KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS
200 - 4185A Still Creek Drv.
Burnaby, B.C.
V5C 6G9
604-294-2088 P
604-294-2090 F
www.kwl.ca

Technical Memorandum

DATE: December 3, 2010

TO: Jeff Westlake, Operation and Maintenance Manager, PVDD

FROM: Sarah Lawrie, M.A.Sc., E.I.T.
Stefan Joyce, P.Eng.

RE: **LILLOOET LAKE LOWERING ANALYSIS**
Summary of Hydraulic Modelling
Our File: 0713.037-300

The following memorandum summarizes the results of the modelling study done to estimate the impact of lowering Lillooet Lake water levels by 3 m during the 200-year and 50-year return period flood events on the flood profile within the Pemberton Valley Dyking District's (PVDDs) service area. Modelling results indicate that lowering Lillooet Lake water levels by 3 m during these flow events does not have an appreciable impact on the flood profile in the Village of Pemberton. The appreciable impact to the flood profile is confined to the reach of the Lillooet River downstream of its confluence with the Green River.

1. INTRODUCTION

1.1 BACKGROUND

The Pemberton Valley Dyking District (PVDD) has been addressing flood protection issues and maintaining flood protection works in the Pemberton Valley since its inception on January 31, 1947. In 2002, Kerr Wood Leidal Associates Ltd. (KWL) produced the "Engineering Study for Lillooet River Corridor" (KWL, 2002), which included:

- a review of previous engineering studies and works from 1946 to 2002;
- an analysis of fluvial geomorphology for the Lillooet River corridor;
- an analysis of historical climate and hydrology for the Pemberton Valley and estimates of peak flows and lake levels at various return periods;
- development of a one-dimensional hydraulic model (Mike11) for the Lillooet River and flood profile estimates for the valley;
- an assessment of the existing flood protection network;
- recommendations for upgrades to flood protection;
- initial recommendations for gravel management in the Lillooet River; and
- recommendations for implementation of further flood protection works.

One question that has been raised periodically throughout the operation of PVDD is whether lowering of water levels in Lillooet Lake would have a significant, positive impact to the flood profile in Pemberton.

The purpose of this analysis is to address this question through a brief hydraulic modelling exercise and through a review of existing information.

1.2 SCOPE OF WORK

In July 2010, the PVDD retained KWL to conduct an assessment of the impact of lowering the Lillooet Lake water level during a 200-year and 50-year return period flow event on the Lillooet River. The scope of work for this study includes the following:

- **Background Information Review**: Obtain and review existing survey, imaging and Lidar data and existing engineering reports;
- **Hydraulic Assessment**: Update the Mike11 Lillooet River corridor model to estimate the water surface profile during the 200-year and 50-year return period flow events with water levels in Lillooet Lake lowered 3 m from the 200-year and 50-year return period levels;
- **Results Presentation**: Create a Digital Terrain Model (DTM) of the study area using the Lidar data, and prepare figures showing the flood surface created from the water surface profile for the Lillooet River between Lillooet Lake and the Village of Pemberton; and
- **Report Preparation**: Prepare a brief Technical Memorandum summarizing the results and presenting the results figures.

1.3 PREVIOUS STUDIES

Since 1946, a number of engineering studies have looked at the effects of historical lake lowering on the flood profile in Pemberton and what the potential flood profile response would be if the lake were lowered in the future.

The following documents were reviewed for this project:

- Kerr Wood Leidal Associates Ltd. 2002. Engineering Study for Lillooet River Corridor. Prepared for: Pemberton Valley Dyking District, Mount Currie Band, Indian and Northern Affairs Canada and British Columbia Ministry of Water, Land and Air Protection. December, 2002.
- Kerr Wood Leidal Associates Ltd. 2007. Lillooet River Gravel Management Plan. Prepared for Pemberton Valley Dyking District. February, 2007.

- Nesbitt-Porter, H.H. 1985. Pemberton Flood Protection 1985 Study: Lillooet River. Province of British Columbia, Ministry of Environment, Water Management Branch.

- Ranbanda, R. 1992. DRAFT Memorandum. Pemberton Valley Flood Protection. Received from Province of British Columbia, Ministry of Environment. Dated November 25, 1992.

- Wester, J. 1970. Internal Memorandum – Pemberton Valley Flood Control. Province of British Columbia, Ministry of Environment. Dated March 18th, 1970.

2. HYDRAULIC MODELING

2.1 STUDY AREA

The study area encompasses the lower reaches of the Lillooet River between Lillooet Lake and Miller Creek. The project is focussed primarily on the PVDD service area and dyking network but includes the Mount Currie Band lands between the Village of Pemberton and Lillooet Lake.

2.2 LILLOOET RIVER CORRIDOR MODEL

The one-dimensional Mike11 hydraulic model used in this analysis was initially developed for the Engineering Study for the Lillooet River Corridor (KWL 2002). The model extends from Lillooet Lake upstream to Mowich Creek and includes the lower reaches of the major tributaries: Ryan River, Miller Creek, Pemberton Creek, Green River, and Birkenhead River. For more detail as to the development of the model and its inputs, please refer to the 2002 study (KWL 2002).

Since 2002, updates to the model have included:

- increased cross-section density at existing gravel bars with survey information from 2006, 2009 and 2010;
- extension of the model to include a longer reach with more detail for the Ryan River (KWL 2009[1]);
- extension of the model to include Arn Canal (KWL 2009[2]); and
- geo-referencing the model for easier reporting of results (KWL 2009[2]).

Additional hydrologic analysis was completed for the Ryan River Hydraulic and Dyking Assessment (KWL 2009[1]) to estimate a design 200-year return period flow event for the

[1] Kerr Wood Leidal Associates Ltd. 2009. Ryan River Hydraulic and Dyking Assessment. Report prepared for Pemberton Valley Dyking District. February 2009.
[2] Kerr Wood Leidal Associates Ltd. 2009. Field Investigations and Hydraulic Analysis of Arn Canal -DRAFT. Technical Memorandum dated July 20, 2009.

Ryan River. However, for this modelling analysis the 200-year and 50-year return period events established for the 2002 Engineering Study (KWL 2002) were used. This was done to allow for easier comparison with previous results and because hydrologic analysis was not included in the scope of work to develop an updated 50-year return period flow event.

The updated model geometry with the most recent survey information was used to perform this analysis.

2.3 BOUNDARY CONDITIONS

The original model includes estimates of the hourly flow hydrographs for peak flows on the Lillooet River and its tributaries at 200-year (Q_{200}) and 50-year (Q_{50}) return periods with events similar to the flow pattern seen during the 1991 flood event.

The lower boundary condition for the model is the water level in Lillooet Lake. The lake water level is held constant during the model run at a single lake level that corresponds to the 200-year or 50-year return period level (depending on the scenario). Return-period water level estimates are based on 26 years of water level data recorded at the Water Survey of Canada (WSC) station 08MG020 (1972 to 2000).

For the lake lowering scenarios, inflow hydrographs were the same but the corresponding 200-year and 50-year lake water levels were lowered by 3 m. Boundary conditions used for each scenario are summarized in Table 1.

Table 1: Model Scenarios

Model Run	Peak Instantaneous Flow (m^3/s)	Lake Level (m)
Q_{50}, Lake Level 50-year	1,170	199.73
Q_{50}, Lake Level 50-year minus 3 m	1,170	196.73
Q_{200}, Lake Level 200-year	1,520	200.30
Q_{200}, Lake Level 200-year minus 3 m	1,520	197.30

2.4 WATER PROFILE RESULTS AND DISCUSSION

For each scenario, the resulting water surface elevations were extracted from the model Figure 1 shows the effect of the lake lowering on the modeled flood profile for both return-period scenarios.

Based on the modelled water levels, lowering Lillooet Lake by 3 m will decrease the flood profile for approximately 4.8 km and 5.2 km upstream of the lake for the Q_{50} and Q_{200} events, respectively. The flood profile is not appreciably impacted within the PVDD service area lands.

It should be noted that lake lowering is expected to result in channel changes such as degradation and extension of the delta into the lake; however, the existing model does not simulate this response since the bed and planform is fixed. A separate sediment transport module for Mike11 can be used to estimate the channel response to lake lowering.

The model was run with an initial estimate of cross-section geometry incorporating scour due to the lake lowering. The results indicated that the impact to the flood profile was still confined to the reach below the confluence between the Green and Lillooet Rivers and the flood profile in Pemberton was not appreciably changed (results not shown). In addition, any changes to channel cross-sections due to scouring of fine sediment occurring as a result of lowering Lillooet Lake by 3 m is expected to be short-lived (see Section 3.2 for more discussion).

MODEL CALIBRATION

Figure 1 includes high water marks (HWMs) Li31 to Li34 along the Lillooet River established following the October 2003 storm event. The October 2003 recorded instantaneous peak flow was 1,490 m^3/s, which is very similar to the 200-year return period peak instantaneous flow estimate of 1,520 m^3/s used for modelling.

Previous work has demonstrated that the model is capable of replicating observed high water marks collected during high flow events (such as the 2003 event) (KWL 2007). The modelling work carried out for this project is expected to result in changes to the flood profile that cannot be corroborated by observed high water marks as they are hypothetical.

INUNDATION FIGURES

A series of inundation figures have been created based on the modeling results (Figures 2 to 7). These figures were created using 2009 Lidar-based digital terrain model (DTM). The inundated area is approximate and is based on the intersection between the maximum modeled water elevation and the DTM.

It is important to note that the inundation figures show the approximate flood extents based on projecting the peak water level in the river at discrete cross-sections. These are intended for discussion only and to illustrate the relative water levels as they relate to the lowering of Lillooet Lake. They are not floodplain maps as more detailed analysis would be required to produce floodplain mapping.

The inundation figures indicate that the immediate hydraulic impact of lowering Lillooet Lake by 3 m is confined to the lower reach downstream of the confluence between the Green and Lillooet Rivers.

The modeling results indicate that there would be extensive flooding of the lands along the Lillooet River between the Green River confluence and Lillooet Lake during the 50-year and 200-year return period events, regardless of whether the lake is lowered

(Figures 6 and 7). When the lake is lowered by 3 m, some of the flooding is alleviated immediately upstream of the lake; however, this area is largely unpopulated and without standard dykes, low-lying areas are expected to be inundated during higher return period events.

3. MANAGEMENT IMPLICATIONS

3.1 IMPACT OF LAKE LOWERING ON WATER LEVELS IN PEMBERTON

The hydraulic model results indicate that lowering the water levels in Lillooet Lake by 3 m during high flow events would not have an appreciable impact on lands within the PVDD service area. The immediate hydraulic impact of lowering the lake on the flood profile only extends approximately 5 km upstream from the lake.

A number of regulatory approvals would be needed to proceed with lowering Lillooet Lake by 3 m. More investigations would be necessary to determine the impact of lowering the lake by 3 m on fish habitat and approval from both Provincial and Federal agencies including the BC Ministry of Environment and Fisheries and Oceans Canada would be necessary to proceed with the work.

In addition, there may be concern over the transfer of risk to downstream communities between Lillooet and Harrison Lakes if the outlet conditions were changed at Lillooet Lake. Dropping the lake elevation by 3 m could potentially increase peak flows at these communities. A more rigorous investigation would be needed to determine the potential for increased flood risk downstream of the lake.

3.2 COMMENT ON EXPECTED CHANNEL RESPONSE TO LAKE LOWERING

The hydraulic model captures the immediate water level response to lake lowering, without any changes to the channel cross-section geometry. However, lowering the lake would cause channel degradation near the lake since sand can be readily eroded and transported, and the local steepening of the flood profile would have the effect of increasing the transport capacity of the river. When the lake was lowered by 2.5 m in 1946, the river degraded by up to 2.5 m near the lake.

The eroded sediment is deposited downstream, which results in extension of the delta into the lake. As the delta extends into the lake, the overall channel length is increased, which has the effect of reducing the channel gradient. Therefore, although the immediate response is a steepening of the river due to lake lowering, the longer term response is to become less steep again. For example, in response to the 1946 lake lowering, the delta extended approximately 600 m and up to 2.5 m of sediment re-deposited in the river downstream (Wester 1970). Based on the 1946 experience, it is expected that any further lowering of the lake would only have short term benefits (KWL 2002).

Another item of note when discussing the impact of lake lowering on scour is the current location of the gravel-sand transition. In the late 1940s and early 1950s when the lake was lowered and meander cut-offs constructed, the gravel-sand transition was located at approximately 16 km upstream of the lake. The combined effect of the meander cutoffs and lake lowering increased the slope of the river such that the gravel-sand transition migrated to between km 6 and 8, where it is currently (KWL 2002).

However, unlike the sand deposits immediately upstream of Lillooet Lake, it is unlikely that further lake lowering would result in degradation of gravel channel deposits (KWL 2002). Gravel deposits are more resistant to scour, and the local increase in slope induced by lake lowering would likely be insufficient to induce significant degradation.

3.3 Results of Previous Studies

Based on the modeling results, it appears that lowering of the lake would not have a significant impact on flood levels in Pemberton. This conclusion is similar to previous studies including the Pemberton Flood Protection 1985 Study (Nesbitt-Porter, 1985), the Engineering Study for the Lillooet River Corridor (KWL, 2002) and the Lillooet River Gravel Management Plan (KWL, 2007).

Randbanda (1992) recommended that the bridge crossing at Tenas Narrows be upgraded to address backwater concerns and that dredging of the lower Lillooet River and lowering of Lillooet Lake be further investigated as a means to improve the flood profile in the valley. The Forestry Bridge crossing was upgraded in 1998 to address the conveyance concerns at Tenas Narrows. Further investigation and hydraulic modelling summarized here, indicates that lowering the lake would not improve the flood profile in Pemberton.

4. SUMMARY

Modelling results indicate that lowering Lillooet Lake water levels by 3 m during high flow events (200-year and 50-year return period events) does not have an appreciable impact on the flood profile in the PVDDs service area. The impact to the flood profile is felt in the reach downstream of the confluence with the Green River.

Lowering of water levels in the lake may have some short term, limited benefit to the Mount Currie Band lands within the 5 km immediately upstream of Lillooet Lake. However, more investigations are needed to establish whether the potential flood protection gains would offset the potential transfer of risk to the communities downstream of Lillooet Lake, the potential environmental impacts of lowering the lake and the cost of modifying the lake outlet.

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by: Reviewed by:

PROFESSIONAL PROVINCE OF Dec 3, 2010 S. F. JOYCE # 27627 BRITISH COLUMBIA ENGINEER

Sarah Lawrie, M.A.Sc., E.I.T.
Water Resource Engineer

Stefan Joyce, P.Eng.
Senior Water Resource Engineer

SJL/
Encl.

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Revision History

Revision #	Date	Status	Revision	Author
0	Nov 17, 2010	Draft		SJL/SFJ
1	Dec 2, 2010	Final	Revised based on comments received from PVDD	SJL

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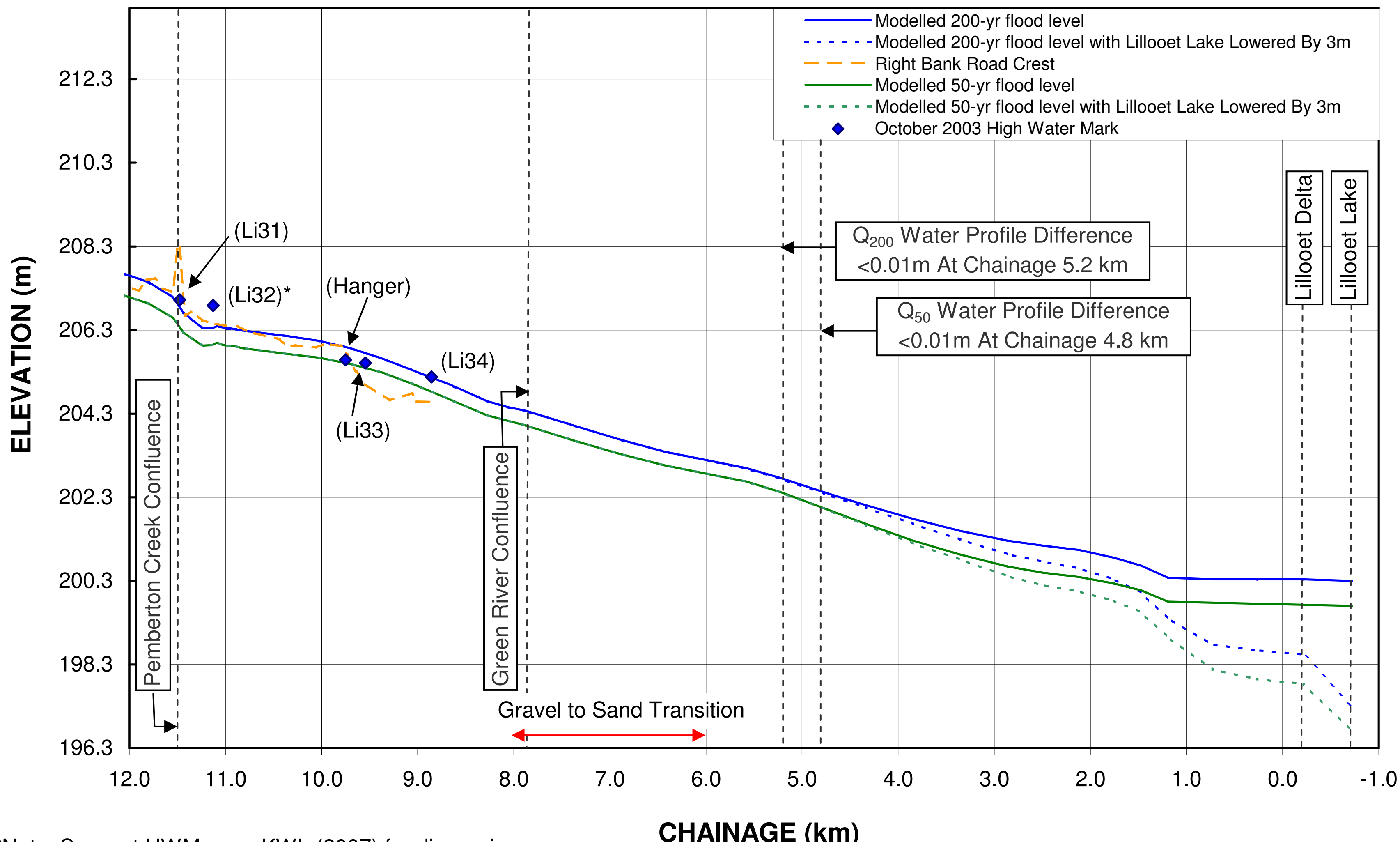
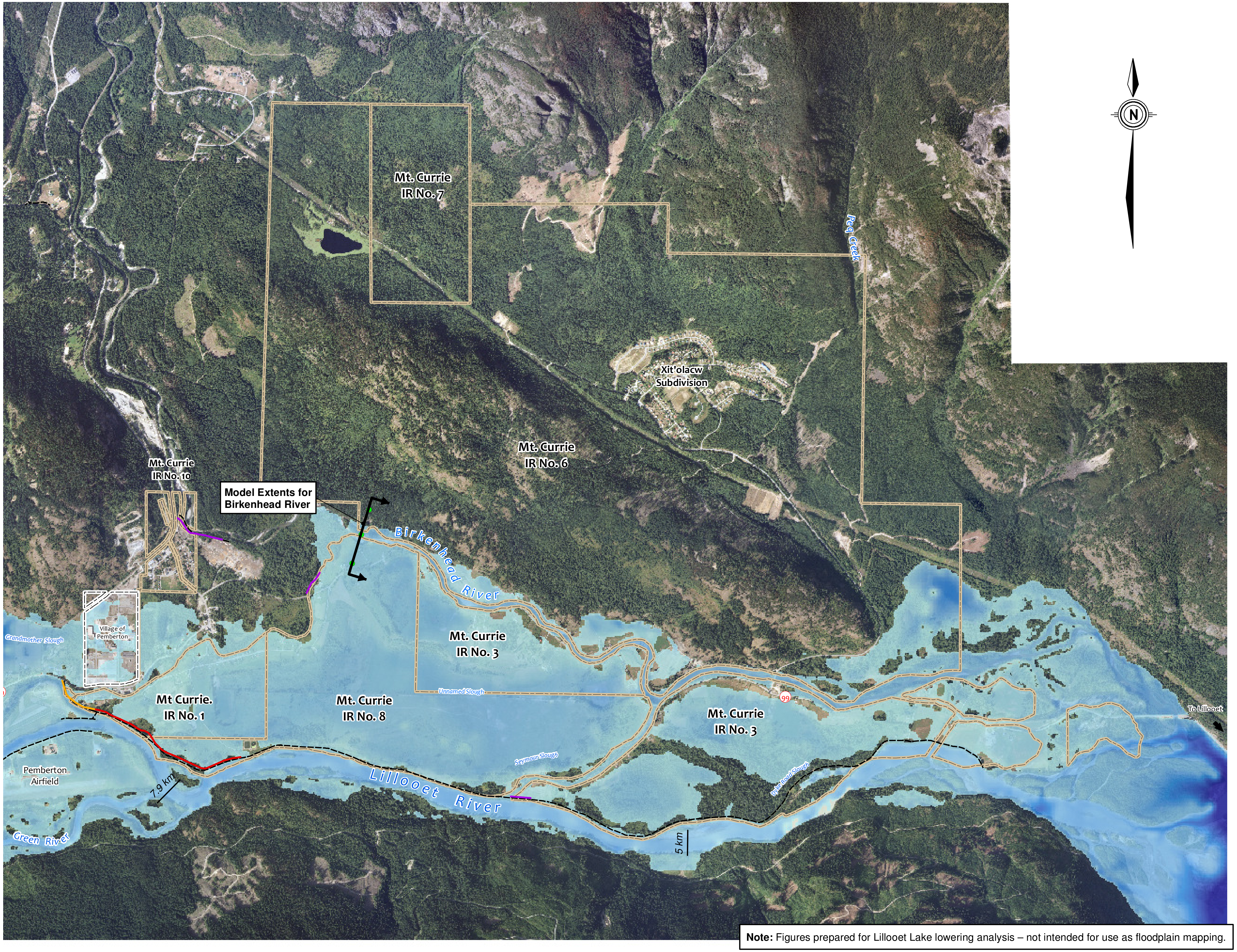
200-year and 50-year Return Period Flood Profile Comparison
Lillooet River - Pemberton Creek to Lillooet Lake



*Note: Suspect HWM - see KWL (2007) for discussion

Figure 1

Pemberton Valley Dyking District



Note: Figures prepared for Lillooet Lake lowering analysis – not intended for use as floodplain mapping.

Legend

- Reserve Boundary
- Muncipal Boundary
- Existing Berm

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Approximate Water Depth

High : 25 m

Low : 0 m

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500 0 500
Scale in Metres 1:30,000

Project No.	Date
713-037	November 2010

Model Results:
Existing 50-Year Return Period Event
Flow = 1,170 m^3/s,
Lillooet Lake 199.73 m)

Figure 2

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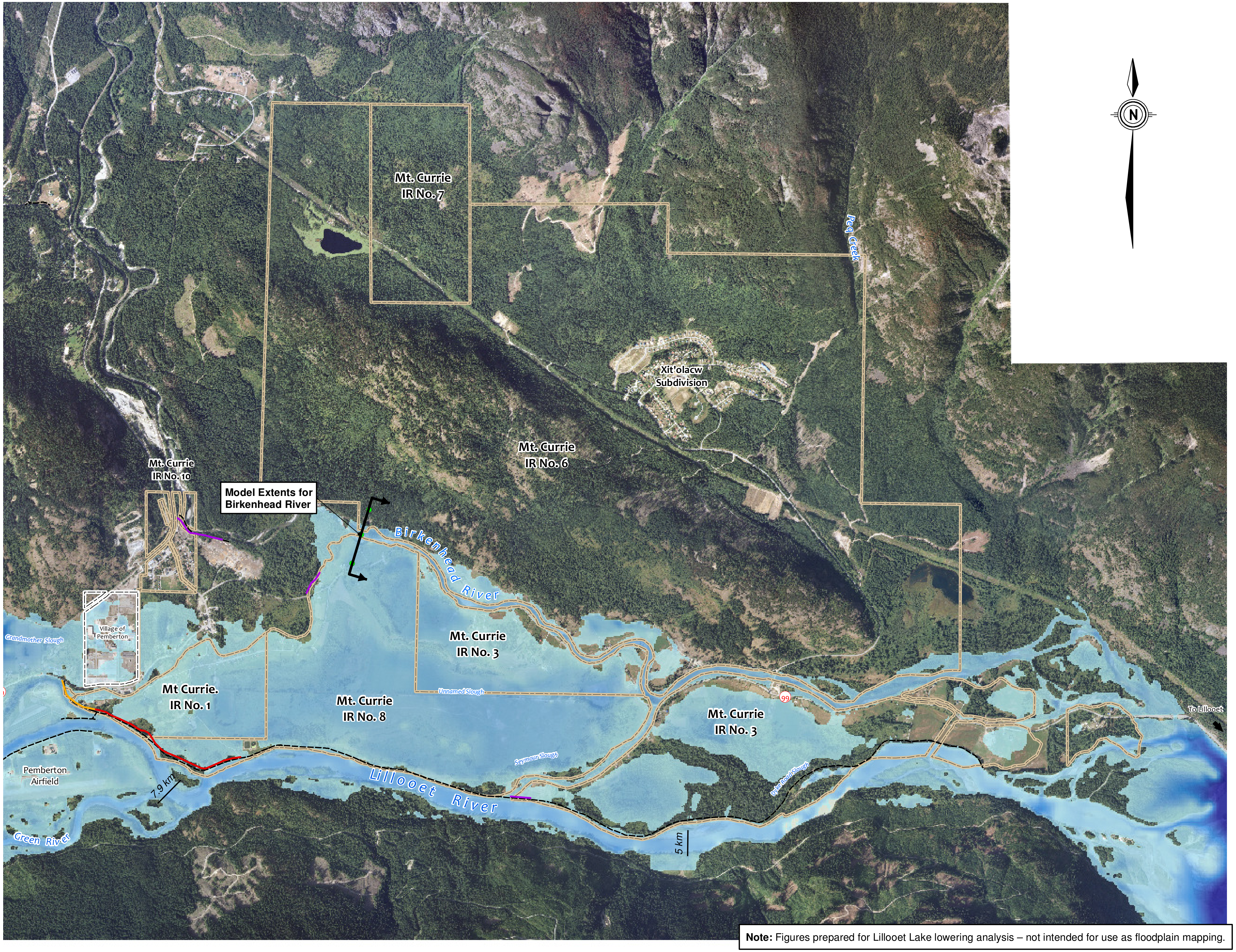

Note: Figures prepared for Lillooet Lake lowering analysis – not intended for use as floodplain mapping.

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Pemberton Valley Dyking District

Legend

- Reserve Boundary
- Muncipal Boundary
- Existing Berm

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Approximate Water Depth

High : 25 m

Low : 0 m

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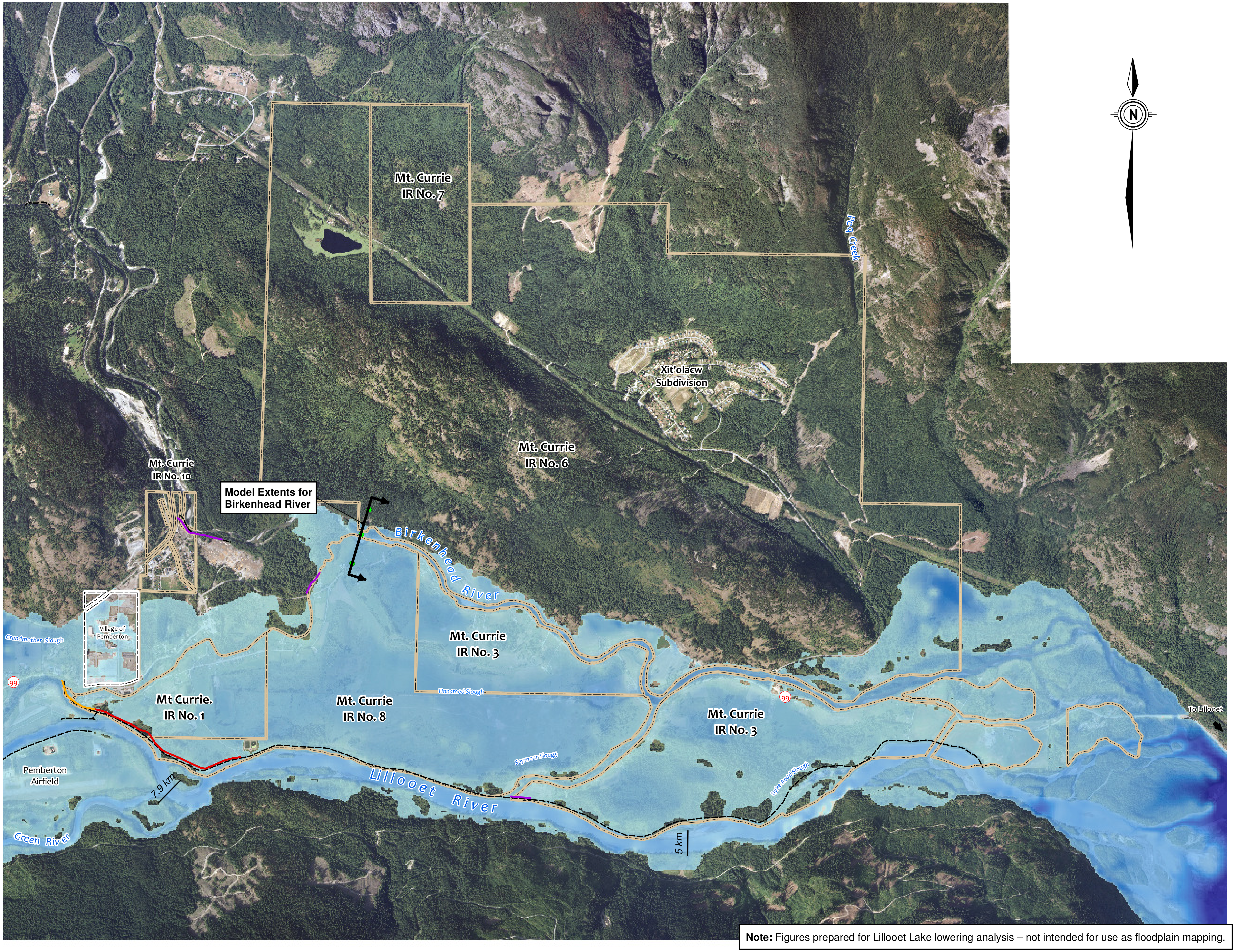
500 0 500
Scale in Metres 1:30,000

Project No.	Date
713-037	November 2010

Model Results: Lowered 50-Year Return Period Event (Flow = 1,170 m^3/s, Lillooet Lake 196.73 m)

Figure 3



Note: Figures prepared for Lillooet Lake lowering analysis – not intended for use as floodplain mapping.

Pemberton Valley Dyking District

Legend

- Reserve Boundary
- Muncipal Boundary
- Existing Berm

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Approximate Water Depth

High : 26 m

Low : 0 m

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500 0 500

Scale in Metres 1:30,000

Project No.	Date
713-037	November 2010

Model Results: Existing 200-Year Return Period Event (Flow = 1,520 m^3/s, Lillooet Lake 200.30 m)

Figure 4

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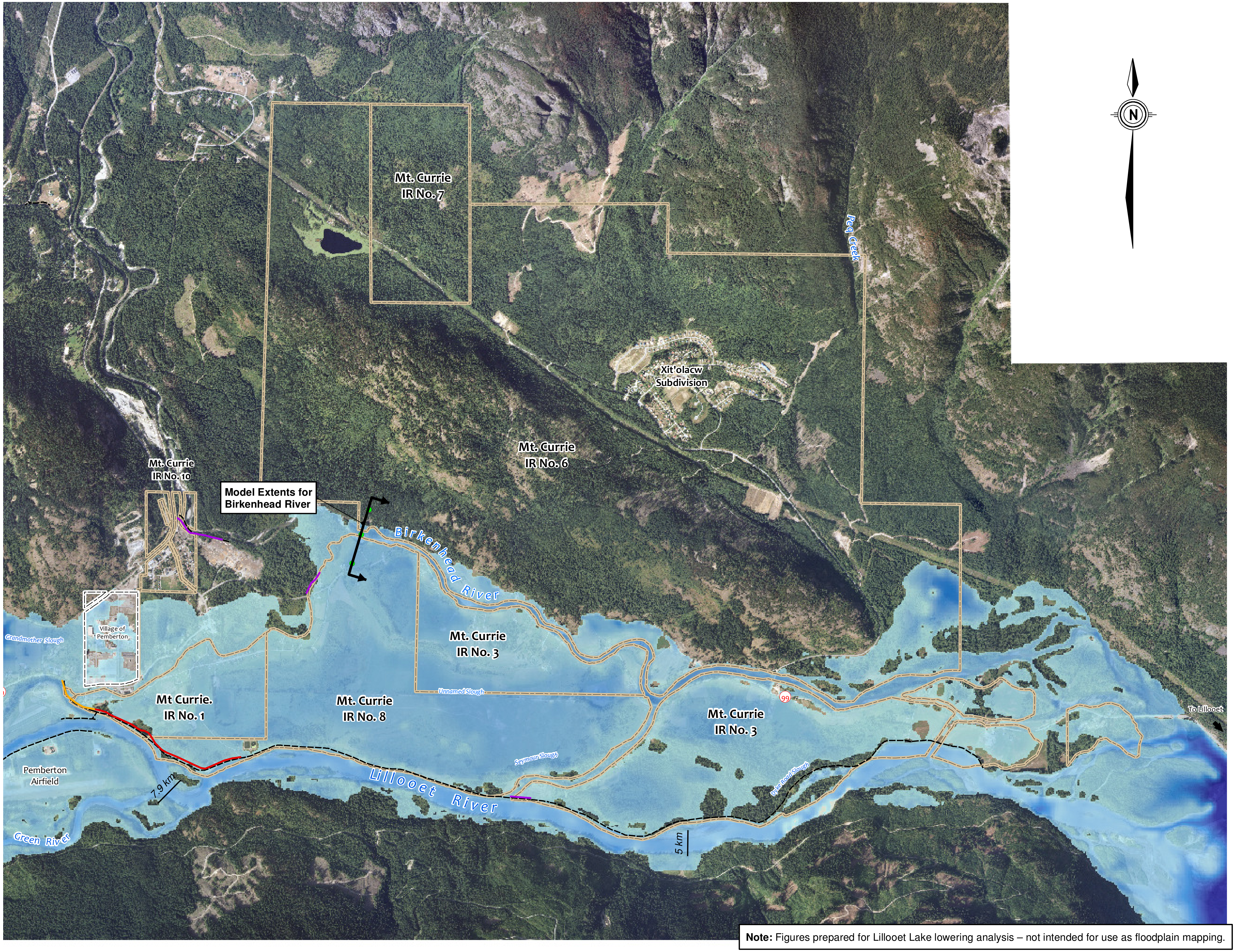
Pemberton Valley Dyking District



Note: Figures prepared for Lillooet Lake lowering analysis – not intended for use as floodplain mapping.

Legend

- Reserve Boundary
- Muncipal Boundary
- Existing Berm

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Approximate Water Depth

High : 26 m

Low : 0 m

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500 0 500

Scale in Metres 1:30,000

Project No.	Date
713-037	November 2010

Model Results: Lowered 200-Year Return Period Event (Flow = 1,520 m^3/s, Lillooet Lake 197.30 m)

Figure 5

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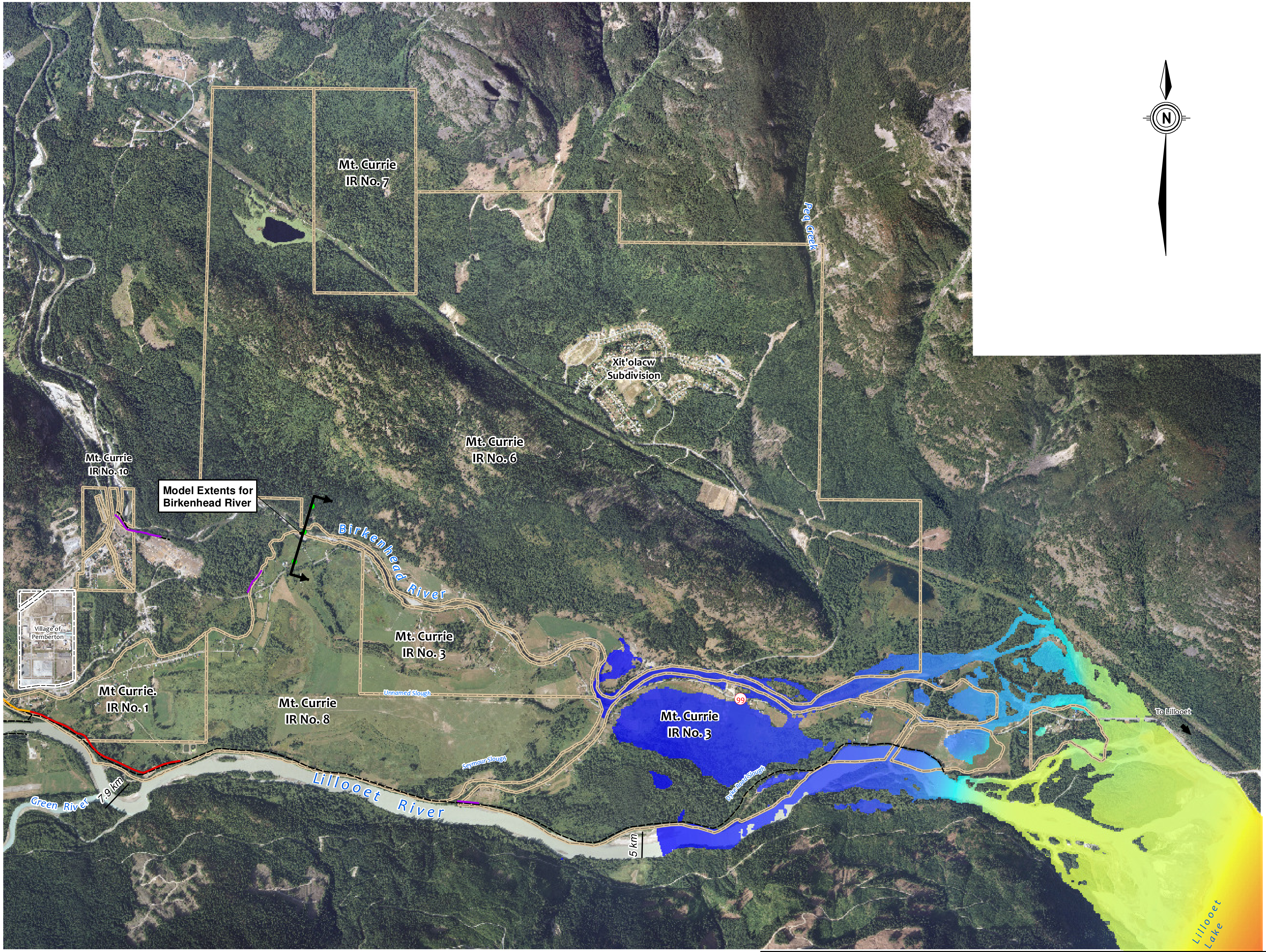

Note: Figures prepared for Lillooet Lake lowering analysis – not intended for use as floodplain mapping.

Pemberton Valley Dyking District

Legend

- Reserve Boundary
- Muncipal Boundary
- Existing Berm

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Water Surface Difference

High : 3 m

Low : 0 m

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500 0 500
Scale in Metres 1:30,000

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50-Year Return Period (Q_{50}) Results - Comparison of Flood Profile with Lillooet Lake Lowered 3 m

Figure 6

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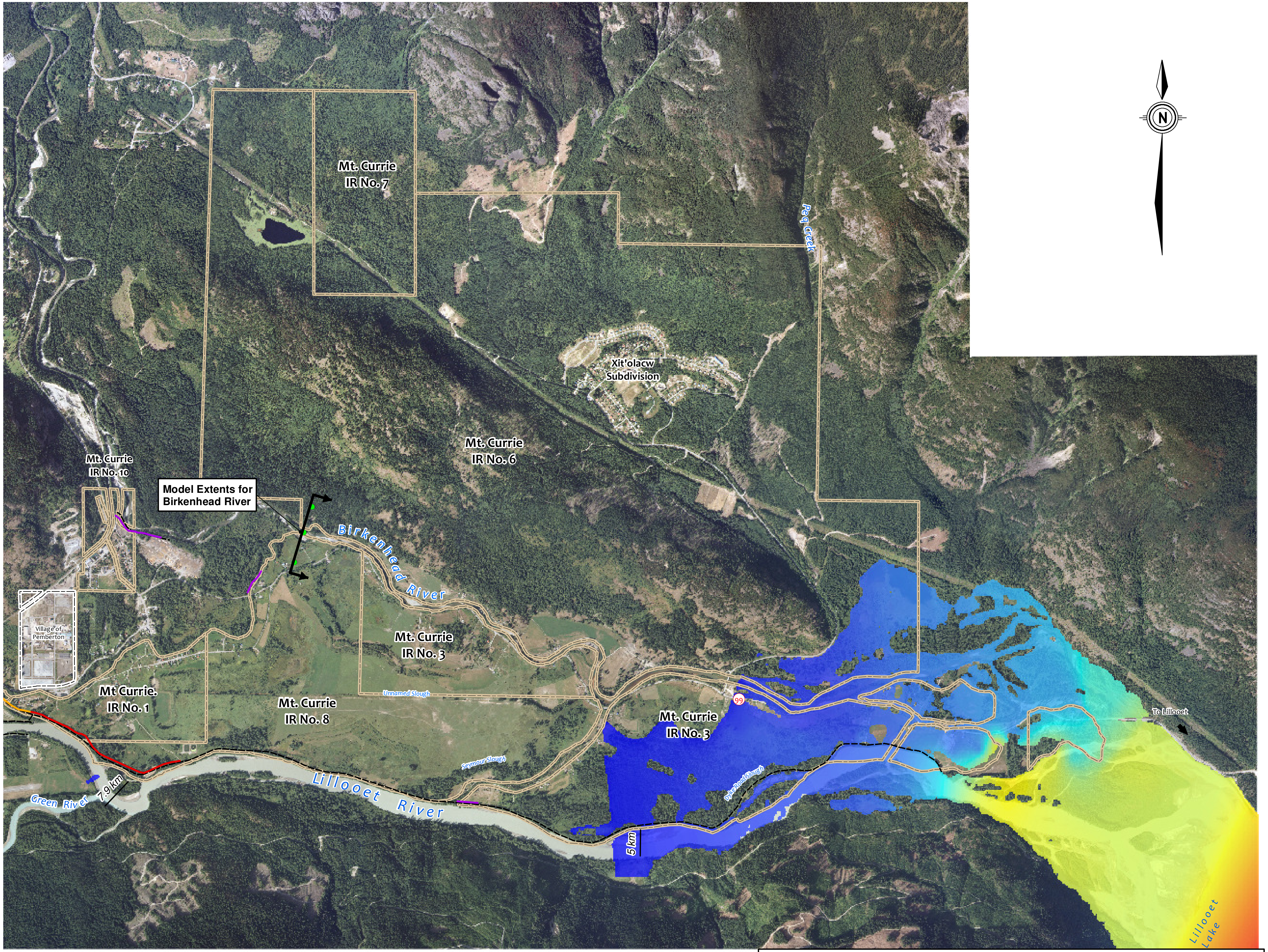
Pemberton Valley Dyking District



Legend

- Reserve Boundary
- Muncipal Boundary
- Existing Berm
- Constructed Dyke
  - Not Modelled
  - Q200 not within 0.3 m of Crest
  - Q200 within 0.3 m of Crest
  - Q200 Overtops Dyke

Water Surface Difference

High : 3 m

Low : 0 m

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500 0 500

Scale in Metres 1:30,000

Project No.	Date
713-037	November 2010

200-Year Return Period (Q_{200}) Results - Comparison of Flood Profile with Lillooet Lake Lowered 3 m

Figure 7

Note: Figures prepared for Lillooet Lake lowering analysis – not intended for use as floodplain mapping.

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