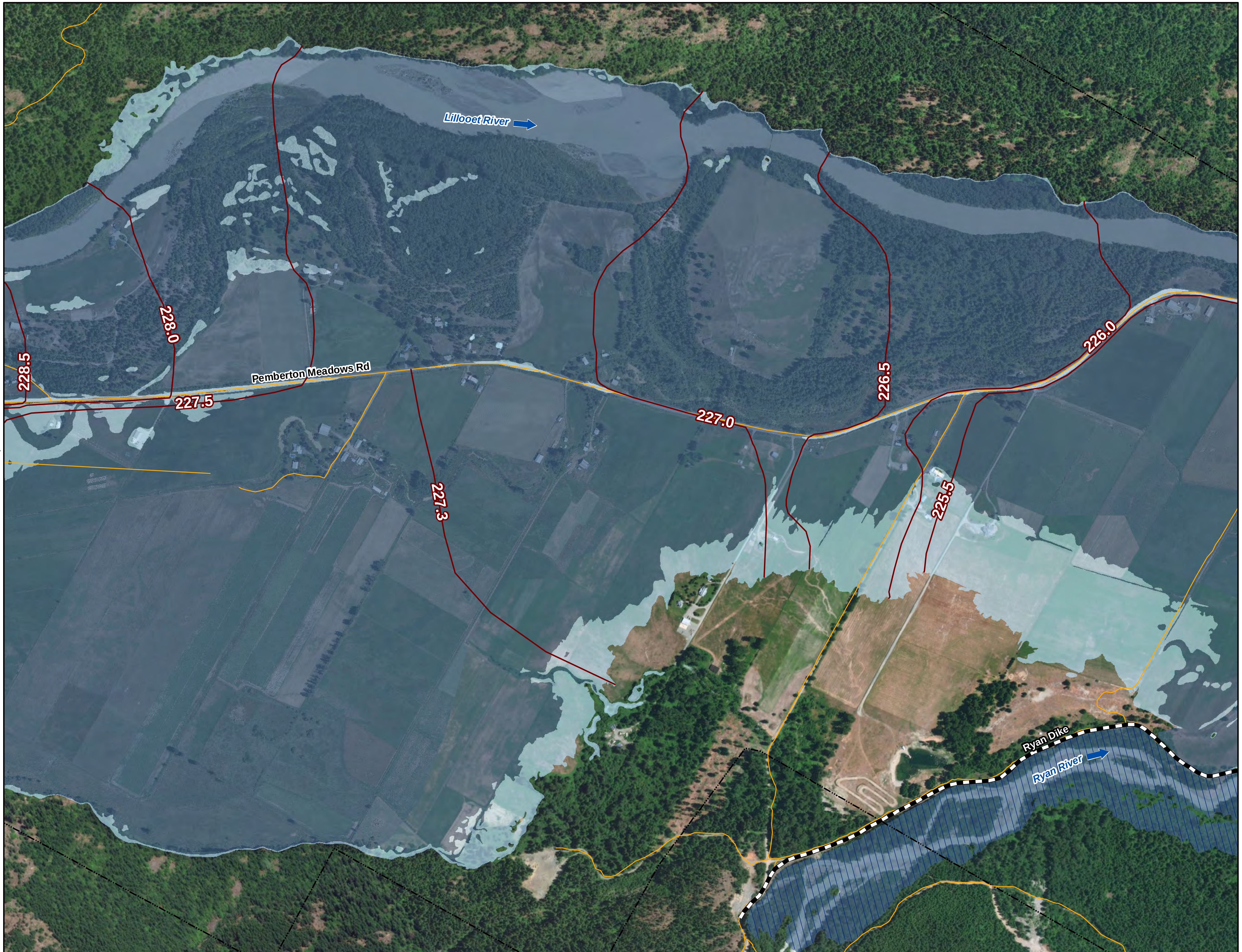
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

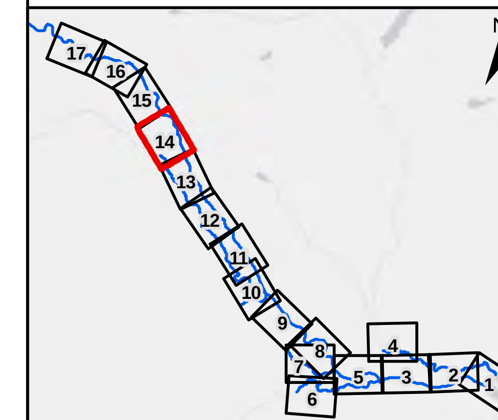
LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
FCL Isoline
Railway
Major Road
Local Road
Pemberton Valley Dyking District
Flood Extents Including 0.6m Freeboard
Flood Extents
Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

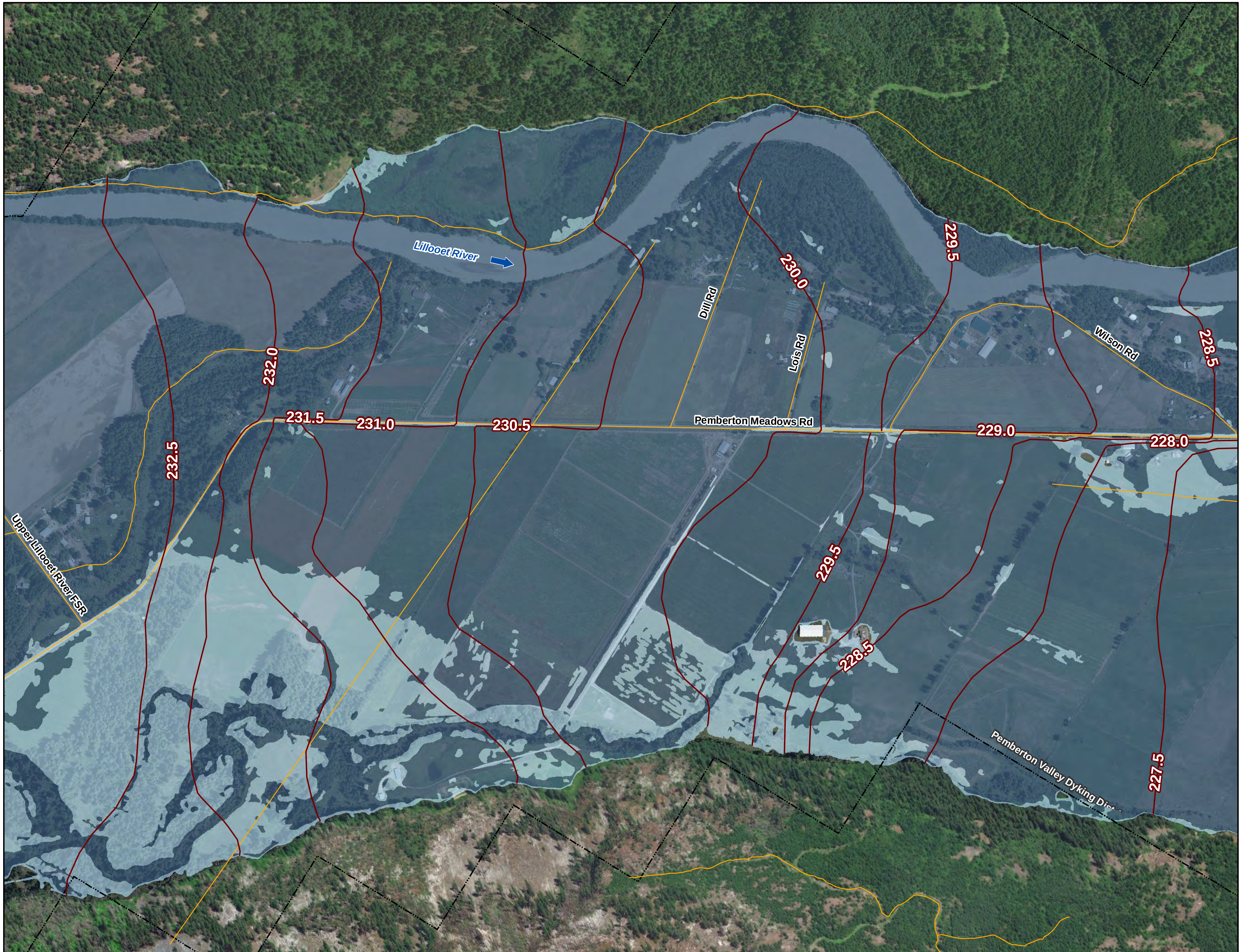
LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 14 OF 17

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd

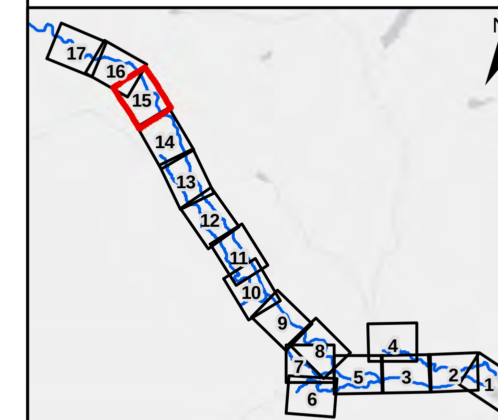
SHEET 16 ↑



SHEET 14 ↓

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

FCL Isoline

Railway

Major Road

Local Road

Pemberton Valley Dyking District

Flood Extents Including 0.6m Freeboard

Flood Extents

Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

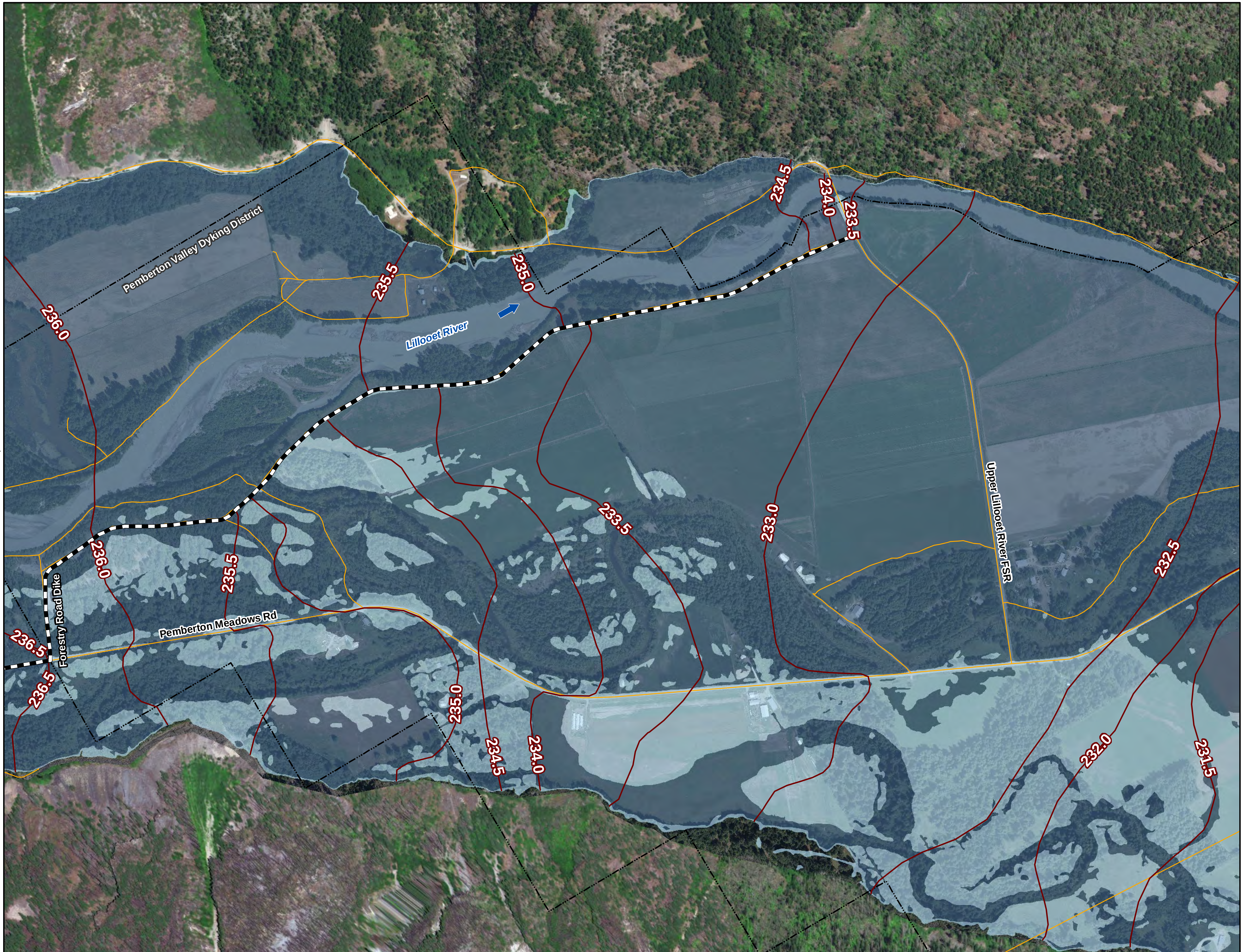
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

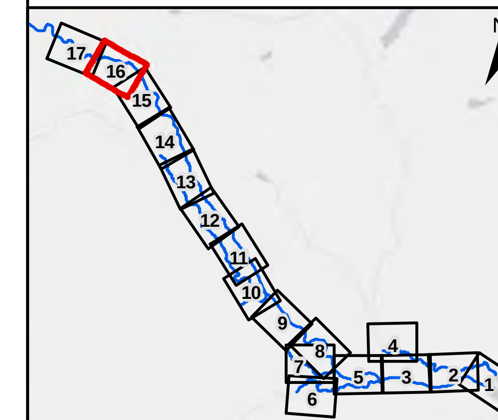
SHEET 15 OF 17

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

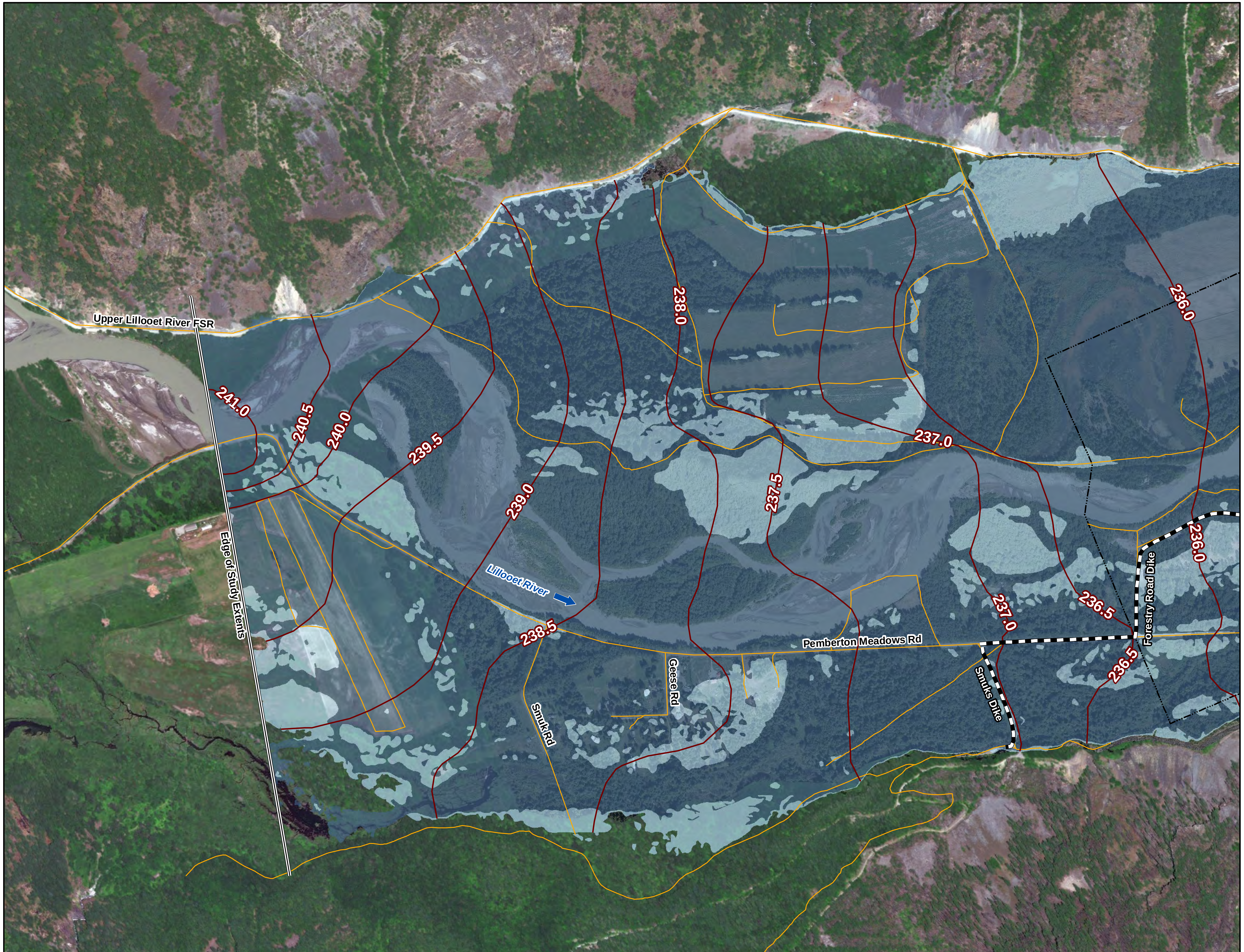
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

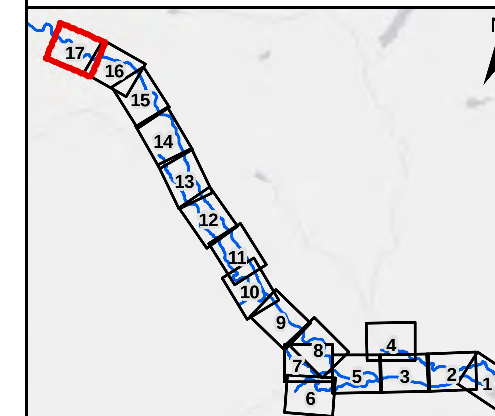
200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 16 OF 17



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



- Flow Direction
- Dike
- FCL Isoline
- Railway
- Major Road
- Local Road
- Pemberton Valley Dyking District
- Flood Extents Including 0.6m Freeboard
- Flood Extents
- Flood Extents - Tributaries

Please refer to General Notes on Map Index Sheet

SCALE - 1:10,000

0 100 200 400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

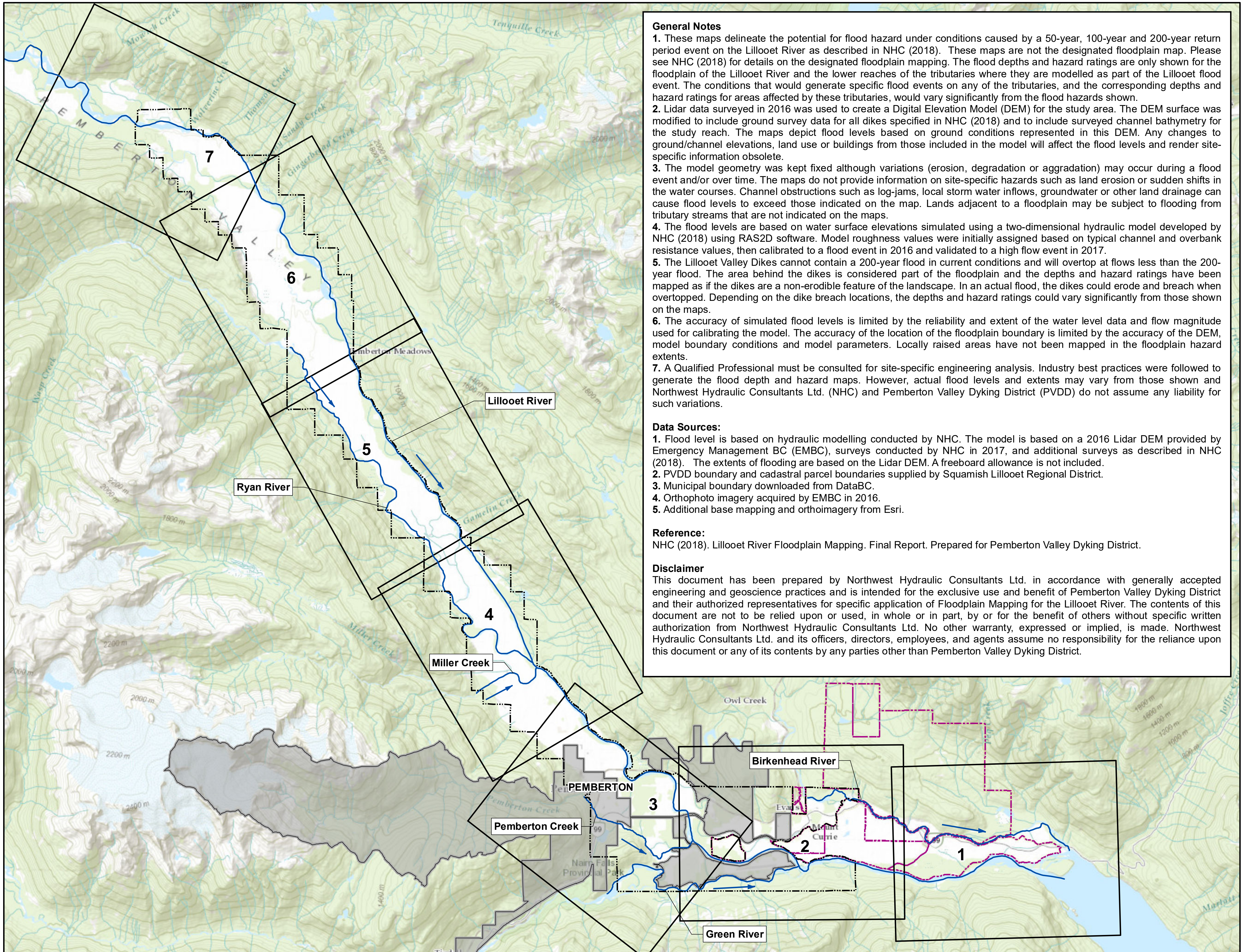
LILLOOET RIVER FLOODPLAIN STUDY

200-YEAR DESIGNATED FLOODPLAIN MAPS INCLUDING FREEBOARD

SHEET 17 OF 17

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_DesignatedFloodplainMaps.mxd

Flood Hazard Maps



General Notes

1. These maps delineate the potential for flood hazard under conditions caused by a 50-year, 100-year and 200-year return period event on the Lillooet River as described in NHC (2018). These maps are not the designated floodplain map. Please see NHC (2018) for details on the designated floodplain mapping. The flood depths and hazard ratings are only shown for the floodplain of the Lillooet River and the lower reaches of the tributaries where they are modelled as part of the Lillooet flood event. The conditions that would generate specific flood events on any of the tributaries, and the corresponding depths and hazard ratings for areas affected by these tributaries, would vary significantly from the flood hazards shown.

2. Lidar data surveyed in 2016 was used to create a Digital Elevation Model (DEM) for the study area. The DEM surface was modified to include ground survey data for all dikes specified in NHC (2018) and to include surveyed channel bathymetry for the study reach. The maps depict flood levels based on ground conditions represented in this DEM. Any changes to ground/channel elevations, land use or buildings from those included in the model will affect the flood levels and render site-specific information obsolete.

3. The model geometry was kept fixed although variations (erosion, degradation or aggradation) may occur during a flood event and/or over time. The maps do not provide information on site-specific hazards such as land erosion or sudden shifts in the water courses. Channel obstructions such as log-jams, local storm water inflows, groundwater or other land drainage can cause flood levels to exceed those indicated on the map. Lands adjacent to a floodplain may be subject to flooding from tributary streams that are not indicated on the maps.

4. The flood levels are based on water surface elevations simulated using a two-dimensional hydraulic model developed by NHC (2018) using RAS2D software. Model roughness values were initially assigned based on typical channel and overbank resistance values, then calibrated to a flood event in 2016 and validated to a high flow event in 2017.

5. The Lillooet Valley Dikes cannot contain a 200-year flood in current conditions and will overtop at flows less than the 200-year flood. The area behind the dikes is considered part of the floodplain and the depths and hazard ratings have been mapped as if the dikes are a non-erodible feature of the landscape. In an actual flood, the dikes could erode and breach when overtopped. Depending on the dike breach locations, the depths and hazard ratings could vary significantly from those shown on the maps.

6. The accuracy of simulated flood levels is limited by the reliability and extent of the water level data and flow magnitude used for calibrating the model. The accuracy of the location of the floodplain boundary is limited by the accuracy of the DEM, model boundary conditions and model parameters. Locally raised areas have not been mapped in the floodplain hazard extents.

7. A Qualified Professional must be consulted for site-specific engineering analysis. Industry best practices were followed to generate the flood depth and hazard maps. However, actual flood levels and extents may vary from those shown and Northwest Hydraulic Consultants Ltd. (NHC) and Pemberton Valley Dyking District (PVDD) do not assume any liability for such variations.

Data Sources:

1. Flood level is based on hydraulic modelling conducted by NHC. The model is based on a 2016 Lidar DEM provided by Emergency Management BC (EMBC), surveys conducted by NHC in 2017, and additional surveys as described in NHC (2018). The extents of flooding are based on the Lidar DEM. A freeboard allowance is not included.
2. PVDD boundary and cadastral parcel boundaries supplied by Squamish Lillooet Regional District.
3. Municipal boundary downloaded from DataBC.
4. Orthophoto imagery acquired by EMBC in 2016.
5. Additional base mapping and orthoimagery from Esri.

Reference:

NHC (2018). Lillooet River Floodplain Mapping. Final Report. Prepared for Pemberton Valley Dyking District.

Disclaimer

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants

- Stream Network Modelled
- Pemberton Valley Dyking District
- Map View Outline
- Village of Pemberton Boundaries (2017)
- First Nation Reserve

Hazard Rating = Depth x (Velocity + 0.5) in m*m/s

SCALE - 1:110,000

0 1,100 2,200 4,400 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

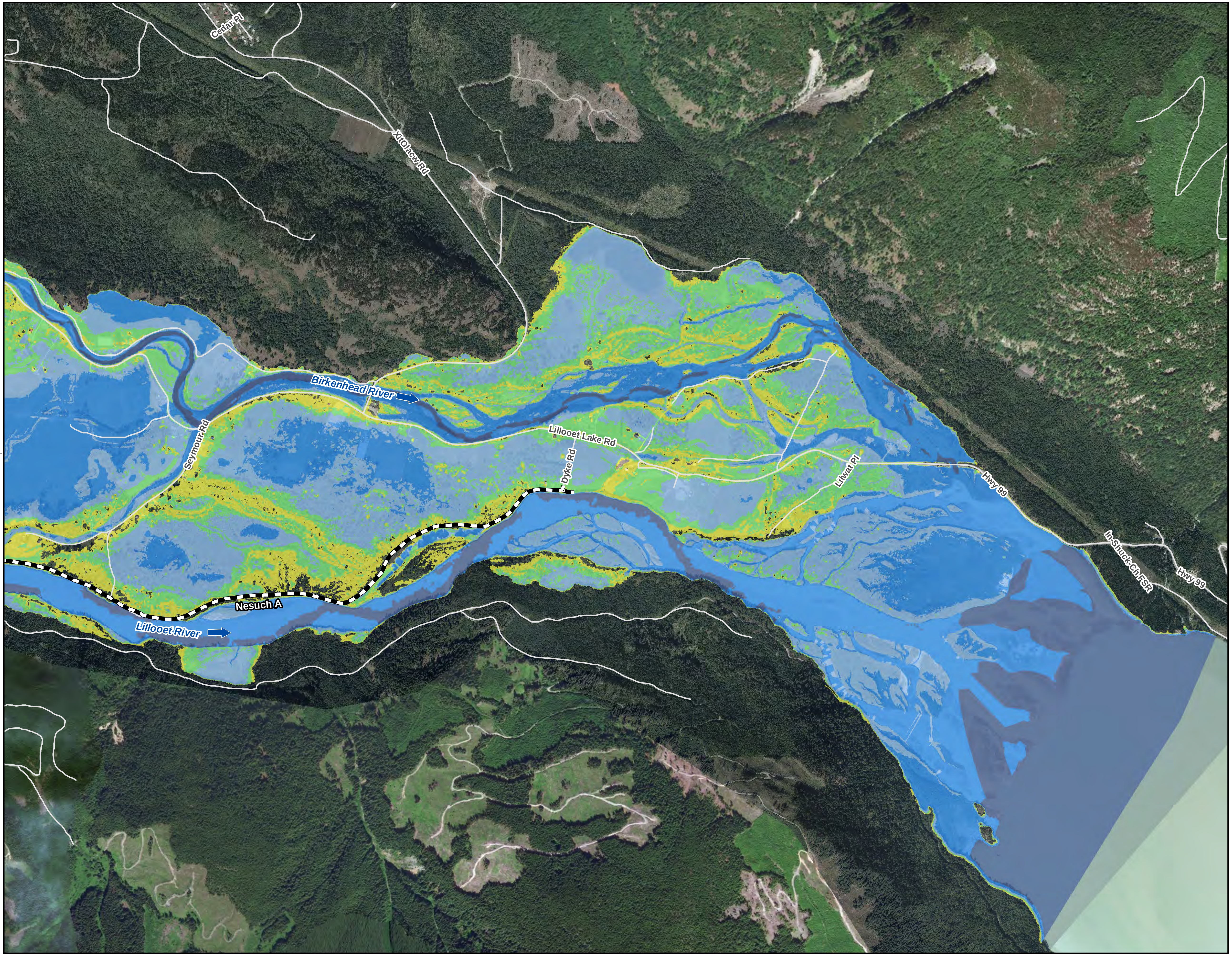
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH AND HAZARD RATING MAPS - KEY PLAN

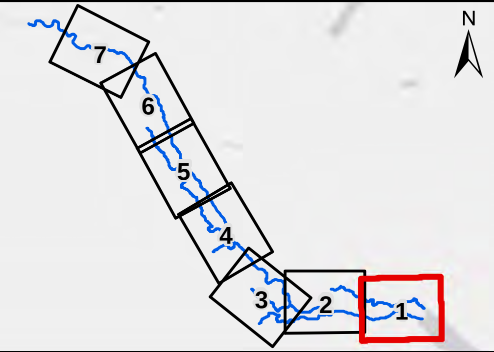
INDEX SHEET

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Index.mxd



PEMBERTON VALLEY DYKING DISTRICT

northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

0 to 0.5

0.5 to 1.0

1.0 to 2.0

2.0 to 5.0

> 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

N

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

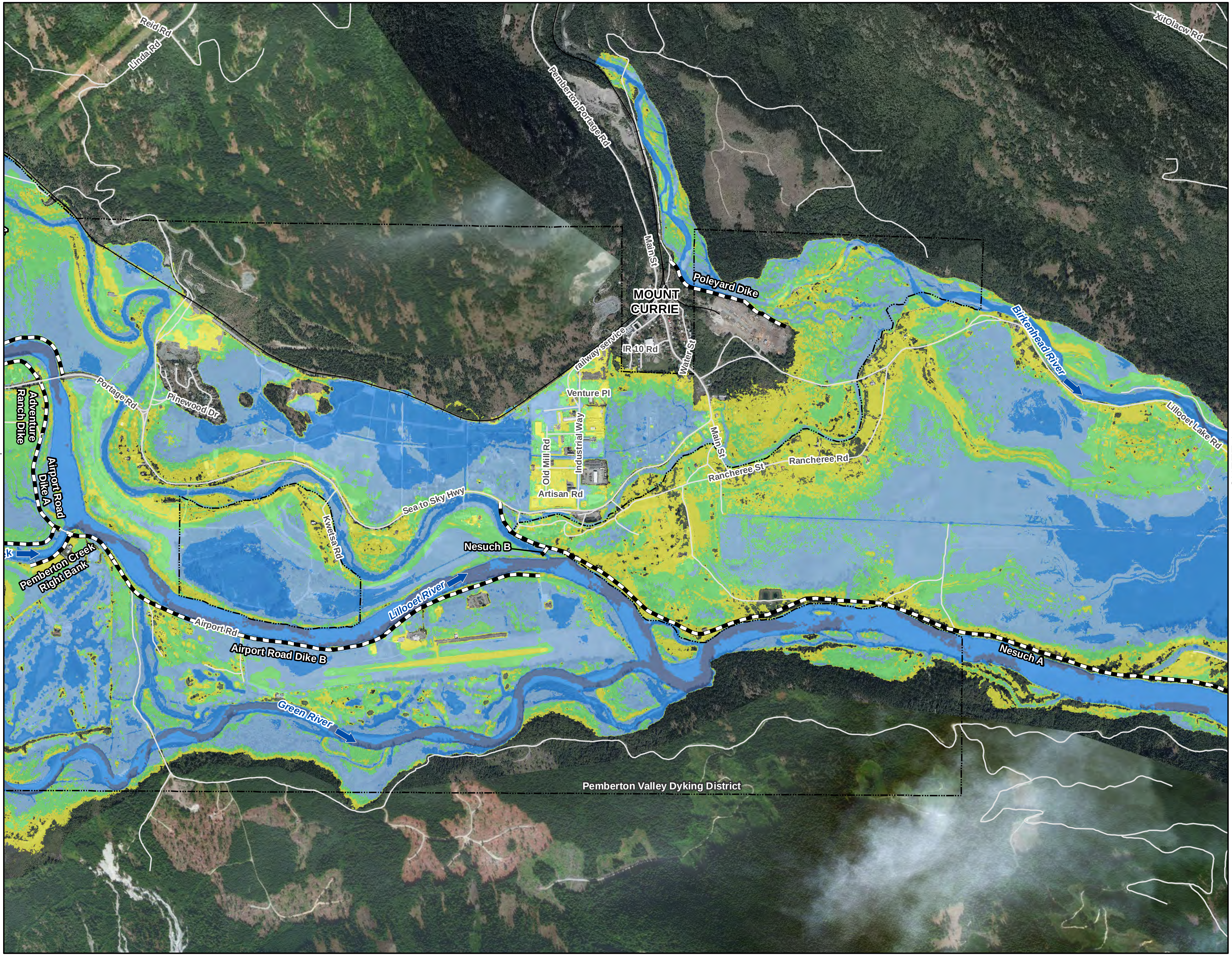
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
50-YEAR LILLOOET EVENT

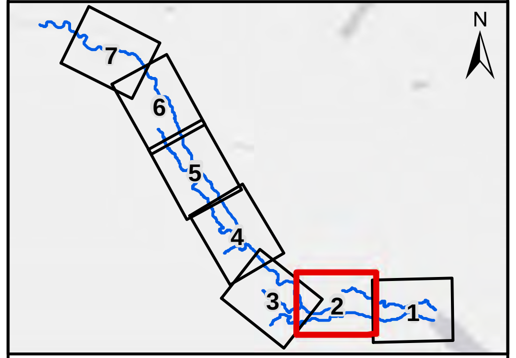
SHEET 1 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

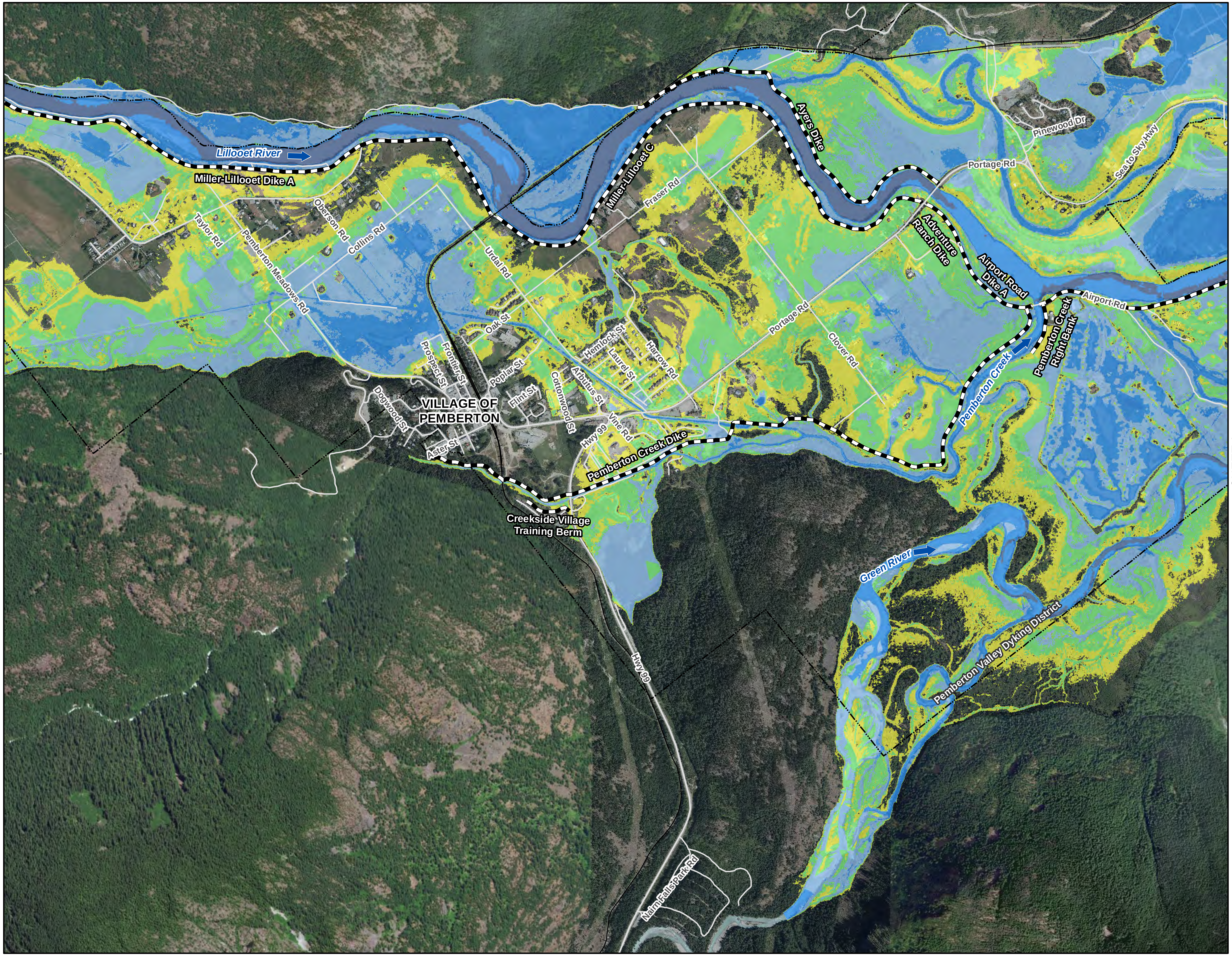
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
50-YEAR LILLOOET EVENT

SHEET 2 OF 7

MAO_Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd

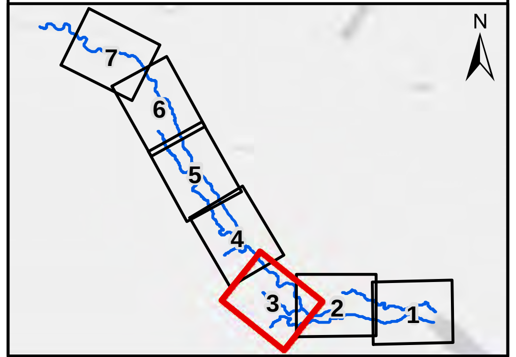


SHEET 4 ↑

SHEET 2 ↓

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

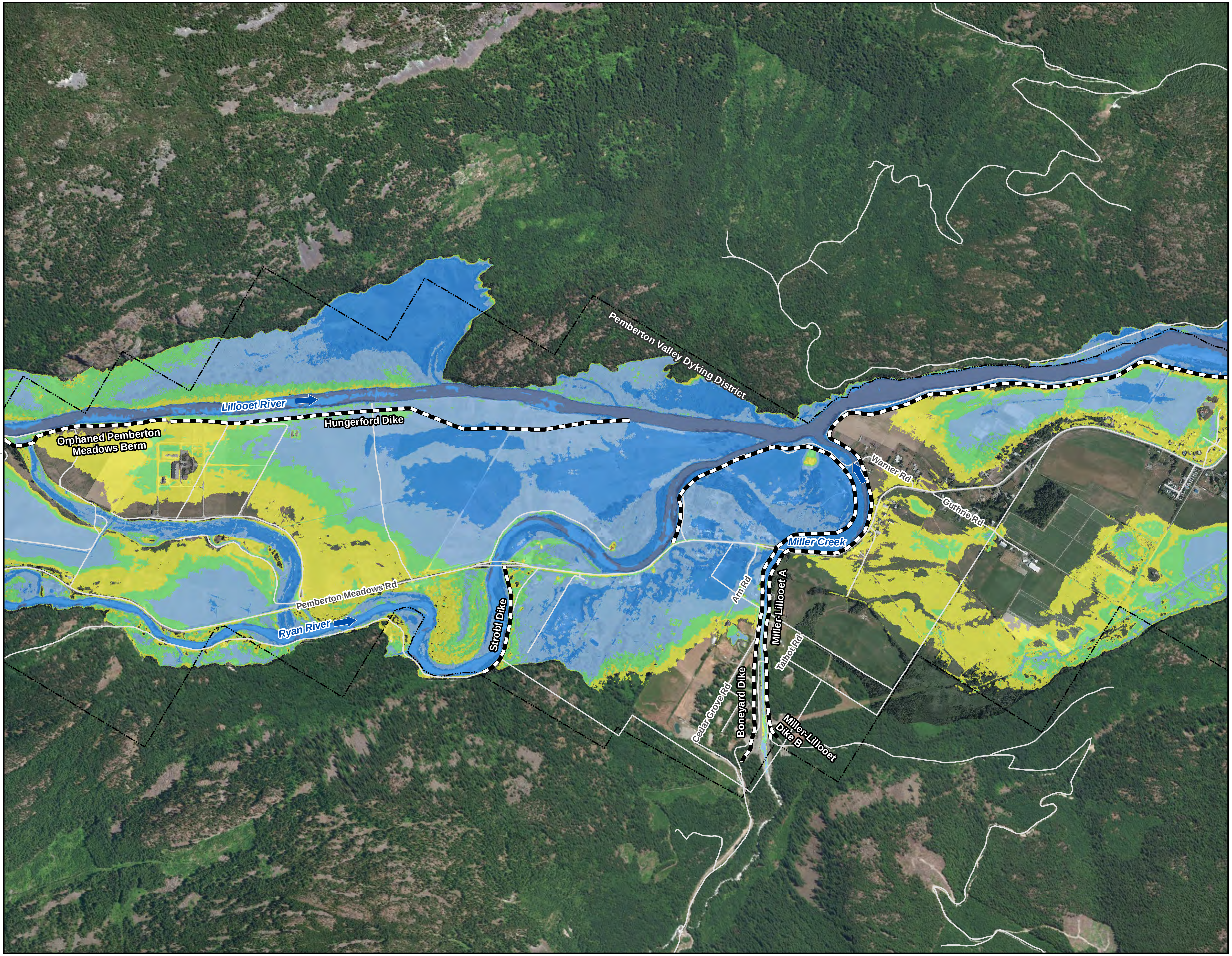
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
50-YEAR LILLOOET EVENT

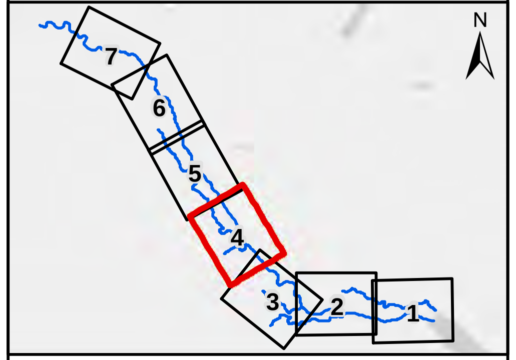
SHEET 3 OF 7

MAO Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

0 to 0.5

0.5 to 1.0

1.0 to 2.0

2.0 to 5.0

> 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

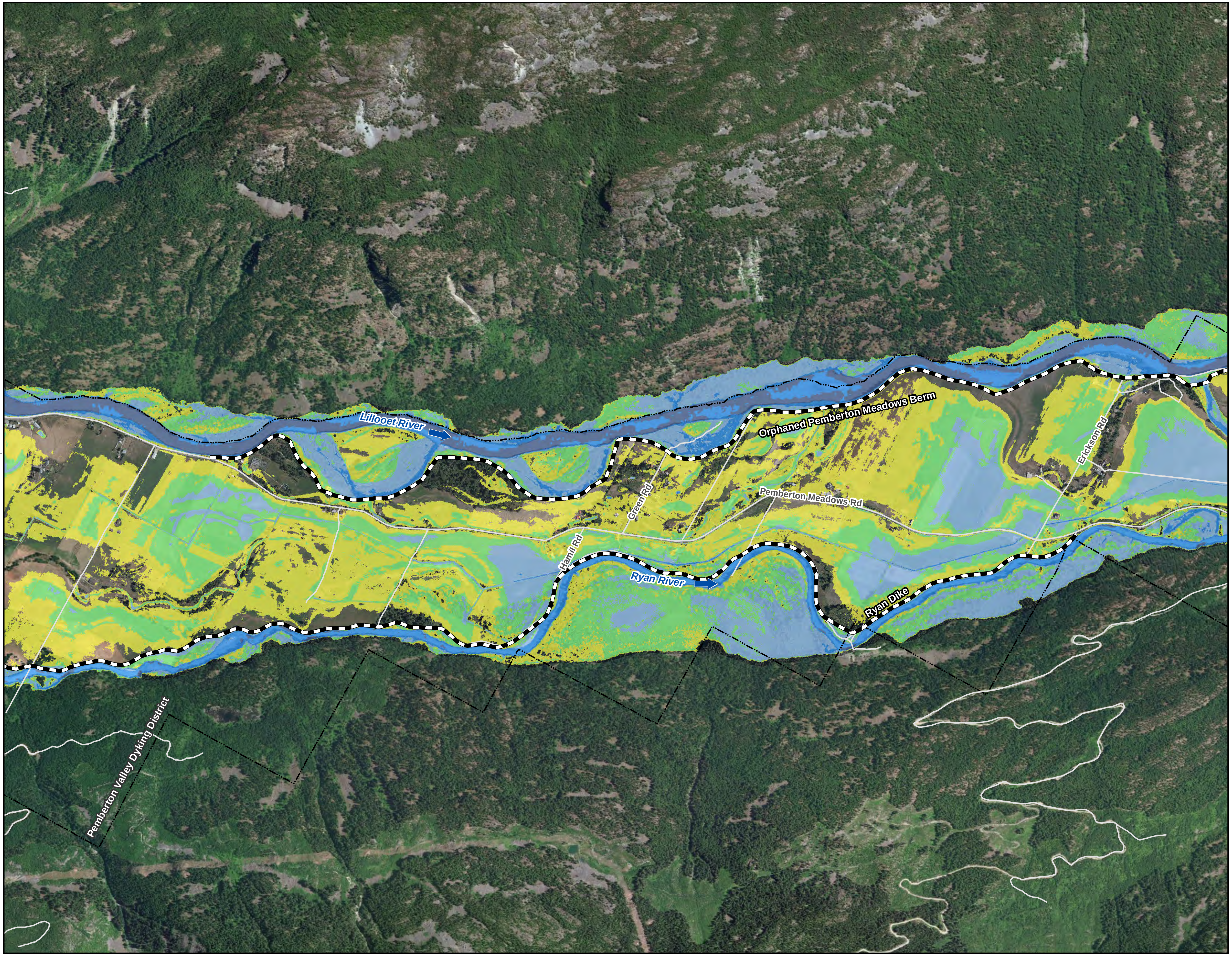
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
50-YEAR LILLOOET EVENT

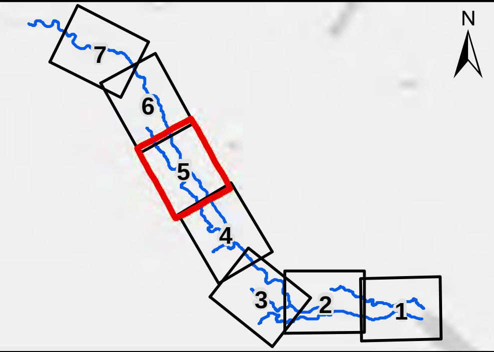
SHEET 4 OF 7

MAO_Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.

0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.

1.0-2.0m: Ground floor flooded; residents evacuate.

2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

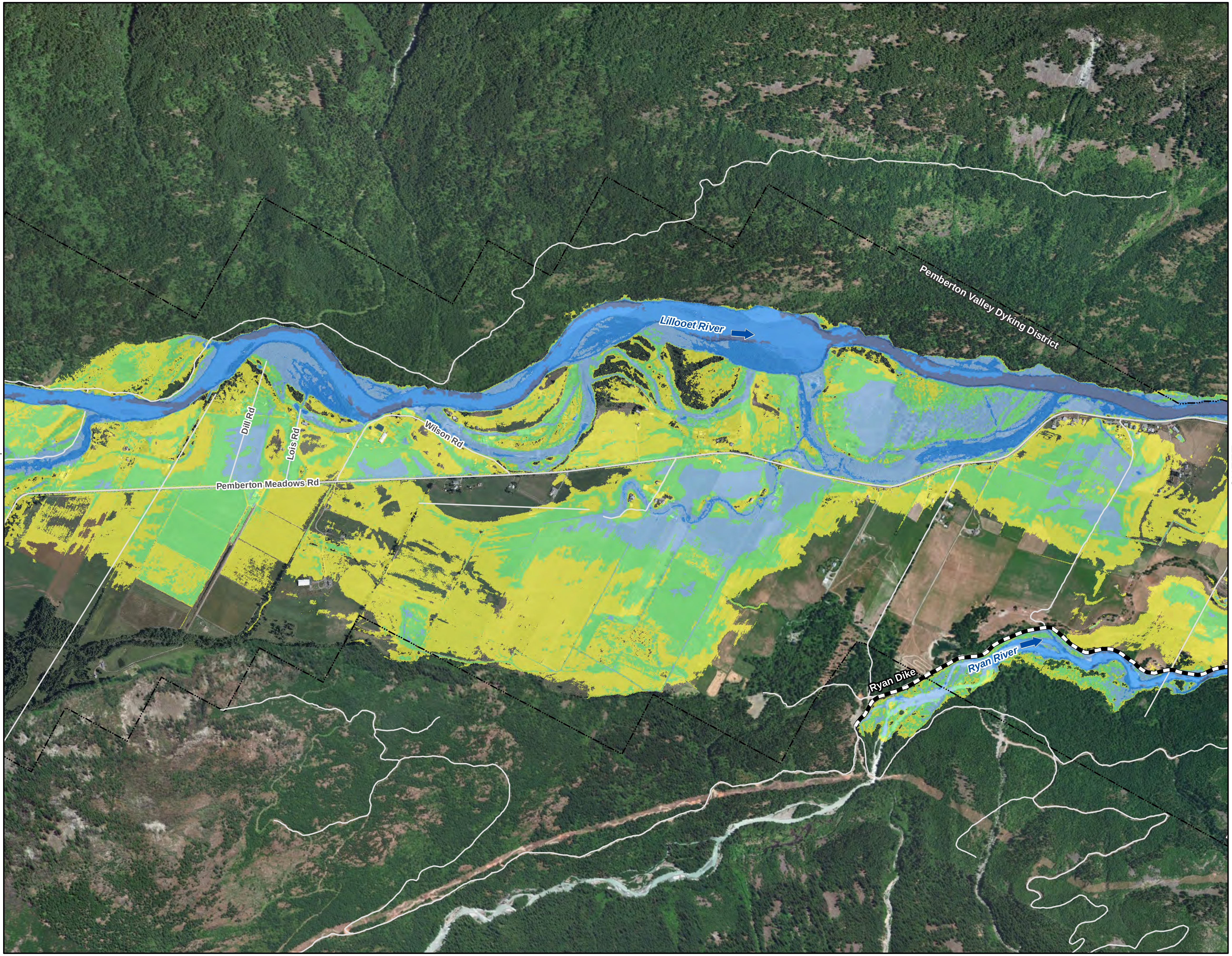
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH 50-YEAR LILLOOET EVENT

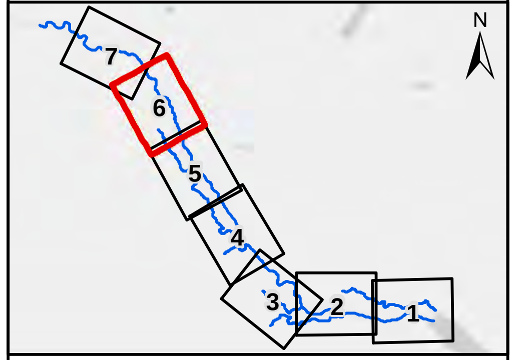
SHEET 5 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

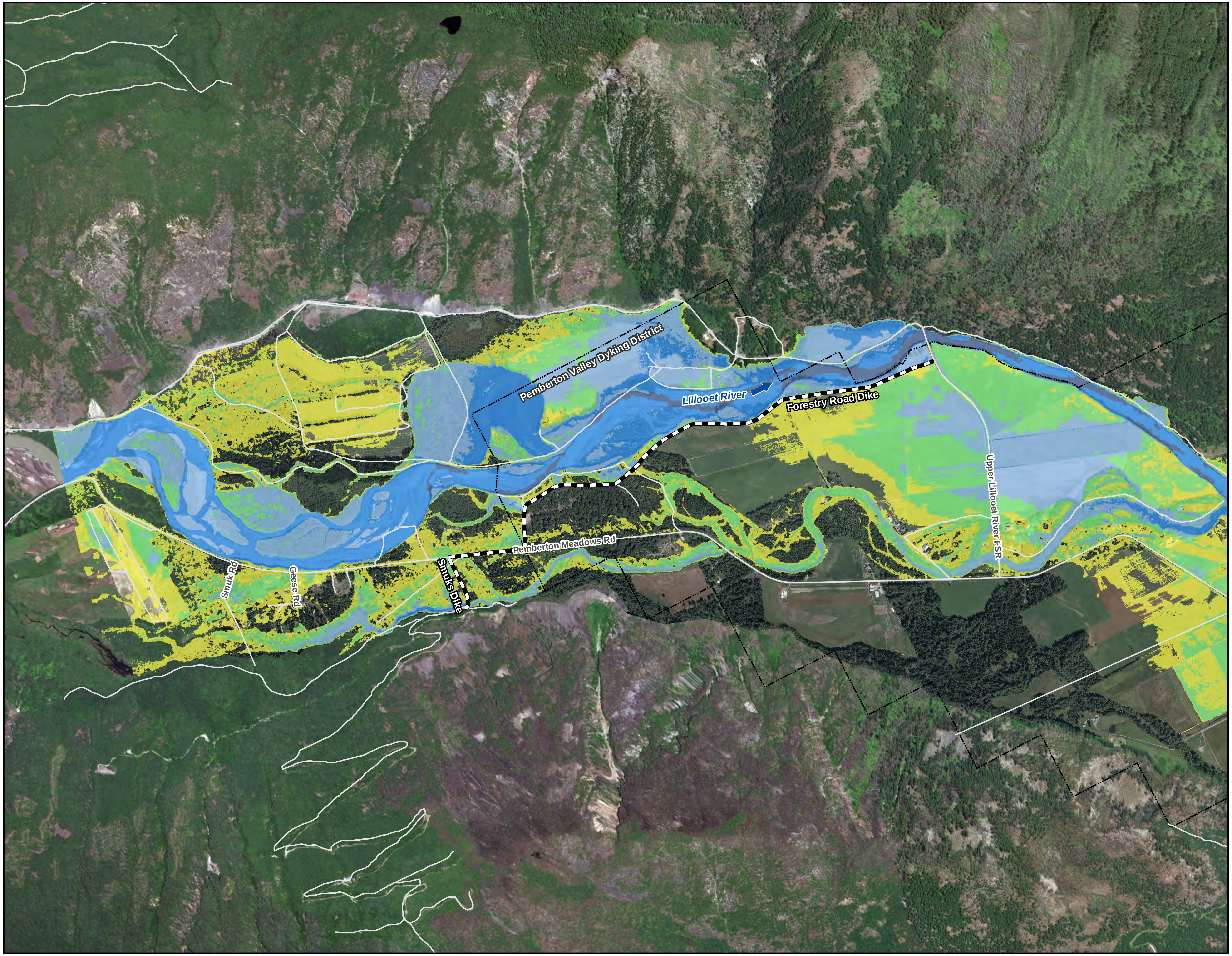
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

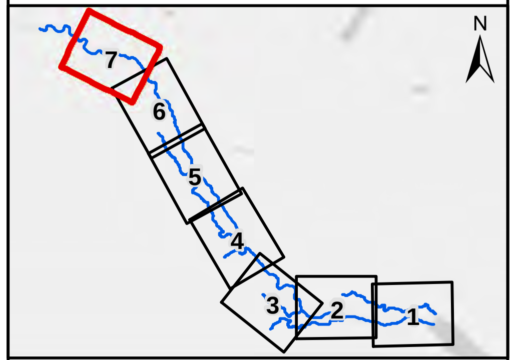
FLOOD DEPTH
50-YEAR LILLOOET EVENT

SHEET 6 OF 7



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

0 to 0.5

0.5 to 1.0

1.0 to 2.0

2.0 to 5.0

> 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

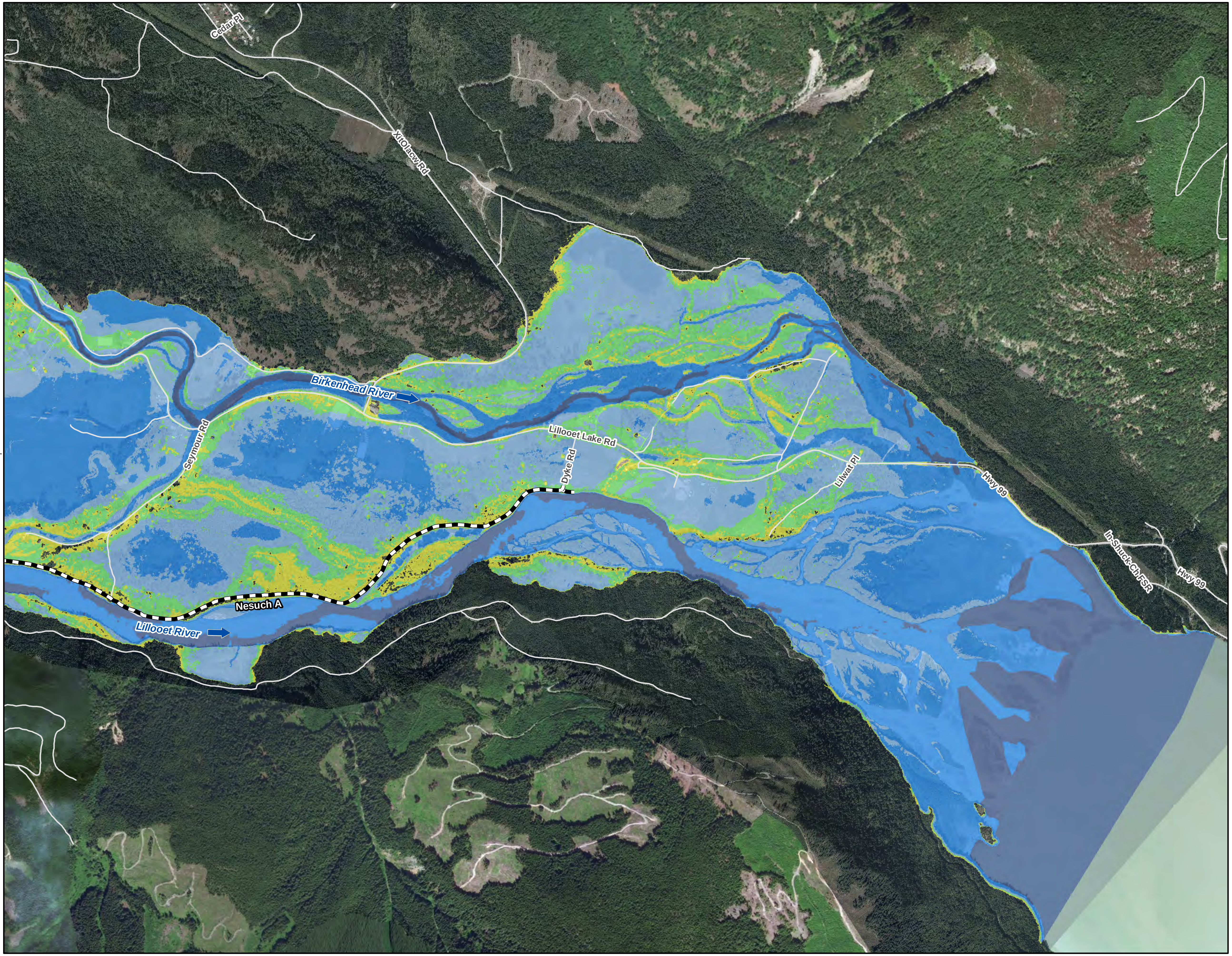
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
50-YEAR LILLOOET EVENT

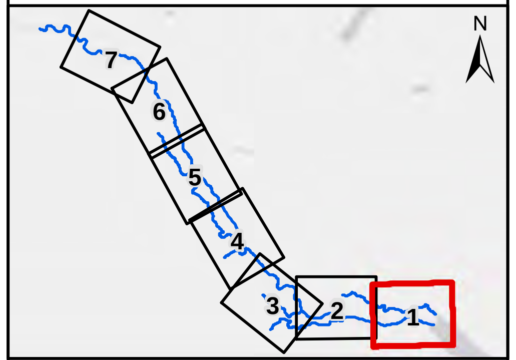
SHEET 7 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

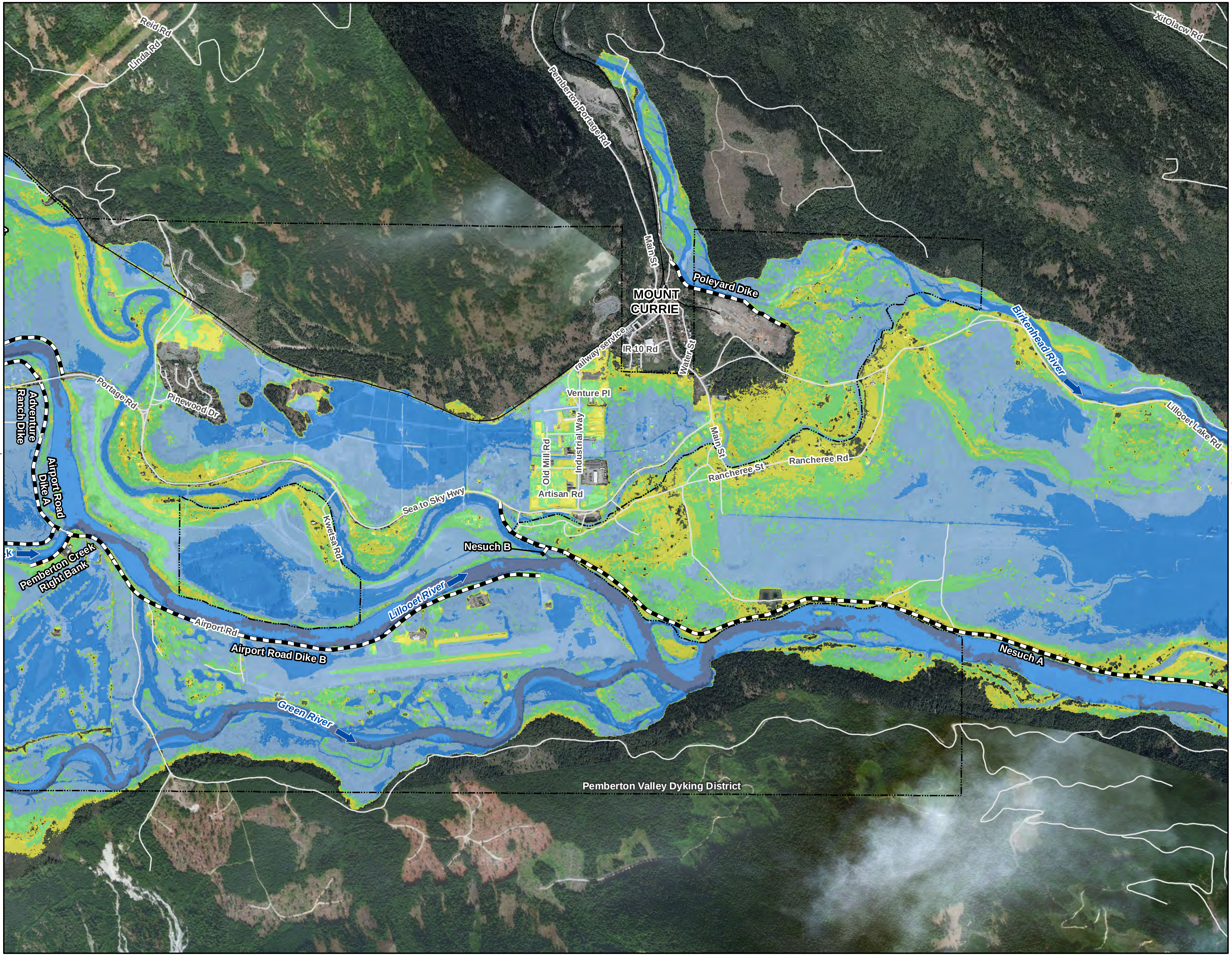
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
100-YEAR LILLOOET EVENT

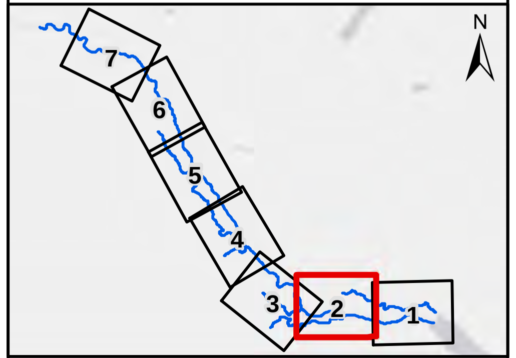
SHEET 1 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

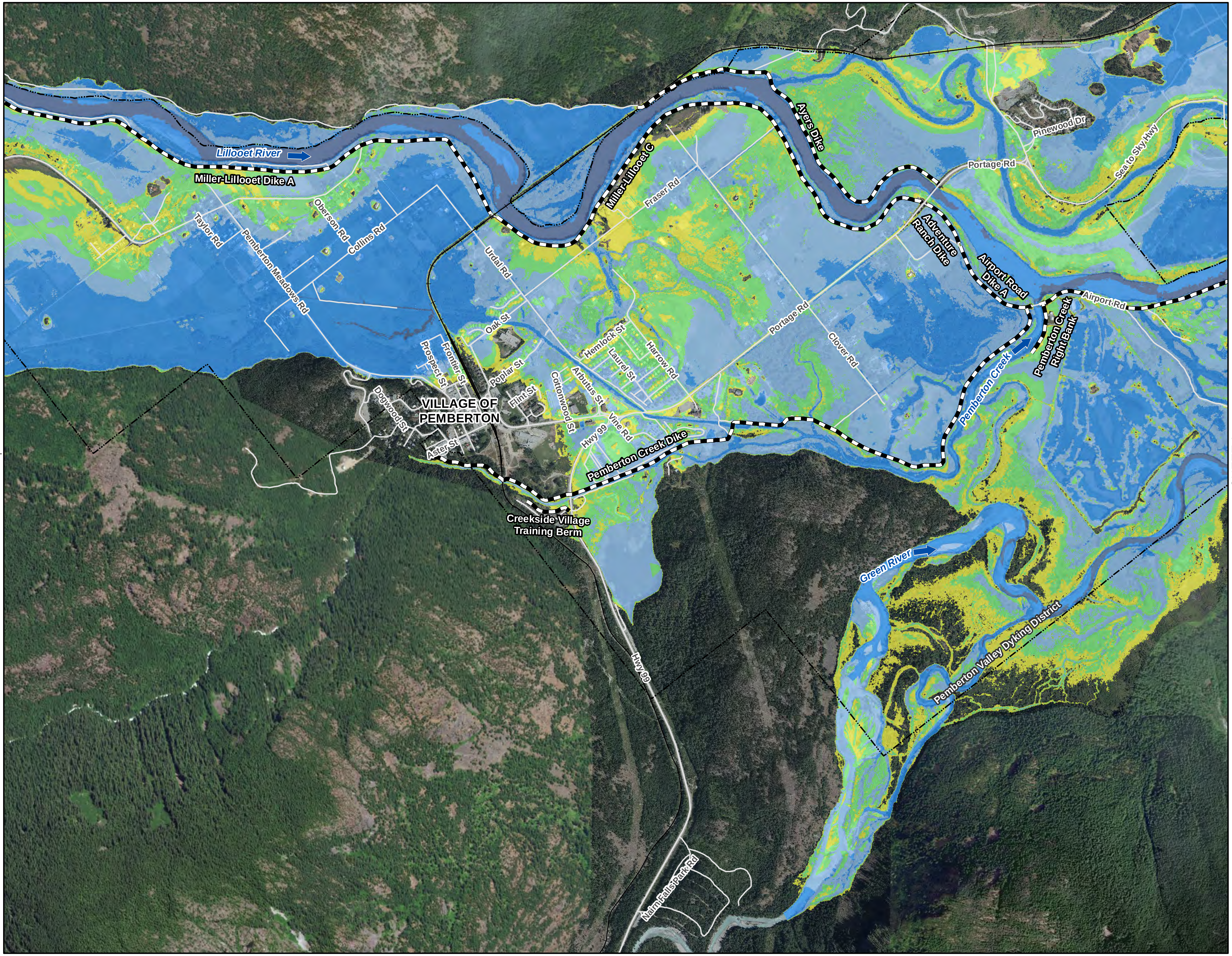
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
100-YEAR LILLOOET EVENT

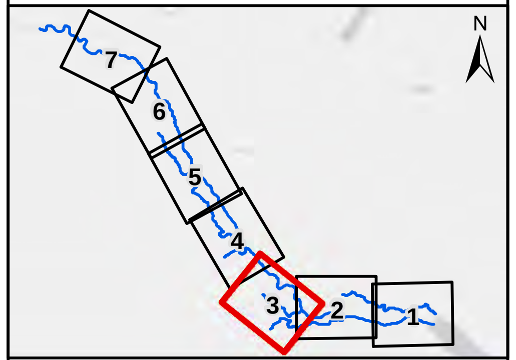
SHEET 2 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

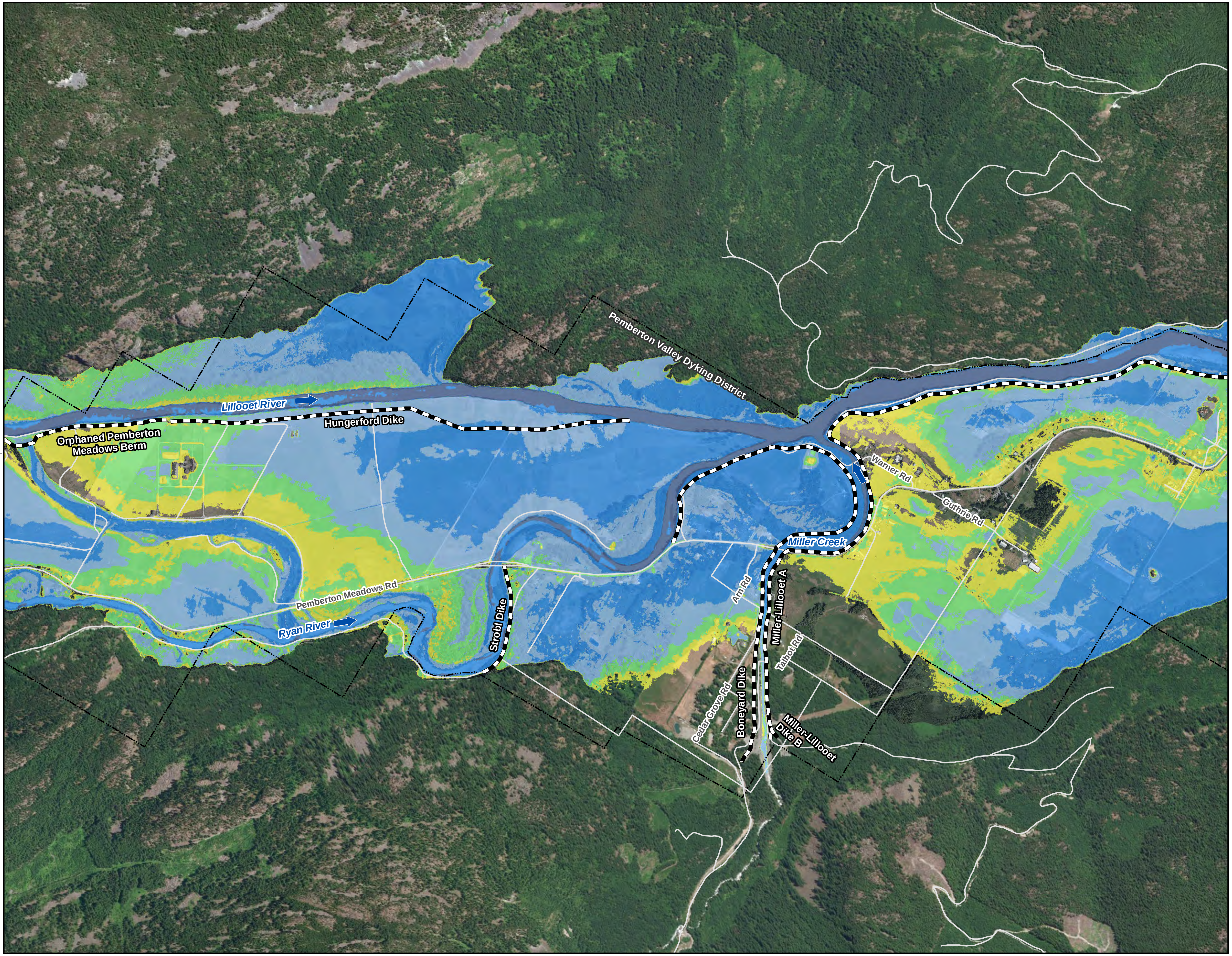
LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
100-YEAR LILLOOET EVENT

SHEET 3 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd

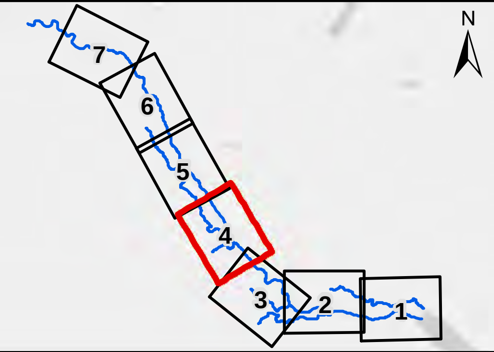
SHEET 5 ↓



SHEET 3 ↓

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

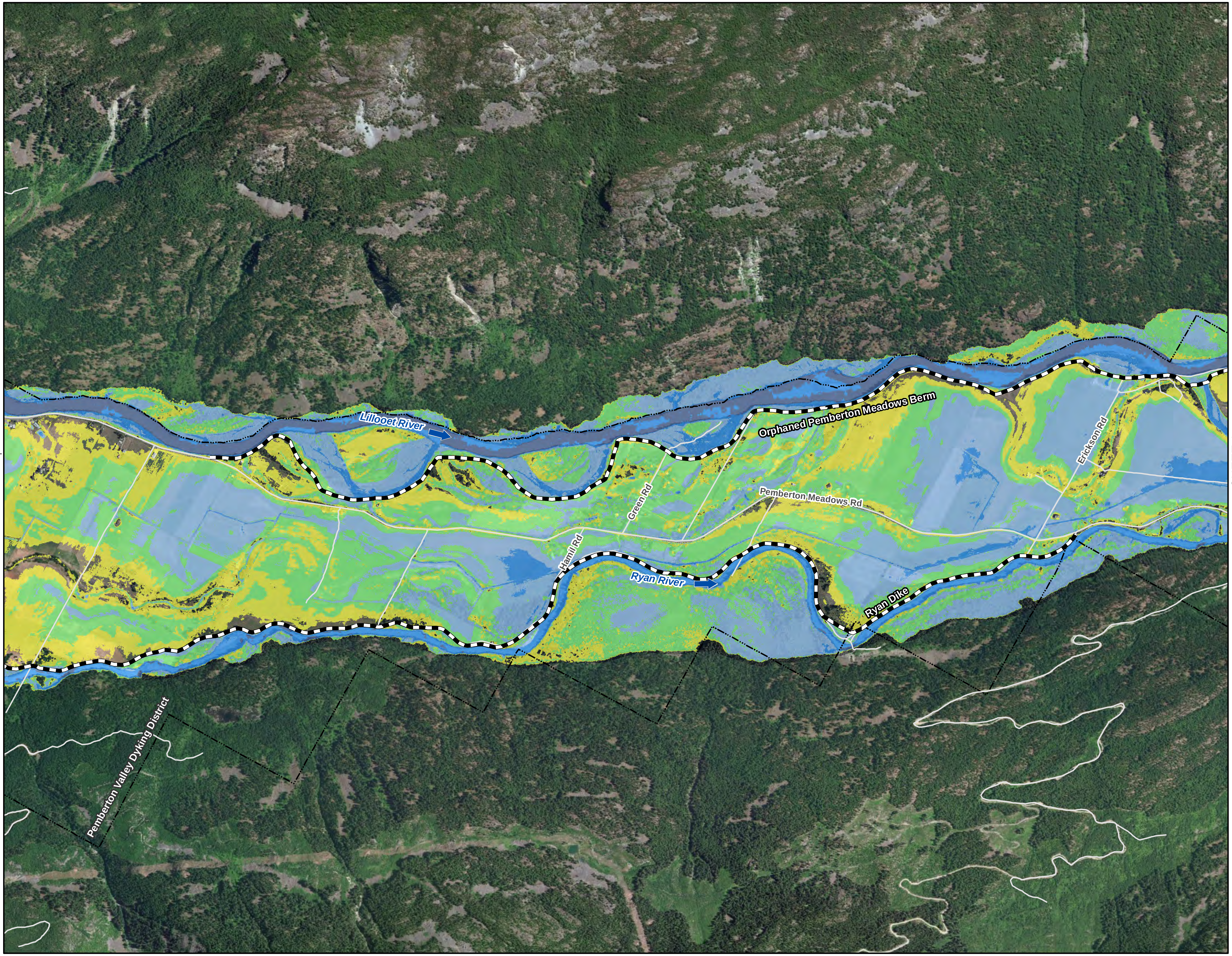
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
100-YEAR LILLOOET EVENT

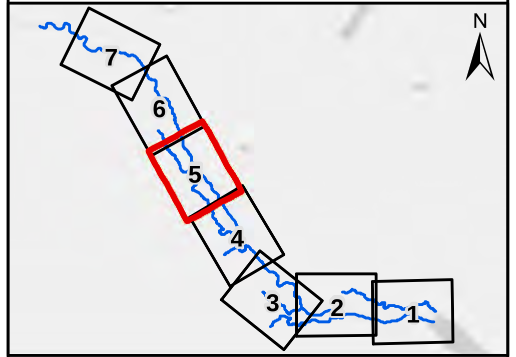
SHEET 4 OF 7

MAO_Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

	0 to 0.5
	0.5 to 1.0
	1.0 to 2.0
	2.0 to 5.0
	> 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

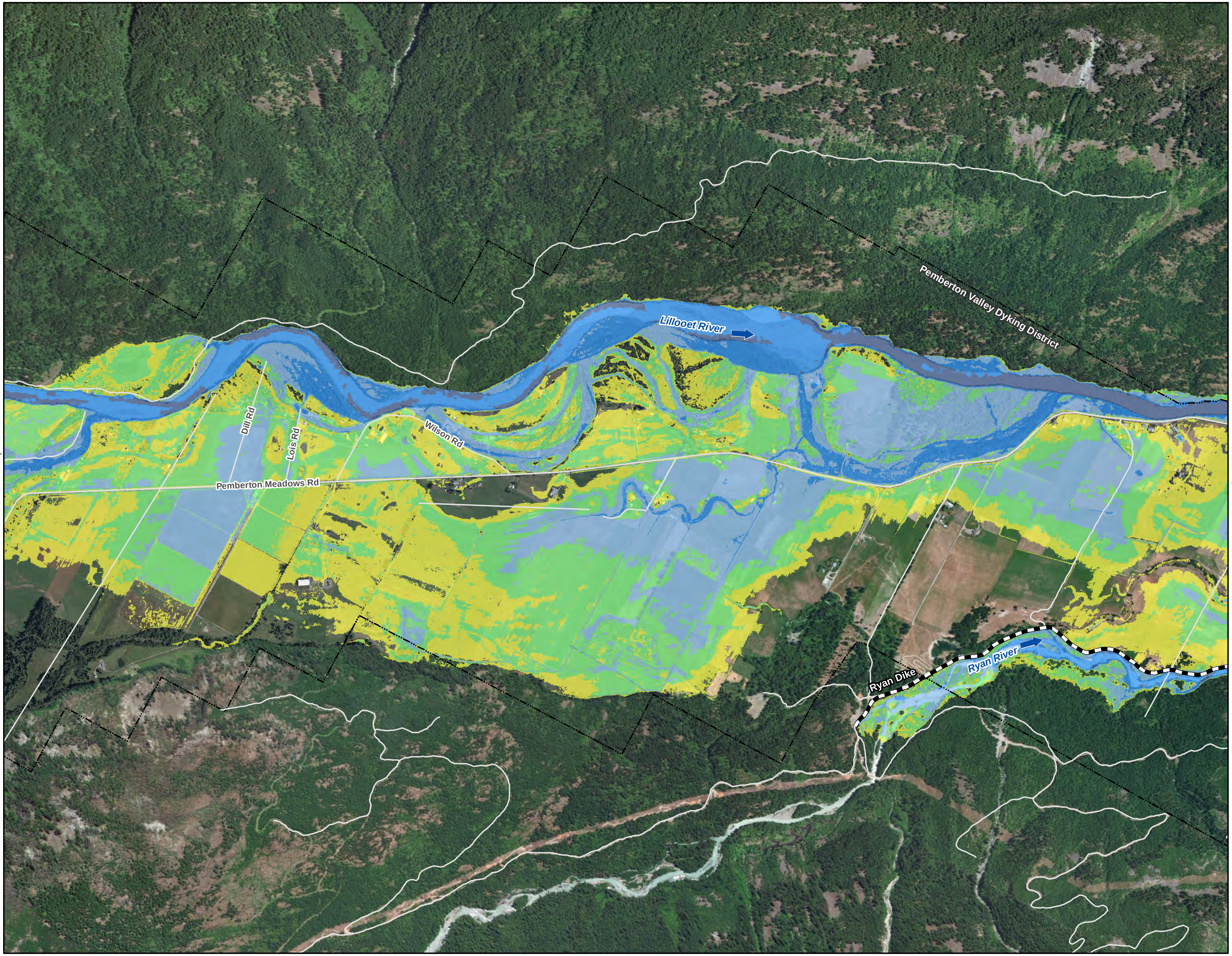
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

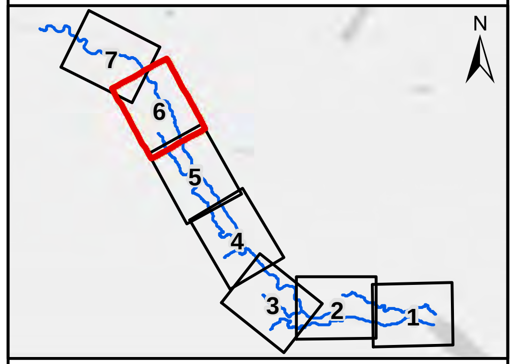
FLOOD DEPTH
100-YEAR LILLOOET EVENT

SHEET 5 OF 7



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

0 to 0.5

0.5 to 1.0

1.0 to 2.0

2.0 to 5.0

> 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	*GIS*	*Reviewer*
CTL	*MAO*	*MCM*

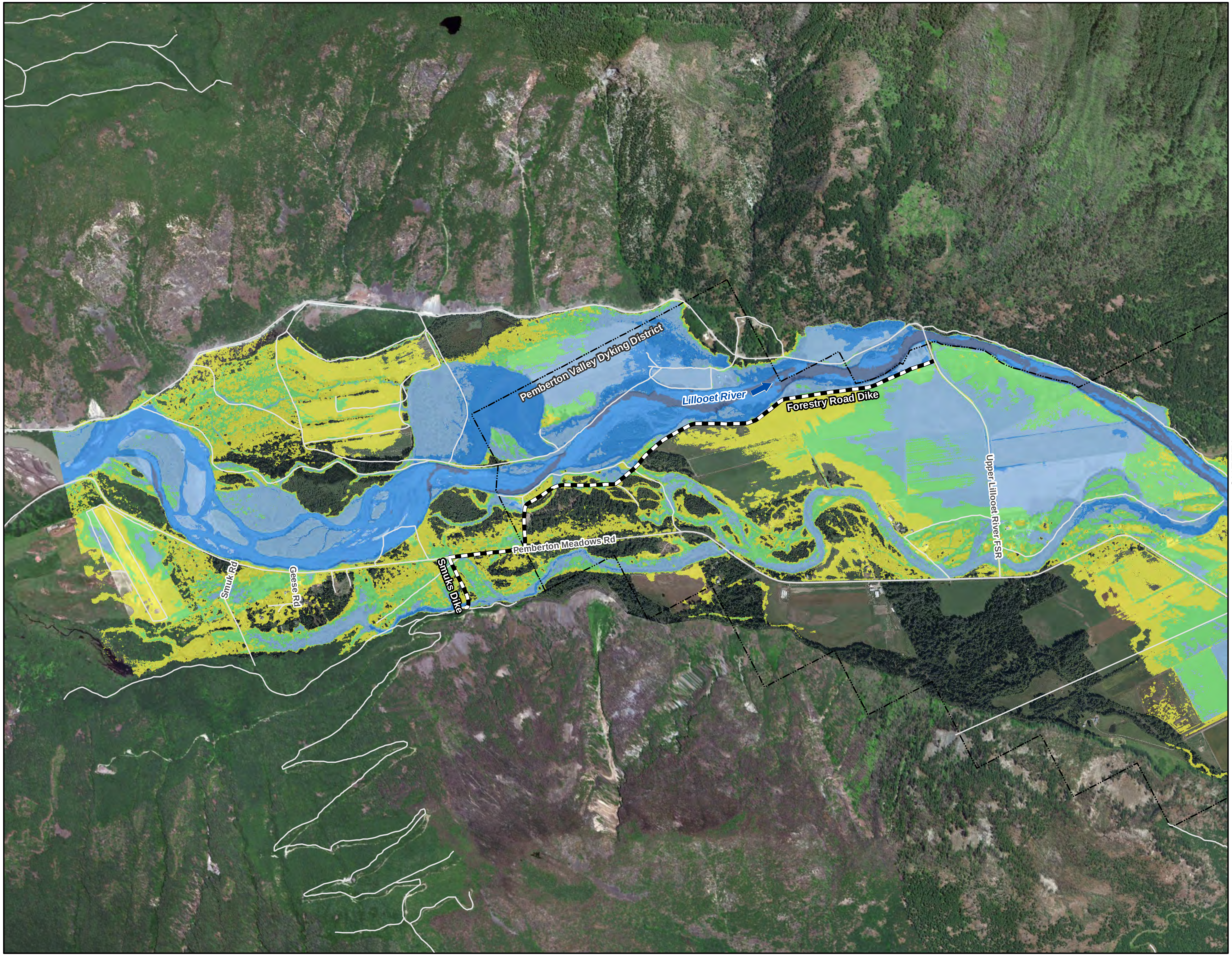
Job Number	*Date*
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
100-YEAR LILLOOET EVENT

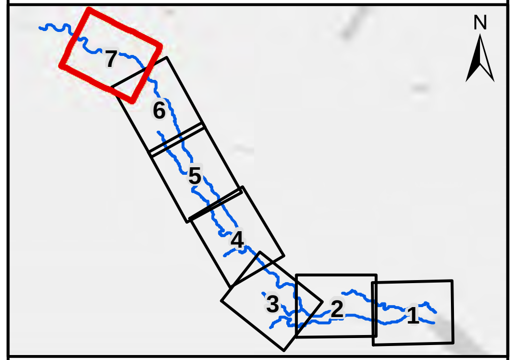
SHEET 6 OF 7

MAO Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



Pemberton Valley Dyking District

nhc
northwest hydraulic consultants



Flow Direction
Dike
Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

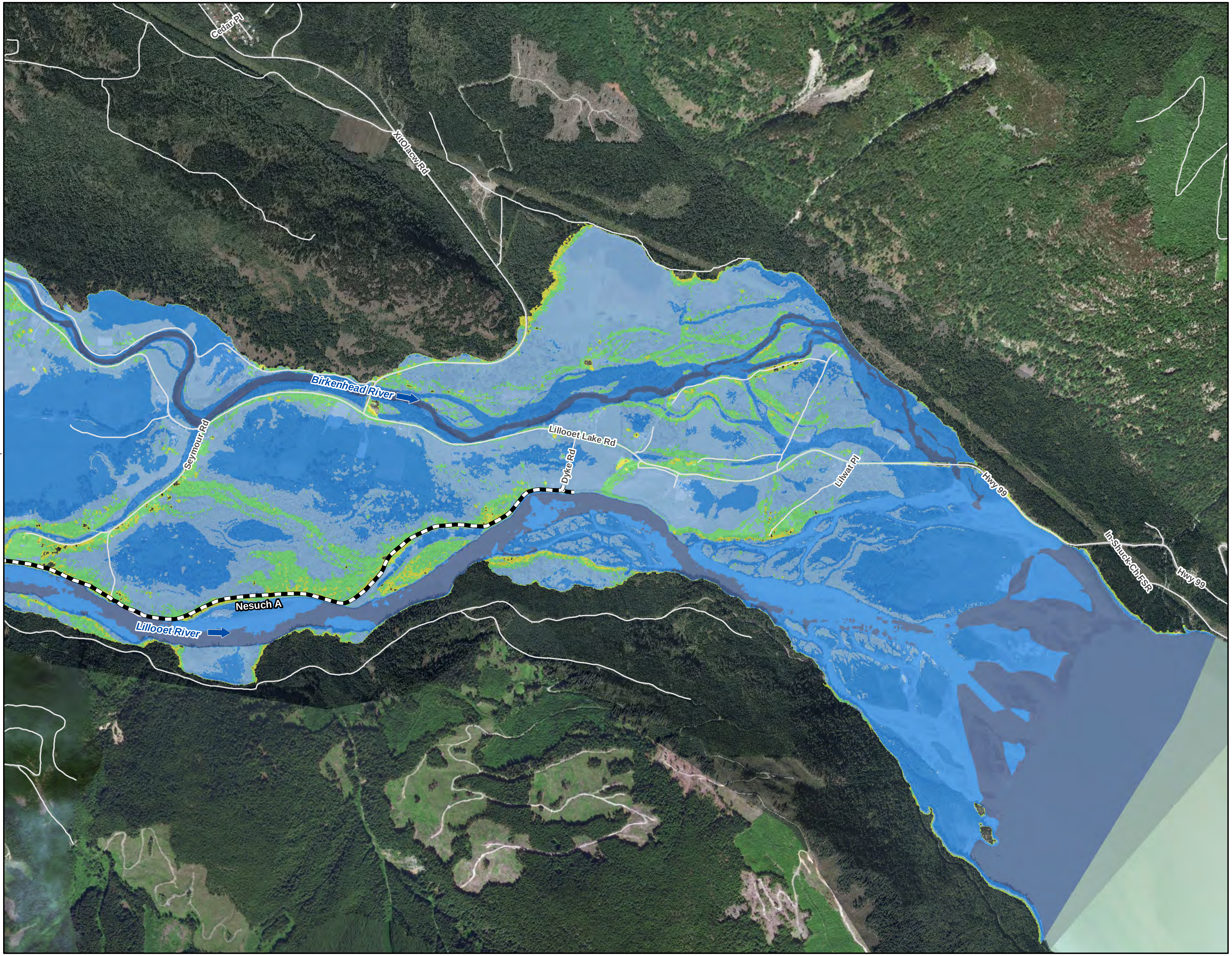
Engineer	GIS	Reviewer
CTL	MAO	MCM
Job Number 3002903	Date 31-AUG-2018	

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
100-YEAR LILLOOET EVENT

SHEET 7 OF 7

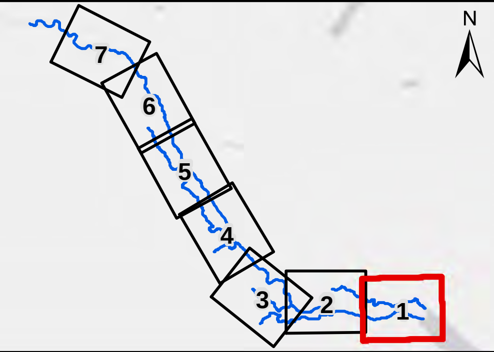
MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



SHEET 2 ↑

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

0 to 0.5

0.5 to 1.0

1.0 to 2.0

2.0 to 5.0

> 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.

0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.

1.0-2.0m: Ground floor flooded; residents evacuate.

2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

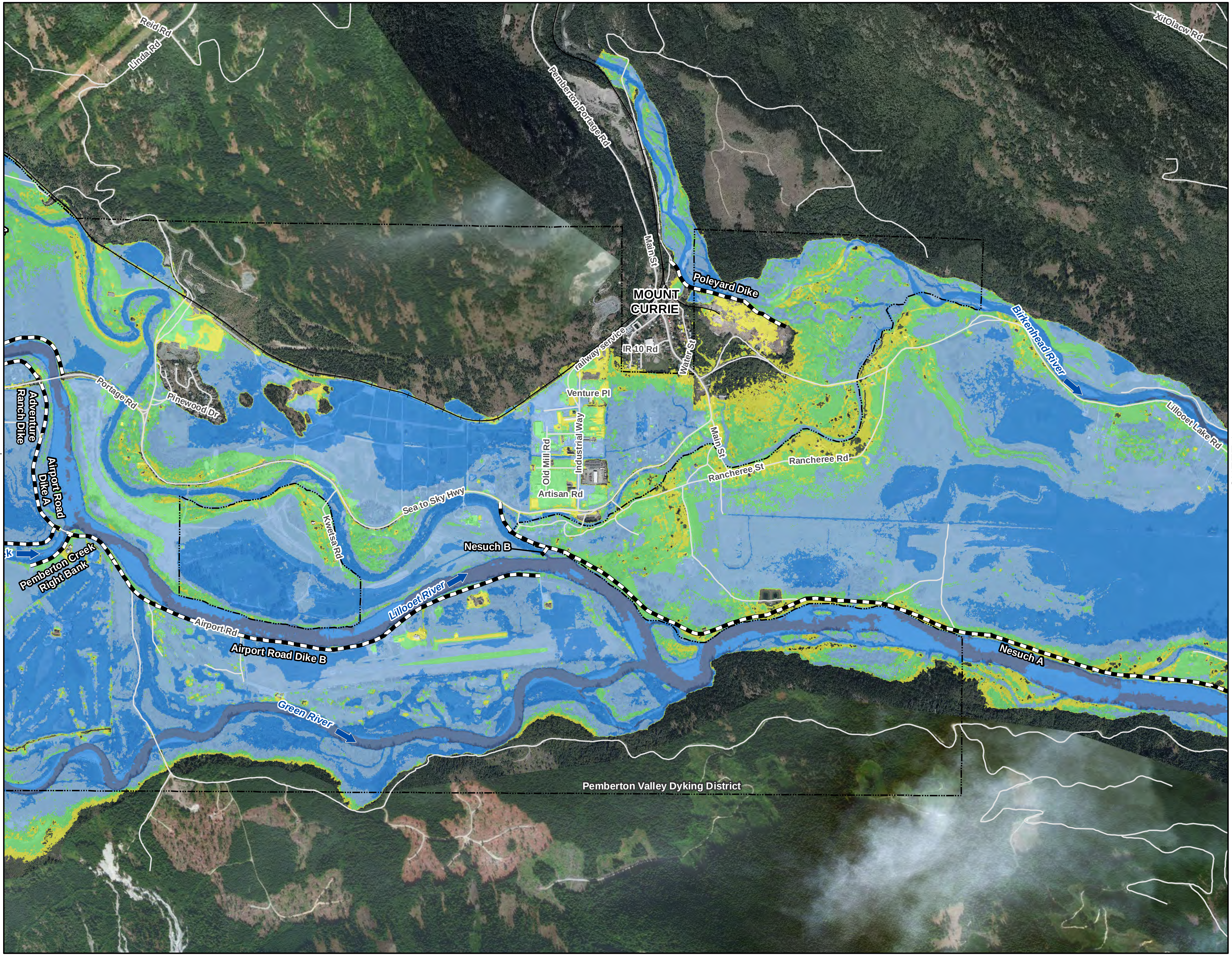
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
200-YEAR LILLOOET EVENT

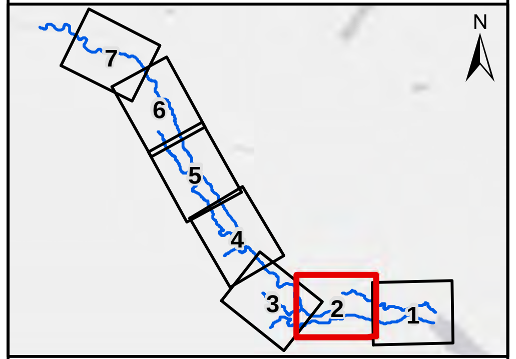
SHEET 1 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000
0 200 400 800 Metres
N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

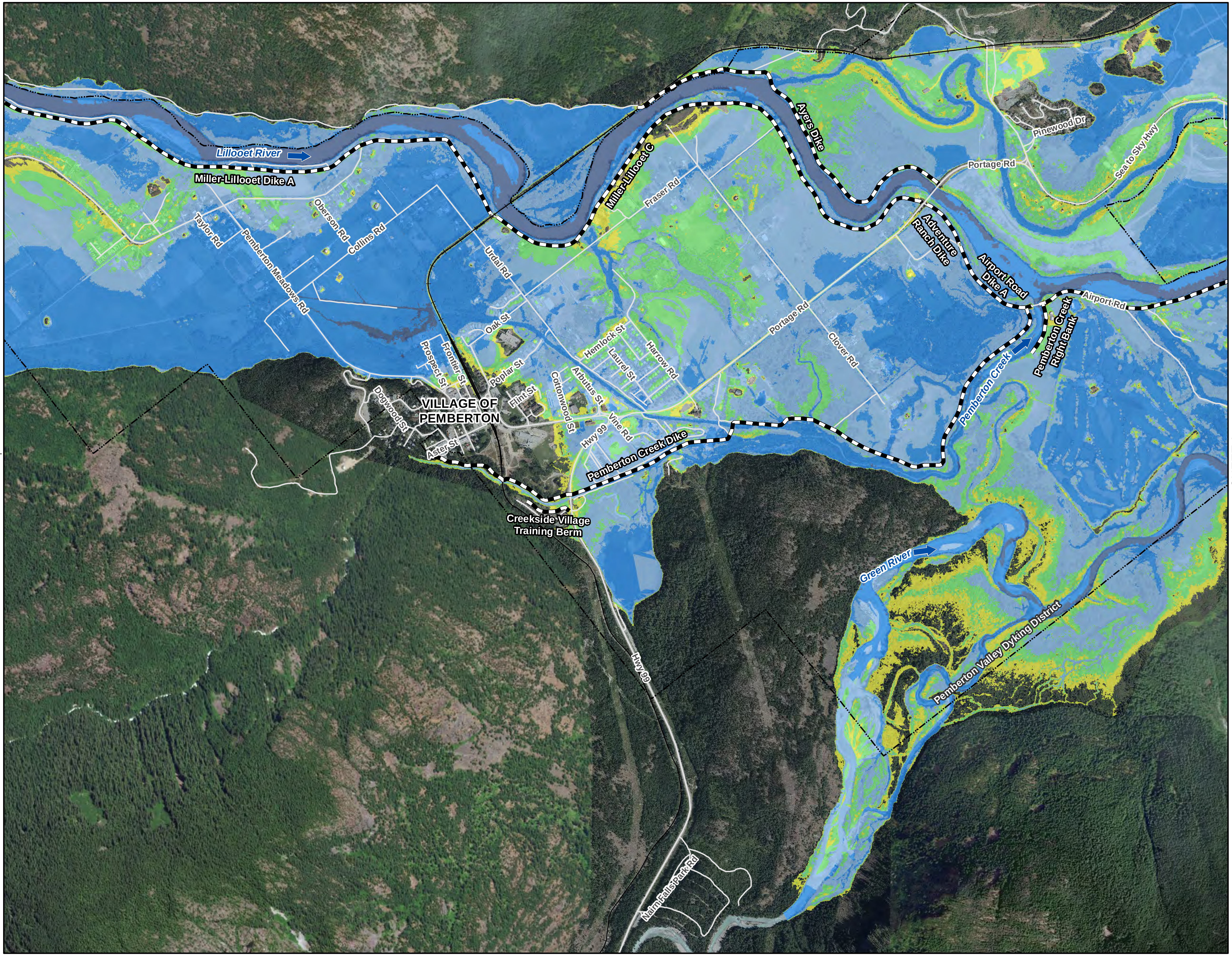
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
200-YEAR LILLOOET EVENT

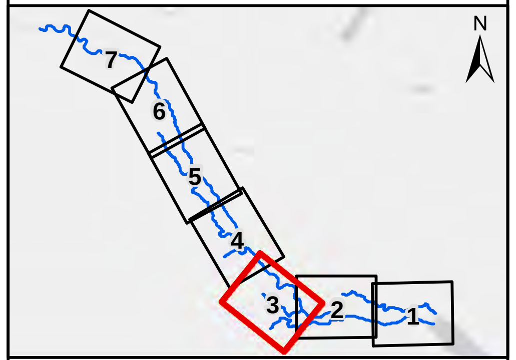
SHEET 2 OF 7

MAO Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

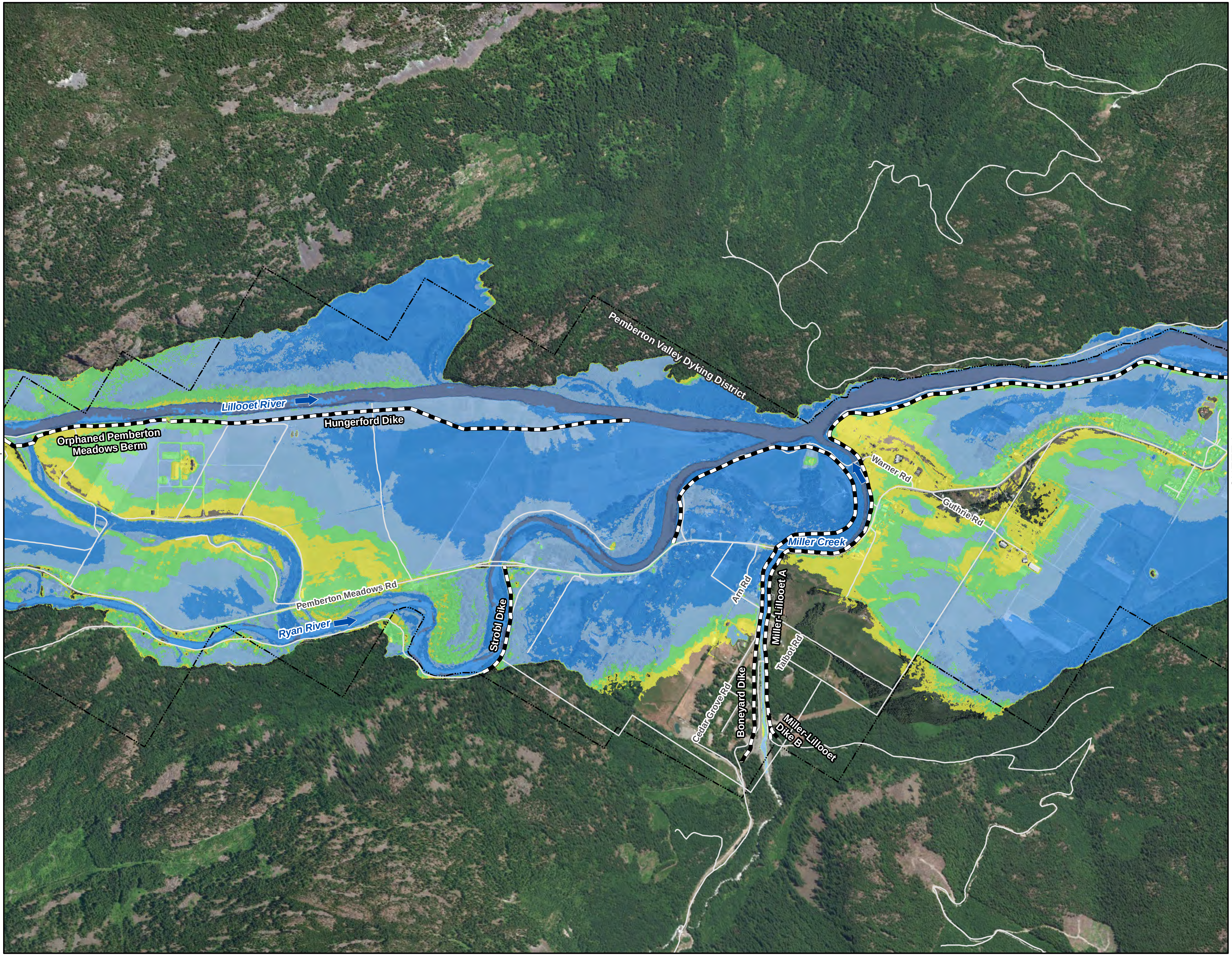
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

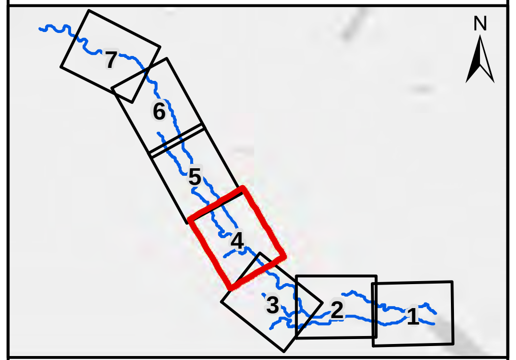
FLOOD DEPTH
200-YEAR LILLOOET EVENT

SHEET 3 OF 7



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

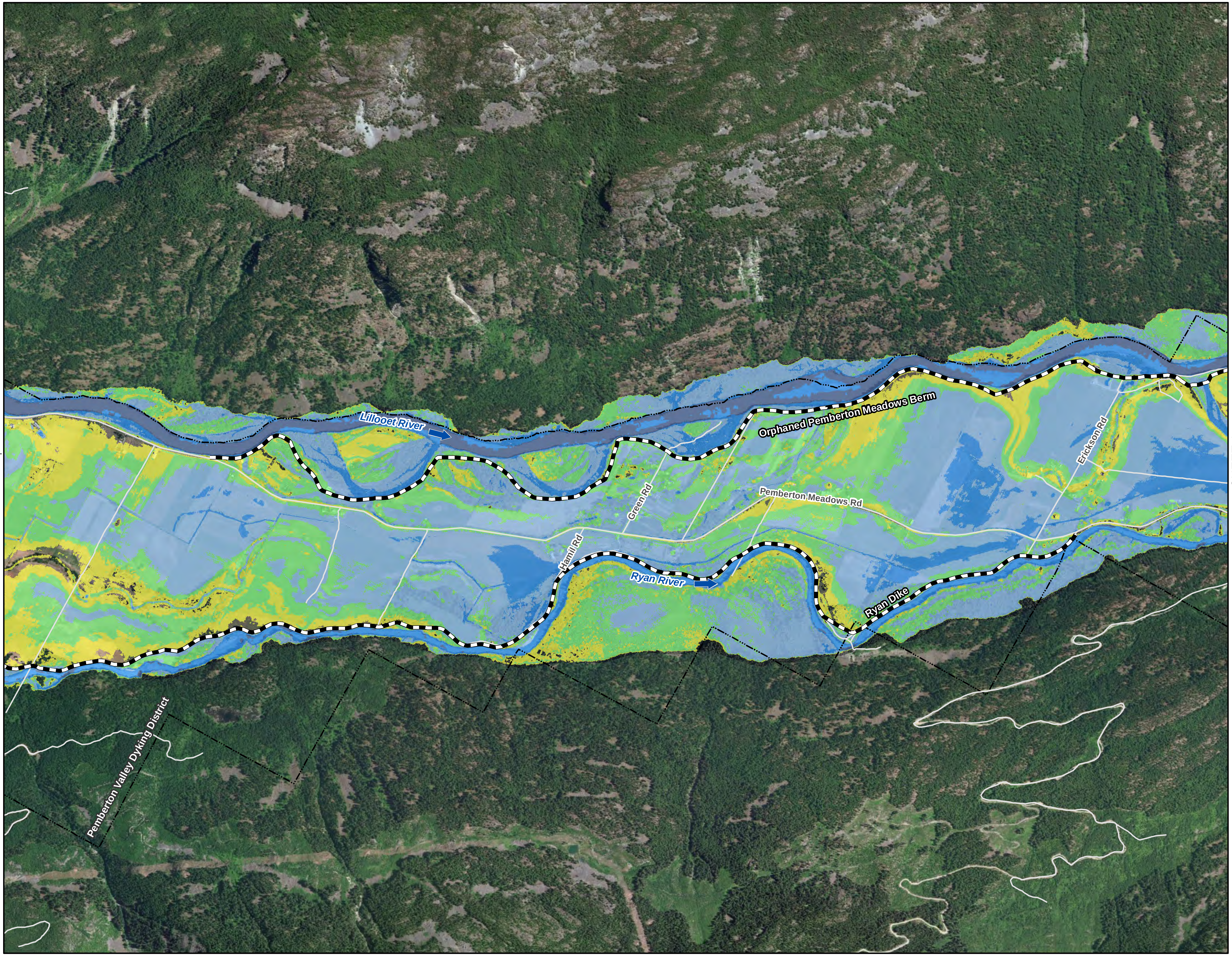
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
200-YEAR LILLOOET EVENT

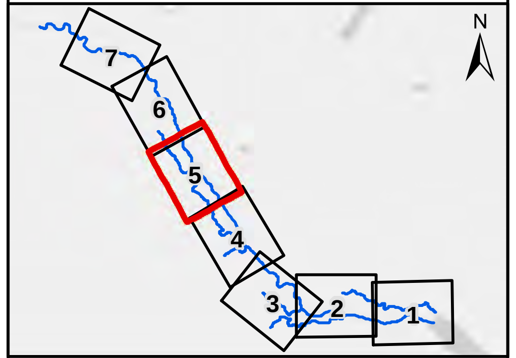
SHEET 4 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction
Dike
Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

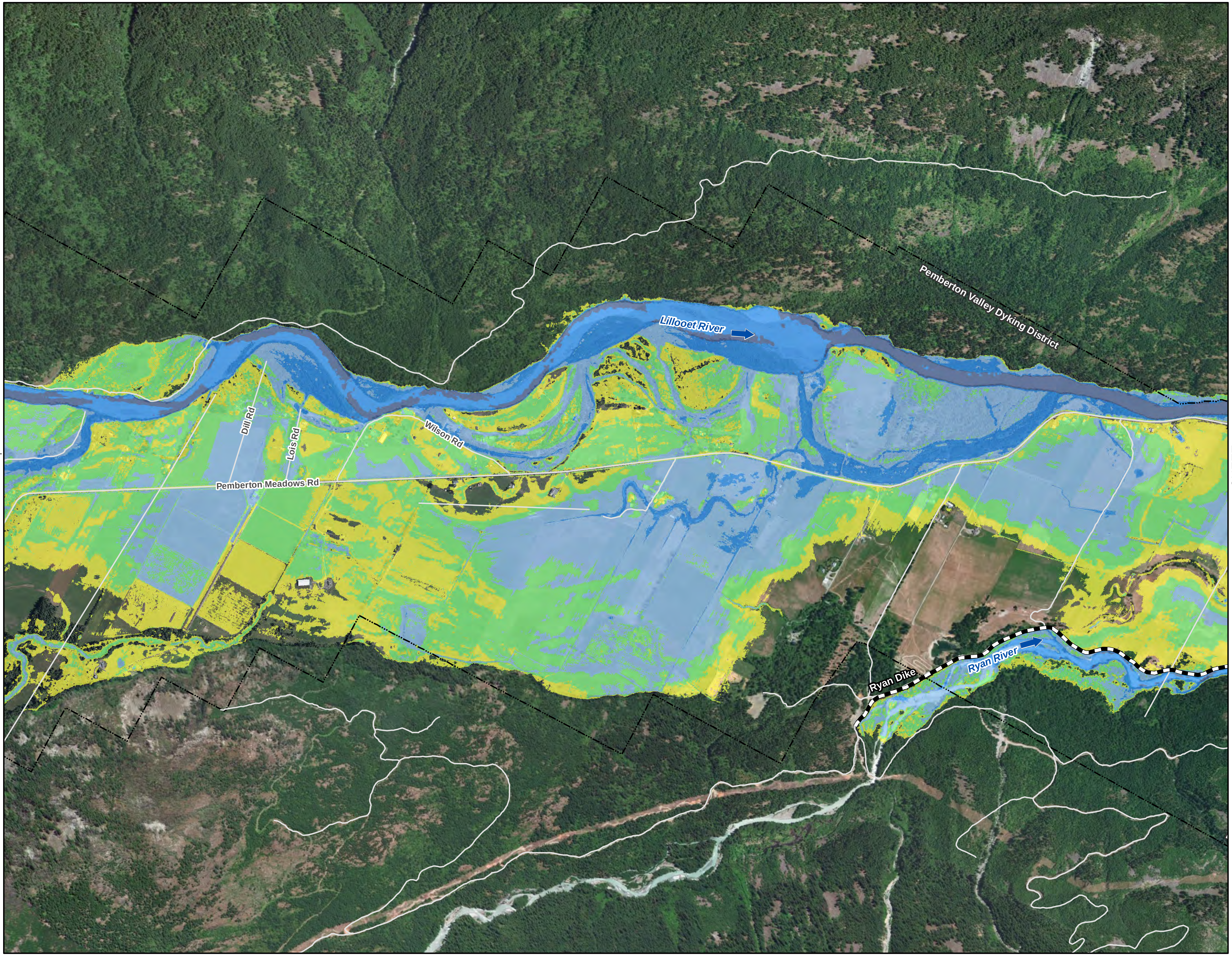
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
200-YEAR LILLOOET EVENT

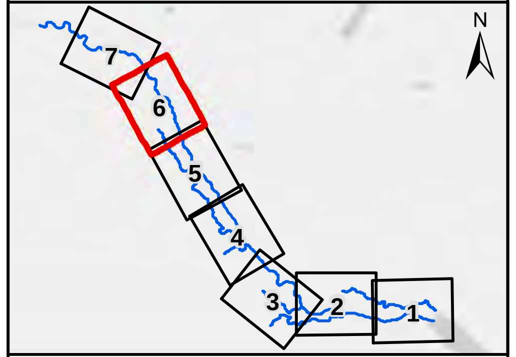
SHEET 5 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.
0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.
1.0-2.0m: Ground floor flooded; residents evacuate.
2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

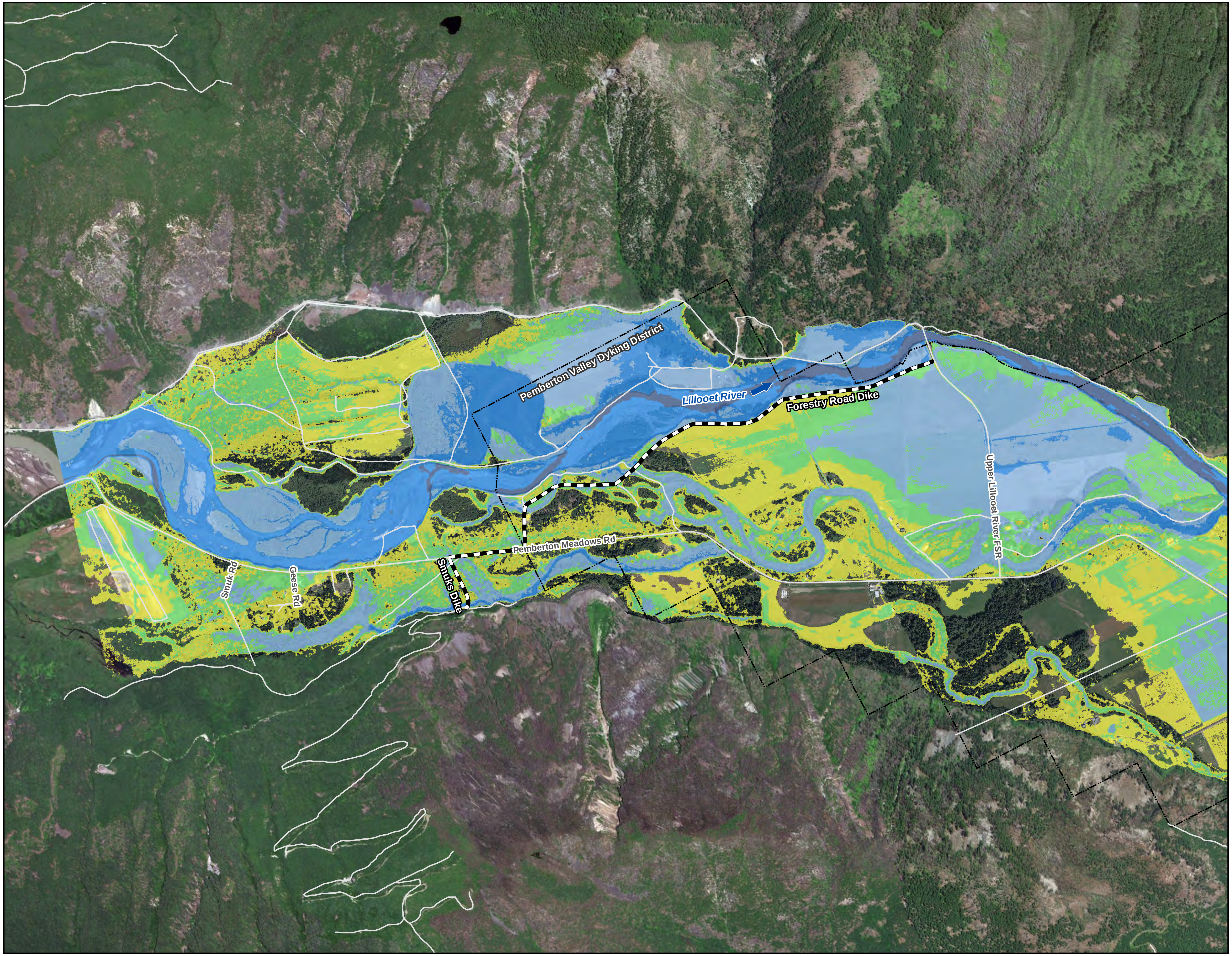
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
200-YEAR LILLOOET EVENT

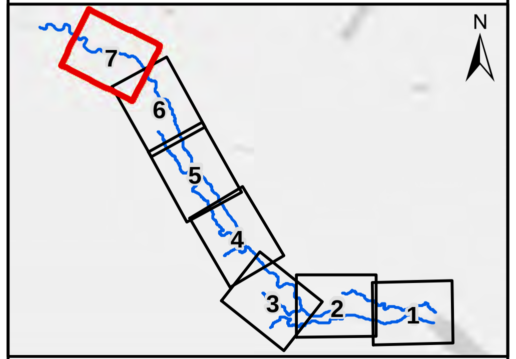
SHEET 6 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY
DYKING DISTRICT

nhc
northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Depth (m)

0 to 0.5

0.5 to 1.0

1.0 to 2.0

2.0 to 5.0

> 5.0; River

0-0.5m: Most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation.

0.5-1.0m: Water on ground floor; basements and underground parking flooded, potentially causing evacuation; electricity failed; vehicles are commonly carried off roadways.

1.0-2.0m: Ground floor flooded; residents evacuate.

2.0-5.0m: First floor and often roof covered by water; residents evacuate.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

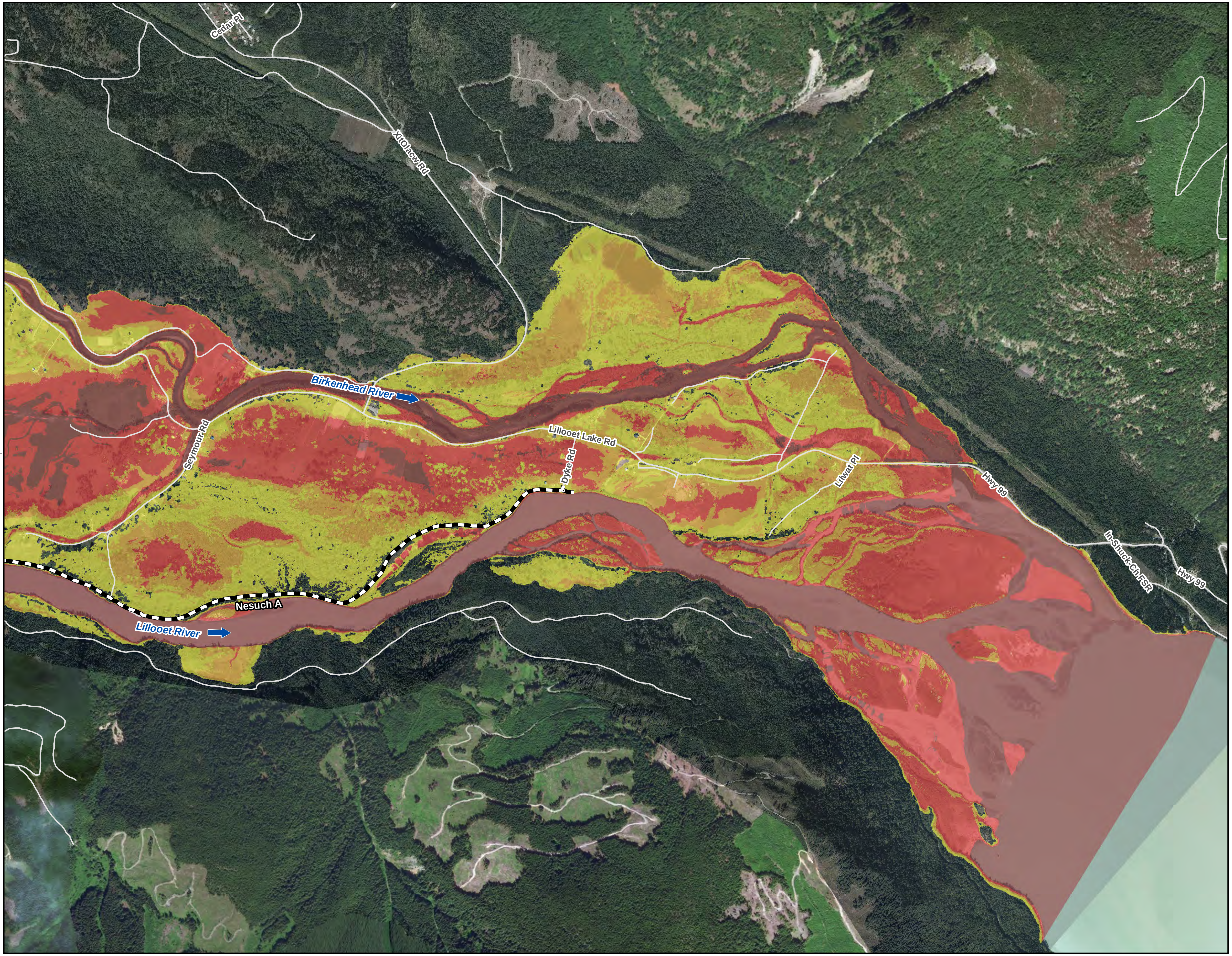
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD DEPTH
200-YEAR LILLOOET EVENT

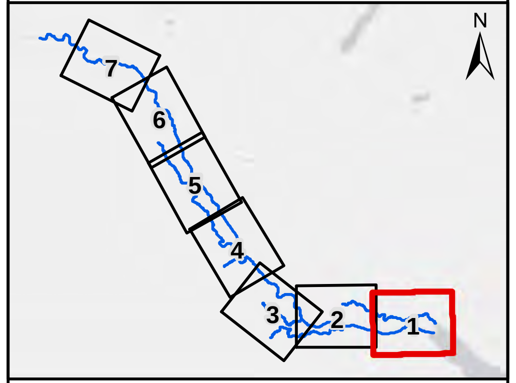
SHEET 7 OF 7

MAO Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Depth.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	*GIS*	*Reviewer*
CTL	*MAO*	*MCM*

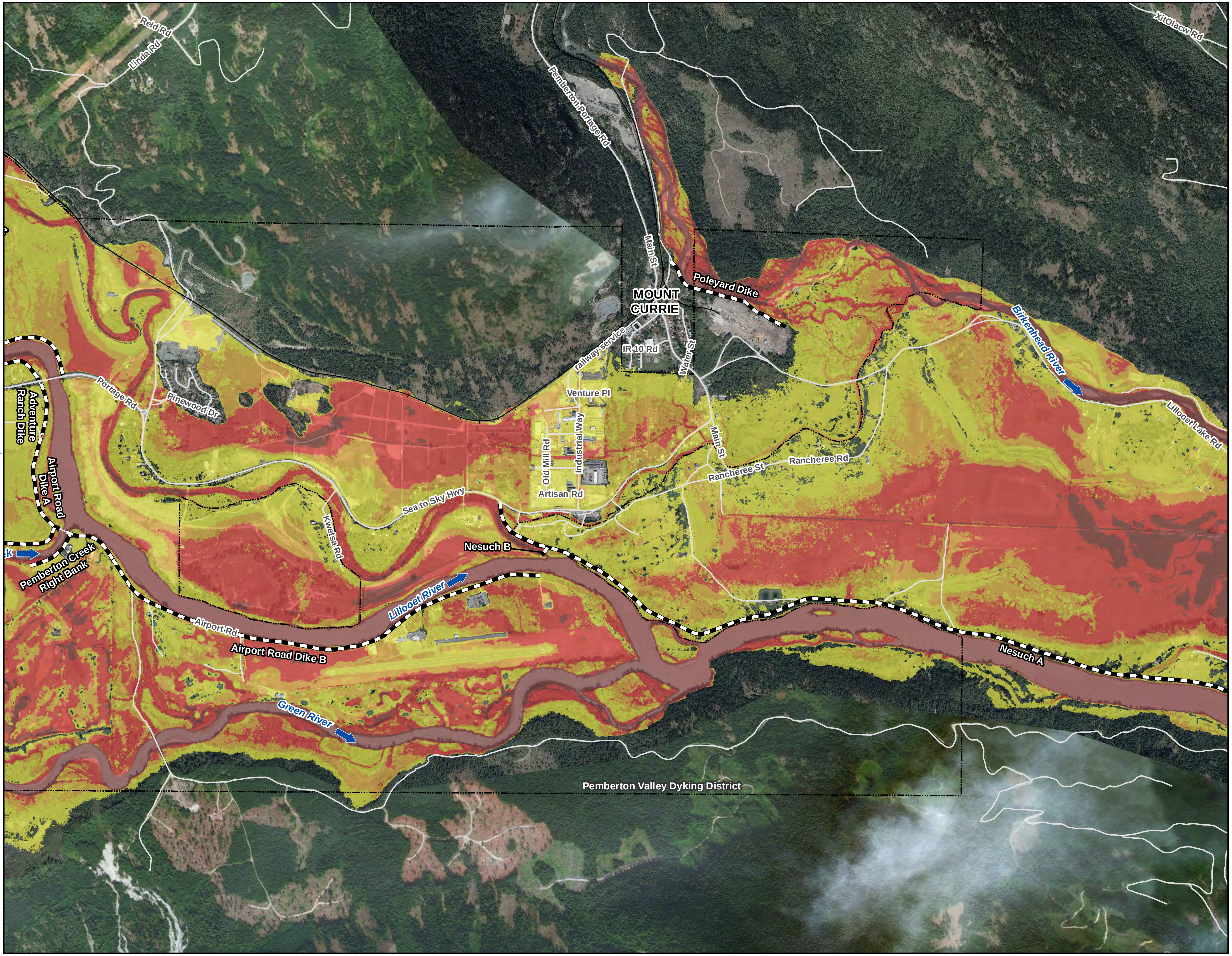
Job Number	*Date*
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
50-YEAR LILLOOET EVENT

SHEET 1 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants

N

1 2 3 4 5 6 7

Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

N

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

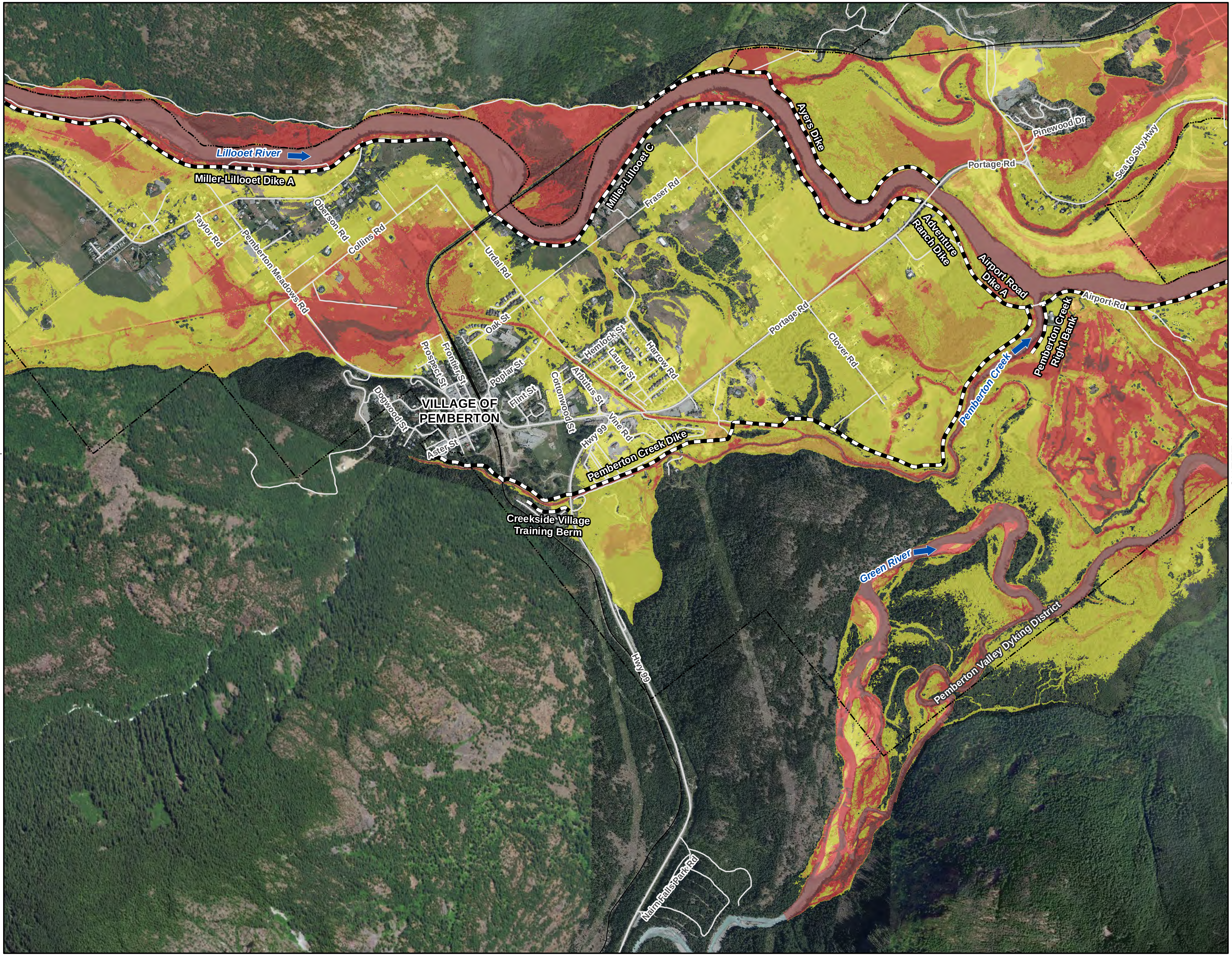
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING 50-YEAR LILLOOET EVENT

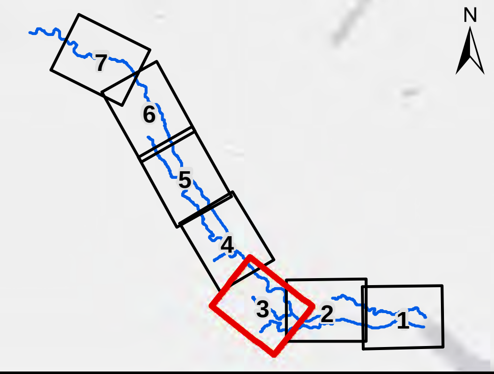
SHEET 2 OF 7

MAO_Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	*GIS*	*Reviewer*
CTL	*MAO*	*MCM*

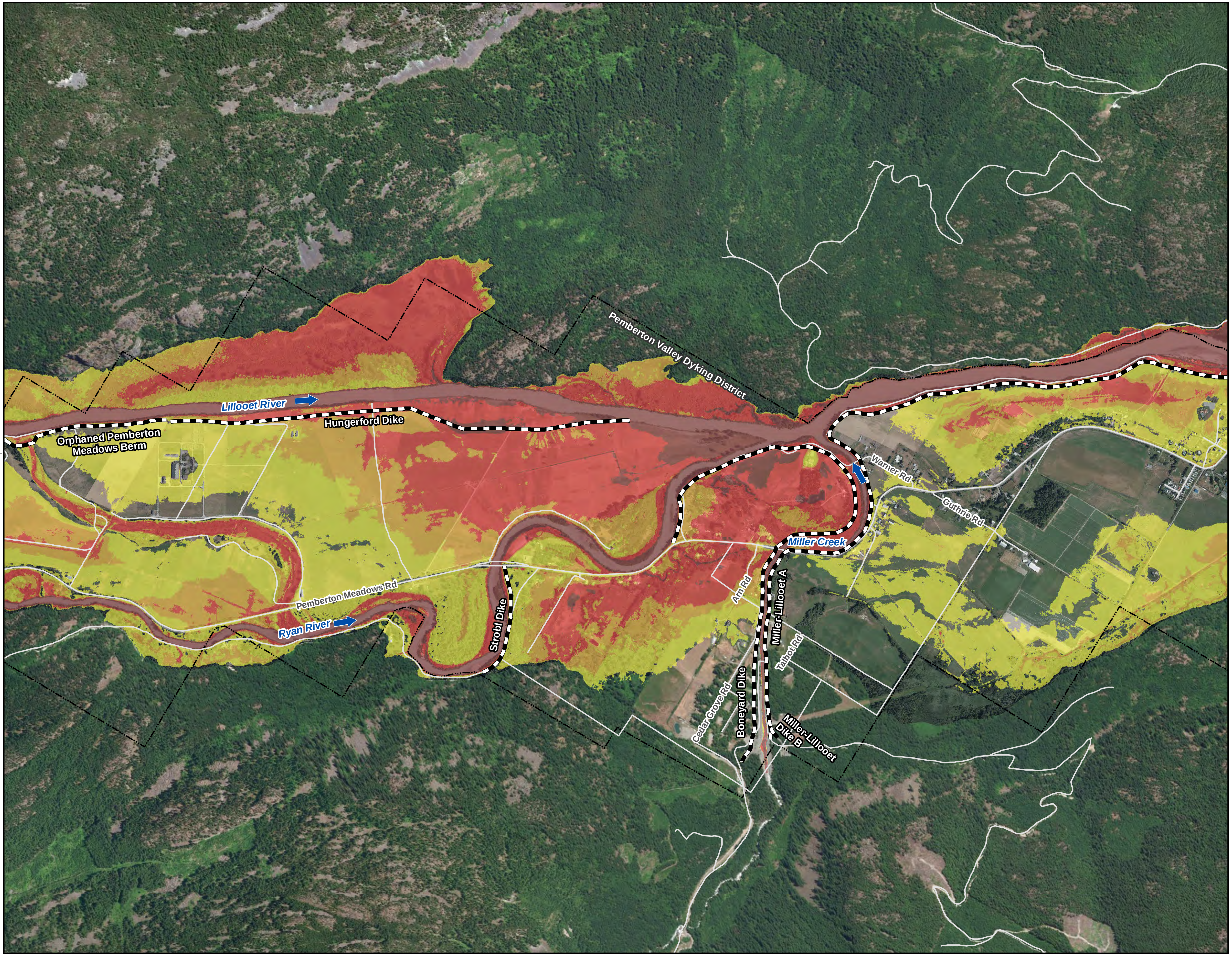
Job Number	*Date*
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING 50-YEAR LILLOOET EVENT

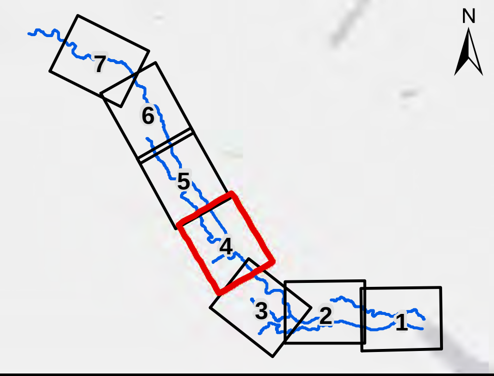
SHEET 3 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

- Low: < 0.75
- Moderate: 0.75 - 1.25
- Significant: 1.25 - 2.5
- Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES *Vertical Datum: CGVD(2013)*

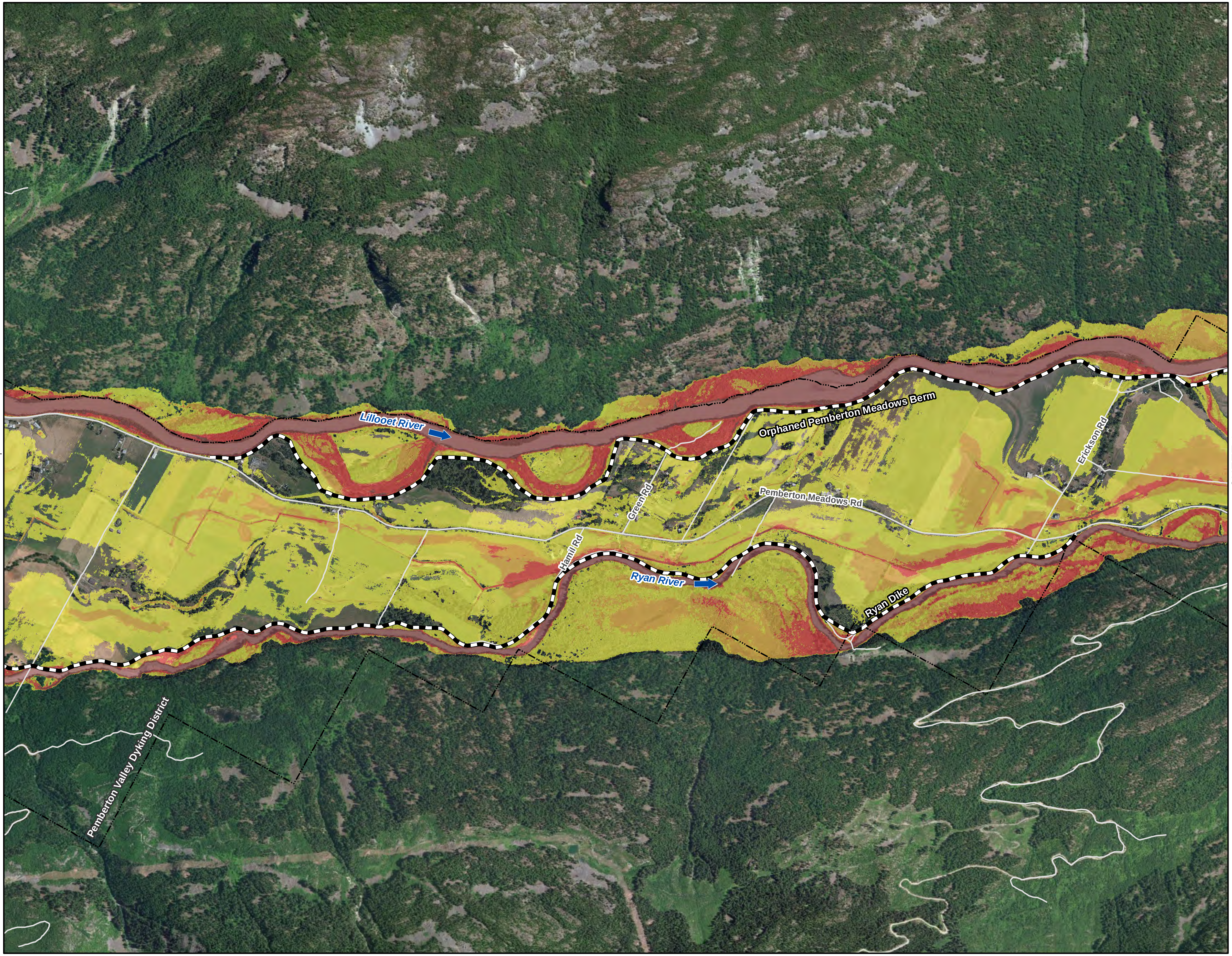
Engineer	*GIS*	*Reviewer*
CTL	*MAO*	*MCM*

Job Number	*Date*
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

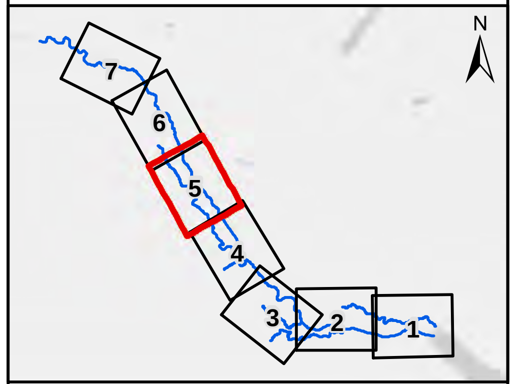
FLOOD HAZARD RATING
50-YEAR LILLOOET EVENT

SHEET 4 OF 7



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES *Vertical Datum: CGVD(2013)*

Engineer	*GIS*	*Reviewer*
CTL	*MAO*	*MCM*

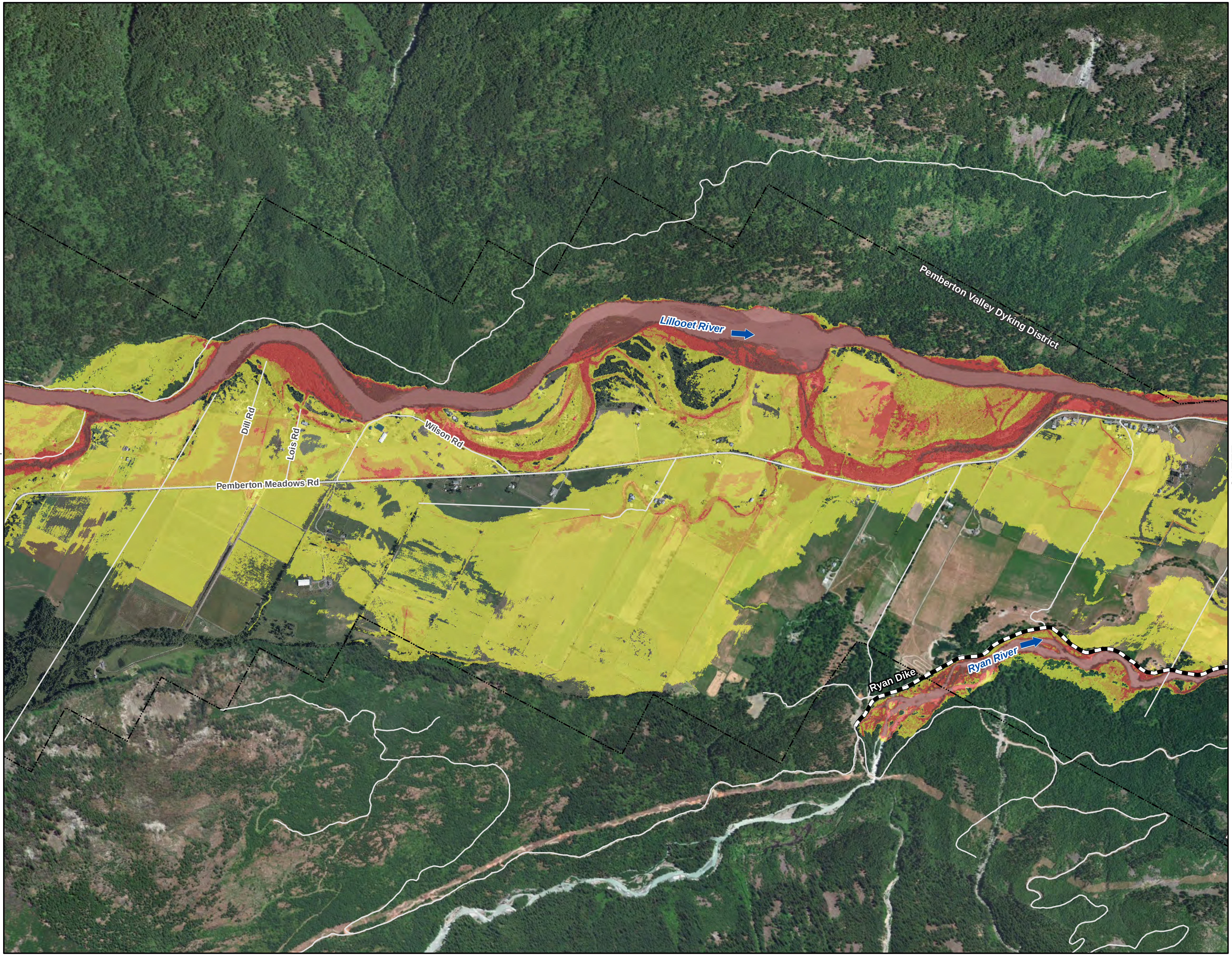
Job Number	*Date*
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
50-YEAR LILLOOET EVENT

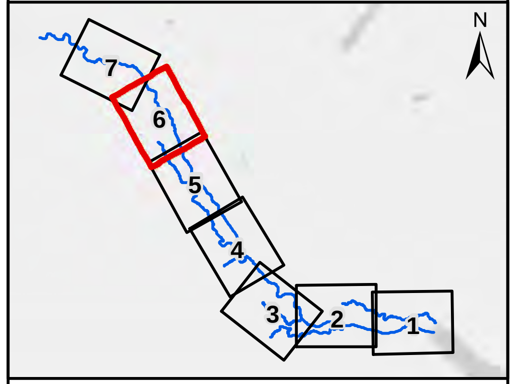
SHEET 5 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

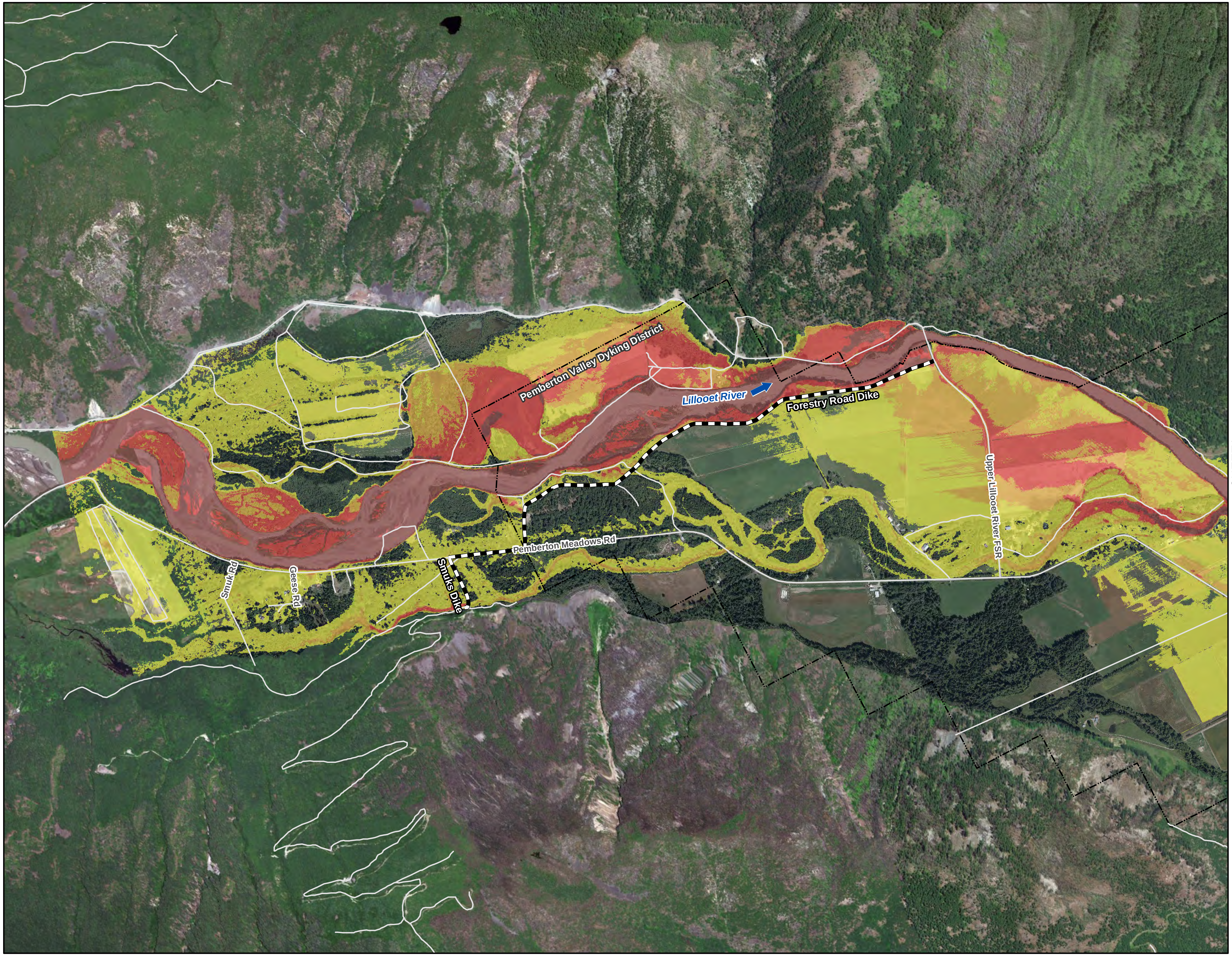
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING 50-YEAR LILLOOET EVENT

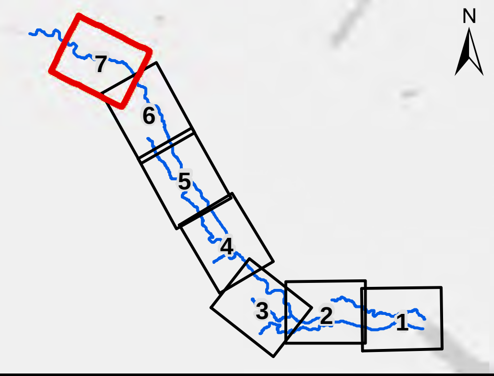
SHEET 6 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

- Low: < 0.75
- Moderate: 0.75 - 1.25
- Significant: 1.25 - 2.5
- Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

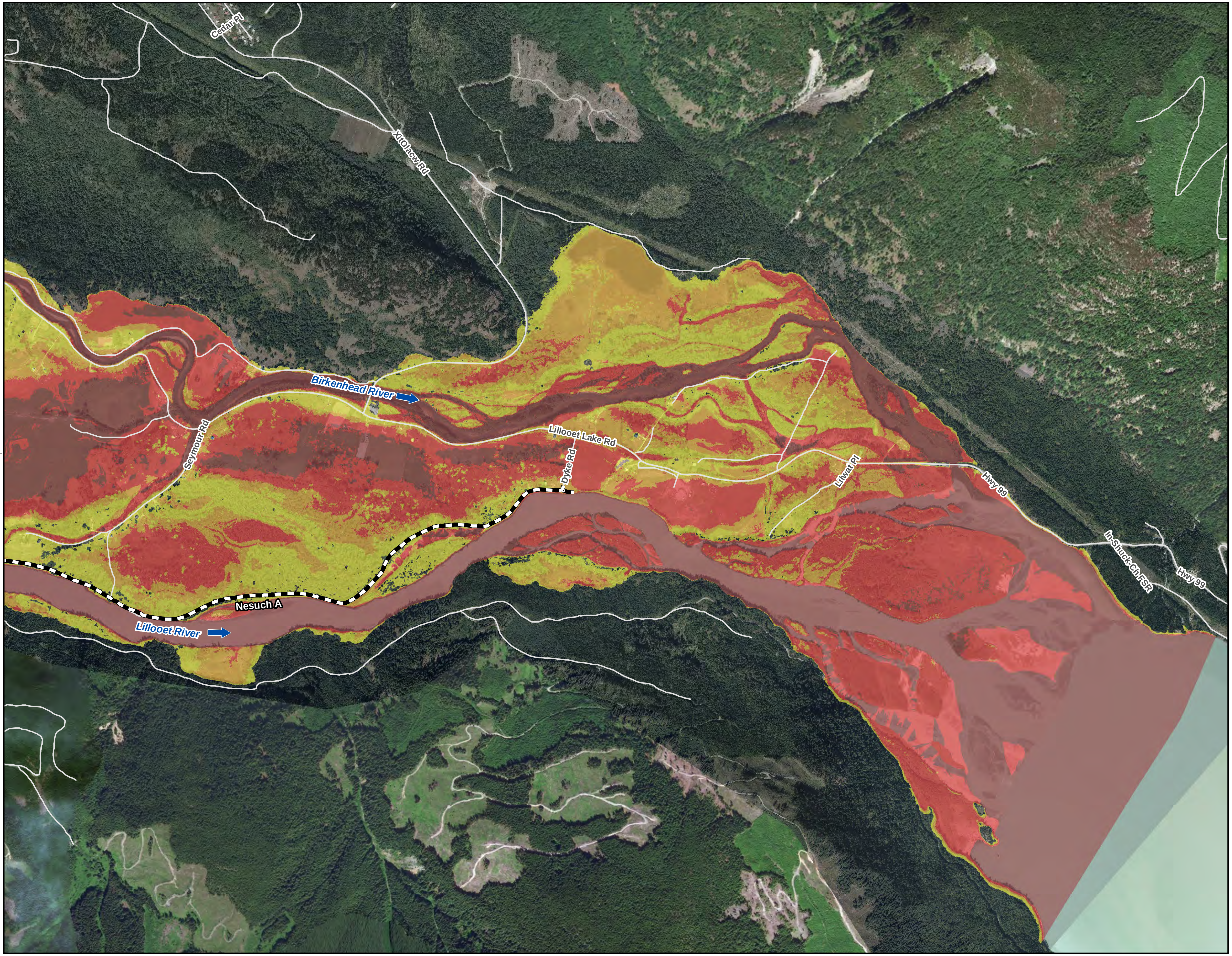
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
50-YEAR LILLOOET EVENT

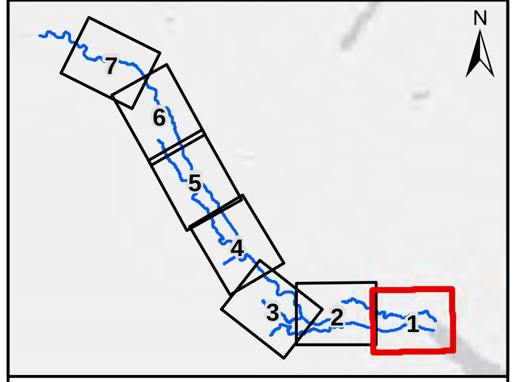
SHEET 7 OF 7

MAO Q:\3002903_Lilloet_River\GIS\95_GIS_Sea\3002903_Lilloet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY
DYKING DISTRICT

nhc
northwest hydraulic consultants



Flow Direction
Dike
Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75
Moderate: 0.75 - 1.25
Significant: 1.25 - 2.5
Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

N

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

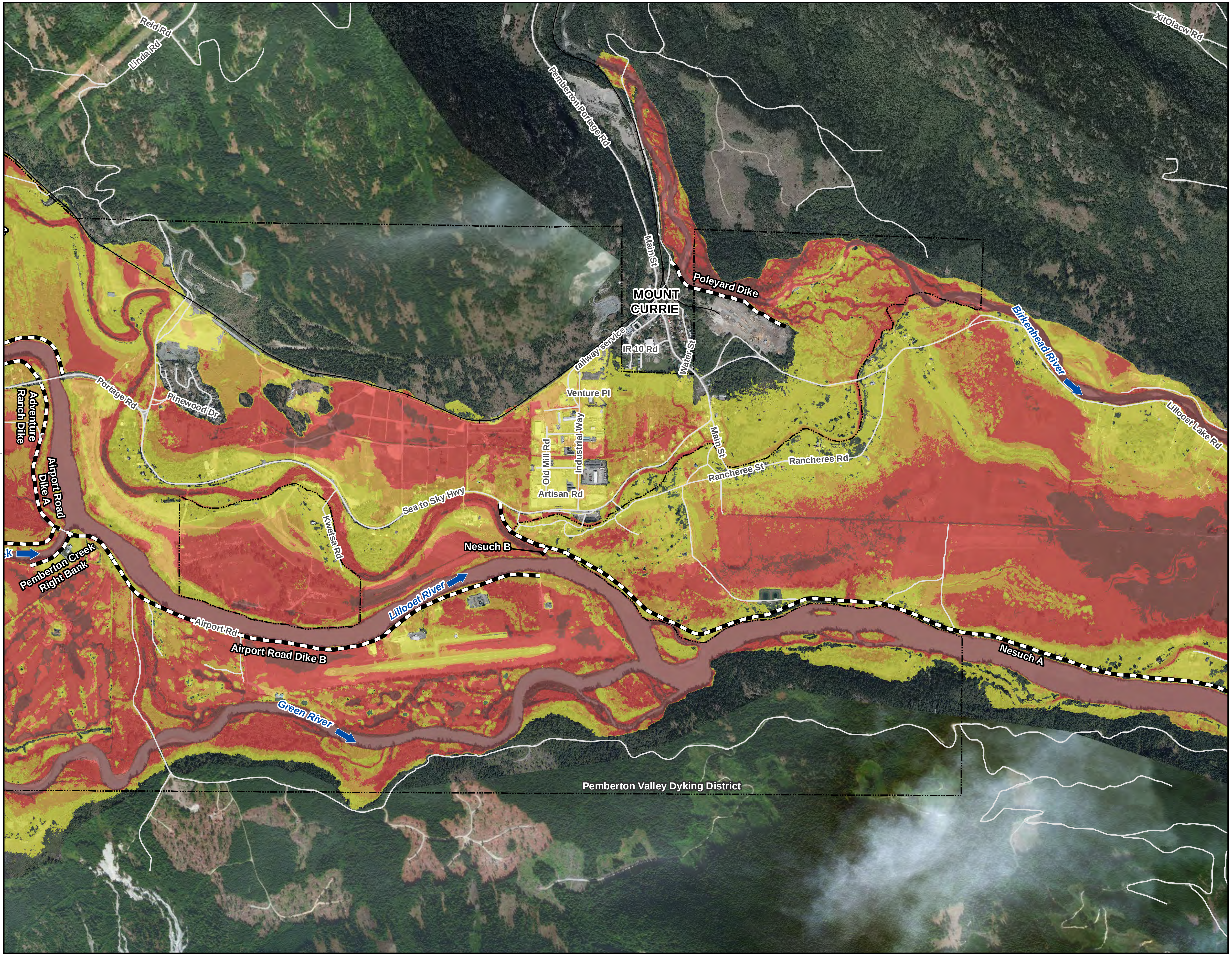
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

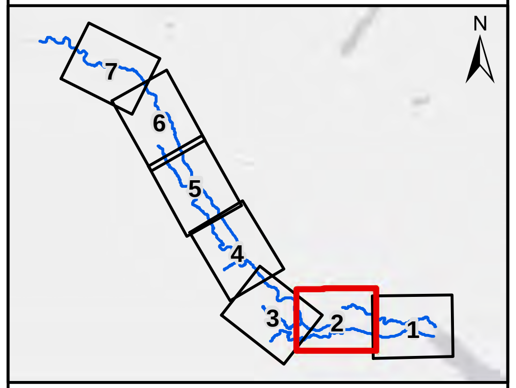
FLOOD HAZARD RATING
100-YEAR LILLOOET EVENT

SHEET 1 OF 7



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres* N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	*GIS*	*Reviewer*
CTL	*MAO*	*MCM*

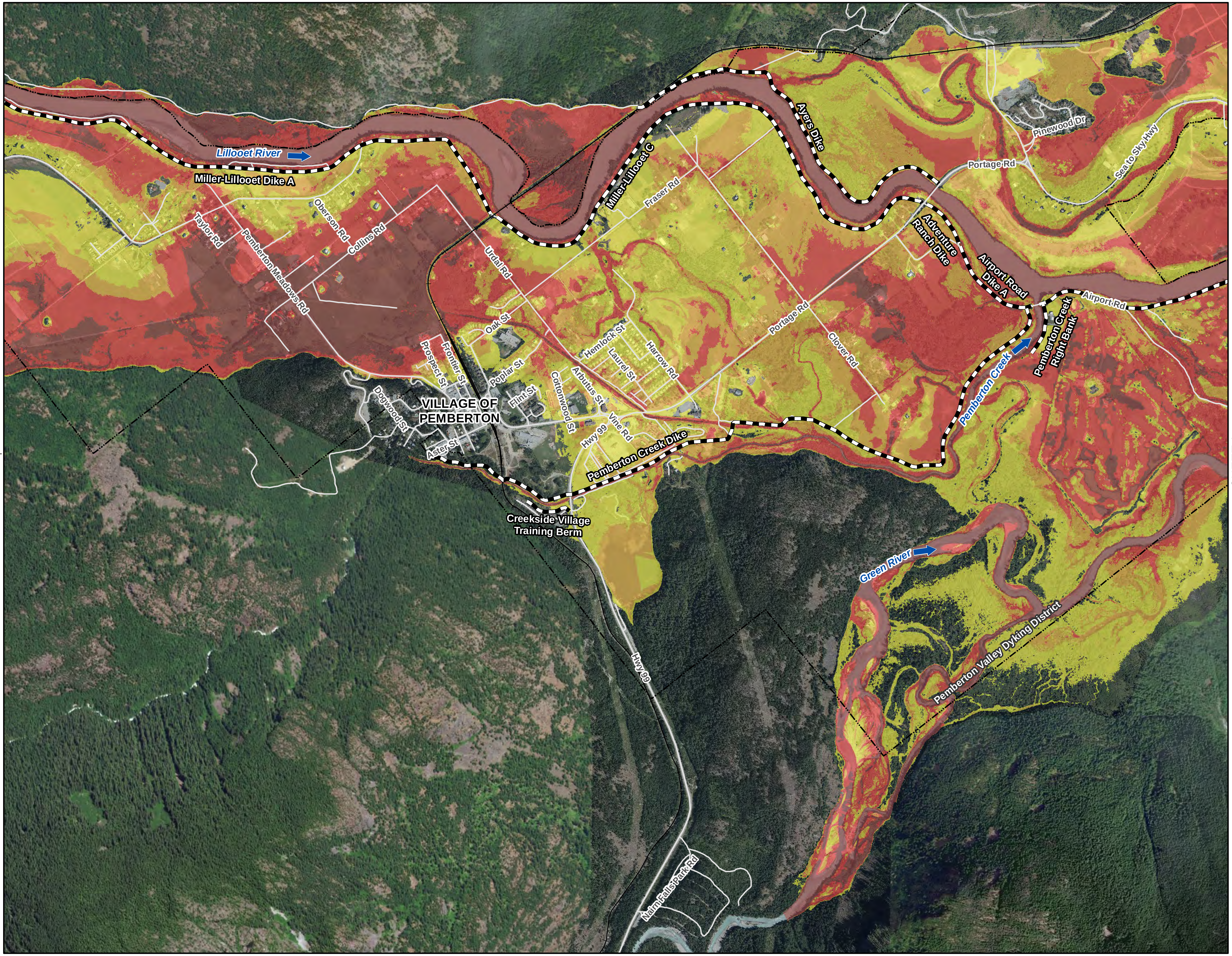
Job Number	*Date*
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
100-YEAR LILLOOET EVENT

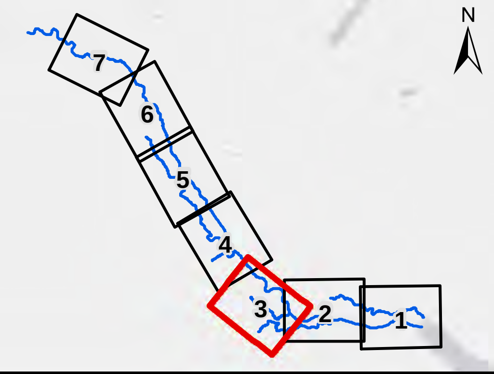
SHEET 2 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

- Low: < 0.75
- Moderate: 0.75 - 1.25
- Significant: 1.25 - 2.5
- Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

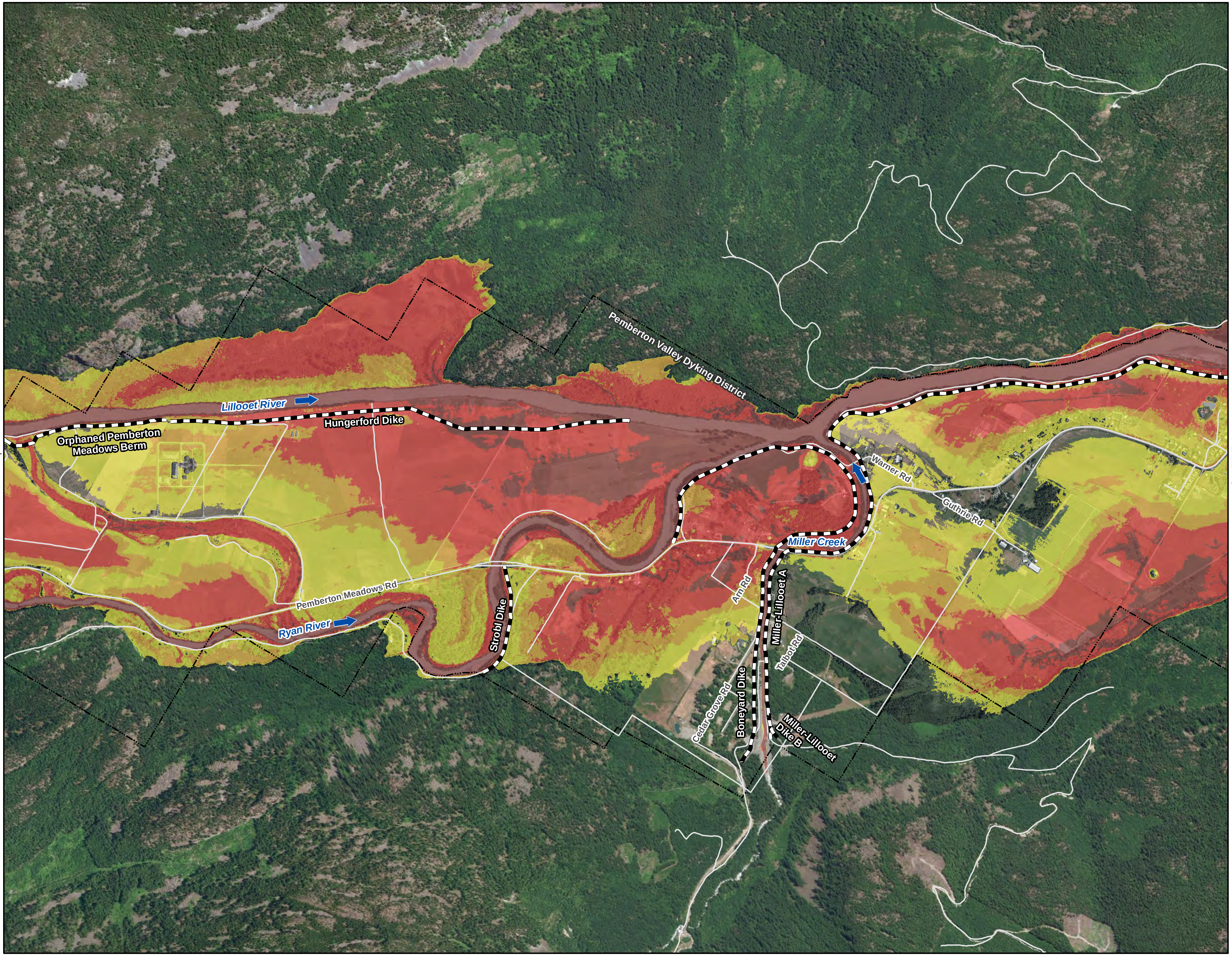
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
100-YEAR LILLOOET EVENT

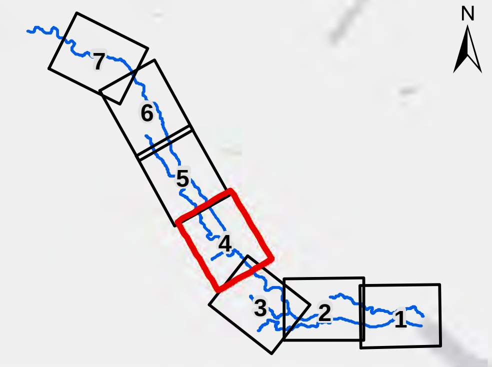
SHEET 3 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

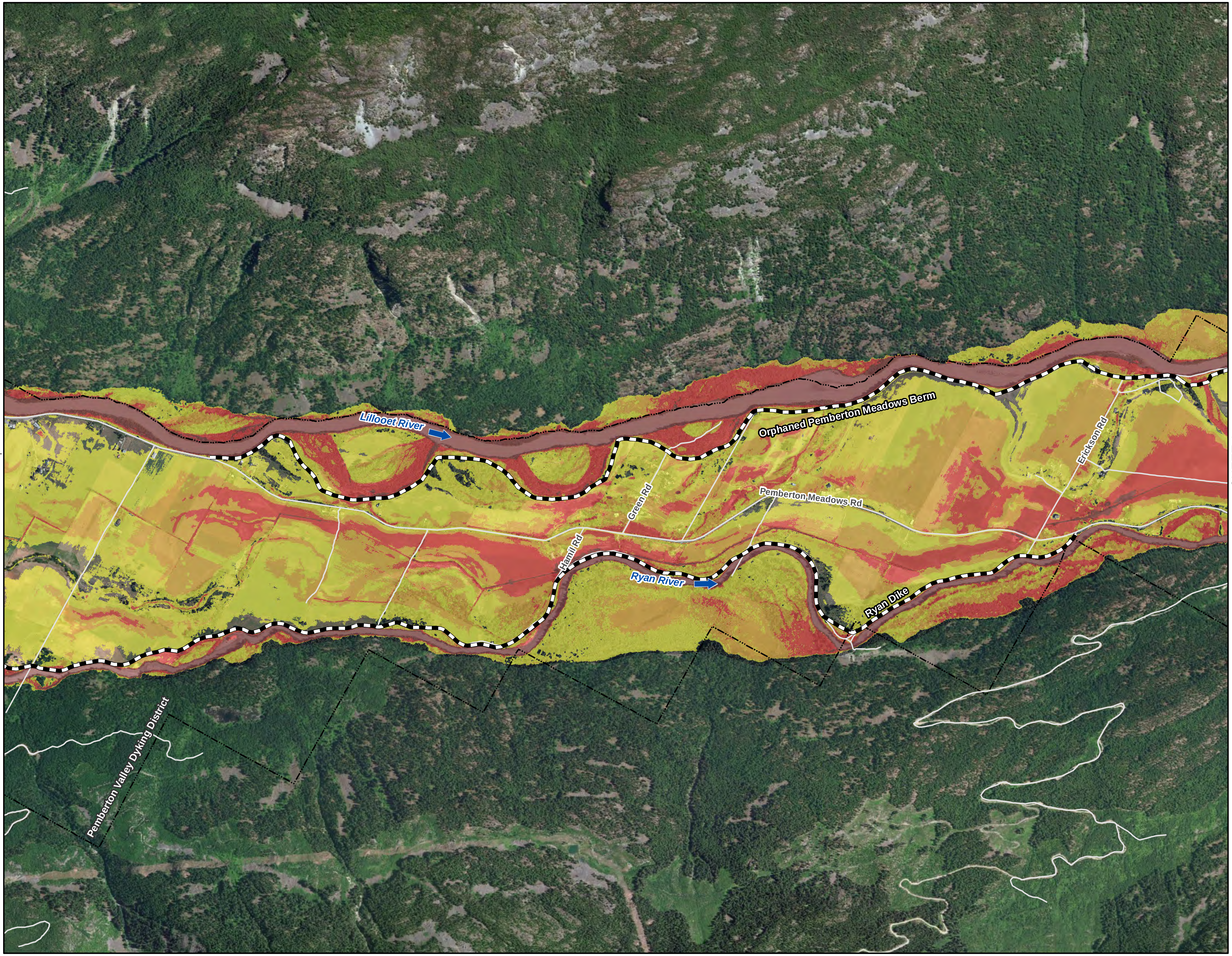
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

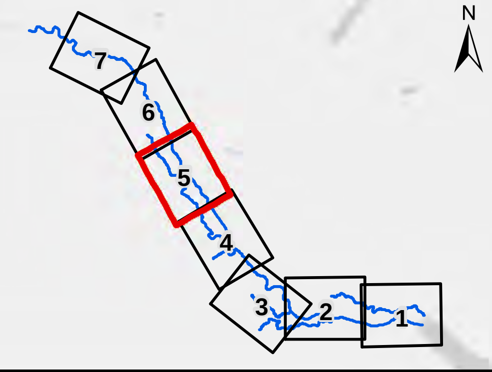
LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING 100-YEAR LILLOOET EVENT



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

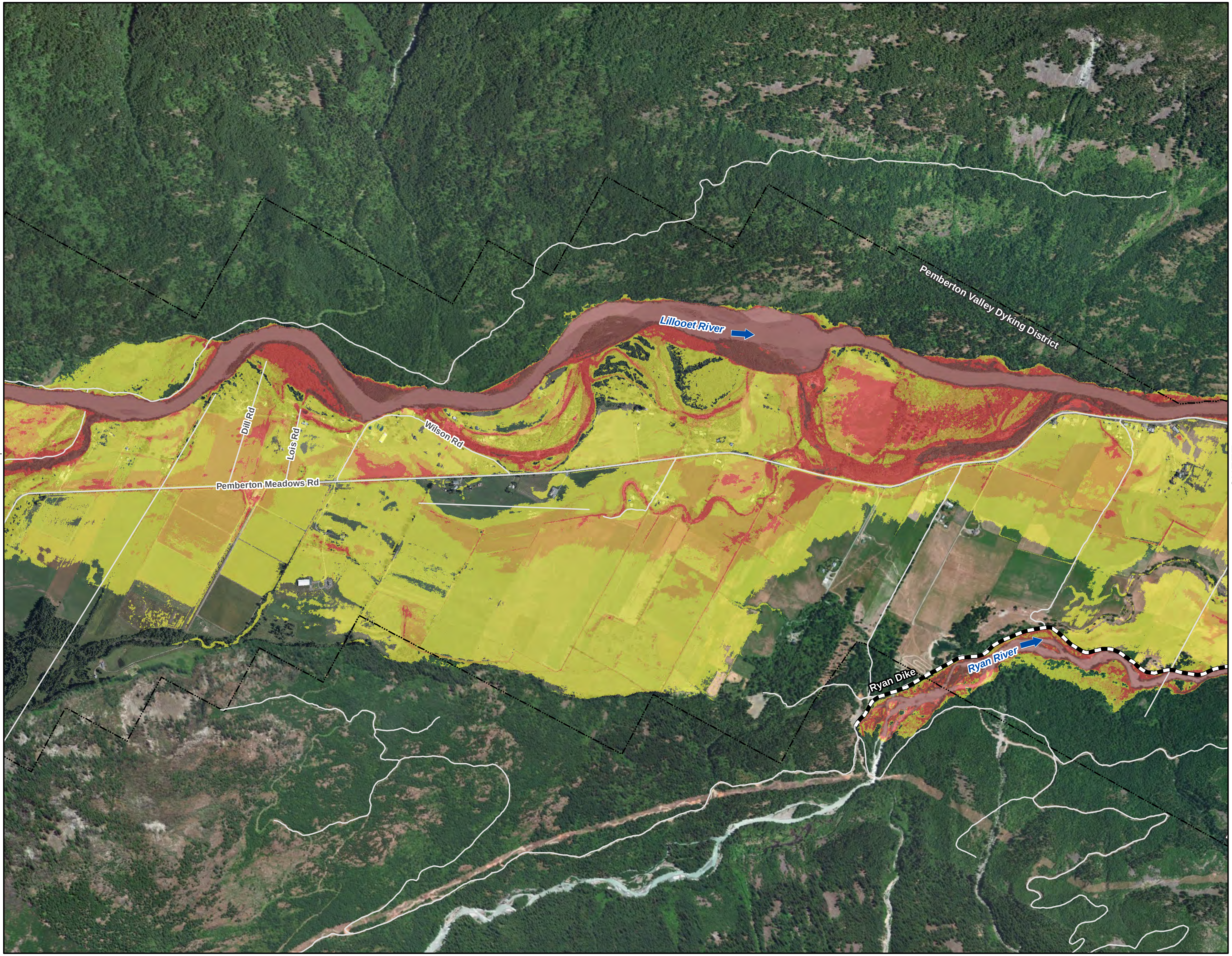
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
100-YEAR LILLOOET EVENT

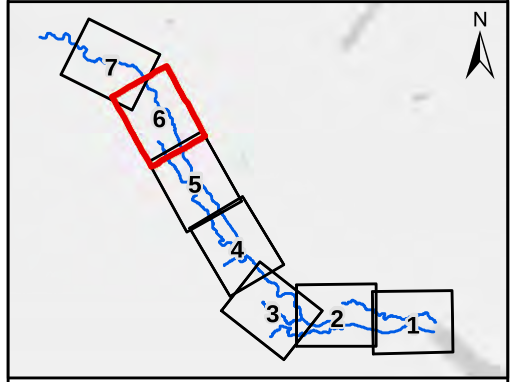
SHEET 5 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

	Low: < 0.75
	Moderate: 0.75 - 1.25
	Significant: 1.25 - 2.5
	Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

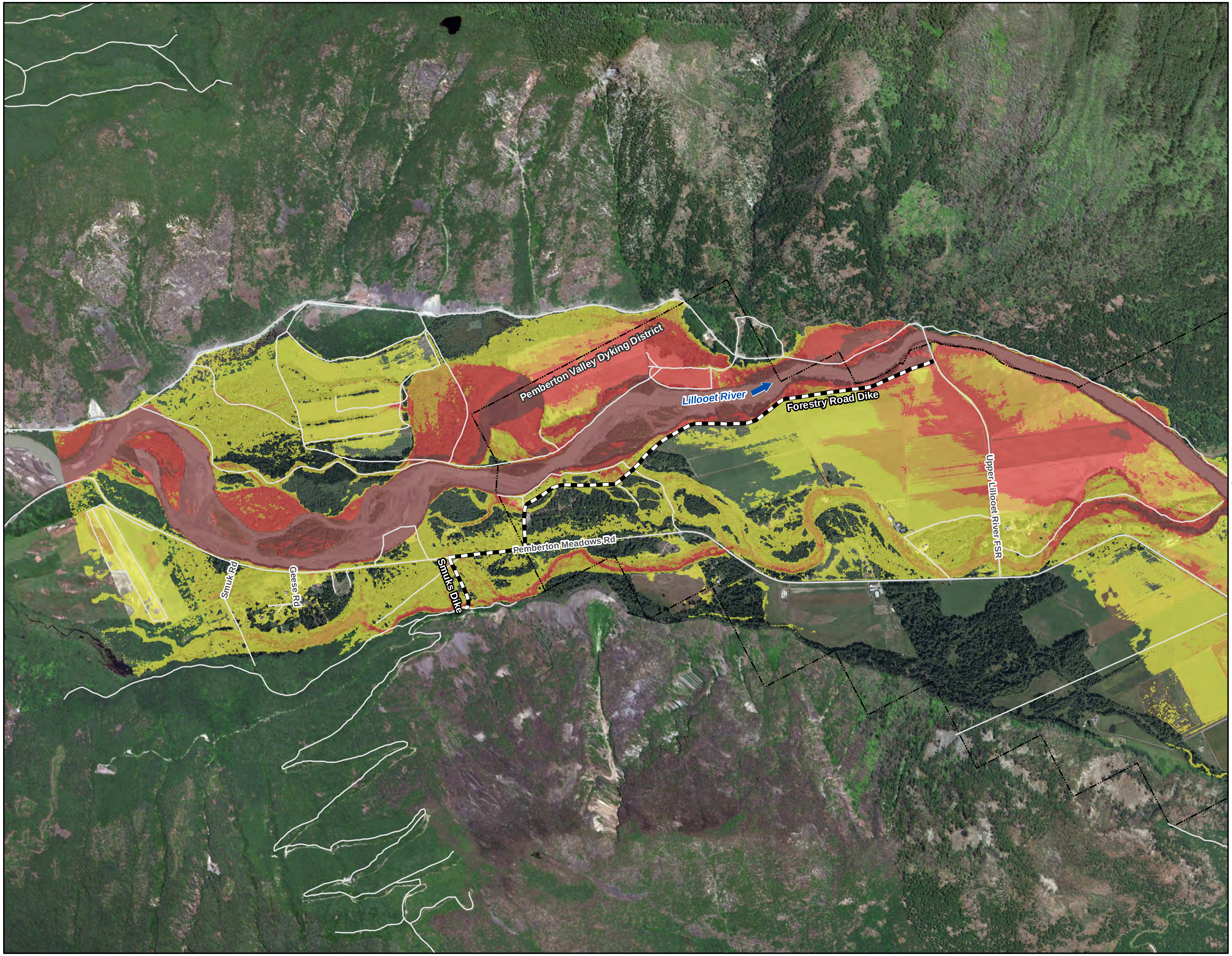
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
100-YEAR LILLOOET EVENT

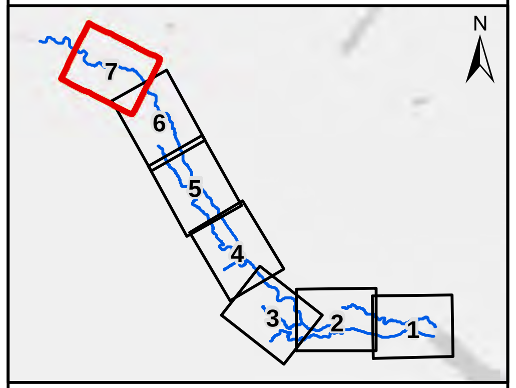
SHEET 6 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Seal\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	*GIS*	*Reviewer*
CTL	*MAO*	*MCM*

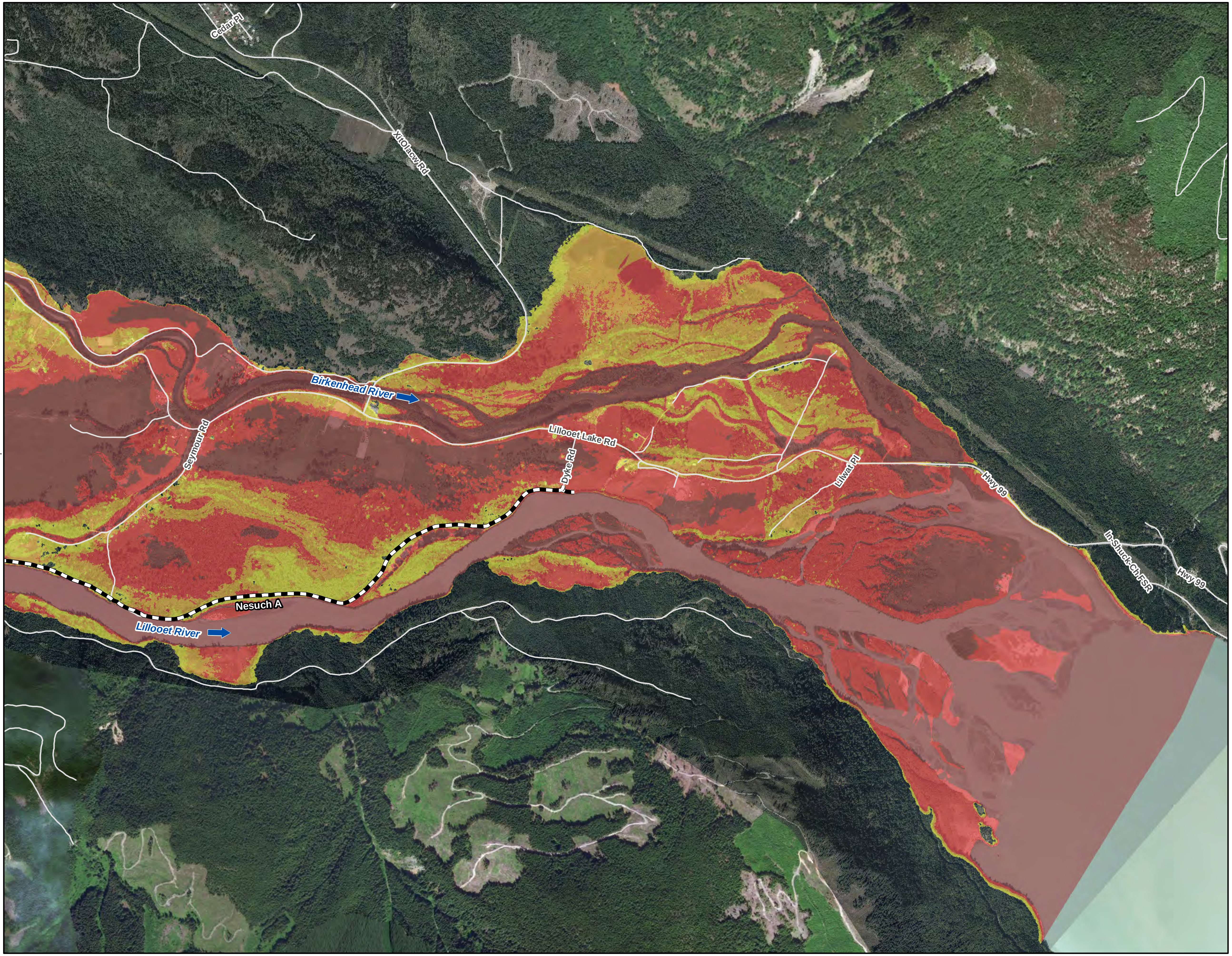
Job Number	*Date*
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
100-YEAR LILLOOET EVENT

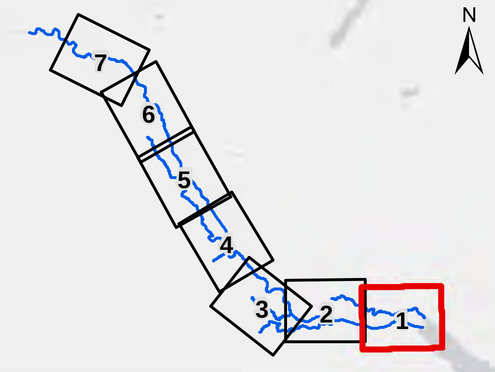
SHEET 7 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

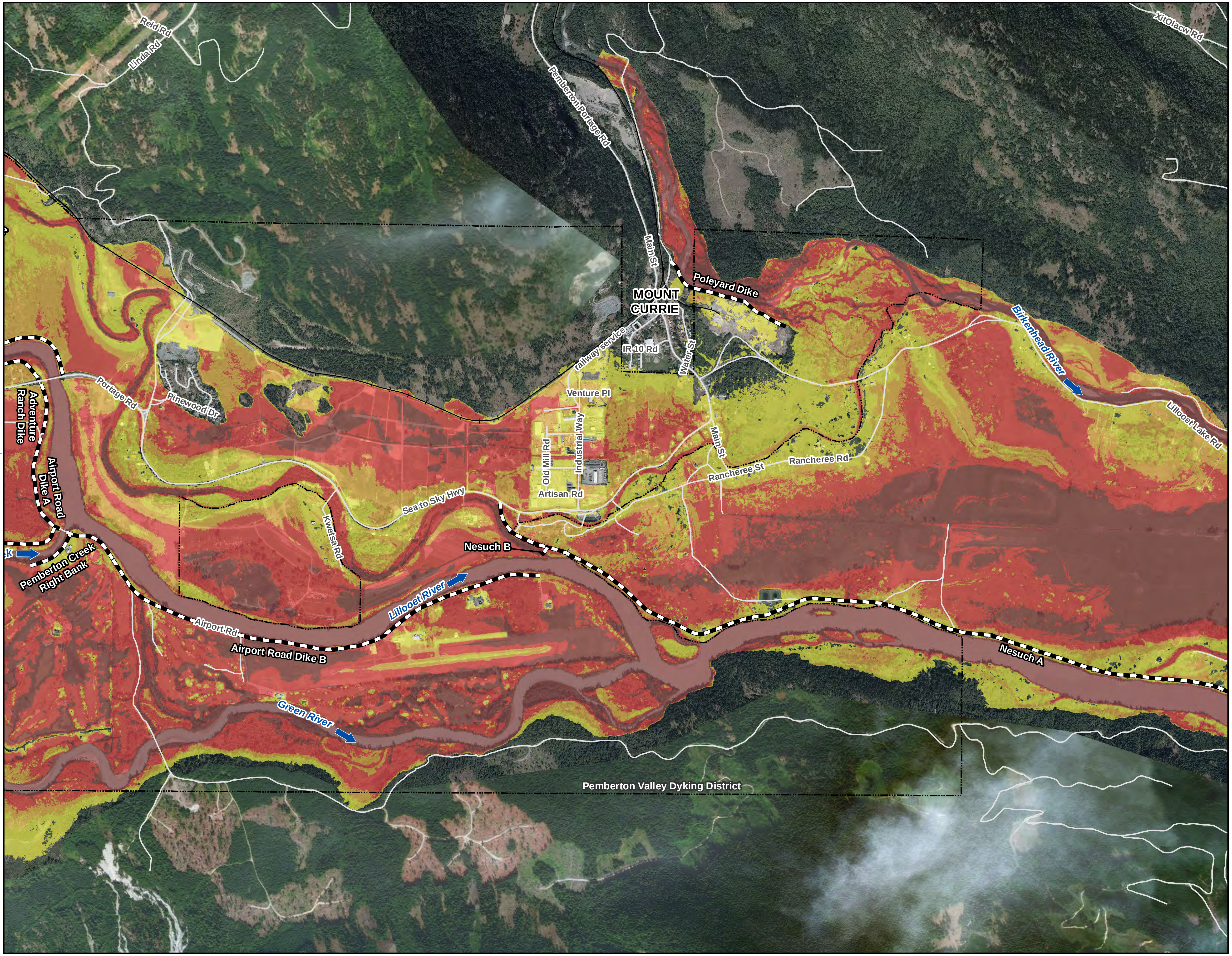
LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
200-YEAR LILLOOET EVENT

SHEET 1 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd

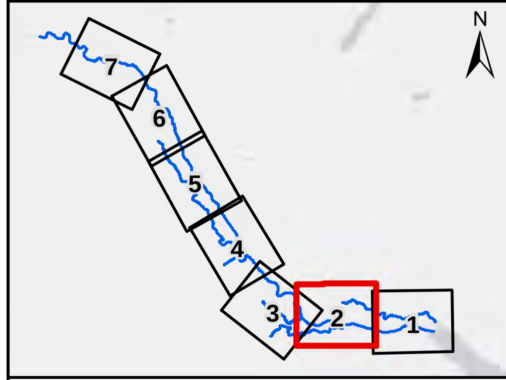
SHEET 3 ↑



SHEET 1 →

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

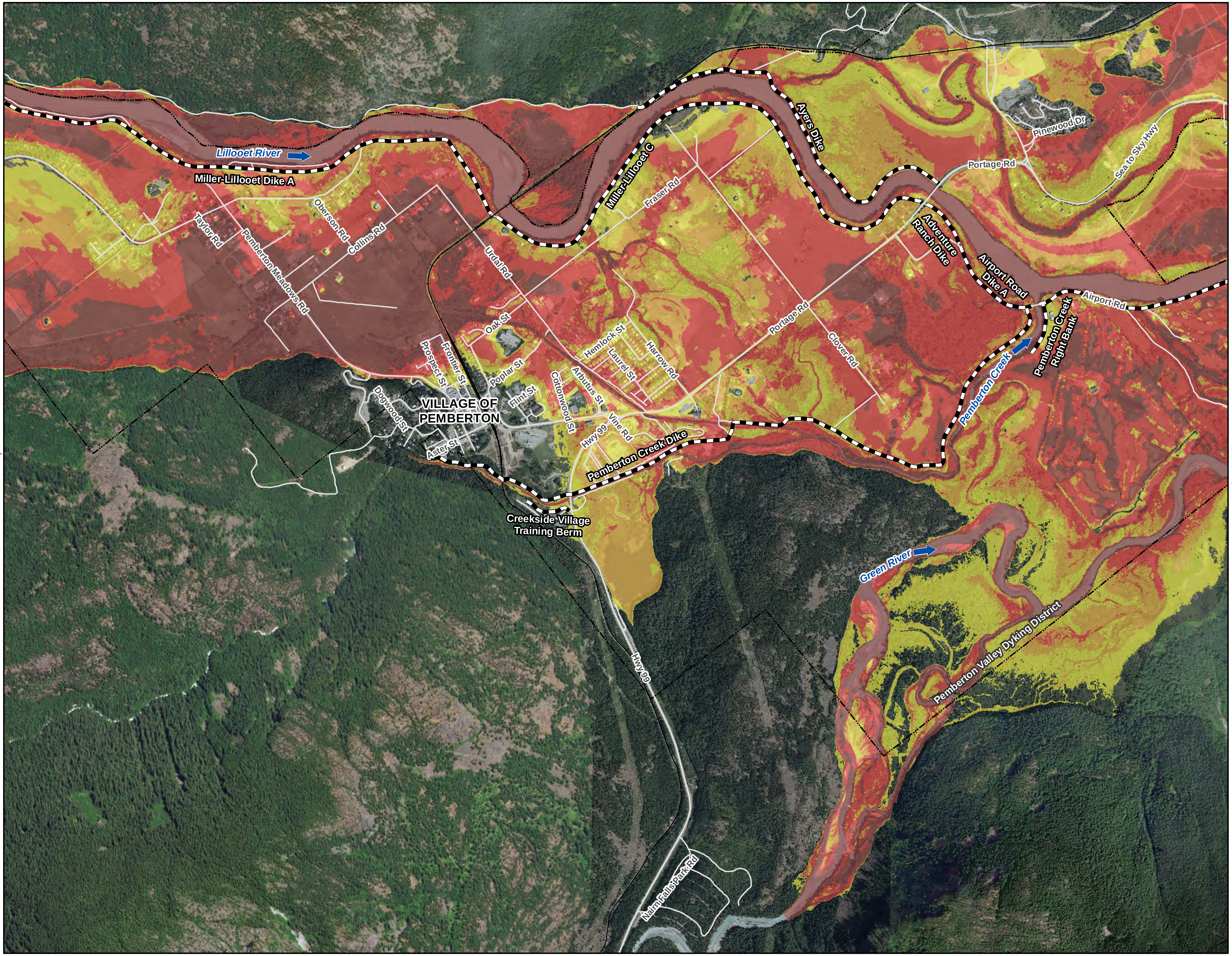
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING 200-YEAR LILLOOET EVENT

SHEET 2 OF 7

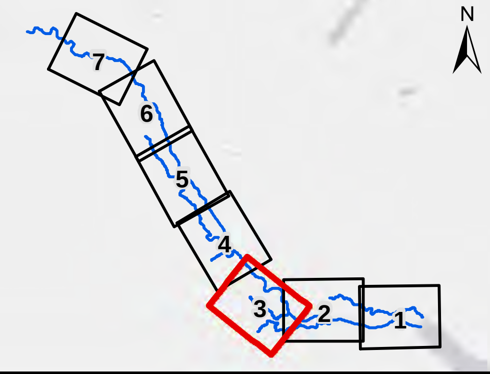


SHEET 4 ↑

SHEET 2 ↓

PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 *Metres*

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES *Vertical Datum: CGVD(2013)*

Engineer	GIS	Reviewer
CTL	MAO	MCM

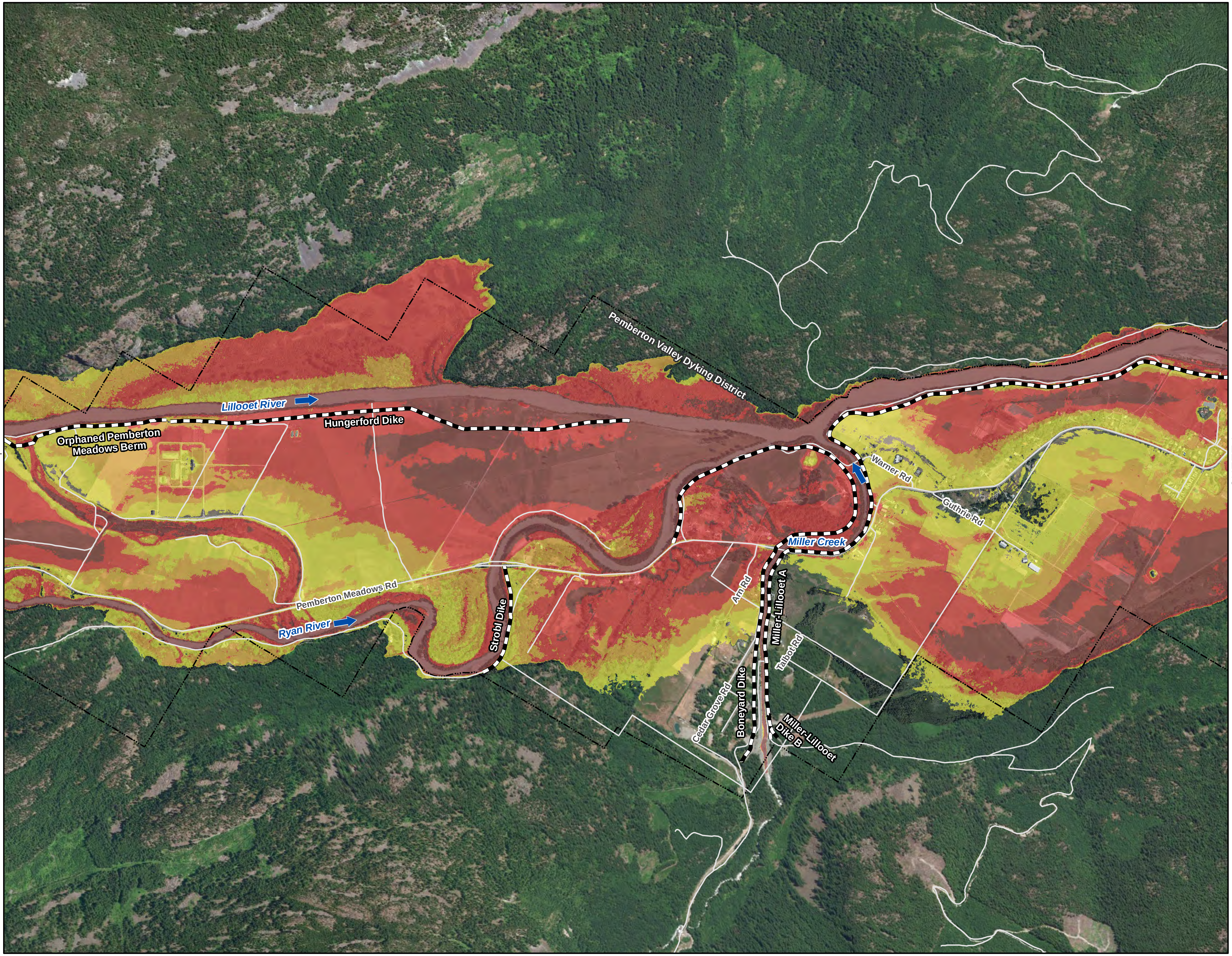
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
200-YEAR LILLOOET EVENT

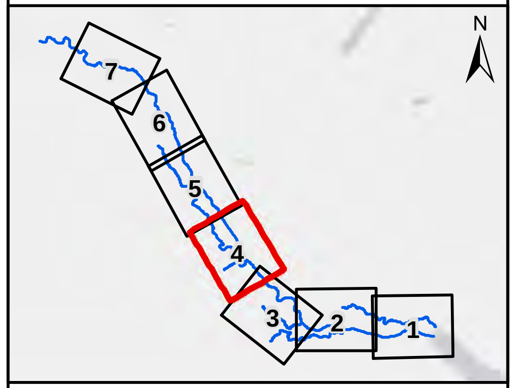
SHEET 3 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

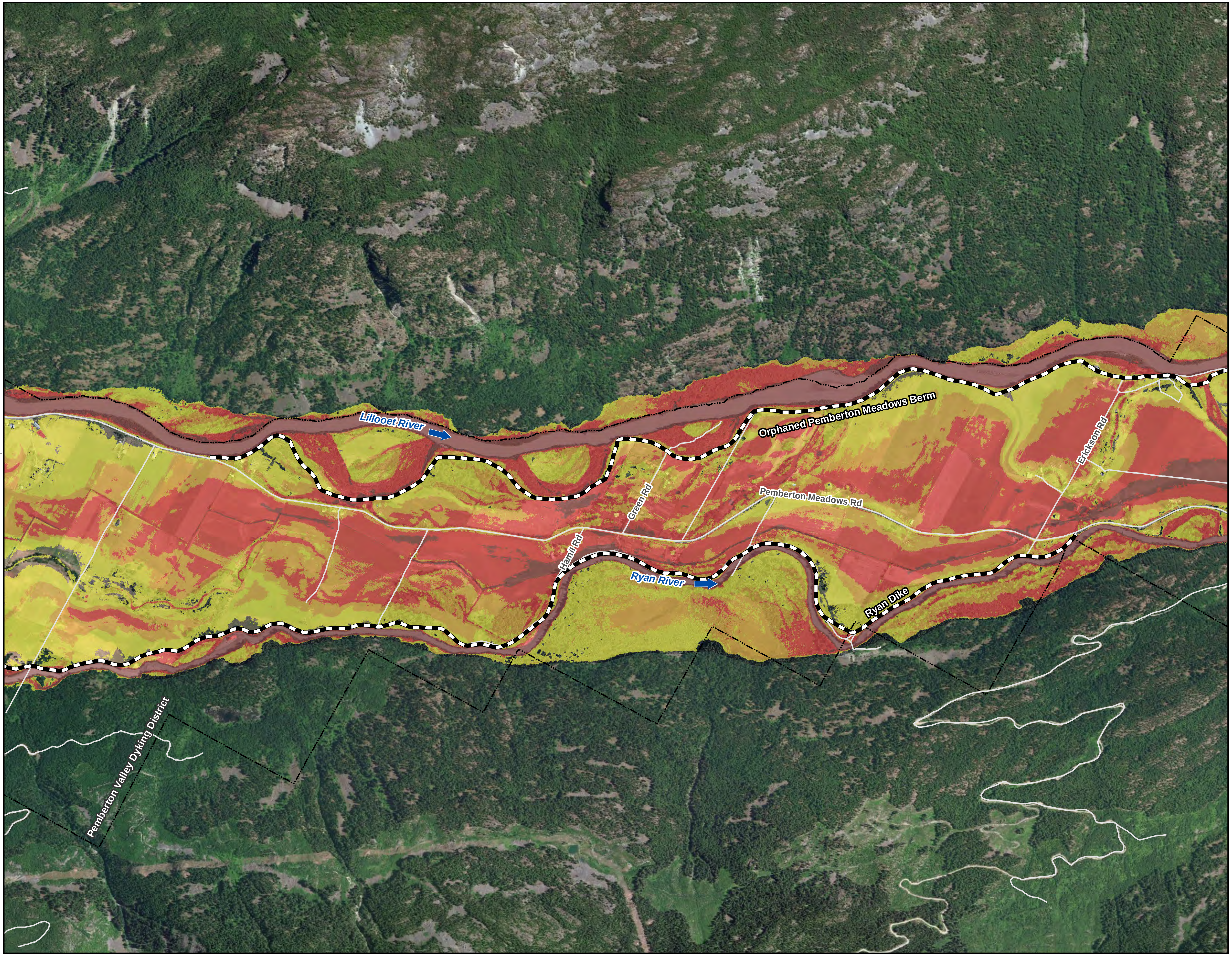
Engineer	GIS	Reviewer
CTL	MAO	MCM

Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

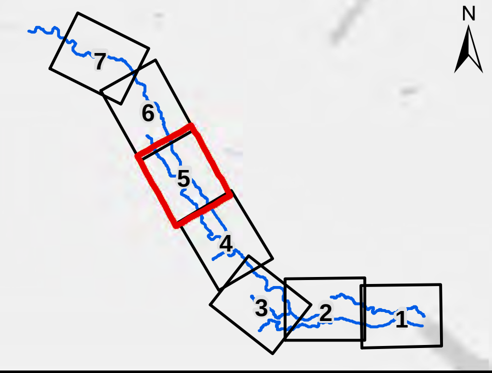
FLOOD HAZARD RATING 200-YEAR LILLOOET EVENT

SHEET 4 OF 7



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

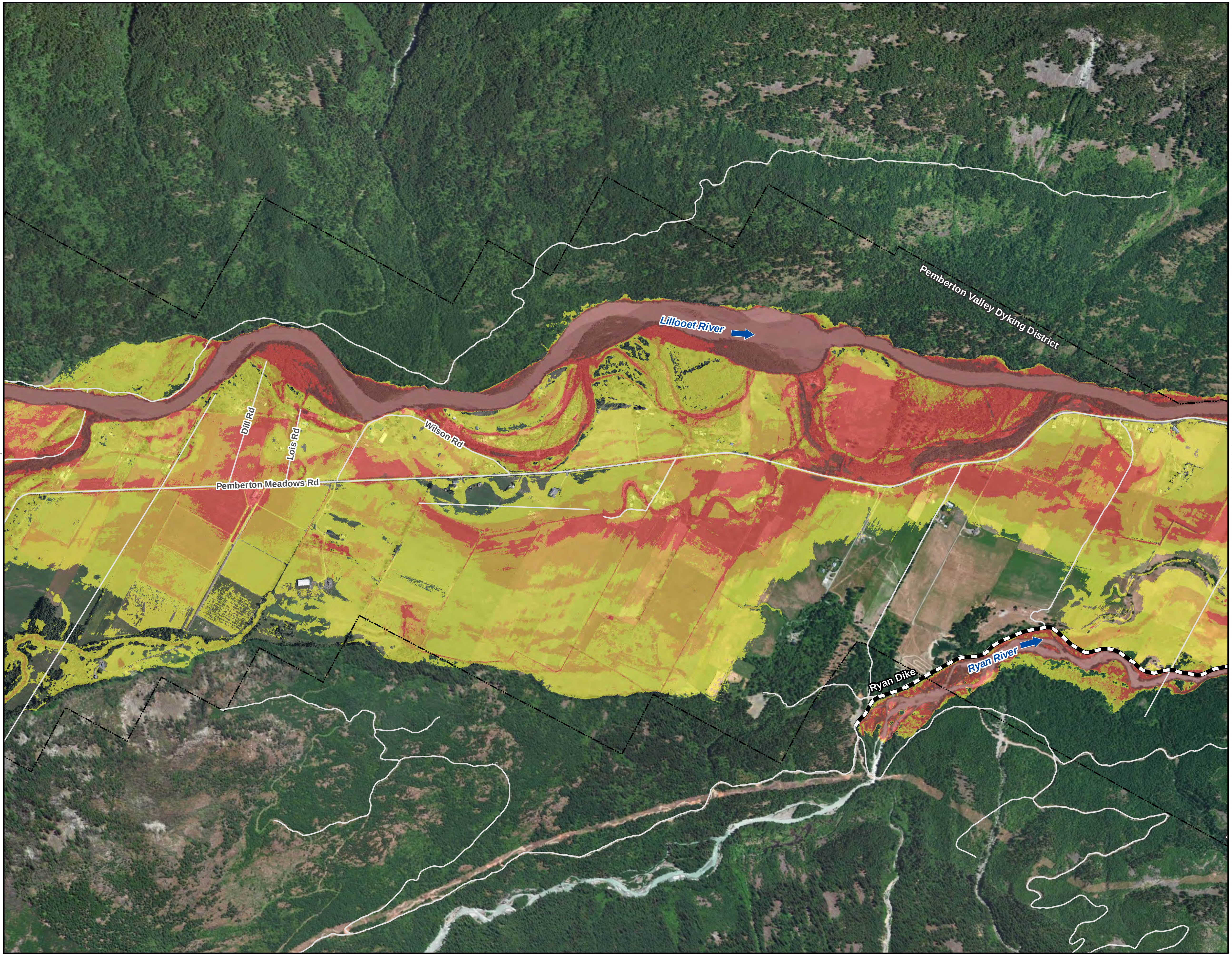
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
200-YEAR LILLOOET EVENT

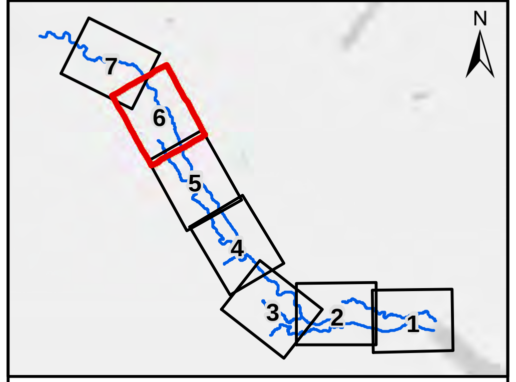
SHEET 5 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	MAO	MCM

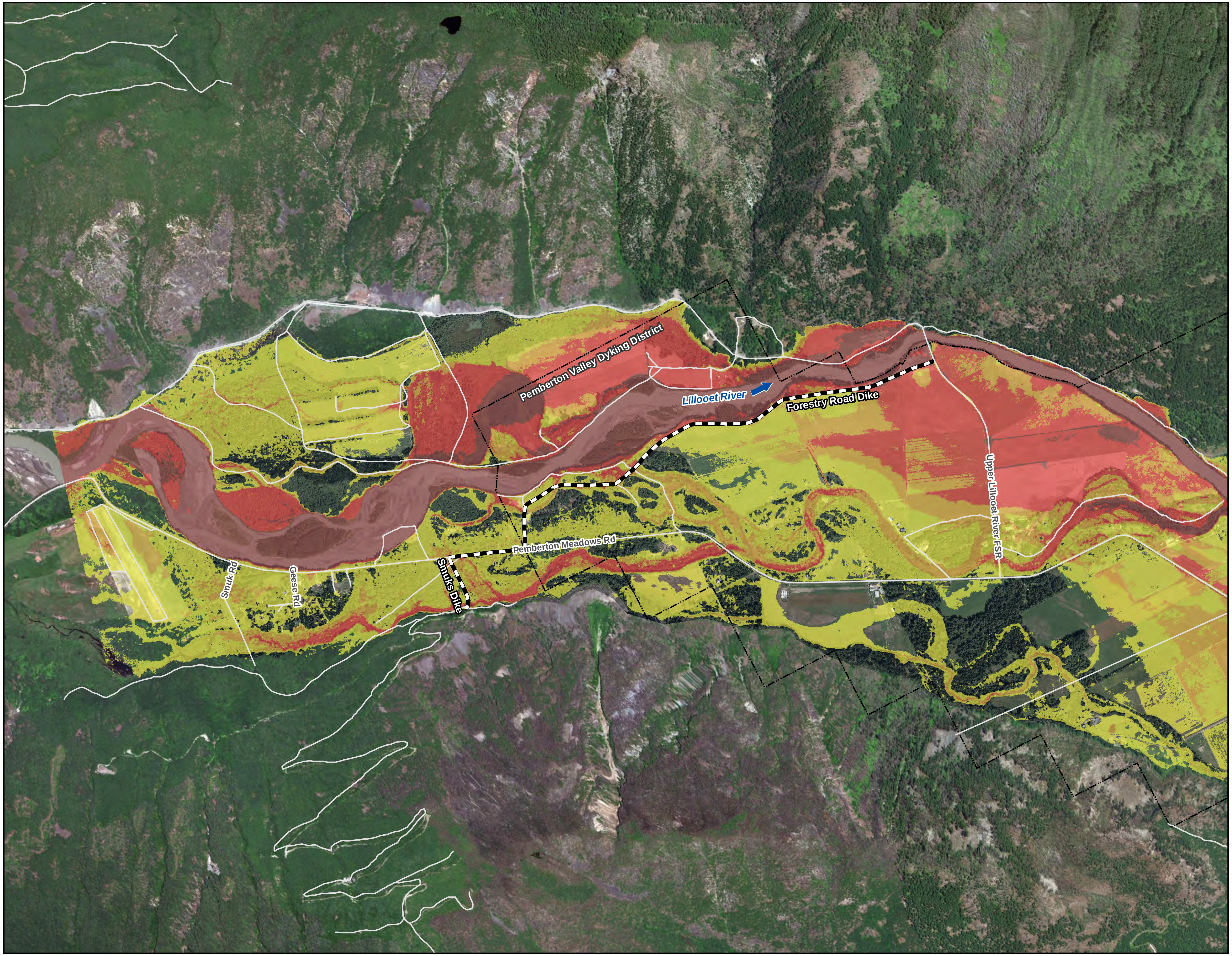
Job Number	Date
3002903	31-AUG-2018

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING
200-YEAR LILLOOET EVENT

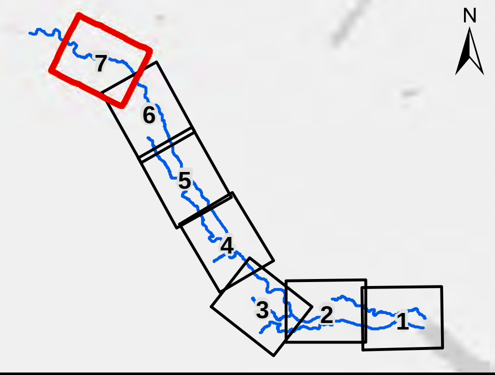
SHEET 6 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd



PEMBERTON VALLEY DYKING DISTRICT

nhc northwest hydraulic consultants



Flow Direction

Dike

Pemberton Valley Dyking District

Hazard Rating (m*m/s)

Hazard Rating = Depth x (Velocity + 0.5)

Low: < 0.75

Moderate: 0.75 - 1.25

Significant: 1.25 - 2.5

Extreme: > 2.5

Low: Caution - Flood zone with shallow flowing water or deep standing water.

Moderate: Dangerous for some (i.e. children) - flood zone with deep or fast flowing water.

Significant: Dangerous for most people - flood zone with deep fast flowing water.

Extreme: Dangerous for all - flood zone with deep, fast flowing water.

Please refer to General Notes on Map Index Sheet

SCALE - 1:20,000

0 200 400 800 Metres

N

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES Vertical Datum: CGVD(2013)

Engineer	GIS	Reviewer
CTL	*MAO*	*MCM*

Job Number	Date
3002903	*31-AUG-2018*

LILLOOET RIVER FLOODPLAIN STUDY

FLOOD HAZARD RATING 200-YEAR LILLOOET EVENT

SHEET 7 OF 7

MAO, Q:\3002903_Lillooet_River\GIS\95_GIS_Sea\3002903_Lillooet_FloodOverview_Hazard100yr.mxd